EXPLORING OPTIONS FOR MISSILE VERIFICATION

Edited by Pavel Podvig

UNIDIR UNITED NATIONS INSTITUTE FOR DISARMAMENT RESEARCH

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Abbreviations and acronyms

ALCM	Air-launched cruise missile
DPRK	Democratic People's Republic of Korea
FROD	Functionally related observable difference
HCOC	Hague Code of Conduct against Ballistic Missile Proliferation
HGV	Hypersonic glide vehicle
ICBM	Intercontinental ballistic missile
INF	Intermediate-range Nuclear Forces (Treaty)
JASSM	Joint Air-to-Surface Standoff Missile
MIRV	Multiple independently targeted re-entry vehicles
MOU	Memorandum of Understanding
MTCR	Missile Technology Control Regime
NATO	North Atlantic Treaty Organization
NTM	National technical means
OST	Outer Space Treaty
PBV	Post-boost vehicle
SAR	Synthetic aperture radar
SLBM	Submarine-launched ballistic missile
SLCM	Sea-launched cruise missile
START	Strategic Arms Reduction Treaty
TEL	Transporter–erector–launcher
UAV	Uncrewed aerial vehicle
WMD	Weapons of mass destruction

Summary

Avoiding a dangerous and destabilizing missile arms race will require the development of measures to constrain some missile-related activities. These could include limits on the number of missiles, their types or areas of deployment, as well as the creation of barriers to the transfer of technologies from peaceful applications to use in missiles. For these limits to form an effective arms control and disarmament instrument, they must be accompanied by robust verification measures that enable confidence in compliance with the commitments made by all parties.

Arms control agreements of the past have provided a set of verification tools that have been proven in practice. These include data exchange, demonstrations, notifications, on-site inspections and perimeter monitoring. This set of tools can be expanded and built upon to provide a foundation for future verification arrangements.

Future agreements should emphasize the cooperative aspect of the verification process and develop their technical and organizational procedures accordingly. While the verification provisions must be designed to deter violations, it is the record of compliance with the verification procedures and a willingness to conduct the verification process in a cooperative manner that can provide the most reliable proof of the commitment of parties to the obligations they accepted.

Introduction *Pavel Podvig*

Missiles are becoming an increasingly prominent element of military arsenals. Modern missile systems can deliver high-precision strikes at long distances, which allows them to carry out a wide range of military missions and pose a threat to critical military infrastructure. Deployment of conventional missiles alongside their nuclear counterparts creates ambiguity about the true nature of a deployed system, and so becomes a source of risk and instability as it which could lead to escalation in a crisis. New types of missile, such as hypersonic cruise missiles or boost-glide vehicles, could bring this instability to a more dangerous level as they leave little time for an assessment of the nature of a threat. If left unchecked, these developments could lead to a dangerous arms race and significantly increase the risk of miscalculation.

The system of arms control agreements that helped provide a check on the missile arms race in the past is currently under considerable stress. The demise of the 1987 Intermediate-range Nuclear Forces (INF) Treaty has removed constraints on the development and deployment of intermediate-range missiles by the Russian Federation and the United States of America. As a result, there is a real possibility that Europe will once again become the scene of a dangerous missile stand-off. The Asia-Pacific region could see a similar dynamic as well.

The current situation in arms control reflects the growing complexity of the issues that new arrangements would have to address. For example, the dispute over the INF Treaty could have been resolved had the treaty included provisions for verifying the range of a cruise missile. Some proposals for managing the post-INF situation in Europe suggest imposing geographical limits on deployment of intermediate-range missiles, but these would have to deal with the fact that these systems are highly mobile. Reducing the risks associated with dual-capable systems would require developing a procedure that can reliably separate nuclear and conventional missiles. Recent advances in space launch technology could present another serious challenge. Since more states are building indigenous space programmes, it is important to develop tools that would ensure that the technology is used only for peaceful purposes.

Addressing these and other challenges will require the development of new approaches to missile verification and taking full advantage of the existing ones. Even though specific limits and verification provisions would depend on the details of any negotiated agreements, should they become possible, it is important to understand in advance the set of verification tools that future arms control arrangements could rely on. It is also important to understand how the recent increase in the volume and quality of open-source data as well as progress in processing and analysing open information could affect future verification arrangements.

The biggest challenge, of course, is political. This project was largely completed by December 2021. By March 2022, the political situation had changed considerably as a result of the ongoing conflict in Ukraine. In the current context, it is extremely difficult to imagine that states would be willing to accept new obligations regarding their missile programs. However, history also suggests that serious conflicts sometimes create incentives for arms control.

Verification as a cooperative process

One of the most important lessons that can be drawn from past and existing verification regimes is that their effectiveness critically depends not only on their ability to deter violations but also on the degree to which they allow the parties to demonstrate commitment to the obligations they assumed.[1] Thus, as reflected in this definition, verification cannot be reduced to a simple set of technical tools and methods:

> At its core, verification is a set of national and cooperative activities, tools, procedures, analytical processes, and fundamentally, judgments about what is happening with regard to specific activities defined in an agreement.[2]

Verification is a complex process that includes various elements, some of which are inherently political. Perhaps most importantly, verification has a well-defined goal – to contribute to a conclusion about a state's compliance with specific obligations that it has assumed. In that regard, verification is different from monitoring, which aims to provide a picture of all relevant developments in a state, or transparency and confidence-building measures, which normally do not require states to accept specific obligations in order to be effective.

An agreement that details obligations can take different shapes. In the most common scenario, it is a bilateral or a multilateral treaty to which states are party. In some cases, obligations can be imposed on a state by the international community. Another possibility is for a state to assume certain obligations voluntarily on a unilateral or reciprocal basis. To demonstrate its commitment, the state could then open its relevant activities to verification. In this case, obligations and verification provisions could be defined in national legislation.

An agreement that imposes certain obligations may not include specific verification provisions. That does not mean, however, that such an agreement would not be verifiable since most of the elements that constitute the verification process, such as monitoring by national technical means (NTM) or analytical assessment, exist independently of any agreement. Inclusion of dedicated tools and procedures in an agreement would, of course, significantly affect the effectiveness of verification arrangements.

Effectiveness in this case is normally understood as the ability of the verification arrangements to detect violations of the agreement in question. Normally it is understood that an agreement can be considered effectively verifiable if parties can detect a significant violation in time to take measures that would deny the violator the benefits of the violation.[3] Implementation of this general principle depends on the specific treaty, but it can be seen that, while the ability to detect potential violations certainly plays an important role, effectiveness critically depends on the judgement about the significance of certain violations as well as the ability and willingness of parties to act in response.

This approach to the effectiveness of verification arrangements usually serves as a starting point for most arms control and disarmament agreements. However, it addresses only one aspect of a verification process – its ability to detect and therefore deter violations. In practice, however, the primary role of verification activities is to provide states with tools that would confirm

1 The author is grateful to Amy Woolf, whose contribution was invaluable in the development of the argument in this section. See also A.F. Woolf, Monitoring and Verification in Arms Control, Congressional Research Service, 2 3 December 2011, https://www.fas.org/sgp/crs/nuke/R41201.pdf, A.S. Krass, Verification: How Much Is Enough?, 1985, pp. 252–59.

2 Nuclear Threat Initiative, "Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks – Overview", Cultivating Confidence Verification Series, July 2014, http://www.nti.org/media/pdfs/VPP_Overview_FINAL.pdf, p. 5.

3 A.F. Woolf, Monitoring and Verification in Arms Control, p. 7.

their compliance with the obligations they assumed. They also give states a mechanism to prove their commitment to the broader goals of the agreement that they have entered. While this assumes that this commitment is strong to begin with, in most cases it is a reasonable assumption.

States enter agreements and assume obligations voluntarily, judging that they correspond to their security interests. Outright violations are exceedingly rare and, in most compliance disputes, the strongest evidence of a violation comes from unwillingness of a state to fully cooperate with the verification process, rather than directly from the information obtained through verification procedures. In fact, the degree of cooperation with verification activities could be a more reliable indicator of compliance than formal conformity with the letter of the procedure. Similarly, willingness to accept intrusive verification procedures, such as declarations, notifications, data exchange or on-site inspections, could serve as an important sign of the readiness of a state to comply with its obligations.

This approach to verification is the primary focus of this report. The key assumptions are that verification activities are carried out as part of a cooperative process and that the procedures are designed to provide parties with a way to demonstrate compliance with their obligations. While some of the measures discussed in this report would be difficult to implement in situations where the level of trust between parties is particularly low, even in such situations verification is normally done in a cooperative manner.

Options for missile verification

This report covers various aspects of verification arrangements that could be applied to missiles. The goal is not to suggest specific solutions that would fit a broad range of circumstances, but rather to look at the experience of past arms control and disarmament efforts, provide an overview of existing verification tools, and initiate a discussion of potential arrangements that could make future arms control agreements possible.

Since range is one of the key characteristics of a missile, the opening chapter of the report looks into various approaches to defining and verifying missile range. As Markus Schiller shows in chapter 1, coming up with a definitive formula for range is extremely difficult. However, it should be possible to agree on a set of parameters that could describe missile performance and that could be verified with reasonable access to the missile and its flight tests. This approach could be based on the practice developed in the US–Russian strategic arms control agreements for ballistic missiles. Verifying the range of a cruise missile would be a more difficult task, but there are ways to approach this problem as well.

The mobility of most modern missiles presents a serious challenge for any future verification arrangements. These missiles may be difficult to track and account for. However, this is not a new problem and, as Amy Woolf demonstrates in chapter 2, the United States and Russia have developed tools that assure high confidence in the accuracy of data about the number of mobile missiles and their operational status. As the discussion in chapter 2 shows, the key factor is the multiplicity of channels that provide information about missiles – from data exchange to notifications and from unique identifiers to on-site inspections. The role of NTM is also essential. It is the combination of these tools, as well as the consistency of cooperative participation in verification activities, that provides the required confidence.

Distinguishing nuclear-armed missile systems from their conventional counterparts could present another serious challenge for future verification regimes. In chapter 3, Christine Parthemore shows that this challenge does not have to be unsurmountable. There is a range of methods that could determine whether a certain missile is armed with a nuclear warhead or whether it has this capability. Some of these methods may be more intrusive than others and none seems to provide a simple universal answer, but similar to the case of mobile missiles, a combination of different tools could provide a fairly high degree of confidence in the absence of nuclear-armed missiles in a variety of scenarios.

Chapter 4, jointly authored by Almudena Azcárate Ortega and Dmitry Stefanovich, deals with the widely recognized link between the technologies that are used in space launchers and those used in ballistic missiles. As many states already possess these capabilities and some may be using their space programmes as a way to build a ballistic missile programme, it is important to explore ways to separate the two. This could allow states that are not interested in military applications to demonstrate the exclusively peaceful nature of their space programmes.

The final chapter, chapter 5, co-authored by Pavel Podvig and Decker Eveleth, discusses the increasing role of open-source information in monitoring various activities, including those related to missiles. While they conclude that open-source data analysis is unlikely to replace NTM, it could provide an important addition to the set of tools employed by states and increase their confidence in the robustness of verification arrangements.

The general conclusion of this report is that there is a variety of options to consider in the development of missile verification arrangements. It is true that most verification arrangements would require a fairly high level of transparency, but that is what makes them stronger and more reliable. In a way, readiness to accept openness and cooperation could in itself become an extremely valuable element of the verification process. Moreover, the path to building an effective verification arrangement is to design it in a way that facilitates cooperation and transparency.

CHAPTER 1: Determining missile range *Markus Schiller*

Range is an important characteristic of a missile (and any other weapon-delivery system). Accordingly, in arms control it is often desirable to establish limits on certain delivery systems based on the range of missiles. For example, United States–Russian arms control treaties that limit the number of intercontinental ballistic missiles (ICBMs) define them as missiles with a range of more than 5,500 kilometres. A bomber would be subject to a limitation under the 2010 New Strategic Arms Reduction Treaty (New START) if it is equipped with an air-launched cruise missile (ALCM) that has a range of more than 600 km.[1] In another example, the Intermediate-range Nuclear Forces (INF) Treaty, signed by the United States and the Soviet Union in 1987, prohibited all land-based ballistic and cruise missiles with ranges between 500 and 5,500 km. A dispute about the range of a cruise missile developed by Russia was one of the key factors that led to the demise of that treaty in 2019.[2]

While the term "range" plays an important role in describing missile capabilities or in setting restrictions on their deployment, it is not always well defined or understood. Even though everyone seems to agree that "range" means the distance that the missile can cover to deliver a payload, there seems to be no common agreement on the conditions under which this "range" is achieved. Indeed, there are several conditions that affect a missile's range, some of them with significant results. This is true for both ballistic missiles and cruise missiles, and not forgetting the latest "hypersonic missiles" that might fall into either of the two categories.

In terms of the above-mentioned distance that a missile might cover, every missile is designed with a certain mission in mind. Range, while important, is far from the only parameter that defines missile capability. Others may include the deployment modes (for example, on a submarine) or payload type and size (for example, multiple warheads). Also, once a missile has achieved the range required for a certain mission, variations of that range are usually not important. For example, a ballistic missile with a range of about 10,000 km provides true intercontinental capability in most circumstances. A further increase of that range could help provide additional flexibility in deployment and operations, but does not affect the core mission in a significant way. However, if the mission is redefined to include the capability to counter missile defences, an increase of range (or payload) could be considered essential.

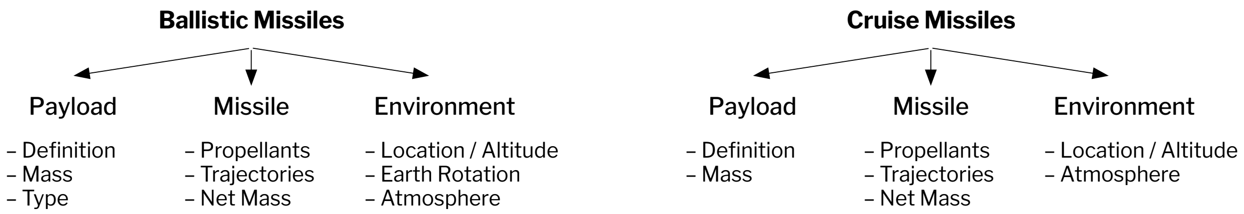
Defining range

Before talking about verification in regard to a missile's range, one should be aware of the problem of actually defining a missile's range. This problem can be illustrated by looking into the various factors that affect the maximum range that a given missile can achieve (see figure 1 on the following page). While these factors are comparable for ballistic and cruise missiles, it makes sense to look at the two missile categories separately.

1 Treaty Between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms (New START), 8 April 2010, Protocol, https://2009-2017.state.gov/documents/organization/140047.pdf, Part One.

2 P. Podvig, "Who Lost the INF Treaty?," Bulletin of the Atomic Scientists, October 26, 2018, https://thebulletin.org/2018/10/who-lost-the-inf-treaty.

Figure 1. *Systemization of range-affecting factors*



Ballistic missile range

Ballistic missiles use rocket propulsion to quickly accelerate to the speed required to place a payload on the trajectory that allows it to reach the target. The main factors that determine a ballistic missile's range are its payload, the missile itself and, to a lesser degree, the environment in which it is operated.

Payload

Assuming two identical missiles are launched in the same environmental conditions, the characteristics of their payloads might still significantly affect their range.

Payload definition

First of all, the problems start with the term "payload". There seems to be no clear and commonly accepted definition of that term in relation to ballistic missiles. Some might refer only to a nuclear weapon, a chemical agent or high explosives when talking about "payload", while others might think of everything sitting on top of the missile's body, which might or might not include one or more re-entry vehicles with airframes and heat shields, a separation system, the fuse, arming and safety devices, fixtures, sensors, power supply, a guidance and control system, a shroud, and maybe even a post-boost vehicle (PBV) including propulsion systems.

Only by agreeing on the term "payload" in advance can there be a common understanding of the key parameter "payload mass".

Payload mass

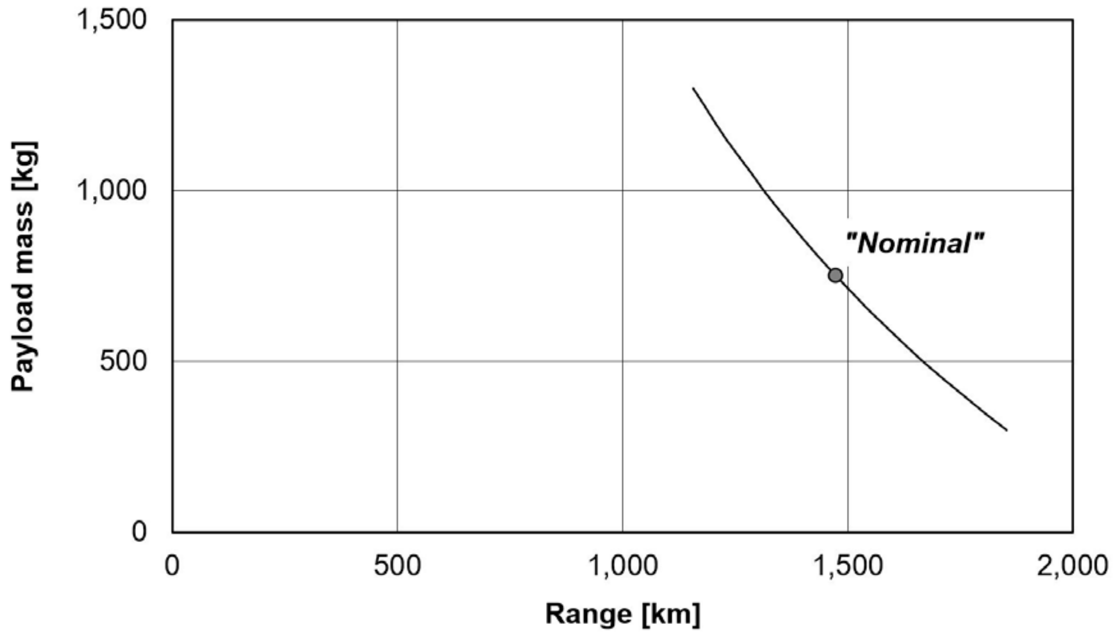
A clear definition of the payload mass is essential, in terms of the precise mass value itself, as well as what this parameter actually includes.

It is important to understand that, while a missile may be designed for a certain payload mass, it may be able to carry more or less of this certain mass as a payload. There are only three major constraints:

- The missile's total weight has to be lower than the missile's thrust (at least at launch and early flight)
- The airframe must be strong enough to carry the resulting loads
- The missile must remain within the design boundaries from the aerodynamic stability point of view (old designs may have a problem with lighter payloads and the resulting shift of the missile's centre of gravity)

It should be obvious that payload mass can be traded against range: the same missile can throw a lighter payload over a longer distance than it could a heavier payload. Technically, it is more accurate to use the concept of a "throw-weight curve" and specify the combination of payload mass and range (for example, "1,500 km with 750 kg" – see figure 2 on the following page).

Figure 2. *Throw-weight curve for an exemplary ballistic missile*



The 1991 Strategic Arms Reduction Treaty (START) already used the term "throw-weight", including definitions of this term, which depended on the missile's status.[3] For "flight demonstrations" (flight tests), the term was defined as the "weight of the payload of the final stage"; for a missile with multiple independently targeted re-entry vehicles (MIRVs), "the aggregate weight of that [final] stage [which manoeuvres to release the re-entry vehicles] including its propellant and elements not separated from the stage ... and its payload".

This definition assumes that the payload includes re-entry vehicles as well as other elements that the missile can carry, such as decoys or penetration aids. For missiles that carry MIRVs, the separation stage is included in the throw-weight as well. Historical data suggest that warheads could account for about half of the throw-weight of a modern ICBM, although for early single-warhead missiles, the re-entry vehicle would probably be responsible for most of the throw-weight.[4] This definition does not mention range, even though in most flight tests the distance to impact was normally shorter than the nominal range of a missile. It was understood that missiles of existing types had been tested with their nominal or maximum payload by the time the treaty entered into force.

For missiles of any new type, throw-weight was also defined in START as "the greatest throw-weight demonstrated in flight tests", but with the addendum that this should be "no less than the maximum calculated throw-weight that an ICBM or [submarine-launched ballistic missiles (SLBM)] of that type could deliver to a distance of 11,000 kilometers for ICBMs, or to a distance of 9500 kilometers for SLBMs". This provision was included to rule out the possibility of declaring a new missile with fewer warheads than it is capable of carrying. Since START limited the total throw-weight of deployed missiles, it was a way to enforce this limit. It is notable that the

3 Treaty between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms (START), 31 July 1991, Protocol on ICBM and SLBM Throw-Weight, https://2009-2017.state.gov/documents/organization/27381.pdf.

4 P. Podvig, "How Many Warheads?", Russian Strategic Nuclear Forces, 17 May 2007, http://russianforces.org/blog/2007/05/how_many_warheads.shtml.

treaty included provisions for calculating the maximum throw-weight. Each party would use its own model to do so, using a number of agreed assumptions regarding the propellant load and other parameters.

Payload type

The type of payload also has implications for the range. A hypothetical ICBM with a launch mass of 100 tonnes may carry one or several re-entry vehicles that weigh a combined 4,000 kg (see figure 3). If this payload is substituted by a PBV with one (or several) warheads, also weighing a total of 4,000 kg (perhaps by reducing the number of re-entry vehicles), targets at a greater range can be attacked due to the extra speed (or "delta-v") that the PBV can add to the re-entry vehicles – but technically, the missile still carries a payload of 4,000 kg (see figure 4). And if that missile is instead armed with a 4,000 kg hypersonic glide vehicle (HGV), the potential range will again be increased significantly by the payload's aerodynamic glide phase. The same is, of course, true for an exemplary medium-range ballistic missile with a standard range of roughly 1,500 km, if only on a smaller scale.

Figure 3. *Different payload types*

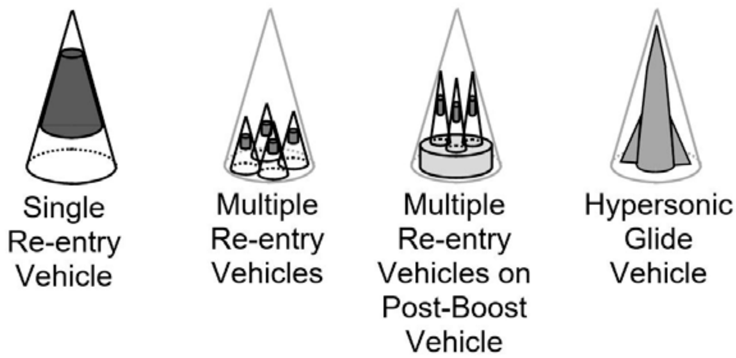
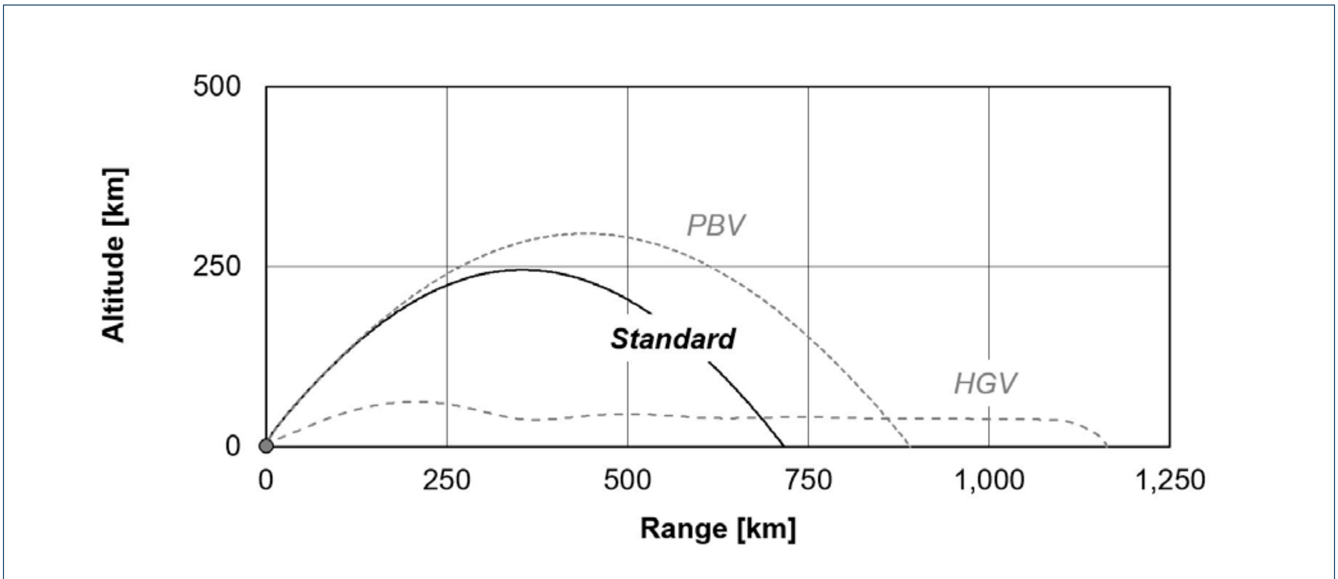


Figure 4. *Missile range with different payload types*



Missile

The missile itself might easily be modified to achieve different ranges, even with a given payload mass.

Propellants

This brief excursion into how propellants might affect missile range does not touch the issue of using different propellant types. While the resulting different performance values would obviously have effects on the missile's range, this aspect is mostly academic for liquid-fuelled rockets because their engines are designed for specific propellant mixtures. Any change in fuel would require significant modifications in engine design due to different mass flows, cooling properties or combustion temperatures. In contrast, the range of solid-propellant rockets could be affected by minor variations in propellant mixture that the rocket motor could have been designed to endure. Examples of variations might include the proportion of aluminium powder added to composite propellants, or the addition of more exotic compounds.

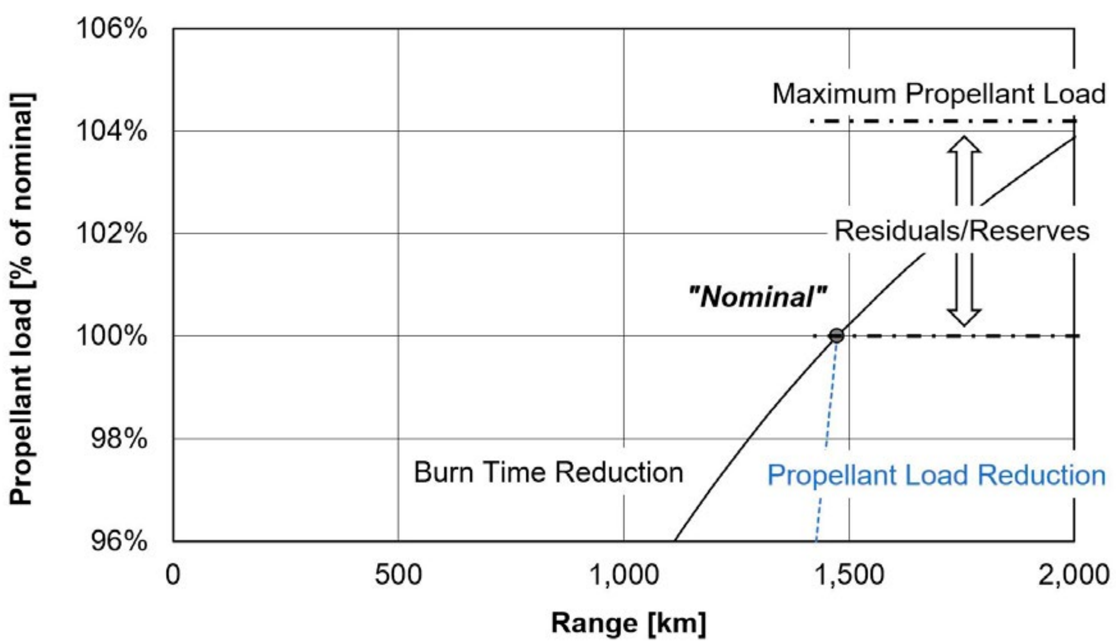
There are simpler ways to change the actual range of liquid-fuelled rockets, which are usually designed to switch their engines off at command. It is also important to understand that no liquid-fuelled missile is completely filled up with propellant and then uses all of the propellant in flight.

The "empty space" that is not filled up at the filling process, usually around 5 per cent of the theoretically available volume, is called ullage. This ullage is used to allow the propellant to grow or shrink in volume due to significant temperature changes, but it also exists because of the simple physical problem of filling up a completely integrated missile.

More importantly, a missile usually carries along residuals of the propellant that will still be in its tanks and feed system after cut-off. Also, liquid-fuelled rockets require reserves to compensate for unexpected extra propellant use (for example, due to cross winds or misaligned propellant mixture ratios) and to avoid the engine running dry of propellant before controlled cut-off (which would lead to catastrophic turbo pump failure and perhaps loss of the rocket). Therefore, residuals and reserves must be accounted for in the nominal propellant load of any liquid-fuelled missile.

These two aspects – ullage and reserves or residuals – are a major source of uncertainty for performance reconstructions as well as for external measurements of performance. A rocket could cut off before nominal engine cut-off in demonstration flights, allowing for longer range in later flights than previously demonstrated. It could also cut off later, thus eating into the nominal reserves and residuals, risking catastrophic engine failure but signficantly extending potential flight range. Additional propellant could also perhaps be filled in, reducing the nominal ullage but allowing for longer engine operations, and thus longer range. Even minor changes will have significant effects on the missile's range (see figure 5).

Figure 5. *The effect of different propellant loads and reserves or residuals on missile range*

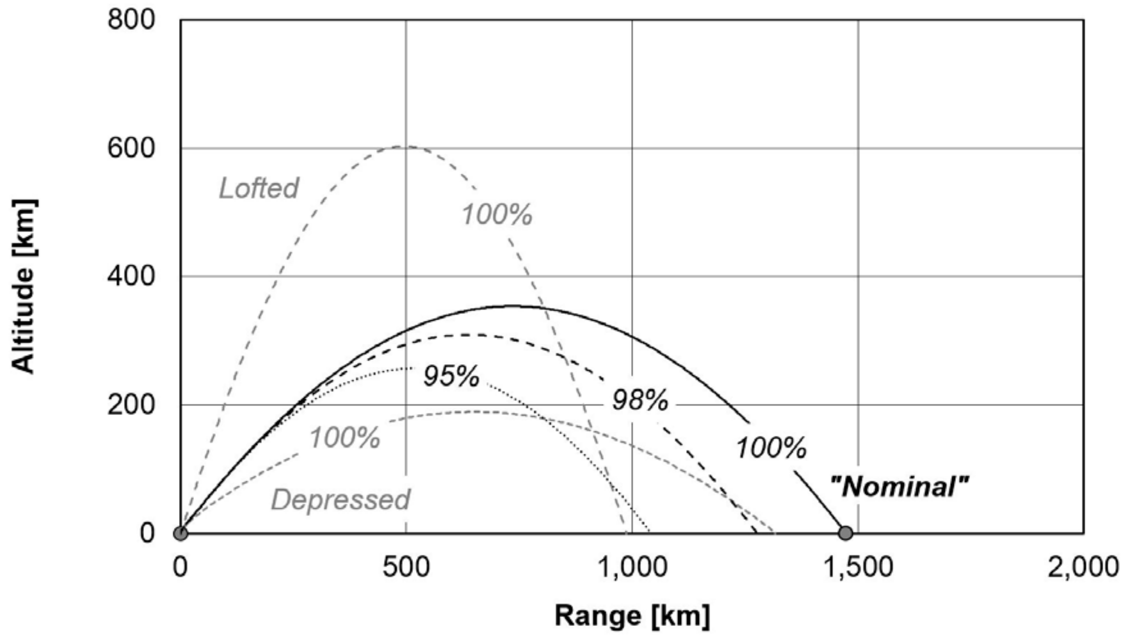


Trajectories

Excluding range extension by aerodynamic means (for example, carrying an HGV as a payload), there's only one maximum range trajectory, the so-called minimum energy trajectory. But missiles can easily be launched on shorter ranges by modifying the trajectory shape into lofted or depressed trajectories or by reducing the burn time (that is, the time before engine cut-off – see figure 6). Any demonstrated flight might not offer the actual range potential, a fact that could be concealed as long as the trajectory's peak altitude is not communicated along with the covered range.

However, even if that parameter is published, there is still the chance of an early engine or motor cut-off. Since ballistic missiles gain most of their range just before cut-off (when the propellant is almost used up and the missile is light, so acceleration is high), even a slightly shorter burn time might have significant effects on the achieved range. For a missile with roughly 100 seconds of nominal burn time, reducing nominal burn time to 98 per cent translates to just 2 seconds of early cut-off. Therefore, communicating the actual burn time and comparing that number with the estimated or reported propellant load and propellant mass flow may give an idea of whether the missile was indeed flown to its full nominal range, or to a shorter distance.

Figure 6. *Various trajectories for an exemplary ballistic missile*

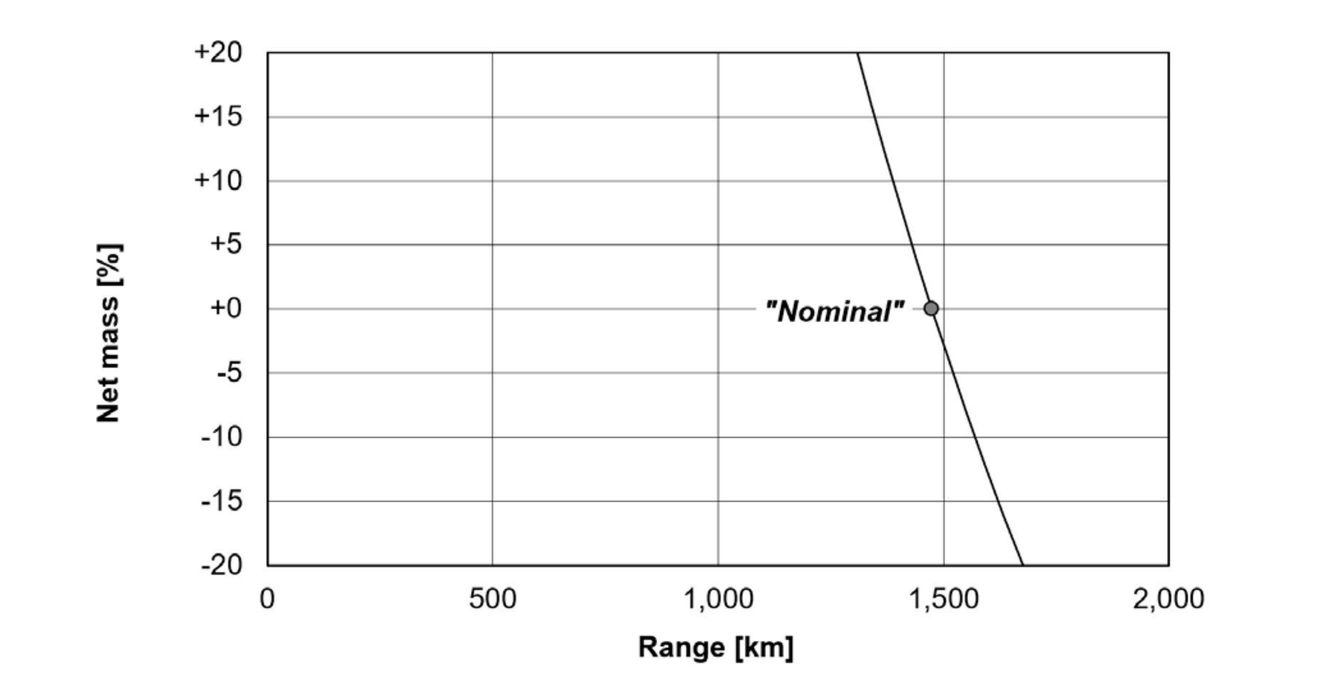


Net mass

A lighter missile logically offers more range, as the above-described effects of payload and propellant mass variations show. The weight of the missile itself should also be looked at, as expressed by the missile's net mass. This term is used for the empty missile without propellants and warhead or payload.

Missiles are built as lightly as possible. It is therefore unlikely that a missile can easily be lightened by quickly reducing the net mass even further. But additional weight could be added to a missile prior to demonstration flights in order to reduce the demonstrated range and conceal the actual range potential. This is the same effect on range that a heavier payload would have (see figure 7 and compare with figure 2). The effect of extra weight is pronounced for single-stage missiles and for the upper stages of multistage missiles, where every kilogram of extra weight added is a kilogram extra to be carried all the way – if it is added to the first stage, for example, it would be dropped at the first stage separation, thus reducing the overall effect of adding that kilogram.

Figure 7. *Various net mass values affecting missile range*



External factors

Several external factors may affect a ballistic missile's range, all of them linked to each other in one way or another. For example, for ICBMs the rotation of the Earth could contribute to a significant difference between the range demonstrated in flight tests and the actual range of a missile. This factor, of course, is accounted for in calculating the missile trajectory that is required to reach a designated target from a certain launch point. Other factors, such as the atmospheric conditions at the launch site, would affect range as well, but these are normally compensated for by the missile guidance system.

Cruise missile range

Cruise missiles are essentially uncrewed aeroplanes. They follow trajectories within the Earth's atmosphere and use lift created by their wings to stay airborne, thus creating aerial drag that slows them down. Therefore, while ballistic missiles stop operating their engines once they reach their intended speed, cruise missiles have to keep operating their engines to overcome the continuous drag. The payload is carried all the way to the target.

Where ballistic missiles have to follow the relentless dictates of the famous Tsiolkovsky rocket equation, resulting in optimized designs with huge amounts of propellant onboard (90 per cent or more of the launch mass can be propellant), cruise missiles follow the same laws as aeroplanes, where wings, airframe, engines and payload account for the bulk of the launch mass (and usually much less than 50 per cent of the launch mass is propellant).

Having been a subject of debate for years, the line between cruise missiles and uncrewed aerial vehicle (UAVs) and drones has become even more blurred over the past years. Because of their nature, many of the aspects presented in the following paragraphs are valid for UAVs and drones as well as cruise missiles – all follow the laws of aviation-related physics. However, since the subject here is “missile range”, the following considerations only mention cruise missiles.

There have been attempts to define cruise missile range in international treaties, of course. Most of them were somewhat imprecise, however. For example, START defines the range of an ALCM to be “the maximum distance that can be covered by an ALCM of that type in its standard design mode flying until fuel exhaustion, determined by projecting its flight path onto the Earth’s sphere from the point of launch to the point of impact”.[5] This definition is not very precise, for example in its use of the vague term “standard design mode”. This alone implies that a modified design with larger fuel tanks may be attributed with the range of the “standard design mode”.

Some of the problematic issues that impede a clear and simple, generally accepted definition of “cruise missile range” are therefore presented here.

Payload

In terms of the payload, cruise missile range is only affected by the mass, not the type, of payload.

Payload definition

Definition of the term “payload” is not as complicated as for ballistic missiles. Since cruise missiles carry their payload all the way to the target, their warheads do not separate. They do not have to undertake atmospheric re-entry, so no thermal protection system (“heat shield”) is required either. The warhead section is simply a part of the airframe. This section can of course be dismounted for maintenance, or to change the actual warhead type. Nonetheless, it seems that it is not always clear if the term “payload” refers to the whole warhead section, or only to the weapon load inside the airframe.

Payload mass

If a certain effect is expected at the target, the warhead must have a certain weight. Explosives only deliver limited energy per mass, so a certain mass of explosives has to be carried along for the desired effect. Even nuclear warheads have certain weights. Therefore, cruise missiles of longer range usually carry warheads weighing several hundred kilograms. For example, the mass of the nuclear warhead carried by US ALCMs is about 130 kg.[6] Conventional warheads could be considerably heavier. The warhead can account for a significant fraction of the missile’s total launch weight.[7]

In contrast to most ballistic missiles, the weights of cruise missile warheads cannot be varied that easily, or over a significant range. A cruise missile is a well-balanced system, with various forces and momenta that neutralize each other to guarantee stable flight conditions. Significant changes in warhead weight affect the position of the cruise missile’s centre of gravity, which might quickly lead to unintended consequences, for example increased drag due to increased efforts to balance out the shift of the centre of gravity, thus affecting range.

As a bottom line, payload weight certainly can be increased or reduced within limits, thereby increasing or reducing range – with the same airframe, propellant load and engine, a lighter missile will cover more distance than a heavier one.

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5 Treaty between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms (START), 31 July 1991, Annex on Terms and Their Definitions, https://2009-2017.state.gov/documents/organization/27362.pdf.

6 “The W80 Warhead”, Nuclear Weapon Archive, 29 August 2007, https://nuclearweaponarchive.org/Usa/Weapons/W80.html.

7 Missile Threat, “AGM-86 Air-Launched Cruise Missile (ALCM)”, Center for Strategic and International Studies, 31 July 2021, https://missilethreat.csis.org/missile/alcm.

Missile

Trajectories of cruise missiles can be modified to reduce their apparent range, but there are limits to the extent to which this can be concealed. The major problem for cruise missile range analysis is the size and load of the propellant tank.

Propellants

As mentioned above, cruise missiles have a small propellant tank compared to ballistic missiles. Where ballistic missiles actually are "flying fuel tanks", consisting of up to 90 per cent propellant, cruise missiles are like aeroplanes, and their propellant loads are much lower. Also, in contrast to ballistic missiles, cruise missiles use air-breathing propulsion, using external oxygen to burn fuel in flight, while rockets have to carry along not only their fuel, but also their oxidizer.

All this has several effects. If the cruise missile's design allows for it, fuel tank size can easily be increased significantly without any airframe modification, meaning that this cannot be seen from outside (unlike for ballistic missiles). Reduction of fuel tank size is also possible for any cruise missile, but is rather pointless.

Also, the propellant load of the standard-size fuel tanks can be easily reduced for flight demonstrations. Indeed, weight and balance have to be correct over the whole course of the missile's flight, meaning that an almost empty missile should also be capable of stable flight.

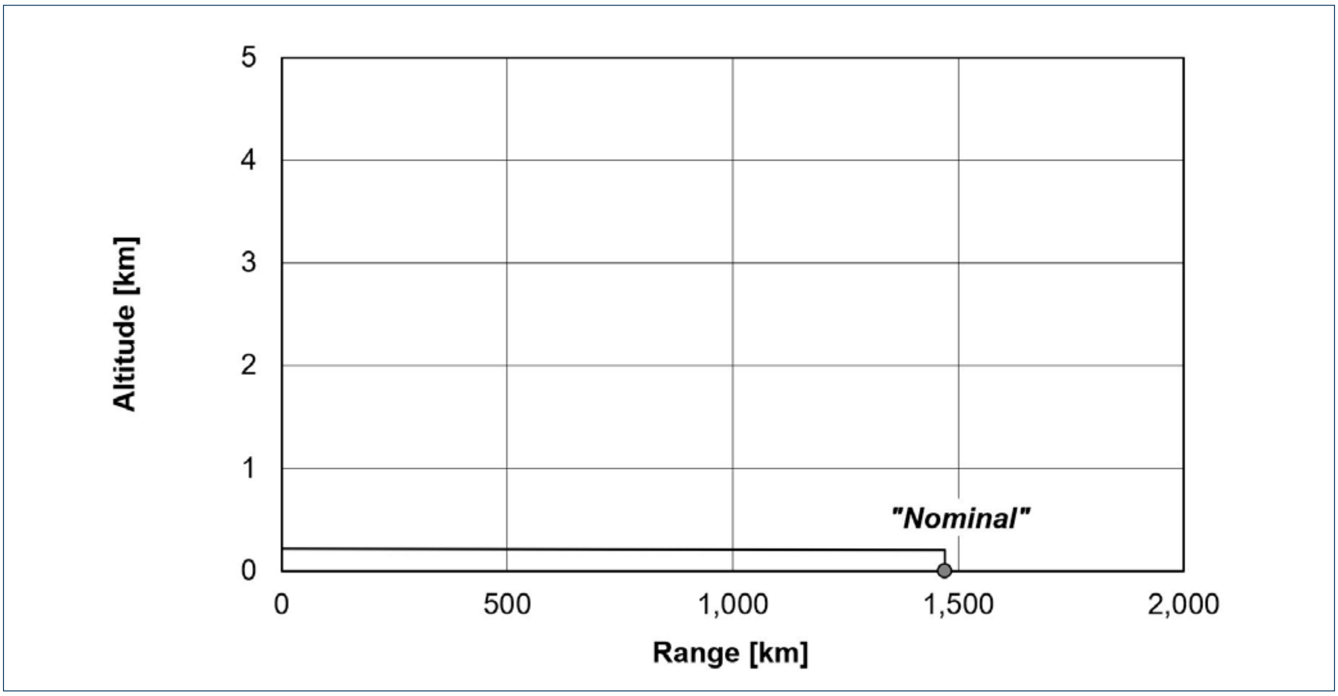
Increasing fuel tank size certainly has its limits with weight and balance, but the share of propellant in the total mass of the cruise missile is low. If a third of a cruise missile's launch mass is propellant mass, an increase of that mass by 25 per cent is not too complicated: for a 1.2-t missile with 400 kg of fuel, this means adding 100 kg to the launch mass – an increase of little more than 8 per cent to the launch mass of 1.2 t, but with a potentially significant gain of range. Moreover, finding the required extra 0.1 cubic metres of space within the airframe should not be that hard – for a cruise missile with diameter of 50 centimetres, this would be a section of just 60 cm length somewhere along the airframe, translating to perhaps 10 per cent of the total cruise missile length. And there is still the option of adding a small external tank.

Trajectories

Just like aeroplanes, cruise missiles are designed to operate within a flight envelope (that is, within certain limits on speed and altitude), and at an optimized point within that envelope. Straying from that point will always have an effect on the range. This could be done by flying at high altitudes instead of low altitudes, or at higher or lower speeds than the standard nominal cruise speed. However, while these effects may be significant at the extremes, they do not make much sense from an operational point of view.

Reducing a cruise missile's range down from nominal range by trajectory modifications is a trivial task. The cruise missile may simply switch off its engine early, it may just dive down and hit a target at short range (see figure 8 on the following page).

Figure 8. *Typical cruise missile trajectory*



Net mass

Just like ballistic missiles, cruise missiles are built with as light a mass as possible. The margins are more forgiving than with ballistic missiles (especially long-range ballistic missiles). However, it seems unlikely that significant amounts of net mass can be shaved off a demonstrated cruise missile to extend its maximum range. Exemplary missiles could, of course, be modified with additional weight, reducing their demonstrated range – there certainly is enough room within any cruise missile's airframe to do that. Again, the question is not if this is possible, but if it makes sense.

Environment

Environmental effects on cruise missile range are limited, the most significant being the wind. Cruise missiles are uncrewed aeroplanes flying at low altitude in the dense layers of Earth's atmosphere. They usually fly at subsonic speeds, around 700–900 km/hour, thus requiring up to 2 hours of flight to cover distances of more than 1,500 km. The speed is always optimized relative to the surrounding air; if the air is moving, the cruise missile is affected.

A constant breeze of 25 km/h against flight direction means that the cruise missile's speed relative to the ground is reduced by 25 km/h. Engine operations are limited to a given duration by the available fuel load. So, if the cruise missile has enough fuel onboard to operate for two hours and has a cruise speed of 750 km/h, it can cover a maximum range of 1,500 km in that time. With a 25 km/h headwind, effective speed drops to 725 km/h, and the missile can cover only 1,450 km before it runs out of fuel.

The same effect applies for a tailwind, of course, but range is extended instead of reduced. Since wind direction is unpredictable, for the purposes of determining the nominal range of a cruise missile, its effects can be disregarded.

Classifying range

While the insights above demonstrate the problems of defining the term "range" in relation to missiles, there have nonetheless always been common definitions of range classes for both ballistic and cruise missiles. Sometimes, the nominal "range" of a certain missile is close to the line between two categories, thus making it hard to clearly categorize. This is where political considerations usually come into effect, especially when talking about arms control efforts and treaties. Missile systems are then often categorized according to the intended result, and not according to detailed technical considerations. A famous example is the Soviet Oka (SS-23) ballistic missile system, which – according to Soviet handbooks – had a nominal range of 50–400 km but was nonetheless counted as having a range of over 500 km under the INF Treaty and had to be phased out.

Ballistic missiles are usually categorized as short range, medium range or long range. The use of these terms has evolved over the years (in Germany in the 1940s, the V2 missile with a range of 300 km was seen as a medium-range missile) and has also varied between arms control treaties. While there is no internationally binding definitions of missile ranges, the definitions currently used by the US Missile Defense Agency (MDA) are widely accepted (see table 1).[8]

Table 1. *Definitions of categories of missile range*

Category	Range
Short-range ballistic missile (SRBM)	<1,000 km
Medium-range ballistic missile (MRBM)	1,000–3,000 km
Intermediate-range ballistic missile (IRBM)	3,000–5,500 km
Intercontinental ballistic missile (ICBM)	>5,500 km

There also is the special category of submarine-launched ballistic missiles. For SLBMs, different range categories were never widely used. While modern SLBMs usually offer ranges beyond 5,500 km, thus “intercontinental range”, the earliest SLBMs had only very low ranges. For example, the first operational SLBM, the Soviet R-11FM (SS-N-1), had a nominal range of less than 170 km – but would nonetheless be classified alongside modern SLBMs. However, arms control treaties have sometimes treated them differently. START, for example, defined only missiles with a range beyond 600 km as SLBMs – but 600 km was an important treaty threshold also applied to define long-range air-to-surface ballistic missiles (ASBMs) and long-range ALCMs. In agreed statements made at the time of the treaty signature, this threshold was also used to define long-range sea-launched cruise missiles (SLCMs). In addition, the parties agreed to exchange information about the number of deployed SLCMs with a range of between 300 km and 600 km.

A different categorization was included in the INF Treaty, which prohibited the deployment of ground-launched ballistic and cruise missiles with a range between 500 km and 5,500 km. These missiles divided into two categories – intermediate-range missiles, with a range between 1,000 km and 5,500 km, and shorter-range missiles with a range between 500 km and 1,000 km.[9]

8 See for example “Targets and Countermeasures”, MDA Fact Sheet, 30 September 2020 https://www.mda.mil/global/documents/pdf/targets.pdf

9 Treaty between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles (INF Treaty), 8 December 1987, https://2009-2017.state.gov/t/avc/trty/102360.htm#text, Article II.

Additionally, cruise missiles are often categorized according to their cruise speed, widely ignoring their potential range. This leads to the terms subsonic, supersonic and hypersonic cruise missile.

In the end, while some terms such as ICBM, with its 5,500 km range threshold definition, are widely accepted and used, other classifications are expected to vary and change in the future, depending on their intended use and the treaties or other circumstances that they are defined for.

Verifying range

Given the factors outlined above, it should be obvious that there is nothing like a fixed "range" number for any missile. How range is actually affected, and may therefore vary, differs for ballistic missiles and cruise missiles. Therefore, verification issues for these two types of missile should also be addressed separately.

Ballistic missile range verification

A ballistic missile can be modelled with several parameters that are all linked one way or another, and according to physical laws and mathematical equations that define the performance of that missile. The most important parameters are the launch weight of the missile and the amount of propellant. Also important are the propellant mass flow and the burn time, which together determine the thrust of the rocket engine. Summarizing, to accurately verify the actual range potential of a given ballistic missile, the following parameters are required:

- Launch weight
- Propellant type
- Onboard propellant mass
- Propellant mass flow
- Nominal burn time
- Actual burn time at demonstrated flight

The accuracy of range predictions increases further with knowledge of the following parameters:

- Missile dimensions
- Propellant reserves or residuals
- Payload mass
- Thrust (at sea level and in a vacuum)

This may be done most easily by exchanging telemetry of launches. On-site inspections could be required to verify missile dimensions and propulsion details. Informed observers at test launches may help to verify if the missile was launched for nominal or maximum range and, if not, if the range achieved under given conditions can be used to get a better understanding of the missile's potential maximum range.

While the potential range of a missile may vary widely depending on the factors discussed above, a sufficient understanding of the listed parameters narrows down the range potential to a very small band. After all, the missile has to follow laws of physics, and these are well known.

The more information that is available, the more confident analysts can be in their range estimates. A crucial number related to test activities is the precise burn time of each rocket stage. Data on the altitude of that missile at cut-off may further help to refine the models.

Of course, range can still be significantly enhanced by switching from ballistic warheads to an aerodynamic glide vehicle or adding an additional stage at deployment. If that seems a likely option for the affected party, these issues also have to be addressed.

Cruise missile range verification

Cruise missile range can be verified by communicating the following parameters:

- Launch weight
- Missile dimensions
- Onboard propellant mass
- Fuel mass flow
- Nominal burn time
- Actual burn time at demonstrated flight

Again, accuracy may be increased with knowledge of the following:

- Wing dimensions and profile
- Propellant reserves or residuals
- Payload mass
- Thrust (at sea level)

Since fuel tank size has such a significant effect on a cruise missile's range, and the amount of onboard fuel can be easily varied without visible external modifications of the missile, verifying the tank size of a cruise missile is key to range verification. All other parameters are secondary to that. It is hard to think of another way to verify tank size beyond granting inspectors access to the missile.

Conclusion

In general, simply communicating range numbers, and pointing at distances covered by the missile at demonstration flights, is not sufficient for a resilient verification regime. There must be a certain degree of openness from the parties involved, requiring communication – and verification – of key parameters that significantly affect a missile's range.

In some cases, a very basic knowledge of a missile could satisfy the requirements of an agreement. For example, the size of a missile (and the number of stages of a ballistic missile) could provide an initial estimate of its capability. If a more accurate estimate is required, parties could exchange more detailed information about missile characteristics. For example, in START the United States and the Soviet Union exchanged some key characteristics of their ballistic missiles and developed an approach to verifying their throw-weight.

Another important element of START was the exchange of telemetry recorded during flight tests of ballistic missiles and a ban on encryption of the telemetry (with some exceptions). As discussed above, telemetry provides a reliable way of determining key parameters of a flight test and gaining confidence in the accuracy of the assumptions about the missile performance. If an exchange of telemetry information is considered too intrusive, parties could agree to provide a more limited set of data, for example, burn time and parameters of the trajectory of the missile.

Verifying the range capability of a cruise missile appears to be more challenging. Nevertheless, the same general approach could also be used in this case. Information about basic external characteristics of the missile, such as size and weight, would provide an initial estimate of its capability. This, however, would still leave uncertainty about the amount of fuel that the missile can be loaded with and therefore about its range. It is possible to develop a procedure that would verify the size of a fuel tank, but it would require fairly intrusive access to the missile. One potential option here is an agreement that would specify that, in the absence of access, all missiles would be assumed to carry a certain amount of fuel (as a fraction of weight or volume). If a party believes that this leads to an overestimate of the actual range of its missile, it will have to provide access to the missile that would demonstrate its actual capabilities.

In the end, it appears that classifying missiles by their range for the purposes of arms control has its limitations. Nevertheless, it is possible to develop verification arrangements that would provide parties with a good understanding of relevant capabilities of their missiles. These arrangements are likely to require a certain degree of transparency, but this transparency would also serve as an important element of a verification regime if it is implemented in a cooperative manner.

CHAPTER 2: Monitoring mobile missiles: lessons from US–Soviet arms control *Amy F. Woolf*[1]

Missiles deployed on mobile launchers create challenges for arms control. Difficulties are particularly evident in efforts to verify compliance with limits on their numbers or restrictions on their location.

To confirm compliance with an agreement that limits the number of mobile missiles, the parties would want to account for all the missiles deployed before the treaty entered into force, to monitor their numbers and locations during the implementation of the treaty, and to confirm their elimination as they completed any required reductions. The mobility of missiles could make it difficult for the parties to count each unique missile and confirm that all unique missiles were counted.

If an agreement limited the numbers or restricted the locations of permitted missiles, but allowed additional missiles to deploy outside those locations, then the parties would want to ensure that missiles legal in an area were not moved into another in which the numbers were limited. However, the mobility of missiles permitted outside the restricted locations would complicate efforts to distinguish them from missiles subject to a limit and would create opportunities to conceal extra missiles in restricted areas.

It is certainly possible to conceive of monitoring mechanisms that would provide the parties with the information and access needed to address these challenges. However, a monitoring regime that identified and tracked all legal missiles, assured access to information about all locations that might hide illegal missiles, and created impenetrable barriers to the movement of excess missiles into restricted areas would be likely to prove too intrusive, expensive and politically fraught for inclusion in a negotiated arms control agreement. For example, to identify and count each unique missile, the parties could attach sensors to each one, identifying the number of missiles in existence and tracking them during the implementation of the treaty. But such sensors might also allow the parties to track and target the missiles if a conflict were to occur, a situation that would likely be untenable for all parties.

In addition to ensure that illegal missiles had not been stored at hidden locations, the parties could agree to permit short-notice on-site inspections at any location where they suspected the storage of illegal missiles. But such a scheme would certainly prove too intrusive if it allowed inspectors access to a full range of military facilities in another country regardless of their relationship to the deployment of mobile missiles or the limits in the agreement. An arrangement of this kind was, in fact, included in the 1990 Conventional Armed Forces in Europe (CFE) Treaty, which allowed the parties to conduct a limited number of challenge inspections at specified types of site.[2] That treaty, however, primarily dealt with relatively large military units that could include hundreds of items of heavy military equipment, such as tanks, which limited the range of facilities that would be liable to an inspection of this kind. In the case of missiles, especially nuclear-armed ones, this approach would indeed be too intrusive.

1 The author is a Specialist in Nuclear Weapons Policy at the Congressional Research Service at the United States Library of Congress. The views expressed here are her own and are not necessarily shared by the Congressional Research Service or the Library of Congress.

2 J.P. Harahan and J.C. Kuhn, On-Site Inspections Under the CFE Treaty: A History of the On-Site Inspection Agency and CFE Treaty Implementation, 1990–1996, US On-Site Inspection Agency, 1996, https://www.dtra.mil/Portals/61/Documents/History/On-Site Inspections CFE Treaty--final.pdf.

The United States and the Soviet Union confronted these issues when they negotiated the 1987 Intermediate-range Nuclear Forces (INF) Treaty and the 1991 Strategic Arms Reduction Treaty (START). In the INF Treaty, they agreed to ban all intermediate- and shorter-range ballistic and cruise missiles (those with ranges between 500 and 5,500 kilometres). In START, they agreed to limit the numbers and restrict the locations of deployed mobile intercontinental ballistic missiles (ICBMs) and to limit the numbers and locations of spare mobile missiles and launchers in storage. To manage these challenges, they developed verification regimes that combined collateral constraints on the locations and movement of mobile missiles with cooperative monitoring mechanisms both to confirm that forces were consistent with the limits in the treaty and to detect and deter potential violations. These provisions did not provide the two parties with perfect knowledge of the numbers of permitted missiles or complete confidence in the absence of illegal missiles, but they did create a structure that offered enough confidence in compliance to allow the parties to sign and implement agreements that imposed limits on missiles deployed on mobile launchers.

This chapter provides an overview of the measures adopted in the INF Treaty and START. It reviews the ways in which these measures addressed the challenges of mobile missiles and the goals of monitoring and verification. It then reviews possible "lessons learned" for other arms control initiatives.

Monitoring mobile missiles in the INF Treaty and START

The verification regimes of the INF Treaty and START rested on a foundation set by the limits, restrictions and procedures outlined in the treaty texts. By describing the parties' obligations and providing detailed definitions of the treaty-limited items, the text identified the forces and activities that complied with the terms of the treaty. The details and specific processes included in the text not only guided implementation, but also helped the parties focus on what they should look for when monitoring the other country's forces and activities. Hence, compliance with the treaty limits required not only reaching the required outcome but following a scripted process to do so. The INF Treaty and START also contained a number of complementary, and sometimes overlapping, cooperative monitoring mechanisms. These location restrictions, data exchanges, notifications, exhibitions and on-site inspections were designed to account for missiles limited by the treaties, confirm the absence of missiles in excess of those captured by the official saccounts and complicate efforts to exceed the limits in the treaty.

The INF Treaty

The INF Treaty obligated the United States and the Soviet Union to eliminate their land-based intermediate- and shorter-range missile systems (those with ranges between 500 km and 5,500 km) within a three-year elimination period.[3] It also mandated that the parties eliminate the launchers for these missiles, along with the support structures and support equipment associated with the banned missiles. The treaty identified the specific procedures that the parties had to use to eliminate banned systems and specified the locations where these eliminations had to occur. It also mandated that, prior to elimination, the parties locate all intermediate- and shorter-range missiles and their launchers in designated deployment areas or missile-support facilities, unless they were in transit between designated facilities. They could not locate these missiles at other facilities that were not defined by and listed in the

3 Treaty between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-Range and Shorter-Range Missiles (INF Treaty), 8 December 1987, https://2009-2017.state.gov/t/avc/trty/102360.htm#text.

treaty. The treaty also prohibited the production and flight testing of any intermediate- or shorter-range missile, precluding their return to the force in the future.

The ban on all land-based intermediate- and shorter-range missiles, their launchers, their supporting infrastructure, and any future flight tests simplified the task of monitoring compliance with the treaty because any missile found anywhere in the parties' territories after the three-year elimination period would violate the treaty. The parties did not have to identify and count missiles as they entered the force because any evidence of new production would be a violation. They did not have to detect or deter efforts to move legal missiles from other regions into the area where the missiles were limited because the missiles were banned everywhere. The United States and Soviet Union also did not have to distinguish between missiles armed with nuclear warheads and those armed with conventional warheads as the treaty banned both. The task, then, for the monitoring regime was to identify all missiles in existence when the treaty entered into force, confirm their elimination according to treaty-mandated procedures, confirm that none of these missiles or their launchers had been removed to secret locations, and confirm that no new missiles were produced or tested after the treaty entered into force.

Identifying and accounting for declared systems

Memorandum of Understanding on data

The cooperative monitoring mechanisms in the INF Treaty began with an extensive exchange of data. The Memorandum of Understanding (MOU) on data listed all the facilities associated with missiles limited by the treaty and the number of missiles present at each of these facilities when the treaty entered into force. The MOU described several characteristics of each missile system and its support equipment, including their length, diameter and weight. It also described the geographic boundaries associated with each facility. The parties provided periodic updates of this data and notified each other when that data changed. This process allowed each party to account for all systems covered by the agreement without requiring the other party to actually count each unique missile.

The INF Treaty also permitted the parties to conduct various types of on-site inspection to confirm the MOU data. These inspections could occur only at facilities listed in the MOU; inspectors could not visit other sites, even sites that might have the capacity to store or support hidden missiles.

Baseline inspections

The INF Treaty permitted each side to conduct initial baseline inspections at deployment, storage, repair, and elimination facilities listed in the MOU.[4] During these inspections, the teams counted missiles and launchers, measured the systems, and compared them with the photographs provided in the MOU. When possible, the inspectors also filled in details on the diagrams describing the layout of the facilities.

Notifications and elimination inspections

According to the INF Treaty, both the United States and the Soviet Union had to notify each other, at least 30 days in advance, when they planned to eliminate INF systems. This notice had to describe the numbers and types of items (missiles, missile stages, launchers or support equipment) that would be eliminated, the site where the elimination would occur, and the sites from which the items were moved to the elimination facility. The other party could then use national technical means (NTM) to monitor the movement

4 US On-Site Inspection Agency, A Guide to INF On-Site Inspections, Reprinted in US House of Representatives, Committee on Foreign Affairs, "On-Site Inspection Agency", January 1989, p. 11.

of the missiles, launchers and support equipment, and their elimination.

The parties could also send inspection teams to observe the process and confirm that the systems had been eliminated.[5] At the start of an elimination inspection, the inspectors counted, measured and inspected the missiles, launchers and support equipment at the elimination site to confirm the information provided when they were notified of the elimination. The inspectors maintained a constant watch over these items to ensure that those identified before the process began were the same as those that were eventually destroyed. The inspectors also watched the actual elimination process and inspected the items after the process was completed in order to confirm that the procedures and requirements outlined in the treaty's Protocol on Elimination had been satisfied.[6]

Deterring violations at declared facilities

Location restrictions, data exchanges and short-notice quota inspections

The INF Treaty included several cooperative measures designed to complicate efforts to maintain a militarily useful force of illegal INF missiles. Each party was required to locate all INF systems at declared facilities and notify the other when it moved its systems. The other party could then focus its NTM assets to monitor the movement, which helped it track the number and location of declared missiles. This might also have deterred attempts to divert the systems to hidden storage or deployment areas or to move illegal missiles into the declared facilities, as NTM might detect activities that were not consistent with details provided in the required notifications

The INF Treaty also permitted the parties to conduct a limited number of inspections at facilities listed in the MOU to confirm the expected presence or absence of treaty-limited items. These short-notice inspections provided the parties with the opportunity to confirm changes listed in the MOU and to detect evidence of any efforts to conceal extra missiles at the facilities. Inspectors could visit all the declared missile-operating bases and missile-support facilities, including the operating bases and support facilities that had been eliminated according to the procedures outlined in the treaty. The inspecting country could provide less than 24 hours' notice when it intended to visit a facility. After receiving notice of the inspection, the officials at the facility could not move any items limited by the treaty into or out of the facility. Consequently, they probably could not have concealed the absence of declared items or the presence of illegal items in the time before the inspection team arrived. The parties could conduct these inspections during the treaty's 3-year elimination period and for 10 years after that period to confirm that these facilities remained free of items banned by the INF Treaty.

Perimeter portal continuous monitoring

The INF Treaty permitted both the parties to monitor continuously for up to 13 years the portal outside one missile-assembly plant in the other party. This provision was designed to assure both sides that production of missiles that were limited by the treaty – in particular the Soviet RSD-10 (SS-20) and the US Pershing II – had ceased. All vehicles that could carry intermediate-range missiles or the longest stage of such a missile had to leave the facility through a single entrance. The rest of the facility was surrounded by a perimeter fence. When a vehicle large enough to include either an intermediate-range missile or the longest stage of such a missile left the facility, the inspectors could measure and visually inspect the outside of the vehicle and use remote sensors to collect

5 Ibid, p. 11.
6 Protocol on Procedures Governing the Elimination of the Missile Systems Subject to the Treaty between the United States of America and the Union of Soviet Socialist Republics on the Elimination of Their Intermediate-range and Shorter-range Missiles, 8 December 1987, https://2009-2017.state.gov/t/avc/trty/102360.htm#elimination.

an image of the items inside the vehicle. The inspectors could also open such a vehicle and visually inspect the items inside eight times each year without providing the host country with any advance notice. This provision was designed to deter efforts to ship illegal missiles because there was a chance that the inspectors would ask to open the vehicle carrying an illegal missile.

This did not prevent production of banned missiles at other facilities. But the combination of the cost of converting those facilities, the possibility that NTM would detect efforts to ship out those missiles and the random inspections that would keep the missiles away from declared infrastructure was thought to deter such efforts.

Deterring violations outside declared facilities

The INF Treaty only permitted on-site inspections at facilities listed in the MOU. The inspections would not have detected violations if a party had tried to use any other military facilities to support INF systems, had secretly constructed new facilities to produce and maintain INF systems, or had hidden illegal missiles in secret storage areas. Nonetheless, because the on-site inspections were designed to complicate efforts to violate the treaty at declared facilities, they did contribute to the deterrent effect created by the rest of the verification regime. When combined with the ban on all flight tests of intermediate- and shorter-range missiles, the eventual elimination of equipment and structures needed to support INF systems, and the possibility that NTM might detect evidence of secret facilities or illegal missiles, the on-site inspections helped increase the costs of producing and maintaining a significant force of illegal missiles and reduced the military utility of any missiles that the countries might retain in violation of the INF Treaty.

START

START imposed limits on US and Soviet strategic offensive forces – ICBMs, submarine-launched ballistic missiles (SLBMs) and heavy bombers.[7] It limited both the number of strategic nuclear delivery vehicles – the missiles and bombers – and the number of warheads that could be carried on those delivery vehicles.[8] The parties could deploy no more than 6,000 warheads on 1,600 strategic offensive delivery vehicles, including no more than 4,900 warheads on land-based ICBMs.[9] The treaty also included a number of additional limits, one of which required the parties to have no more than 1,100 warheads on missiles deployed on mobile launchers.

START contained a number of provisions in the treaty text that were designed to help the parties count the numbers of deployed mobile missiles. While these provisions applied to both parties, when the treaty entered into force in 1994, the only party that had deployed mobile missiles was Russia. It operated road-mobile Topol (SS-25) missiles

7 Treaty between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms (START), 31 July 1991, https://2009-2017.state.gov/documents/organization/27360.pdf.

8 The treaty also limited the amount of throw-weight permitted on ballistic missiles. Throw-weight is the combined weight of the post-boost vehicle, warheads, guidance system, penetration aids and other equipment on the front end of a missile. It is considered to be a measure of a missile's destructive capacity because larger missiles with greater throw-weight can carry larger warheads or a greater number of warheads than smaller missiles. See also chapter 1.

9 START used counting rules that attributed a number of warheads to each type of missile and bomber in order to calculate the number of warheads deployed in each party's force. The number of warheads attributed to ICBMs and SLBMs usually equalled the number actually deployed on that type of missile. But bombers equipped with cruise missiles counted as half the number of warheads they were permitted to carry. Thus, each US bomber counted as 10 warheads, even though it could carry up to 20 weapons; and each Soviet/Russian bomber counted as 8 warheads, even though it could carry up to 16 weapons. A bombers that was not equipped to carry cruise missiles counted as 1 warhead, regardless of the number of weapons that it could carry.

and a rail-mobile version of the RT-23UTTH (SS-24) missile. The latter was withdrawn from service in the early 2000s.

As had been the case in the INF Treaty, the parties agreed to deploy mobile missiles only at designated deployment areas and to limit the number of structures that could house missiles at those locations. START also limited the numbers of mobile missiles and launchers that could be held in storage. Each side could retain 250 missiles and 110 launchers for mobile ICBMs, with no more than 125 missiles and 18 launchers for rail-mobile ICBMs. These limits were designed to limit "break-out" potential by limiting the number of missiles that could be added to the deployed force in a relatively short period of time.

Because START permitted a limited number of deployed and non-deployed mobile missiles, the challenges for the verification regime were different from those under the INF Treaty. Under START, the parties not only had to count the number of mobile missiles (and calculate the number of warheads attributed to those missiles) deployed when the treaty entered into force; they also had to keep track of the number of deployed missiles for 15 years, while the treaty remained in force. They had to confirm the number of non-deployed missiles and launchers retained in storage and ensure that those missiles and launchers were not moved into the deployed forces. And, as was the case in the INF Treaty, they had to be sure that missiles deployed before the treaty entered into force were not concealed within or outside the permitted infrastructure. In addition, because the deployed missiles were allowed to leave their designated operating bases to conduct operational exercises, the treaty had to provide the parties with the means to ensure that hidden, uncounted missiles did not enter the force by mixing with permitted missiles during those exercises.

Identifying and accounting for declared systems

Memorandum of Understanding on data

As with the INF Treaty, the cooperative monitoring process in START began with an extensive exchange of data in a Memorandum of Understanding that listed all the facilities associated with delivery vehicles limited by the treaty and the number of delivery vehicles present at each of these facilities. It contained data on the characteristics of each missile system and its support equipment, including their length, diameter and weight. It also described the geographic boundaries associated with each facility. The parties provided notifications any time they moved treaty-limited delivery vehicles between listed facilities and updated the entire database every six months. As with the INF Treaty, this process allowed the parties to account for all systems covered by the agreement without requiring that they actually track each unique missile.

Baseline inspections, notifications and data-update inspections

START also permitted each side to conduct initial "baseline" inspections at deployment, storage, repair, test and launcher-production facilities listed in the MOU to confirm the accuracy of data on the numbers and types of items specified for each facility in the initial exchange of data. Each party had to notify the other when it moved any treaty-limited item from one designated facility to another. The other party would be likely to monitor this movement with NTM, but each party could also conduct 15 short-notice data-update inspections each year to confirm the accuracy of updated data on the numbers and types of items specified for such facilities. The treaty also allowed the parties to conduct these short-notice inspections at "suspect sites" that might house or support systems limited by the treaty.

These did not permit inspections at any facility or location that might raise concern but referred to a few select facilities that had supported missiles similar to those limited by the treaty in the past. These inspections combined with the data included in the MOU to provide the parties with the ability to count and keep track of the numbers and locations of all the strategic offensive delivery vehicles limited by START, and, therefore, provided baseline accounting for the number of mobile missiles.

Perimeter and portal continuous monitoring

START permitted each party to establish continuous monitoring around the perimeter and outside the portals of one final assembly facility for mobile missiles in the other country. This allowed these missiles to be counted as they left the facility and moved into the force.[10] Although the United States used the same perimeter-monitoring system under START that it had installed under the INF Treaty, the goals were different. Under the INF Treaty, the system was designed to deter and detect any effort to produce secret INF missiles, so the goal was to confirm the absence of such missiles in shipments leaving the facilities. Under START, the goal was to confirm the presence of the first stages of mobile missiles and provide an accurate count of the numbers of these systems leaving the facilities.

START mandated that each party should provide notifications when missile stages bound for deployment left the assembly facility and when they arrived at other facilities within the permitted infrastructure. This provided the other party with the data needed to use NTM to track the shipment and make sure that it was not diverted to hidden storage areas, where it might evade the treaty limits. Counting the missiles as they passed through the portal at the assembly facility added confidence to this process. If a party sought to add covert missiles to its force and failed to provide notification when the missiles left the assembly facility, the portal monitors might detect the shipment. Thus, these systems also helped deter efforts to conceal extra mobile missiles outside the permitted infrastructure.

Unique identifiers

Under START, the parties were required to attach a unique numerical identifier to each ICBM that could be deployed on a mobile launcher and each mobile launcher that could deploy with an ICBM. The treaty indicated that this unique identifier would be a "non-repeating, alpha-numeric production number, or a copy thereof".[11] The parties applied such serial numbers to each missile and launcher during the production process, before it entered the deployed force. They recorded them, both for mobile missiles in existence when the treaty entered into force and for new missiles as they left the production facilities, in the MOU on data.

The serial numbers helped the parties track the numbers of deployed mobile missiles and deter the deployment of covert missiles within the permitted infrastructure. The parties could check the serial numbers on selected missiles during their periodic data-update inspections, thus confirming that the missiles they encountered were those that they expected to see at the facility during the

10 The perimeter/portal continuous monitoring systems (PPCMS) consisted of fences surrounding the entire perimeter of the facility and one restricted portal through which all vehicles large enough to carry items limited by the treaty (such as the first stage of a mobile ICBM) had to pass. The portal contained scales and other measuring devices that the monitoring party could use to determine whether the vehicle carried an item limited by the treaty. Although the United States did not deploy any missiles on mobile launchers, it had considered doing so with the MX (Peacekeeper) ICBM. As a result, START allowed the Soviet Union to establish a PPCMS system around the missile's final assembly facility in Magna, Utah.

11 Protocol on Inspections and Continuous Monitoring Activities Relating to the Treaty between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms, Annex 6, "Procedures Relating to Unique Identifiers", https://2009-2017.state.gov/documents/organization/27371.pdf, para. 1.

inspection. Even without viewing and confirming the number on each missile at an operating base or support facility, this process would deter efforts to bring extra missiles into the facility because they might be discovered during a short-notice inspection.

Deterring violations at declared facilities

Mobile missiles presented a unique monitoring concern because the missiles could leave their operating bases when moving to support facilities and when conducting exercises. It could be difficult for the other party to track these missiles when they moved outside their bases or to ensure that the missiles arriving at a support facility or returning after an exercise were the same as those that had left the operating base at the start. Consequently, these movements might provide an opportunity to mix previously hidden, undeclared missiles with the deployed force in the declared infrastructure.

Exercises and post-exercise dispersal inspections

To address these concerns, START restricted the movements of both road- and rail-mobile missiles, allowing rail-mobile missiles to leave the restricted area of their operating base only for routine movements, relocations or dispersals, and road-mobile missiles to leave their deployment areas only for relocations or operational dispersals. The treaty also mandated that the parties provide notifications when the missiles left their operating bases and when they arrived at alternative facilities. In addition, to provide the parties with confidence that extra road-mobile missiles were not located at a declared operating base, each party could request that the other display the mobile missiles on their launchers in the open, either next to or halfway out of their fixed launch shelters, with the roofs open to demonstrate that there were no additional missiles inside.

START also limited the number of exercise dispersals that the parties could conduct and mandated that they provide notifications, both before and after the exercise, when mobile missiles moved out of their main operating bases for this purpose. Each party could conduct inspections after the conclusion of an exercise by the other party to confirm that the number of mobile missiles and launchers located at the inspected ICBM base did not exceed the number specified for that base. This not only deterred the addition of extra missiles to the force, but also discouraged possible attempts to remove permitted missiles so that they would not count against the treaty limits.

START recognized that exercise dispersals could potentially interfere with routine on-site inspections. It specifically indicated that these dispersals could not be conducted during the time allowed for baseline inspections or inspections to confirm the number of missiles deployed at new facilities. They could also not occur at a base that the other party had already designated for a data-update inspection until that inspection was complete. On the other hand, the inspecting party could not request data-update inspections at a base for mobile missiles after the other party had provided notification of its intent to conduct an exercise dispersal. Thus, the parties could not use exercise dispersals to disrupt a data-update inspection that might reveal excess missiles at a deployment area, but they also could not use data-update inspections to disrupt a dispersal exercise even if they suspected it was being used as cover for covert missile activities.

Elimination inspections

START, like the INF Treaty, also mandated that missiles and launchers removed from the force had to be eliminated according to specific procedures outlined in the treaty. The other party could then conduct inspections at the elimination facility to determine that the procedures were followed and that the elimination was complete. This not only helped the parties keep an accurate count of the deployed missiles but served as a further deterrent to efforts to hide extra missiles outside the treaty regime.

Prospects for future limits on mobile missiles

Lessons from the INF Treaty and START

Even with these complex and detailed verification regimes, the United States and Russia discovered gaps during the implementation of START and the INF Treaty. In most cases, the parties worked together in the compliance commissions established by the treaties to resolve their differences and fill the gaps.[12] For example, in one case under START, a road connecting two areas of a single facility had not been included on the site map for that facility. Technically, moving treaty-limited items along that road without providing a notification would violate the treaty, but the parties addressed the issue by altering the map of the facility to include the road within its boundaries. Moreover, the treaty provisions governing the overlap between exercise dispersals and data-update inspections apparently did not preclude disputes in that area. Rose Gottemoeller, the US negotiator for the 2010 New Strategic Arms Reduction Treaty (New START), notes in her recent memoir that Russia's ability to "flush the mobile missiles out of range of our inspectors once an inspection had been announced … had led to many frustrated exchanges in the Joint Compliance and Inspection Commission".[13] The treaty indeed allows such dispersals within an one-hour window, so this kind of activity was not a technical violation of the treaty obligations. It should be noted, however, that these actions are visible and if they become persistent and are not resolved through the treaty consultative bodies, they would certainly affect a party's judgement regarding the other's commitment to the agreement.

Proposals for future limits

The question of verifying various limits on mobile missiles has a practical dimension. After the United States announced its withdrawal from the INF Treaty in 2019, Russian President Vladimir Putin stated that Russia would not deploy intermediate- or shorter-range weapons in "Europe nor anywhere else until US weapons of this kind are deployed to the corresponding regions of the world".[14] He later proposed a formal moratorium on the deployment of INF missiles in Europe. US and North Atlantic Treaty Organization (NATO) officials dismissed these gestures, noting that Russia had already deployed the 9M729 (SSC-8) missile within range of European territory. Although Russian officials have asserted that the 9M729 missile was in full compliance with the INF Treaty, President Putin offered to include it in the moratorium. The Kremlin stated that Russia "is ready, in the spirit of good will, to continue not to deploy 9M729 missiles in [the] European part of the territory of Russia, but only provided that NATO countries take reciprocal steps".[15] At the same time, Russia suggested that the former parties allow bilateral inspections so that the Russians could confirm the absence of land-based cruise missiles at the US Aegis Ashore missile defence sites in Poland and Romania and the United States could confirm the absence of 9M729 missiles in the Russian exclave of Kaliningrad.

The United States and other NATO members did not engage with Russia on its proposal, in part because it lacked specifics on how the parties would monitor the moratorium and because the apparent focus on inspections would be limited to Kaliningrad, at least

12 These were known as the Special Verification Commission (SVC) in the INF Treaty and the Joint Compliance and Inspection Commission (JCIC) in START.

13 R. Gottemoeller, Negotiating the New START Treaty, May 2021, p. 130.

14 President of Russia, "Meeting with Sergei Lavrov and Sergei Shoigu", 2 February 2019, http://en.kremlin.ru/events/president/news/59763.

15 President of Russia, "Statement by Vladimir Putin on Additional Steps to De-escalate the Situation in Europe in the Wake of the Termination of the Intermediate-Range Nuclear Forces Treaty (INF Treaty)", 26 October 2020, http://en.kremlin.ru/events/president/news/64270.

initially.[16] Even though subsequent statements by Russian officials suggested that the verification measures would cover all European Russia, NATO responded that the moratorium "would not prevent Russia from building up such missiles outside of its European territory" and therefore cannot be accepted.[17] The idea of replacing the INF Treaty, or at least reviving some of its restrictions, with a ban on intermediate- and shorter-range missiles in Europe has enjoyed some support in analytic circles, but its practical implementation would require development of robust verification measures.

Others have suggested that the United States should consider a replacement for the INF Treaty that bans only nuclear-armed intermediate-range missiles, without affecting missiles with conventional warheads. Both the regional intermediate-range missile ban and the nuclear-only INF ban would allow the United States (and presumably Russia) to deploy conventional intermediate-range missiles in Asia, in response to China's growing capabilities, while protecting Europe from a return to the instability and insecurity associated with nuclear-armed intermediate-range missiles in the 1980s.[18]

Each of these proposals suggests that the United States and Russia could use on-site inspections similar to those permitted by the INF Treaty to confirm the absence of missiles or warheads banned by the new prohibitions. In each proposal, the parties would declare their intent to prohibit the deployment of specified items at designated sites, then allow inspectors to visit those sites to confirm the absence of those items. These proposals are, obviously, intended to be illustrative, so they do not offer any details on how those inspections would work or whether they would be incorporated into a more comprehensive verification regime. But they seem to overestimate the value of on-site inspections in the INF Treaty and misunderstand their role in its monitoring and verification regime. Moreover, many of these proposals seem to assume that on-site inspections could provide confidence in compliance because inspectors would be able to get a close-up look at actual deployments. But, as the US–Soviet experience with the INF Treaty and START shows, inspectors did not actually have the ability to wander around a declared site and search for prohibited items or activities. The on-site inspections were the last step in a monitoring process that began with a detailed exchange of data and incorporated specific, and often quite limited, rules about how to conduct the inspections.

Conclusion

There is little doubt that the United States and the Soviet Union would have been unable to conclude the INF Treaty and START without their agreement to include cooperative monitoring mechanisms in the treaties' verification regimes. But these measures did not stand alone. They were anchored in treaty text that included not only the central limits but also detailed definitions, collateral constraints and procedural requirements. They were embedded in a process that included remote monitoring conducted without cooperation from the other side; shared data and notifications that established a baseline and generated updates on the status of missiles

16 Ibid.

17 "Владимир Ермаков: мы пока не знаем, что на уме у команды Байдена" [Vladimir Yermakov: we do not yet know what Biden's team has in mind], RIA Novosti, 25 December 2020, https://ria.ru/20201225/ermakov-1590913968.html; and North Atlantic Council, "Brussels Summit Communiqué", 14 June 2021, https://www.nato.int/cps/en/natohq/news_185000.htm.

18 See, for example, R. Gottemoeller, "Rethinking Nuclear Arms Control", Washington Quarterly, vol. 43, no. 3, 2020, pp 139–159, https://doi.org/10.1080/0163660X.2020.1813382. See also A. Vershbow, "Reflections on NATO Deterrence in the 21st Century", in Policy Review Roundtable: The Future of Trans-Atlantic Nuclear Deterrence, Texas National Security Review, 23 August 2021, https://tnsr.org/roundtable/policy-roundtable-the-future-of-trans-atlantic-nuclear-deterrence/#essay4.

limited by the treaties; and allowed on-site visits to facilities that supported treaty-limited missiles. Even with this comprehensive web of provisions and monitoring mechanisms, the parties recognized that they would not be able to collect perfect, unambiguous information about the other side's forces and activities. Nevertheless, they concluded that the process would allow them to gather the data needed to assess compliance, detect militarily significant violations in time to respond, and deter violations by increasing the cost and complexity of evading the limits in the treaties.

Nonetheless, gaps in a verification regime discovered during implementation can raise concerns about the other side's intentions and can undermine confidence in compliance with the treaty. Negotiating an agreement without a comprehensive web of restrictions and cooperative measures, and essentially accepting that some gaps will exist in the monitoring process, will almost certainly undermine confidence and reduce the value of the resulting agreement. Moreover, efforts to implement such an agreement, in spite of such ambiguities, could undermine support, more generally, for arms control as a means to address challenges to international security.

CHAPTER 3: Distinguishing between nuclear and conventional missiles *Christine Parthemore*

With the demise of past nuclear arms control treaties and numerous on-going geopolitical changes, it is important to think expansively about the potential shape of future agreements and how they might be verified. One option that warrants exploration focuses on building confidence that specific systems or items in specific locations at a given time are not nuclear armed or that certain delivery systems are not capable of carrying nuclear weapons.

This chapter explores various aspects of what might constitute a toolkit for verification in this regard along with examples of circumstances in which they might apply. This assumes, of course, that states are prepared to accept an obligation to denuclearize their systems as part of an agreement or perhaps as a unilateral commitment. This chapter offers a list of options that may be combined to best suit specific circumstances in which countries wish to demonstrate their adherence to a commitment or obligation of this kind. Specific approaches will, of course, depend on the specific obligation and on the degree of transparency and access.

This examination begins with a brief overview of the conditions that are making it more salient to develop verification concepts related to determining whether or not specific items, systems or bases are nuclear capable. It then discusses options that reflect the various degrees of nuclear–conventional entanglement – both technological and geographic – that may exist, showing the value of nuclear-armed states reducing entanglement as much as possible. The chapter then highlights various approaches to the use of observable differences in raising confidence that specific assets are not nuclear capable, followed by a brief section offering several next steps in deepening our understanding of how to verify lack of nuclear capability in the future.

Future need for verifying nuclear capability

Several trends in the global security environment are driving a need to develop concepts for how nuclear-armed states might demonstrate that specific military systems are not nuclear armed or that certain sites are not capable of hosting nuclear weapons. Some states are moving away from the approach of specific missile types being associated solely with conventional or nuclear weapons, which may raise the bar for countries trusting in future arms control measures. The world is also now in an era with almost no nuclear arms control treaties for curtailing or eliminating highly destabilizing dual-capable systems. There is also a strong possibility that future arms control measures may focus solely on nuclear forces while allowing for conventional variants of the same or similar delivery systems.

Advancements in missile capabilities – a trend seen for multiple nuclear-armed states – are also making it even more imperative that states re-establish firm lines between conventional and nuclear strategic forces. Toward the end of the Cold War, for example, the United States Navy specifically focused on increasing the accuracy of its submarine-launched ballistic missiles (SLBMs). This has led some analysts to conclude that, if today's Trident missiles of the United States and the United Kingdom were armed with conventional warheads, then their accuracy would make them of higher utility than their nuclear counterparts of the past, at least in some circumstances. Indeed, the United States has considered using the Trident missile (as well as land-based intercontinental ballistic missiles, ICBMs) in its conventional Prompt Global Strike programme.[1] Other states have also increased the accuracy of their delivery systems that could be deployed with either nuclear or conventional warheads if they decide to pursue such dual capability.[2] All together, these trends are introducing risky new dynamics that may increase the stabilizing power of measures that prove that specific systems are not intended to carry nuclear payloads.

Past arms control agreements included various measures to limit deployed nuclear weapons or overall nuclear arsenals, including limits on locations, ranges, numbers and types of weapons. After successes from several US–Soviet and US–Russian agreements in reducing the numbers of deployed systems and total nuclear warheads, today many concepts that have been envisioned for future nuclear arms control measures focus on agreements not to arm specific delivery systems with nuclear weapons while allowing parties to retain the capability to keep conventionally armed variants of these systems. These include calls for a follow-on to the 1987 Intermediate-range Nuclear Forces (INF) Treaty that would limit only nuclear-armed missiles and include an agreement not to arm cruise missiles with nuclear warheads (either specific variants or all such missiles).

There are a number of options within this general type of approach as well. One possibility is to prohibit deployment of nuclear-armed variants of certain missiles within a specific geographic area. For example, in a recent statement, the North Atlantic Treaty Organization (NATO) affirmed that it has "no intention to deploy land-based nuclear missiles in Europe".[3] Another commitment that can, in principle, be verified is the one made in the agreement between Australia, the United Kingdom and the United States to provide nuclear-powered submarines to Australia, in which the parties stated that these submarines will not be armed with nuclear weapons.[4]

These types of commitment assume that, even if nuclear-armed missiles are not present in a certain region, they could be deployed elsewhere. If countries are allowed to retain some number of nuclear-armed missiles of a certain type (as opposed to a full ban on such nuclear weapons), they will still possess the infrastructure and personnel to design, test, manufacture, move and secure these weapons. If some number of nuclear-armed missiles is permitted, verifying the absence of deployed nuclear-armed missiles in a certain region would be rather difficult and potentially quite intrusive.

This complexity is contributing to a focus on arms control measures that would outright ban all nuclear missiles of a specific type, for example air-, ground- or sea-launched cruise missiles, as this would be easier to verify. Such measures could be effective in the absence of conventionally armed missiles of the same type – or if the possessing states are willing and able to demonstrate solely conventional arming.

Countries that possess nuclear weapons will remain theoretically capable of arming most delivery systems with nuclear arms even if they have agreed not to do so. The question then turns to the relative ease or difficulty

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1 A.F. Woolf, "Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues" US Congress, Congressional Research Service, 16 July 2021, https://crsreports.congress.gov/product/pdf/R/R41464/52.

2 J.M. Acton, Is It a Nuke? Pre-Launch Ambiguity and Inadvertent Escalation, Carnegie Endowment for International Peace, 2020, https://carnegieendowment.org/files/Acton_NukeorNot_final.pdf.

3 North Atlantic Council, "Brussels Summit Communiqué", 14 June 2021, https://www.nato.int/cps/en/natohq/news_185000.htm.

4 "Remarks by President Biden, Prime Minister Morrison of Australia, and Prime Minister Johnson of the United Kingdom Announcing the Creation of AUKUS", White House, 15 September 2021, https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/09/15/remarks-by-president-biden-prime-minister-morrison-of-australia-and-prime-minister-johnson-of-the-united-kingdom-announcing-the-creation-of-aukus.

with which nuclear and conventional warheads could be exchanged on a specific system, and the relative ease or difficulty of maintaining this capability. Would it require replacing a mostly similar warhead with another, potentially accompanied by a few operational adjustments that could be both fast and imperceptible to other states? Or would it require more extensive, time-consuming and observable modifications to weapon systems and changes to patterns of behaviour, such as physical changes to launchers and movement of specific handling equipment and personnel?

As a general point, if nuclear-armed states shape their systems, weapon storage facilities and deployment policies in a way that disentangles conventional and nuclear systems, measures of this kind would facilitate higher confidence in arrangements to verify that certain systems are not nuclear armed or nuclear capable.

As verifying whether states possess nuclear capability can pertain to both specific weapon systems and specific geographic locations, both approaches are best facilitated by countries avoiding entanglement between their nuclear and conventional forces. Hopefully, states that are modernizing their nuclear forces will take the need for future cooperative arms control arrangements into account and work toward greater separation of nuclear and non-nuclear forces in the coming years in order to make future mutually beneficial arms control steps less complicated. Such steps, described below, may involve reducing entanglement regarding the systems themselves and the places where specific assets are stored.

Separating nuclear and conventional systems

Restricting the presence of nuclear weapons to specific military units and sites so that they are not deployed alongside conventional arms could be a particularly useful component of future risk-reduction agreements. These measures would reduce the risks of miscalculation as launches from assets based at conventional sites and the assets of specific units would be less likely to be mistaken for nuclear launches. Such agreements, of course, would be more effective if they include measures that verify the separation of nuclear and conventional systems.

These verification measures could include a combination of observable differences, information sharing and inspections. For example, initial inspections could verify that specific dual-capable bombers at specific locations do not carry nuclear weapons and carry observable markings to verify via national technical means (NTM) that those conventional-only assets are the only bombers at that site.

This can be coupled with another layer of disentanglement that could create another type of observable difference: the absence of nuclear weapon storage infrastructure where specific delivery systems are located. Russia, for example, is believed to hold nuclear weapons at separate storage locations and to have specific protocols (movement of specific equipment, procedures run by specific personnel, etc.) that would kick in if it were to move to arm delivery systems with nuclear weapons.[5] Specific procedures, which may be observable and shared in general terms with other countries, may serve as another indicator that specific delivery platforms are not capable of carrying nuclear weapons until such a time when such procedures would be carried out and would be likely to be observed.

Geographic restrictions on solely nuclear assets may be more palatable in the future than approaches that affect operations of larger numbers of sites where conventional weapons are also housed. For verification purposes, such disentanglement would be

5 P. Podvig, "Verifying the Absence of Nuclear Weapons in a Field Exercise", Proceedings of the Institute of Nuclear Materials Management (INMM) and European Safeguards Research and Development Association (ESARDA) Joint Annual Meeting, August 2021.

most effective if the parties to an agreement traded declarations regarding this information. For the units certified to operate nuclear-focused sites, this could include relatively non-intrusive information regarding the units certified to operate there, such as uniform insignia, general rotation patterns and basic information about the personnel reliability programmes these nuclear units have in place.

These indicators are not foolproof. In theory, personnel with the training to handle nuclear weapons could possess different uniforms or could move between nuclear and non-nuclear sites in ways that may not be easy to perceive without regular on-the-ground knowledge. Yet this information can still contribute to confidence-building in compliance, especially if we can reasonably assume that states will treat sites that hold important strategic assets with high security standards.

For many governments, personnel are often cleared to easily access only one or a few select sites, where they normally work or live. The presence of specific personnel at sites where they do not work regularly could be noticed, raising concerns about the activity at the site. Even elaborate plans to hide such behaviour would not give a guarantee that it will not be detected. Moreover, the handling of nuclear weapons would require multiple people, compounding the risk of detection of unusual patterns of behaviour around highly secure sites and further increasing the risks of exposure. Transparency regarding units and personnel expected at nuclear sites can therefore still complement other means of confirming compliance, in particular in situations where countries agree to take steps towards disentanglement of nuclear and conventional weapon systems.

In addition to information related to trained personnel, indicators used to verify the absence of nuclear weapons could include the differences that would distinguish nuclear from conventional bases. The presence or absence of strong security perimeters may help distinguish nuclear from non-nuclear sites. The presence of ancillary equipment and perhaps basic information on personnel- and technology-related security augmentations would also serve as indicators.

As sensitive as this may seem, it is a tried-and-true approach: INF Treaty inspections included the exchange of information about support equipment, including photographs that could be useful for NTM verification.[6] For better or worse, for many countries, this kind of information on nuclear-certified units, sites and patterns of behaviour is already public knowledge (even if not always confirmed as such by the states themselves). For Russia and the United States, the public knowledge is also enhanced by these countries' experiences with arms control verification work conducted over the past decades, which is a helpful history to lean on in the future.

Verification protocols by which countries agree to allow limited interviews with personnel at these sites could further strengthen confidence. This would be somewhat akin to inspectors being permitted to randomly inspect specific missiles, and may be more acceptable in a more politically accommodating future. Such measures could mirror the verification protocols of the 1993 Chemical Weapons Convention, in which "Inspectors shall have the right to interview any facility personnel in the presence of representatives of the inspected State Party with the purpose of establishing relevant facts"[7]. The provision that any

6 J.P. Harahan, On-Site Inspections Under the INF Treaty, US On-Site Inspection Agency, 1993, https://web.archive.org/web/20211220203129/https://www.dtra.mil/Portals/61/Documents/History/On-Site%20Inspections%20INF%20Treaty-opt.pdf.

7 Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction, 13 January 1993, Annex on Implementation and Verification, Part II, https://www.opcw.org/chemical-weapons-convention/annexes/verification-annex/part-ii-general-rules-verification, para. 46.

personnel at the site can be asked questions (as long as those questions are relevant) could be an extremely valuable verification tool.

As discussed in chapter 5, agreed verification procedures would be implemented in an environment that is characterized by a substantial degree of transparency. There are numerous publicly known indicators and factors that might be useful, such as the knowledge that handling nuclear weapons on submarines consumes precious space and requires special equipment; and knowledge of which countries and regions prohibit the entry of nuclear weapons into their territories, including via regional nuclear weapon-free zones. While open-source information alone might not be able to play a role as a verification tool, the transparency associated with it could significantly strengthen confidence in the accuracy of various declarations submitted by parties to an agreement.

Accounting for nuclear-armed systems

Separating nuclear and conventional systems requires development of procedures that would account for them separately. A significant step in that direction was made in the 2010 New Strategic Arms Reduction Treaty (New START), which accounts for the actual number of nuclear warheads deployed on ballistic missiles.[8] Even though in practice the treaty treats nuclear and conventional warheads equally, this opens a way for distinguishing between the two in the future. In the words of Rose Gottemoeller, the head of the US New START negotiating team,

> Moving away from the counting rule and focusing on confirming what is actually on the front end of missiles was a big change from the past, but it also opened up new opportunities for future arms control agreements. In particular, banning or limiting nuclear warheads while letting conventionally armed missiles continue to be deployed becomes an option. Thus, the New START verification regime has a bigger value than the treaty itself: it bodes well for future arms control regimes that focus more on accounting for warheads, nuclear and conventional, than has been possible in the past.[9]

The types of on-site inspection of re-entry vehicles designed for New START can be applied by countries wishing to demonstrate that specific missiles are not nuclear armed, for example to complement protocols regarding functionally observable differences. This differs from demonstrating nuclear capability. However, in conditions in which entanglement between nuclear and conventional capabilities is minimized, it could serve as a component of methods for countries to demonstrate that specific missiles they possess are indeed not nuclear armed.

For example, under current plans for the US Joint Air-to-Surface Standoff Missile (JASSM), it will be a solely conventional air-launched cruise missile (ALCM). The United States may wish to demonstrate adherence to this in the future, given that in the past some US officials have publicly indicated a desire to build a nuclear variant of the same missile. This may be accomplished by a combination of (a) on-site inspections in which tested missiles are selected at random, carried out in ways similar to the above-cited example from New START, (b) selective information exchanges, and (c) observable differences between the JASSM and nuclear-armed ALCMs. Examples of such differences are described further in the following subsections; they could span from only specific aircraft and bases holding

8 Treaty Between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms (New START), 8 April 2010, https://2009-2017.state.gov/documents/organization/140035.pdf.

9 R. Gottemoeller, Negotiating the New START Treaty, May 2021, p. 55.

the JASSM to visible differences between the JASSM and other cruise missiles. While not foolproof, this should convey relatively high confidence of the absence of nuclear-armed missiles of this type.

Aiding in this approach is the fact that researchers continue to develop new and better tools for verifying that specific objects are non-nuclear for the types of inspection described above. The 1991 Strategic Arms Reduction Treaty (START) and New START already included a procedure for using passive radiation measurements to verify the non-nuclear nature of some inspected objects, even with light-visible shielding to cloak other details. These tools can be further improved upon to provide greater confidence and reliable protection of sensitive details. Furthermore, if the object of verification is not expected to have any nuclear weapons on site, inspectors could use more capable measurement methods:

> For example, gamma-ray measurements could determine whether the amount of fissile material in a container exceeds a certain threshold, even in the presence of a shielding material. Active neutron interrogation could also be used to confirm the absence of fissile material. If it is possible to make certain assumptions about nuclear weapons whose absence is verified, this technique could be used to confirm the absence of weapons.[10]

As new verification approaches and tools continue to be tested and enter into use, they may become highly valuable for countries wishing to demonstrate that specific missiles are not nuclear, in particular in cases in which a nuclear-armed state claims that these missiles are not designed or certified as being armed with nuclear weapons.

Verifying production

While the New START accounting procedures could be applied in a variety of circumstances, certain situations may benefit from additional verification procedures. For example, it has been long acknowledged that sea-launched cruise missiles (SLCMs) present a challenge from a verification point of view. Nuclear-armed SLCMs are very similar to the conventional ones, which are deployed in large numbers and have been used in military action (which is a major difference between SLCMs and SLBMs).

For verification of arms control measures regarding SLCMs, various approaches have therefore included confirming that they are not nuclear armed in advance of them being loaded and shipboard inspections. In 1989, foreseeing the potential coverage of SLCMs in arms control treaties, experts explored how to verify a ban on nuclear SLCMs of all ranges with no constraints on conventional variants.[11] They devised a layered approach that begins with inspections of SLCMs at a designated verification facility using known detection methods to confirm the absence

10 P. Podvig, "Verifying the Absence of Nuclear Weapons in a Field Exercise", Proceedings of the Institute of Nuclear Materials Management (INMM) and European Safeguards Research and Development Association (ESARDA) Joint Annual Meeting, August 2021. For this descriptions the author draws upon E. Lepowsky, J. Jeon and A. Glaser, "Confirming the Absence of Nuclear Warheads via Passive Gamma-Ray Measurements", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 990, 21 February 2021, article 164983, https://doi.org/10.1016/j.nima.2020.164983; and D. L. Chichester et al., "Active Neutron Interrogation as a Method for Verification of the Absence of Special Nuclear Material in Arms Control Dismantlement", Proceedings of the Institute of Nuclear Materials Management (INMM) and European Safeguards Research and Development Association (ESARDA) Joint Annual Meeting, August 2021, https://resources.inmm.org/sites/default/files/2021-09/a143.pdf.

11 G.N. Lewis, S.K. Ride and J.S. Townsend, "Dispelling Myths About Verification of Sea-Launched Cruise Missiles", Science, 10 November 1989, https://doi.org/10.1126/science.246.4931.765; and V. Thomas, "Verification of Limits on Long-Range Nuclear SLCMs", Science & Global Security, vol. 1, nos 1–2, 1989, pp. 27–57, https://doi.org/10.1080/08929888908426322.

of nuclear warheads, followed by tagging and sealing launch canisters. While these do not prevent alteration of the weapon, they would provide a clear, visible sign of past tampering on later inspection. The system centres on specific verification facilities in which tagged and sealed canisters undergo routine inspection. This would be augmented by national technical means of monitoring movements to and from such facilities and of the launchers. The approach would be further enhanced by short-notice inspections to help increase confidence in compliance.

Whether for sea-launched or other delivery systems, verification protocols that focus on what is occurring in specific facilities should have strong portal monitoring as one component, and many experts around the world are working on improved tools for this. Under the INF Treaty, inspectors were permitted to conduct portal monitoring on-site, including at the facility where missiles not banned by the treaty were assembled.[12] Given that future agreements are likely to include multiple parties, the use of modern portal-monitoring equipment may be more likely than on-site conduct of this work by inspectors. For some monitoring systems in development, there is continuing work on technical issues that would support monitoring of this kind.[13]

Additionally, countries could agree to portal-monitoring regimes that have been used in the past for nuclear arms control verification but applied at sites where conventionally armed missiles are assembled and housed. This would pertain to states wishing to demonstrate that specific facilities are non-nuclear, for example if formerly nuclear sites are converted for conventional-only uses. Multiple states and laboratories are advancing new technologies and methods for using them that would allow for more thorough portal monitoring conducted without the physical presence of inspectors, which could be more palatable than having inspectors on site for some conventional weapon facilities.

Agreed observable differences

An extremely important concept developed by past arms control agreements is the provision that certain systems have observable differences that distinguish weapon systems covered by the treaty from those not covered, or nuclear from non-nuclear weapons. This can take a range of forms and can apply to delivery platforms, missiles and warheads themselves. Such observable differences can be added to existing systems, incorporated into new ones or applied if nuclear components are converted for conventional-only uses.

One consideration for future arms control agreements, in particular multilateral ones, is whether all participating nuclear weapon-possessing countries could proactively develop a set of agreed attributes that would indicate nuclear capability or lack thereof. This is a common concept for verification regarding nuclear warheads and may hold great potential for countries showcasing compliance to a wide range of future arms control steps.

No matter the shape of future arms control agreements to which they may apply, a benefit of agreeing to confirmable differences is that such a wide range of options for them exists. They do not have to involve radiation measurements (or indeed any kind of measurement) as they can be straightforward markings that are designed to be easily observable, including from a distance. They may include ensuring nuclear warheads have different colour coatings or have highly visible tags or ribbons attached externally.

12 P. Harahan, On-Site Inspections Under the INF Treaty, US On-Site Inspection Agency, 1993, p. 48. see also chapter 2. https://web.archive.org/web/20211220203129/https://www.dtra.mil/Portals/61/Documents/History/On-Site%20Inspections%20INF%20Treaty-opt.pdf.

13 A. Swift, "Overview of the U.S.-U.K. Portal Monitor for Authentication and Certification (PMAC) Project", Y-12 National Security Complex, Oak Ridge, 28 October 2020, https://doi.org/10.2172/1798810.

This approach was used to avoid the United States declaring Russia in breach of START, which required new missiles to have observable differences. When Russia introduced the new RS-24 (SS-27 Mod 2) missile, the parties agreed to distinguish it from the otherwise almost identical predecessor by a mark painted on the launchers for the new missiles and a red box attached onto missile containers.[14]

For agreements that allow for more up-close inspections, states could also include unobtrusive bar codes or advanced-material tags with unique serial numbers that could be matched to shared lists. Such differences can also aid in the safe handling of nuclear weapons by the possessing state.[15]

In addition to such externally observable design features with no real functional role, future agreements may include functionally related observable differences (FRODs). Both have been used in verification for past nuclear arms control treaties. FRODs may provide higher levels of assurance in the future, depending on the states involved, the types of weapon system they possess and other confidence-building measures.

Verifying non-nuclear design

In one example, future cooperative measures could include agreement not to design conventional SLCMs in ways that make it easier for them to carry nuclear warheads – a concern as countries such as China and India are working to expand their maritime capabilities and as the United States considers reviving nuclear variants of its SLCMs. This may be a politically and operationally attractive agreement, as substituting nuclear for conventional SLCMs once they are deployed would be likely to be difficult to carry out without complicating operations and risking detection (at least based on what is known of US weapon designs).[16]

Extensive analysis of options in this regard has been done for ALCMs in the past; it may apply to ballistic missiles as well. The specific functional differences described in public documents may pertain more to older weapon systems than those systems that countries are more likely to possess in the future. However, they illustrate possibilities at a time when many arms control discussions of recent years have focused on agreements that would allow conventional cruise missiles while ending their nuclear arming.

In 1990, the US JASON advisory group evaluated approaches to verifying that future designs of ALCMs were conventionally and incapable, in a short period of time, of being converted to carry nuclear warheads. It summarized:

> In order to meet the requirement that a new advanced cruise missile be unambiguously conventionally armed and not readily convertible to carrying a nuclear warhead, its structure must be designed so that it contains no unobstructed chamber of diameter comparable to the missile diameter… With active transmission radiography one can verify that the cruise missile airframe is constructed appropriately so that it cannot accommodate an existing fission weapon, and also cannot be readily converted to accept one. Finally, we note that there is no reason, in principle, that one could

14 P. Podvig and A. Woolf, "Monitoring, Verification, & Compliance Resolution in US–Russian Arms Control", WMD Compliance and Enforcement Series no. 5, UNIDIR, December 2019, https://doi.org/10.37559/WMD/19/WMDCE5, pp. 12–13.

15 These types of observable difference are described regarding a 2007 US incident in which AGM-129 cruise missiles accidentally armed with nuclear warheads were loaded onto aircraft and flown across the country. See J. Warrick and W. Pincus, "Missteps in the Bunker", Washington Post, 23 September 2007, http://www.washingtonpost.com/wp-dyn/content/article/2007/09/22/AR2007092201447.html.

16 S. Drell (Chairman), "Verification Technology: Unclassified Version", JASON, October 1990, https://irp.fas.org/agency/dod/jason/verif.pdf, pp. 38–39.

not develop smaller or segmented fission bombs – particularly a simple gun type bomb using highly enriched uranium – if low yield underground nuclear testing continues.[17]

There are multiple optional design features detailed in the JASON report that would not interfere with proper functioning of a conventional cruise missile. They would make it difficult for the possessors to modify to accommodate a nuclear warhead – not impossible, but such that the time, personnel and resources required for modification could raise new avenues for detecting suspect behaviour, and for which flight testing of the modified weapons (which could be detected) would be important. Since the time of writing of the JASON analysis, additional options are likely to have been explored for including additional design features, including options to use advanced materials that have been developed in recent decades.

As the JASON report indicates, such an approach to verifying that conventional ALCMs are relatively incapable of carrying nuclear warheads sets a sufficiently high bar for the purpose of trust in arms control agreements of this nature. Changes to such design features can be conducted, but keeping such work covert would require avoiding flight tests, and planners would be hesitant to use such weapons without significant flight testing (except, perhaps, in an all-out crisis).

A linchpin in this, however, would be exchanging telemetry data. This has been done in the past with the United States and Soviet Union or Russia. However, it may be a taller hurdle for other nuclear-armed states with less experience in arms control agreements and verification procedures. Likewise, it may be more politically acceptable in circumstances in which countries agree to reduce entanglement between nuclear and conventional systems, thus making this information less revealing of the conventional capabilities of the states involved.

It would be no small matter to get countries to agree to stick to designs of existing and future military aircraft and missiles that indicate that they are non-nuclear. However, one can see this being easier to agree to in cases when there is already political momentum to further distinguish nuclear from conventional air-launch systems (for example, if a state decides to arm only ballistic missiles with nuclear warheads and to use cruise missiles only for conventional payloads). This approach may also be useful if future agreements include bomber counting rules, in which case countries have an incentive to make it easy to distinguish bombers that can carry nuclear-armed missiles from those that cannot without noticeable modifications.

One challenge with agreements to include observable differences in platforms and plans is that, depending on the terms, high levels of information may need to be exchanged. Of course, this has been done in verifying past treaties. Yet, due to the difficulties that challenging political circumstances may bring, it is important to also consider measures that focus on observable differences based on geographic location of nuclear versus non-nuclear assets. In particular, with new countries less familiar with executing arms control verification, this may be an easier early step until additional trust is built.

Next steps

A few initial steps may help advance the portfolio of options presented in this chapter, including working further through details of which elements may best combine to instil confidence in verification for specific types of situation.

Nuclear-armed states, non-governmental interested parties, or both, should begin by exploring examples of how to verify that

17 Ibid., p. 21.

specific assets are not nuclear capable, beginning with systems which countries currently claim are not nuclear capable (for example, US ground-launched intermediate-range missiles and JASSM). Another strong candidate would be Tomahawk cruise missiles if the United States does not pursue the revival of nuclear variants, given the 2021 announcement of the sale of conventional Tomahawk cruise missiles to Australia as part of its agreement with the United Kingdom and United States regarding the provision of nuclear-powered submarines.

Building on work to detail verification protocols related to such current pledges, stakeholders should begin to work through options that would apply to diverse scenarios that involve a range of cooperation levels and access. These should include cases in which technological and geographic entanglement persist and ones in which such entanglement is minimized; and situations in which on-site access can vary from limited to robust. This variety can help to envision which of the numerous options outlined in this chapter (and others) can be best combined to fit the widest range of scenarios.

If political conditions allow it, exercises to walk through application of such concepts would be a strong step, including for raising the confidence levels of states that are not yet as familiar with the conduct of verification measures.

As a potential avenue for advancing these steps, nuclear-armed states should consider new laboratory-to-laboratory exchange initiatives. Historically, many verification concepts have come from national laboratories within states and collaborations across those of various states. Additionally, the international community should revive and expand upon the example of the International Science and Technology Center to create new cooperative, multinational laboratories to advance specific technical details related to verifying nuclear capability and other hard questions. As others have proposed: "To facilitate and promote confidence-building for a new round of bilateral and perhaps multilateral arms control negotiations seeking deeper reductions in the nuclear arsenals, a network of laboratories with international participation, including nuclear weapon states and non-nuclear weapon states, should be established as soon as possible."[18]

Conclusion

Options to verify that specific military assets are not nuclear capable in certain circumstances are becoming a more important aspect of the future arms control toolkit. There are numerous methods for countries to explore in order to demonstrate that specific assets are not nuclear armed or nuclear capable which, put together, can form strong confidence that violations that others would consider to be militarily significant are not occurring. In the coming decades, such possibilities may be applied to unilateral pledges and policies as well as bilateral or multilateral arms control commitments. This chapter offers an early attempt to consider options and dynamics regarding their potential application, carrying the hope that this aspect of verification will be elaborated in much deeper detail in the coming years.

18 J. Yan and A. Glaser, "Nuclear Warhead Verification: A Review of Attribute and Template Systems", Science and Global Security, vol 23, no. 3, 2015, https://doi.org/10.1080/08929882.2015.1087221, p. 166.

CHAPTER 4: Space launch vehicles and ballistic missiles

Almudena Azcárate Ortega and Dmitry Stefanovich

The close relationship between missiles and space launchers goes back to the early days of space exploration as many space launch vehicles have origins in ballistic missile programmes. The most notable example is the Soviet R-7 (SS-6) missile that became both the first intercontinental ballistic missile (ICBM) and the first space launch vehicle. In the United States, the first space launch vehicle was adapted from the Redstone medium-range ballistic missile. This link can be seen today as well – in the US Minotaur family of space launchers, which use stages of the MX (Peacekeeper) ICBM, or in China's Long March 2C space launch vehicle, which is based on the Dong Feng 5 (CSS-4) ICBM.[1] There were similar dynamics in other counties as well. Israel's Shavit family of space launch vehicles is derived from the Jericho II ballistic missile, and India's Polar space launch vehicle apparently uses the rocket motors of the Agni ballistic missile programme.[2]

The relationship goes the other way as well. Since many technologies are used in both applications, states that develop indigenous space launch capability can use this programme to support the development of ballistic missiles. While states usually maintain separation between these efforts or insist on the exclusively peaceful nature of their programmes, the transfer of technology and expertise within a state is difficult to monitor or restrict.

The recent emergence of commercial enterprises that successfully develop and operate space launch vehicles suggests that the technological barriers on the way to building high-performance rocket motors are getting lower and it is likely that more states will be capable of building indigenous rocket programmes. Even though missions, and therefore technical requirements, are different for space launchers and ballistic missiles, there are enough similarities between them to be of concern.

At the same time, most states that will pursue a space launch capability would not be doing so to use it in military applications and would be ready to make a corresponding voluntary commitment. It is also possible to imagine circumstances in which a state would be willing to accept restrictions on its space launcher programme as part of an agreement that limits it to exclusively peaceful applications. These cases would require a mechanism that could verify this commitment and provide confidence in the absence of a military dimension of a space launch programme. This chapter provides an overview of existing legal and institutional frameworks as well as some technical approaches that could contribute to potential verification arrangements in this area.

Legal frameworks

In the nuclear sphere, the 1968 Non-Proliferation Treaty (NPT) affirms the principle of access of states parties to peaceful uses of nuclear energy while creating a system of safeguards to prevent diversion of nuclear materials to non-peaceful purposes by non-nuclear weapon states. In contrast, no

1 G.D. Krebs, "Minotaur-3/-4/-5/-6 (OSP-2 Peacekeeper SLV)", Gunter's Space Page, 15 July 2021, https://space.skyrocket.de/doc_lau/minotaur-4.htm; and "Chang Zheng-2C (Long March-2C)", SinoDefence, archived 6 July 2015, https://web.archive.org/web/20150706002847/http://sinodefence.com/rocketry/cz2c.

2 J.M. Logsdon, "Shavit", Encyclopedia Britannica, 23 Nov. 2017, https://www.britannica.com/topic/Shavit; M. Kraig, "The Indian Drive towards Weaponization: The Agni Missile Program", Federation of American Scientists, May 2000, https://nuke.fas.org/guide/india/missile/agni-improvements.htm.

similar mechanism exists in the area of rocket and missile development. The development of missile technology is not prohibited by international law for most countries. The key exception to this is the Democratic People's Republic of Korea (DPRK), which the United Nations Security Council has demanded to suspend all activities related to its ballistic missile programme.[3] Another notable case is the Islamic Republic of Iran, which was called upon not to undertake any activity related to ballistic missiles designed to be capable of delivering nuclear weapons in the United Nations Security Council resolution that approved the 2015 Joint Comprehensive Plan of Action.[4] Other than that, a state that is building an indigenous space programme is not restricted from repurposing this technology into development of ballistic missiles. This technology transfer has certainly happened in the past and it could happen again as space technology becomes more commonplace and easier to obtain.

In the past, export control regulations have served as effective ways to control the spread of missile technologies. However, its effectiveness may be eroding as indigenous programmes emerge, particularly in the light of the increase in the number of spacefaring states. In the face of this reality, the question of verification becomes a logical concern: How can it be ascertained that a programme to develop space launch vehicles is not being used as a cover for a missile programme?

Outer space law

The primary goal of the international space law regime is the maintenance of international peace and security.[5] That was the key objective of the drafters of the 1966 Outer Space Treaty (OST), which serves as the basis for all space law. The OST drafters sought to avoid the extension of the rivalries that existed during the Cold War to the then new domain of outer space, thus proclaiming it a domain "free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law" which should be used for "peaceful purposes".[6]

However, beyond that, the Outer Space Treaty does not provide any guidance on arms control or verification matters. Article IV forbids the "place[ment] in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install[ation] such weapons on celestial bodies, or station[ing] such weapons in outer space in any other manner". The treaty purposefully used this language to allow an ICBM to pass through space for a short period before descending to its target.[7]

Since the OST declared space exploration and use "the province of all [hu]mankind", the development of space launch vehicles for this purpose is not only allowed, but actively encouraged. The treaty, however, requires that these activities must be carried out in accordance with international law, which is

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3 Most notably United Nations Security Council resolutions S/RES/1718 (2006), S/RES/1874 (2009), S/RES/2087 (2013) and S/RES/2270 (2016).

4 Security Council, S/RES/2231, 20 July 2015, https://undocs.org/S/RES/2231(2015).

5 This was already made evident in the General Assembly resolution that preceded the OST. See General Assembly, A/RES/1348 (XIII), 13 December 1958, https://undocs.org/A/RES/1348(XIII).

6 See General Assembly, A/RES/1348 (XIII); and Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies (Outer Space Treaty), 19 December 1966, http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html, Preamble, Article I, Article IV. This is also echoed in all other subsequent space treaties enacted under the auspices of the United Nations: the 1967 Rescue and Return Agreement, the 1972 Liability Convention, the 1975 Registration Convention and the 1979 Moon Treaty.

7 D.A. Koplow, "ASAT-isfaction: Customary International Law and the Regulation of Anti-Satellite Weapons", Michigan Journal of International Law, vol. 30, no. 4, 2009, https://repository.law.umich.edu/mjil/vol30/iss4/3, p. 1198.

why it is important to look at international law beyond space law to analyse whether it sheds additional light on the issue of arms control and verification.

United Nations Security Council resolutions

In addition to the limitations indicated above, there are several United Nations Security Council resolutions that set certain restrictions on the development and use of ballistic missile technology in some states.

First, in relation to the DPRK, the Security Council has since 2006 adopted nine major sanctions resolutions in response to the country's nuclear and missile activities. Resolution 1718 (2006) demanded that the DPRK suspend all nuclear or missile tests, the development of any weapons of mass destruction (WMD), and all ballistic missile activities. Resolution 1874 (2009) reiterated a number of provisions from Resolution 1718 and explicitly called for the DPRK to "not conduct any further nuclear test or any launch using ballistic missile technology". While the resolution does not say so explicitly, this prohibition extends to space launches as well as tests of ballistic missiles.

The DPRK subsequently carried out two satellite launches, on 12 December 2012 and on 7 February 2016. It justified these launches and its space programme in general as peaceful and thus outside the scope of Security Council resolutions sanctioning its missile technology-related activities. The Security Council nevertheless condemned these actions as violations of the prohibitions to abstain from using ballistic missile technology.[8]

Compliance with these resolutions is monitored by the 1718 Committee, established by Security Council resolution 1718 in 2006, and a Panel of Experts, established by resolution 1874 in 2009. The panel produces regular reports relating to the status of the sanctions and enforcement.[9] However, neither the committee nor the panel has access to any of the DPRK's facilities.

In relation to Iran, Security Council resolution 2231 (2015) calls upon the state "not to undertake any activity related to ballistic missiles designed to be capable of delivering nuclear weapons, including launches using such ballistic missile technology".[10] On 20 April 2020, Iran successfully launched its first satellite, garnering the criticism of some in the international community. Chief among these were the United States, the United Kingdom, France and Germany, which stated that the launch constituted a violation of resolution 2231 (2015) as it had used ballistic missile technology. Russia, on the other hand, stated that "neither the resolution itself, nor the Joint Comprehensive Plan of Action (JCPOA) on the Iranian nuclear program in any way limits Tehran's rights and capabilities in terms of space exploration and development of relevant national programs".[11] Since there is no agreed understanding of what kinds of missile should be considered "designed to be capable of delivering nuclear weapons", the issue remained unresolved.

8 The condemnations were expressed in Security Council, S/RES/2087 (2013) and S/RES/2270 (2016).
9 K. Davenport, "UN Security Council Resolutions on North Korea", Arms Control Today, April 2018, https://www.armscontrol.org/factsheets/UN-Security-Council-Resolutions-on-North-Korea.
10 Security Council, S/RES/2231 (2015), https://www.undocs.org/S/RES/2231(2015).
11 "Russia: Iran's Military Satellite Launch Not against UN Resolution", Tehran Times, 24 April 2020, https://www.tehrantimes.com/news/447138/Russia-Iran-s-military-satellite-launch-not-against-UN-resolution.

Export control law

Export control systems are designed to prevent the spread of sensitive technologies to foreign actors that could threaten the interests of a particular state.[12] Export control regulations are especially important when it comes to space technologies because they can be a significant enabler of advanced weapon technologies. As a result, export control regulations serve to block the proliferation of these technologies, which, as highlighted above, can be used in a ballistic missile programme.

At the international level, the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies is the first global multilateral arrangement on export controls for conventional weapons and sensitive dual-use goods and technologies. It received final approval by 33 co-founding countries in July 1996 and began operations in September 1996.[13] The Wassenaar Arrangement serves as a non-binding framework through which states agree on which items should be controlled, and aims to promote transparency by calling on states to disclose information regarding their export activities related to weapons and items appearing on the arrangement's two control lists – the List of Dual-Use Goods and Technologies and the Munitions List.[14] Space technology is included on the agreed control list, with an emphasis on launch vehicles, which can be repurposed as ballistic missiles.[15]

The objective of the Wassenaar Arrangement is to reinforce and complement existing domestic export control regimes to promote transparency.[16] Although it is not a binding tool, the participating states maintain effective export controls for the items on the agreed lists. These lists are reviewed periodically to take into account any technological developments and experience gained. Through a transparent exchange of information, suppliers of arms and dual-use items can develop common understandings of the risks associated with their transfer and assess the scope for coordinating national control policies to combat these risks.[17] To achieve this, the Wassenaar Arrangement requires the participating states to exchange information every six months on the transfer or denial of transfer of both arms and dual-use assets. However, the decision to transfer or not to transfer is the sole responsibility of the individual states.[18]

The Missile Technology Control Regime (MTCR) is another international set of guidelines that seeks to control the exports of missile and rocket technology. Like the Wassenaar Arrangement, it is a non-binding, informal political understanding among states that aims to limit the proliferation of such technology. The MTCR was formed in 1987 by the G7 industrialized countries (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States) with the objective of limiting the risks of proliferation of WMD by controlling exports of goods and technologies that could contribute to their delivery

12 US Department of Commerce Federal Aviation Administration, Introduction to U.S. Export Controls for the Commercial Space Industry, 2nd edn., November 2017, https://www.faa.gov/about/office_org/headquarters_offices/ast/media/export_controls_guidebook_for_commercial_space_industry_doc_faa_nov_508.pdf.
13 Wassenaar Arrangement, "What Is the Wassenaar Arrangement?", 23 December 2021, https://www.wassenaar.org/the-wassenaar-arrangement.
14 D. Kimball, "The Wassenaar Arrangement at a Glance", Arms Control Association, December 2017, https://www.armscontrol.org/factsheets/wassenaar.
15 Wassenaar Arrangement, List of Dual-Use Goods and Technologies, December 2018, https://www.wassenaar.org/app/uploads/2019/consolidated/WA-DOC-18-PUB-001-Public-Docs-Vol-II-2018-List-of-DU-Goods-and-Technologies-and-Munitions-List-Dec-18.pdf, Category 9, entry 9.A.10.
16 F. von der Dunk (ed.), Handbook of Space Law, 2015, https://doi.org/10.4337/9781781000366, p. 365.
17 Wassenaar Arrangement, "What Is the Wassenaar Arrangement?", 23 December 2021, https://www.wassenaar.org/the-wassenaar-arrangement.
18 F. von der Dunk (ed.), Handbook of Space Law, 2015, https://doi.org/10.4337/9781781000366, p. 364.

systems (other than crewed aircraft). Currently 35 countries are MTCR partners.[19] The MTCR technical annex on technology that should be controlled includes space launch technology.[20] The focus of the MTCR is on "missile-related" technology. It was developed primarily to focus on arms and munitions. As such, it does not establish as clear a division between munitions and dual-use assets as the Wassenaar Arrangement, but it nevertheless covers space assets. The MTCR states that "the technology used in a [space launch vehicle] is virtually identical to that used in a ballistic missile" and bans the sale of its key technologies.[21] The ban excludes "responsible" governments which commit to strict measures of end-use and provide assurances that "[t]he items will be used only for the purpose stated" and that they will not be transferred to a third party without authorization of the supplying state.[22] This suggests that the supplier could put in place measures to verify compliance with this obligation. However, these measures are the sole responsibility of the supplying state.

The implementation of the MTCR depends on the resolve of its partner states. The MTCR guidelines encourage the exchange of "relevant information with other governments applying the same Guidelines".[23]

While export control regulations have traditionally been quite effective in avoiding the proliferation of missile technology, the technological advancements in space launch vehicles in recent years, coupled with the accessibility of these technologies due to the increase of commercial actors, has caused the technological barriers to lower and blur.

The Hague Code of Conduct

The Hague Code of Conduct against Ballistic Missile Proliferation (HCoC) is a non-legally binding set of guidelines that regulates the area of ballistic missiles capable of carrying WMD. Although it is not an export-control mechanism, it is the only multilateral instrument, along with the MTCR, which establishes transparency and confidence-building measures concerning the spread of ballistic missiles.[24]

HCoC is a widely subscribed multilateral instrument, with 143 subscribing states.[25] It aims to contribute to the process of strengthening existing national and international security arrangements and disarmament by curbing the proliferation of ballistic missiles.[26] With regards to space technology, the HCoC seeks to prevent the use of space launch vehicle programmes to conceal the acquisition of ballistic missiles capable of delivering WMD.[27]

19 Missile Technology Control Regime, "Frequently Asked Questions (FAQs)", https://mtcr.info/frequently-asked-questions-faqs.

20 Missile Technology Control Regime, "Equipment, Software and Technology Annex", 19 October 2017, https://mtcr.info/wordpress/wp-content/uploads/2017/10/MTCR-TEM-Technical_Annex_2017-10-19.pdf.

21 Missile Technology Control Regime, "MTCR Guidelines and the Equipment, Software and Technology Annex", https://mtcr.info/mtcr-guidelines.

22 Missile Technology Control Regime, "Guidelines for Sensitive Missile-Relevant Transfers", https://mtcr.info/guidelines-for-sensitive-missile-relevant-transfers.

23 Missile Technology Control Regime, "Guidelines for Sensitive Missile-Relevant Transfers", https://mtcr.info/guidelines-for-sensitive-missile-relevant-transfers, Guideline 6.

24 Hague Code of Conduct, "Description of HCoC", https://www.hcoc.at.

25 Of the states that possess (or that are believed to possess) nuclear weapons, five have signed the HCoC: France, India, Russia, the United Kingdom and the United States. Pakistan, China, Israel and the DPRK have not signed it. The full list of subscribing states is available at Hague Code of Conduct, "List of HCoC Subscribing States", February 2020, https://www.hcoc.at/subscribing-states/list-of-hcoc-subscribing-states.html.

26 Hague Code of Conduct, "Frequently Asked Questions about HCoC", January 2021, https://www.hcoc.at/what-is-hcoc/frequently-asked-questions.html.

27 Hague Code of Conduct, "Code of Conduct against Ballistic Missile Proliferation", https://www.hcoc.at/what-is-hcoc/text-of-the-hcoc.html, Article 2(g).

To achieve this objective, HCoC encourages subscribing states to sign and ratify existing space treaties, in particular the OST, the 1972 Convention on International Liability for Damage Caused by Space Objects and the 1975 Convention on Registration of Objects Launched into Outer Space. It also urges states to "curb and prevent the proliferation" of ballistic missiles, as well as to "exercise maximum possible restraint in [their] development, testing and deployment".[28]

Furthermore, it establishes a set of transparency and confidence-building mechanisms that would allow states to exchange information on ballistic missile and space launch vehicle programmes, as well as the number of each launched annually. It additionally proposes the exchange of pre-launch notifications.

States are free to adopt the obligations outlined in the HCoC in a voluntary manner, and they are further encouraged to adopt bilateral or regional transparency measures, in addition to those explicitly established by the HCoC.[29] However, being a set of voluntary guidelines, HCoC does not provide any verification mechanism of its own.

Drawing the line between space launch vehicles and ballistic missiles

While it is understood that there is a significant overlap between space launch vehicles and ballistic missiles, differences do exist and in principle it is possible to find a way to establish that a space programme is not providing cover for the development of ballistic missiles.

One way to separate space launch vehicles from ballistic missiles is to focus on relevant technologies. An analysis by US Congressional Research Service that specifically looked at the possibilities of technology transfer divided the technologies into three categories.[30] Several crucial technologies are considered "the same" in space launch vehicles and ballistic missiles – staging mechanisms, propellants, air frame, motor cases, liners and insulation, engines or motors and their thrust vector control systems, and exhaust nozzles. Some technologies are classified as "similar" between space launch vehicles and ballistic missiles, which means that they should be considered on a case-by-case basis. These include the re-entry vehicle, payload separation, inertial guidance and control systems. The only technology "generally unique to ballistic missiles" is the warhead, the actual payload used to destroy the target.

Another way to separate the two types of system is to look at the qualities the developers and operators tend to focus on. One such classification suggests that the most important qualities for a ballistic missile are range, payload type and weight, the capability to carry multiple independently targeted re-entry vehicles (MIRVs), accuracy, launch readiness time, as well as other operational requirements. For a space launcher, the key parameters include payload weight for a designated orbit, orbital precision, orbital arrival time precision and launch readiness time.[31]

Because of the different mission requirements, space launch vehicles traditionally use liquid-fuel engines, which provide better performance. For ballistic missiles, the use of solid-propellant motors normally provides better operational flexibility. This difference, however, cannot be a reliable indicator of the nature of a rocket-development programme. While modern ballistic missiles increasingly use solid-propellant motors, liquid-fuelled missiles are still being developed. Moreover,

28 Ibid., Article 3.
29 Ibid., Article 4(b).
30 China: Possible Missile Technology Transfers Under U.S. Satellite Export Policy – Actions and Chronology, US Congress, Congressional Research Service, 6 October 2003, https://www.everycrsreport.com/reports/98-485.html.
31 V.P. Legostayev (ed.), "Mashinostroyeniye" [Machine building], Encyclopaedia, vol. IV-22, 2012, pp. 515, 526.

a number of space launch programmes, such as the Polar space launch vehicle in India, H-IIA and Epsilon in Japan, and the Vega in Europe, use solid-propellant motors either in boosters or in some or all stages of the launch vehicle.

Different requirements determined by their missions lead to significant differences in optimal configurations between space launch vehicles and ballistic missiles, but the underlying technologies are largely the same.

Payload and re-entry vehicle

The most important difference between space launch vehicles and ballistic missiles is the nature of the payload. A ballistic missile must deliver the payload intact to the designated part of the Earth surface or a sector of the atmosphere above it, while for the space launch vehicle the payload should be placed in a designated orbit. Most importantly, an orbital payload does not have to re-enter the atmosphere, while a ballistic missile payload must survive re-entry and hit its designated target with some accuracy. Another important characteristic of a ballistic missile payload is its capability to counter missile defence. Designing a payload and re-entry vehicle that can support military missions is one of the most challenging parts of building an effective ballistic missile system. Even though some space-based systems include re-entry vehicles – for example, to return crews from space or deliver film capsules of early reconnaissance satellites – high accuracy is not as important for these types of mission as it is for ballistic missile applications. Development of a system that can meet all ballistic missile-specific requirements would normally involve an extensive testing programme that is difficult to conceal.

It should be noted that some technologies developed for space-related applications can be repurposed for use in military missions. Sophisticated manoeuvrable re-entry vehicles, including hypersonic glide vehicles (HGVs) are in many respects similar to the vehicles that have been developed as part of reusable spacecraft projects, such as the Space Shuttle and the X-37B orbiter in the United States, Spiral and Buran in the Soviet Union, or the orbiter tested by China in 2021. However, while these kinds of vehicle can have military applications, they would normally follow, rather than precede, traditional re-entry vehicles.

Launch and testing programmes

A difference between programmes that develop space launch vehicles and those dedicated to ballistic missiles is the ways in which these programmes conduct launches and flight tests.

A ballistic missile development programme requires a dedicated test range that would support tests to a variety of ranges, from maximum to minimum. To support a flight test programme, this test range must be equipped with telemetry gathering system (sometimes including instrumentation ships), tracking radars and the means of monitoring the areas of impact. Normally, performance of re-entry vehicles is evaluated by seismic, acoustic and ballistic sensors, and, eventually, by an analysis of the retrieved re-entry vehicles.[32]

This system would be rather different from one that supports space applications and should be relatively easily detectable. In principle, one can obtain some basic data on the survivability of a re-entry vehicle from relatively simple tests, for example, by

32 D. Andreyev, “Ob’yekt Kura” [The Kura object], Krasnaya Zvezda, 16 December 2009, http://old.redstar.ru/2009/12/16_12/4_03.html.

launching a missile along a very lofted trajectory. However, even though these tests could replicate most of the conditions of a longer-range re-entry, to take full advantage of them one would still need to collect and analyse the data.[33]

Another distinction between space launch vehicles and ballistic missiles is the launch facilities that they use. A ballistic missile would normally use a dedicated launcher, such as a mobile transporter–erector–launcher (TEL) or a hardened and protected silo. A ballistic missile programme must also involve test launches from these launchers. Even though these could be located at space launch facilities, as is the case with Russia's Plesetsk Cosmodrome and the United States' Vandenberg Space Force Base, they are distinctly separate from the facilities that support space programmes. A flight test from a mobile TEL would normally be considered a reliable sign of the military nature of a programme. Even though there is a growing number of TEL-based space launch vehicles that were developed as part of programmes for rapid re-deployment of satellites, they are normally based on existing ballistic missiles, rather than developing a new design. For example, China's Kuaizhou programme uses a space launch vehicle derived from an intermediate-range ballistic missile.[34]

Monitoring developments in these domains can contribute to the assessment of the nature of a programme. While the existence of infrastructure that supports launches from mobile TELs or dedicated hardened silos does not necessarily mean that a programme has a military dimension, the absence of such infrastructure could be one indicator of the non-military nature of a rocket-development effort.

Way forward

Given the importance of flight tests for the development of ballistic missiles, one step that could help demonstrate the nature of a rocket-development programme is a universal regime of missile and rocket launch notifications. Most of these launches are already monitored by countries with well-developed early-warning capabilities, but notifications would bring an important element of transparency to any flight test programme and help assess whether the programme can have a military dimension. While elements of this regime exist today, in the form of ballistic missile launch notification agreements between the United States and Russia and Russia and China, they cover only a subset of missile and space launches. Besides, all these states already have long-established ballistic missile development programmes. The Registration Convention requires states to register space objects they place in orbit, but there is no similar obligation that would cover suborbital launches or tests that do not place any object in orbit.[35] Some states have a practice of issuing notifications of upcoming rocket launches, but this practice is far from universal, and it has not been properly formalized.[36]

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33 One example is a launch of a Hwasong-15 rocket conducted by the DPRK in November 2017. While the test could have provided data about re-entry, there is no evidence that this information was collected. D. Wright, "Reentry of North Korea's Hwasong-15 Missile", All Things Nuclear, 7 December 2017, https://allthingsnuclear.org/dwright/reentry-of-hwasong-15.

34 G.D. Krebs, "Kuaizhou-1 (KZ-1) / Fei Tian 1", Gunter's Space Page, 18 December 2021, https://space.skyrocket.de/doc_lau/kuaizhou-1.htm.

35 Convention on Registration of Objects Launched into Outer Space, 12 November 1974, https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/registration-convention.html.

36 It should be added that the lack of a formal notification regime could create some potentially dangerous misunderstandings about the purpose of a launch. See, for example, P. Podvig, "Norway Black Brant Letter", Russian Strategic Nuclear Forces, 8 August 2005, https://russianforces.org/blog/2005/08/norway_black_brant_letter.shtml; and P. Podvig, "Unexpected Dangers", Bulletin of the Atomic Scientists, 7 October 2013, https://thebulletin.org/2013/10/unexpected-dangers.

Two existing notification mechanisms that could provide some information about missile tests are the Notice to Air Missions (NOTAM) and Notice to Mariners (NOTMAR) systems. These notification systems are related to safety and are therefore universal, although states may withhold notifications for some tests flights over their national territories. An analysis of these notifications in some cases could provide valuable information about missile tests and space launches as well as about the type of missile being tested.[37]

A mechanism that could provide a formal institutional framework for a notification regime is the HCoC, which encourages its subscribing states to provide notifications of their space launch vehicle and ballistic missile launches and flight tests. It indicates that these notifications should include such information as the generic class of the ballistic missile or space launch vehicle, the planned launch-notification window, the launch area, and the planned direction.[38]

Another potential arrangement is Russia's initiative on the establishment of a global missile non-proliferation regime: the Global Control System for the Non-Proliferation of Missiles and Missile Technology. Russia initially introduced this idea in late 1990s, but even though the proposal was followed by a number of expert-level meetings, it was not adopted. The idea, however, remains on the table and constitutes part of Russia's long-term vision for missile-related controls. Notably, Russia introduced its proposal for a launch-notification regime in the MTCR agenda, where Russia holds the chairmanship in 2021–2022.[39]

An agreement on detailed notifications of rocket technology transfers as well as obligations to monitor the end-use of this technology, which are already included in the MTCR, can be important as well. These measures can provide some level of transparency and can be taken unilaterally by states interested in providing the international community with information about the peaceful nature of their developments by declaring their acquisitions and their intended purpose.

If a state that has made a commitment to forgo the development of ballistic missiles while pursuing a space launch capability, whether as a voluntary obligation or as part of an agreement, there are a number of measures that could help verify its compliance. These measures could include the following:

- *Inspections of launch facilities.* This could rely primarily on remote monitoring, but may include ground access to the launch sites as well. Such inspections should be focused on verifying absence of infrastructure explicitly associated with military missile programmes, such as hardened silos or TELs.

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37 D. Wright, "How High Did China's May 2013 Launch Go?", All Things Nuclear, 13 March 2014, https://allthingsnuclear.org/dwright/how-high-did-chinas-may-2013-launch-go; J. Lewis, "Iran Launch Forthcoming", Arms Control Wonk, 23 February 2016, https://www.armscontrolwonk.com/archive/1201159/iran-launch-forthcoming/; D. Wright, "Research Note to Hypersonic Boost-Glide Weapons by James M. Acton: Analysis of the Boost Phase of the HTV-2 Hypersonic Glider Tests", Science & Global Security, vol. 23, no. 3, 2015, pp. 220–229, https://doi.org/10.1080/08929882.2015.1088734.

38 Hague Code of Conduct, "Code of Conduct against Ballistic Missile Proliferation", https://www.hcoc.at/what-is-hcoc/text-of-the-hcoc.html, Article 4(a)(iii).

39 S. Ryabkov, Russian Deputy Minister of Foreign Affairs, Address at the opening of the Plenary Meeting of the Missile Technology Control Regime (MTCR), Sochi, 6 October 2021, https://archive.mid.ru/ru/foreign_policy/news/-/asset_publisher/cKNonkJE02Bw/content/id/488131.

- *Transparency during test launches*. This could include the presence of observers and sharing footage of launches to provide assurances of the absence of a military dimension to the system being tested.
- *Telemetry sharing*. Telemetry was and is still shared by Russia and the United States under the START treaties (although somewhat limited in New START), and probably can be shared by a launch service provider with its customers. This suggests that there is no reason why this data cannot be shared with outside observers if the state is committed to proving the peaceful nature of its programme.
- *Transparency regarding the facilities that can monitor re-entry of space objects*. While monitoring re-entry could be a legitimate part of a peaceful space programme, the facilities that support this activity would be likely to be different from those that would be used to develop a military re-entry vehicle.

These measures would provide a fairly high confidence in the absence of a military ballistic missile programme. This confidence would increase in time as the pattern of tests and launches is established.

Conclusion

Distinguishing between space launch vehicle and ballistic missile programmes is extremely difficult in a non-cooperative environment. Even if it can be achieved, a lot of dual-use technologies, including those technologies used for guidance, telemetry acquisition, tracking, payload separation, atmospheric re-entry, will be developed during the course of any space programme. These technologies could have real value for ballistic missile projects. While it is hard (and ineffective) to convert a space launch vehicle into a ballistic missile directly, the technologies used are essentially very similar.

Finally, in the most general terms, any high-profile aerospace project leads to the creation of a national engineering corps, a specialized workforce and a pool of designers that can put their knowledge to a broad use. This is probably where it is, and will remain, impossible to draw a definitive line. So, the most important task is to promote restraint in missile developments, without limiting space-related activities.

It is, however, important to recognize that some states would be willing to make a commitment not to develop ballistic missiles while they are pursuing a space launch capability. If this commitment were to be made, there is a range of steps, undertaken voluntarily or as a part of a formal legally binding arrangement, that could provide confidence in the absence of a military dimension of a space programme. Even though no formal institutional framework for implementing these measures exists today, some of its elements are already in place. In particular, HCoC appears to have the potential to expand the scope of voluntary transparency measures, and Russia's Global Control System proposal could help set up a more elaborate mechanism for technical cooperation and data exchange. Taking advantage of the potential of these mechanisms could help ensure that advances in space launch programmes do not lead to proliferation of ballistic missile capabilities.

CHAPTER 5: The role of open-source data in verification

Pavel Podvig and Decker Eveleth

The growing volume of data about various activities that is available in the public domain is changing many aspects of society. Arms control and disarmament have also been affected by this process, especially as a result of a growing field of public analysis of open-source information.[1] Combined with new technologies, this development directly affects the monitoring and verification capabilities available to states and creates new conditions for future arms control and disarmament agreements.

One possibility is that new technologies could allow the design of verification tools to facilitate disarmament that are more effective and less intrusive.[2] However, it is also possible that new technologies will complicate the calculation of the costs and benefits of arms control and, in fact, make states more cautious about verified arms control.[3] The public-participation component of this issue has received the most attention in recent years as it could have effects that extend beyond mere technological capabilities.[4] It has been argued that it might be possible to "actively engage a self-selected sector of the public in verification".[5]

Whether true societal verification is indeed possible, the role of open-source information is undeniable. In recent years, this role was particularly prominent in (although not limited to) an analysis of various activities related to missile development, testing and operations. It is therefore important to consider how open-source analysis could affect future arms control and disarmament efforts in this area. This chapter provides an overview of some issues and considers their implications.

Open-source data and national technical means

One of the areas where open-source information has the greatest impact on the ability of states to monitor various activities is satellite imagery and space-based observation in general. The number of companies that operate commercial Earth-observation satellites is steadily growing as is the quality of the information that they can provide at a reasonable cost. For most areas of interest, it is now possible to obtain a high-resolution optical image at very short notice and with a high revisit rate. Some satellites can record images in multiple spectral bands, significantly expanding the amount of information available for analysis. While optical observation requires daylight and is often constrained by local cloud conditions, satellites that use other technologies, such as synthetic aperture radar (SAR), are not limited by these factors. Several companies are in the process of building constellations of satellites equipped with SAR sensors, and these images are already commercially available.[6]

1 "Open-Source Intelligence Challenges State Monopolies on Information", The Economist, 7 August 2021, https://econ.st/3mCiZCz.

2 R. Gottemoeller, "Arms Control in the Information Age", US Department of State, 30 March 2012, https://2009-2017.state.gov/t/us/187159.htm; and R. Gottemoeller, "Rethinking Nuclear Arms Control", Washington Quarterly, vol. 43, no. 3, July 2020, pp. 139–59, https://doi.org/10.1080/0163660X.2020.1813382.

3 J. Vaynman, "Better Monitoring and Better Spying: The Implications of Emerging Technology for Arms Control", Texas National Security Review, vol. 4, no. 4, fall 2021, http://doi.org/10.26153/tsw/17498.

4 A. Graef and M. Kütt, "New Opportunities to Build Trust and Ensure Compliance: Using Emerging Technologies for Arms Control and Verification", in Capturing Technology: Rethinking Arms Control, Conference Reader, 2020, pp. 27–33, https://web.archive.org/web/20201031123938/https://rethinkingarmscontrol.de/wp-content/uploads/2020/10/20-AA-RAC-Reader-2020-10-28-final-korr-kompr.pdf.

5 C.W. Stubbs and S.D. Drell, "Public Domain Treaty Compliance Verification in the Digital Age", IEEE Technology and Society Magazine, vol. 32, no. 4, winter 2013, pp. 57–64, https://doi.org/10.1109/MTS.2013.2286432.

6 J. Lewis, "Russia Resumes Burevestnik Testing", Arms Control Wonk, 18 August 2021, https://www.armscontrolwonk.com/archive/1212985/russia-resumes-burevestnik-testing.

In addition, the commercial sector has become an important source of innovation. While in terms of some parameters, such as resolution, commercial images are unlikely to match the capabilities available to some states, the industry is developing systems that would provide the capabilities that a state would not normally deploy. One example is the constellation of imaging satellites deployed by a US company Planet, which provides "3.7 meter resolution images of the entire Earth daily".[7] The availability of commercial satellite images also serves as a strong stimulus for innovation in data processing and analysis. This sector is likely to significantly expand in the coming years.

From the verification point of view, it should not be expected that commercially available satellite data would replace traditional (and often more capable) national technical means (NTM) as the primary monitoring and verification tool. A state entering an arms control agreement is likely to rely solely on those data providers that are under its full and direct control. At the same time, open-source information can significantly augment NTM capabilities and change the assumptions about the conditions in which a verification system operates. Indeed, in the United States, the National Reconnaissance Office is a major customer of US satellite imaging companies.[8] Even though such arrangements could give individual states a certain degree of control over dissemination of information by companies that operate under their jurisdiction, as more states and companies enter the market the diversity of suppliers will prevent full control over data by any individual state or group of states.

The availability of open-source Earth-observation data and commercially developed analytical tools could affect verification arrangements in several ways. The most straightforward one is the fact that the openly available data can serve as an indicator of the capability available to NTM: any activity that is visible to commercial sensors would also be detected by NTM. This means that, in designing verification provisions of an agreement, all parties could agree on a certain standard for the capability of the monitoring tools without disclosing the performance characteristics of their national systems.

To some extent, this approach was used in past US–Soviet and US–Russian arms control agreements, when the parties could confidently assume that certain treaty-limited objects, such as intercontinental ballistic missile (ICBM) silos, can be detected by NTM. As the capabilities of various monitoring systems improve, this approach can be expanded. For example, it might be possible to agree that certain missiles and launchers (or other objects) can be reliably verified remotely. It is likely that satellite imagery can be used to confirm the absence of missile in a silo or a launch tube. For some types of missile, it might be possible to count the number of deployed warheads. In principle, remote monitoring can be used to detect functionally related observable differences (FRODs) defined in an agreement.

The availability of open-source remote-monitoring data can also help design a dispute-resolution mechanism capable of addressing ambiguities that inevitably occur during the implementation of any agreement.

7 "Planet Monitoring - Satellite Imagery and Monitoring," Planet, 2022, https://www.planet.com/products/monitoring.
8 J.E. Barnes, "Intelligence Agencies Pushed to Use More Commercial Satellites", New York Times, 27 September 2021, https://www.nytimes.com/2021/09/27/us/politics/intelligence-agencies-commercial-satellites.html; and T. Hitchens, "Planned NRO Imagery Contracts to Ease Sharing, with One Big Exception", Breaking Defense, 3 November 2021, https://breakingdefense.sites.breakingmedia.com/2021/11/planned-nro-imagery-contracts-to-ease-sharing-with-one-big-exception.

Normally, states are reluctant to use data obtained by NTM because of concerns about disclosing their capabilities. The option of using publicly available information could address these concerns. While this option has been available for some time, it does not seem to have been widely used in the context of arms control treaties in the past.

One reason satellite imagery has not been used in treaty-compliance disputes is probably related to the fact that disagreements that can be resolved in this way are quite rare. Attempts to use satellite images in this context were undertaken by the United States and Russia during the dispute about compliance with the 1987 Intermediate-range Nuclear Forces (INF) Treaty. The United States apparently presented Russia with some images of a test site as proof that a cruise missile test had been conducted there. The source of these images has not been disclosed, but it is highly likely that they were obtained from a commercial provider. Russia also used commercial satellite images to illustrate a point regarding expansion of certain industrial facilities in the United States.[9] Although neither of these attempts contributed to a resolution of the dispute, it is notable that both parties considered the option of using unclassified satellite images.

There are several other cases that illustrate the potential role of commercial satellite images, even though they are not related to verification or treaty compliance.

In August 2019, the United States released an image that showed an unsuccessful attempt to launch a satellite from a launch site in Iran. The image, apparently taken by a US NTM asset, showed the scene of the launch in great detail.[10] However, the launch failure (and indeed preparations for the launch) were detected earlier by independent researchers who had access to commercial satellite imagery of the site.[11] A reference to the open-source image would have been sufficient to confirm the fact of the launch and the release of the more detailed image was unnecessary.

Another recent example of the use of commercial imagery as a substitute for sensitive NTM data was the discovery of silo construction in China. While the United States has long insisted that China intends to expand its missile force, the US government has been reluctant to release data to support these claims. However, in 2021 independent researchers who analysed commercial satellite images discovered at least two sites that showed signs of a large-scale silo-construction activity.[12] US officials publicly validated these findings, in effect using open-source images and analysis to make an argument that was supported by an analysis of data obtained by NTM, even though the openly available data leave some uncertainty about the scale of construction.[13] China has neither confirmed nor denied these claims as it is not party to an agreement that would require it to report or limit its construction activities of a potentially military nature.

9 Russian Ministry of Defence, “Presentation of 9M729 Missile of Iskander-M System”, YouTube, 23 January 2019, https://www.youtube.com/watch?v=Mil6dr5LQnA, 12:00.

10 G. Brumfiel, “Trump Tweets Sensitive Surveillance Image of Iran”, NPR, 30 August 2019, https://www.npr.org/2019/08/30/755994591/president-trump-tweets-sensitive-surveillance-image-of-iran.

11 G. Brumfiel, “Iranian Rocket Launch Ends in Failure, Imagery Shows”, NPR, 29 August 2019, https://www.npr.org/2019/08/29/755406765/iranian-rocket-launch-ends-in-failure-images-show.

12 China Is Building More than 100 New Missile Silos in Its Western Desert, Analysts Say”, Washington Post, 30 June 2021, https://www.washingtonpost.com/national-security/china-nuclear-missile-silos/2021/06/30/0fa8debc-d9c2-11eb-bb9e-70fda8c37057_story.html; D. Eveleth and J. Lewis, “Chinese ICBM Silos”, Arms Control Wonk, 2 July 2021, https://www.armscontrolwonk.com/archive/1212340/chinese-icbm-silos; W.J. Broad and D.E. Sanger, “A 2nd New Nuclear Missile Base for China, and Many Questions About Strategy”, New York Times, 26 July 2021, https://www.nytimes.com/2021/07/26/us/politics/china-nuclear-weapons.html; and M. Korda and H. Kristensen, “China Is Building a Second Nuclear Missile Silo Field”, Federation of American Scientists, 26 July 2021, https://fas.org/blogs/security/2021/07/china-is-building-a-second-nuclear-missile-silo-field.

13 Sean O’Connor, “Questions Remain over Identification of China’s Missile Silos”, Jane’s Intelligence Review, August 6, 2021.

In a somewhat similar case, in an annual report describing military developments in China, the US Department of Defense used commercial satellite images obtained and analysed by non-governmental researchers.[14] This is a marked reversal of the situation in the past, when data released by governments was essentially the only source of information about various military developments or about compliance with treaty obligations.[15]

It should be noted that these three cases all deal with permitted activities that are not constrained by any obligations. They do, however, illustrate the potential use of open-source data as a tool that can provide cooperative monitoring of certain activities.

Sources of open-source data

Satellite imagery is the most prominent example of open-source data that is used as a monitoring tool. However, other types of publicly available information can also provide insight into various activities in a state, including those related to the development, testing, deployment and operation of missiles. These activities often generate various kinds of public data that can significantly change the environment in which verification arrangements are implemented. As is the case with satellite data, this information cannot substitute for the traditional means of monitoring, such as signal intelligence or human intelligence. At the same time, public data could provide a capability that is unavailable to NTM or traditional monitoring tools.

An important source of information of this kind is the scientific and commercial activity that collects and publishes large amounts of data. In some cases, the data is directly linked to missile and space activities and is openly available. Scientific literature could serve as an important source of information about various research and development projects, including those related to missile development. In another example, a network of university-based optical telescopes tracks satellites in geostationary orbit with accuracy that is comparable to or better than that available to most states.[16] There are also commercial providers that operate dedicated space situational awareness radars and other sensors. This data can also be made publicly available.[17] Scientific and commercial data collected for other purposes can in some cases be used to obtain information about missile-related activities. For example, the infrasound data collected by the International Monitoring System operated by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) could in principle be used to detect missile launches.

Another potential source of this kind of open information is the activity of citizens organized to collect certain data. This can be done by activist groups, such as the one that monitors movements of nuclear weapons in the United Kingdom by spotting specialized convoys that transfer weapons.[18] In principle, it is also possible to take advantage of modern information technology and almost universal connectivity to create a large network of

14 Office of the US Secretary of Defense, "Military and Security Developments Involving the People's Republic of China 2020", September 2020, https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.pdf, p. 90; and H. Kristensen, "New Missile Silo and DF-41 Launchers Seen in Chinese Nuclear Missile Training Area", Federation of American Scientists, 3 September 2019, https://fas.org/blogs/security/2019/09/china-silo-df41.

15 See, for example, Thomas B. Cochran et al., Nuclear Weapons Databook: Volume IV – Soviet Nuclear Weapons (New York: Harper & Row, Publishers, New York, 1989).

16 I. Molotov et al., "Current Status and Developments of the ISON Optical Network", International Scientific Optical Network (ISON), August 2013, https://doi.org/10.13140/RG.2.1.2917.2240, p. 26.

17 LeoLabs, "Analysis of the Cosmos 1408 Breakup", Medium, 18 November 2021, https://leolabs-space.medium.com/analysis-of-the-cosmos-1408-breakup-71b32de5641f.

18 NukewatchUK, "Warhead Convoy Movements Summary 2020", January 2021, https://www.nukewatch.org.uk/wp-content/uploads/2021/01/Convoy-log-2020.pdf.

sensors that would collect various kinds of data. This kind of network, for example, was created by a non-governmental group to monitor background radioactivity after the incident at Fukushima Daiichi nuclear power plant in 2011.[19]

An approach based on organized activity by citizens, of course, has its limitations since it implies active participation and since certain types of monitoring could be illegal in some states. However, even if citizens are not asked to collect data or do not do it on purpose, it does not mean that they are not collecting data. Moreover, large amounts of data generated by users of various digital services, such as social media or some applications, are either already publicly available or can be obtained by researchers who work with open-source data.

It must be emphasized that in this case the data collection is often done inadvertently. For example, a photo posted on a social media site can help identify a missile launcher that had not been seen earlier, point at a new missile-development project or uncover clandestine deployment of cruise missiles.[20] Officially released materials, such as broadcasts or photo accounts, could inadvertently disclose very valuable information, despite the efforts to remove sensitive data from materials approved for public release.[21] In some cases, information that is collected and released for a certain purpose can reveal activity that is normally not detectable by traditional monitoring or intelligence tools. In one instance, information about user activity published by a fitness app disclosed locations of multiple military bases around the world.[22] In another example, publicly accessible data collected by an educational application helped identify specific nuclear weapon storage facilities.[23]

Large amounts of relevant information are also released as a result of normal economic activity and the various interactions between companies and individuals that accompany development, testing and production of a military system. These may include tenders, contracts, reports to shareholders, lawsuits and other legal documents. An analysis of this information can provide insights into various programmes long before they are made public.[24]

It should also be noted that an important factor in these disclosures is the existence of multiple connections between people who can identify and disseminate information that would normally escape notice. Since this is not an organized community, the process of finding relevant information cannot be made systematic. Proper operations security procedures could also reduce the digital footprint of military activities. At the same time, as the examples cited above suggest, it

19 A. Graef and M. Kütt, "New Opportunities to Build Trust and Ensure Compliance", p. 30.
20 J. Lewis and J. Ray, "Show and TEL", Arms Control Wonk, 26 March 2013, https://www.armscontrolwonk.com/archive/206385/show-and-tel/; M. Yeo, "Video Reveals Chinese H-6N Bomber Carrying Suspected Hypersonic Weapon", Defense News, 19 October 2020, https://www.defensenews.com/global/asia-pacific/2020/10/19/video-reveals-chinese-h-6n-bomber-carrying-suspected-hypersonic-weapon; and J. Lewis, "Red Bird Express", Arms Control Wonk, 25 January 2015, https://www.armscontrolwonk.com/archive/207496/red-bird-express.
21 D. Eveleth, "China's Mobile ICBM Brigades: The DF-31 and DF-41", Mapping Global Missile Forces, 2 July 2020, https://www.aboyandhis.blog/post/china-s-mobile-icbm-brigades-the-df-31-and-df-41; and D. Eveleth, "Mapping the People's Liberation Army Rocket Force", Mapping Global Missile Forces, 30 March 2020, https://www.aboyandhis.blog/post/mapping-the-people-s-liberation-army-rocket-force.
22 R. Pérez-Peña and M. Rosenberg, "Strava Fitness App Can Reveal Military Sites, Analysts Say", New York Times, 29 January 2018, https://www.nytimes.com/2018/01/29/world/middleeast/strava-heat-map.html.
23 "US Soldiers Expose Nuclear Weapons Secrets Via Flashcard Apps", Bellingcat, 28 May 2021, https://www.bellingcat.com/news/2021/05/28/us-soldiers-expose-nuclear-weapons-secrets-via-flashcard-apps.
24 P. Podvig, "Object 370, Project 4202 and Construction in Dombarovskiy", Russian Strategic Nuclear Forces, 6 February 2013, https://russianforces.org/blog/2013/02/object_370_project_4202_and_co.shtml; and B. Hendrickx, "Aerostat: A Russian Long-Range Anti-Ballistic Missile System with Possible Counterspace Capabilities", Space Review, 11 October 2021, https://www.thespacereview.com/article/4262/1.

is exactly the absence of organization and the distributed nature of this activity that make it virtually impossible to predict specific vulnerabilities or the ways in which information may be released.

While crowdsourcing is an important element of open-source analysis, the network of people involved in it can also rely on its ability to reach various subject matter experts and connect them together. Some of these experts may consider open-source analysis their core professional activity, others may be involved in this work periodically. Collaboration between experts is often informal, but there are also efforts to facilitate joint work and help participants get better access to a variety of data.[25]

The ability of experts to find and analyse all kinds of data from publicly available sources will only grow with time. Even though this activity may not reach the point of true societal verification, it is likely to become an extremely important factor in existing and future verification arrangements.

Availability of data

The potential of open-source analysis and its role in verification arrangements critically depends on the availability of publicly accessible data that can be analysed by independent experts and intelligence communities. As illustrated above, one of the strongest characteristics of open-source analysis is its ability to process data that exists in the public domain regardless of the intent to release it. This ranges from overhead satellite imagery to satellite tracking data and from legal documents to posts on social media. Even though states can try to limit the availability of information in all these domains, it is extremely difficult to achieve a high degree of confidence in its success. Alternatively, in a cooperative verification environment, a state could take steps to ensure availability of certain information precisely for the purpose of facilitating verification.

The cooperative approach to verification can be traced back to the first US–Soviet strategic arms control agreement, the 1972 Strategic Arms Limitation Treaty (SALT).[26] Both parties accepted that NTM would be the primary verification tool and each made a commitment not to interfere with the other's NTM. More importantly, the agreement includes an obligation "not to use deliberate concealment measures which impede verification by national technical means".[27] These obligations were confirmed in all subsequent arms control treaties between the United States and the Soviet Union or Russia. The non-interference obligation is also included in multilateral treaties, such as the 1996 Comprehensive Nuclear-Test-Ban Treaty (CTBT). It is important to note that these obligations are deliberately broad, and they do not refer to specific NTM or any particular concealment techniques.

It is unlikely that a similar formal obligation, especially regarding non-concealment, would be universally accepted or applied to all categories of data relevant for open-source analysis. At the same time, the presence or absence of deliberate effort to limit circulation of information could be readily observed. From the verification point of view, certain steps, such as concealment of missile launchers, would make it more difficult to have confidence in compliance with an agreement that limits the number of missiles. On the other hand, systematic publication of certain records, such as information about military units or corporate reports, could demonstrate stronger commitment of a state to its

25 "Open Nuclear Network", n.d., https://oneearthfuture.org/open-nuclear-network.
26 Interim Agreement between the United States of America and the Union of Soviet Socialist Republics on Certain Measures with Respect to the Limitation of Strategic Offensive Arms, 26 May 1972, https://2009-2017.state.gov/t/isn/4795.htm.
27 Ibid., Article V.

arms control obligations. This does not necessarily require that transparency of this kind must be included in the agreement, although it might be in some cases.

By all indications, the capabilities of open-source analysis are changing attitudes toward transparency in general. Of course, most states take measures to impose secrecy on broader categories of data and improve their operations security. While these measures may have a certain effect, their effectiveness in the long run is questionable. More likely, states will be forced to reconsider their approach to operations and adopt practices that do not rely on secrecy or concealment. This, in turn, would make it possible to simplify verification arrangements in the future.

With regard to missiles, states could further help verification arrangements by releasing additional information in the public domain. This could include releasing technical data about missiles, providing launch notifications, and making public information about the organizational structure of forces and individual units. In the framework of cooperative verification, these measures, even if they are not formally included in an agreement, could be strong evidence of parties' commitment to their obligations.

Open-source data and compliance assessment

While open-source information could augment NTM and facilitate development of new verification methods and tools, it also brings additional complexities to the verification process. Being publicly accessible, open-source information gives independent experts and organizations the capability to conduct their own analysis outside the constraints of a formal state-run evaluation process. This erodes the monopoly of states on judgements regarding various activities, including those related to compliance with obligations under verifiable agreements.

A state's conclusions about compliance are a result of an internal deliberation process that is fundamentally political, rather than purely technical in nature. Judgements about compliance normally reflect a broader range of considerations and are often shaped by the state's internal politics. In certain situations, a state may choose to downplay the importance of some information or even completely ignore it; in others, a state may interpret technical information in a certain way to gain leverage over its partner on issues unrelated to the agreement that is being verified.[28]

The existence of open-source expertise seriously limits the ability of states to control the release and interpretation of information. As a result, it could significantly narrow the range of policy options available to states. In many ways this is a positive development since open-source analysis could provide a valuable check on various claims that are made by states and on their ability to shape public opinion by a selective release of information. There are known cases when independent researchers used openly available information to disprove claims made by states or used their expertise to challenge the interpretation of information released by governmental officials.[29]

At the same time, while a state may have its own agendas and biases, these are produced by a political process that is, at least in theory, supposed to reflect the understanding of the national security interests of the state. This process also implies a degree of accountability,

28 P. Podvig and A. Woolf, "Monitoring, Verification, & Compliance Resolution in US–Russian Arms Control", WMD Compliance and Enforcement Series no. 5, UNIDIR, December 2019, https://doi.org/10.37559/WMD/19/WMDCE5; and P. Podvig, "Treaty Compliance Controversies", Russian Strategic Nuclear Forces, 3 December 2013, https://russianforces.org/blog/2013/12/treaty_compliance_controversie.shtml.

29 G. Kulacki and D. Wright, "A Military Intelligence Failure? The Case of the Parasite Satellite", Union of Concerned Scientists, 16 August 2004, https://www.ucsusa.org/sites/default/files/2019-09/parasite_satellite_8-17-04.pdf; and V. Salama, "Trump Administration Pushes Allies to Pressure China Over Its Nuclear Program", CNN, 29 October 2020, https://edition.cnn.com/2020/10/29/politics/us-china-nuclear-pressure/index.html.

although its mechanism could vary across states, often quite significantly. This does not necessarily mean that judgements and decisions made by a state align with national security interests as understood by the public. It does, however, reflect the political nature of the process.

It is more difficult to assess the motivations of non-state organizations and experts, even when organizations are transparent about their goal and mission. Some organizations can rely on their demonstrated track record and on validation of their findings by their peers or by states. One of the problems with this mechanism is that, even though open-source analysis operates with publicly accessible data, getting access to data could require considerable resources. Similarly, processing the information may also require significant resources and involve algorithms that may not be fully transparent or well understood.

Normally these issues would be addressed by the introduction of mechanisms that are present in any scientific field, such as greater reliance on a peer-review process and improved transparency of data and methods. To a large extent, this process is already underway. At the same time, open-source analysis of issues related to verification and treaty compliance will remain part of a political process, so it is difficult to expect that it will be free from political pressures.

Conclusions

It is undeniable that the growing availability of publicly accessible data has already changed the environment in which states conduct their monitoring and verification activities. It is also likely that this process will continue, probably in ways that are hard to predict. While the full implications of these changes are difficult to assess, they do seem to open new venues for designing verification arrangements that can be included in future arms control and disarmament agreements.

Missile verification appears to be one of the areas where new capabilities could be particularly relevant. Activities involving development, testing and deployment of missiles normally have a significant footprint that can be detected by a variety of monitoring tools.

As discussed in this chapter, open-source intelligence cannot replace NTM as the primary verification tool. It could, however, augment it in some very important ways and expand the capabilities of states to monitor various developments. The availability of open-source data could help build better and potentially less intrusive verification mechanisms as it allows parties to have a common reference point for some verification procedures.

Another factor, especially important in situations of cooperative verification, is that growing transparency provides states with multiple new ways to demonstrate compliance with their obligations. These could include measures that are not formally included in an agreement, such as transparency regarding development and testing of missiles, launch notifications or other similar information. Even if this information may not be subject to verification directly, its availability could allow parties to have greater confidence in their compliance assessments.

At the same time, it should be understood that the increasing amounts of open information and the growing capability of the public to access and analyse the data is seriously changing the political dynamics of the processes of assessing compliance with various agreements. Even though, on balance, these changes are bringing greater accountability into the process, the public should exercise due diligence in assessing their effect and should create mechanisms that would reinforce positive aspects of these changes.

Conclusions

One conclusion that can be drawn from the overview of various options presented in this report is that verifying obligations related to missile activities could be a difficult task. Even basic characteristics of missiles, such as range, can be difficult to define in a verifiable way. The mobility of most modern missile launchers as well as the existence of both nuclear and conventional versions of some missiles add to the challenge. It is also difficult to reliably draw a line between the programmes that develop space launch vehicles and ballistic missile programmes, especially when it comes to the transfer of technology.

This does not mean, however, that the task is impossible. There already exists a rich set of verification tools that have been tested in the practice of arms control. New tools and open source data streams are emerging that could augment verification arrangements. These tools can be developed further and applied to a variety of new arms control and disarmament scenarios. It is, however, important to keep in mind that verification is a complex activity that cannot and should not be reduced to a technical procedure. The increasingly complex nature of missile-related activities creates a situation in which purely technical verification procedures would have to become extremely intrusive and require direct access to missiles, production facilities, or operational sites if they are applied as standalone measures to determine compliance.

While properly designed verification arrangements must be able to detect and therefore deter violations, the associated protocols and procedures play a broader role. The record of compliance with specific procedural requirements of the verification process is a very reliable indicator of the commitment of a party to the obligations that it has accepted. It should be possible to build verification provisions to emphasize this aspect of the process.

As this report demonstrates, this approach will significantly expand the range of options that can be considered in future agreements. While some of these options – such as data exchange, notifications, on-site inspections or demonstrations – could still be rather intrusive, they can also be flexible enough to be adapted to specific obligations that an agreement might include. Importantly, most measures discussed in this report are based on well-established practices and do not involve complex and untested technologies. Challenges will remain, as some solutions may require a serious political commitment and others would benefit from the development of new verification technologies. However, if states are willing to accept limits on their missile-related activities, they will find a solid foundation on which to build verification arrangements.

Missiles are becoming an increasingly prominent element of military arsenals, but the system of arms control that helped provide a check on the missile arms race is under considerable stress. Addressing this challenge will require verifiable limits on missile-related activities to be established in a cooperative arms control and disarmament process.

This report covers various aspects of verification that could be applied to missiles. The authors look at the experience of past arms control and disarmament efforts, provide an overview of existing verification tools, and initiate a discussion of potential arrangements that could make future arms control agreements possible.

The general conclusion of the report is that there is a variety of options to consider. Most verification arrangements would require a fairly high level of transparency, but that is what makes them stronger and more reliable. Future agreements should emphasize the cooperative aspect of the verification process and develop the technical and organizational procedures accordingly.

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