Direct Verification of Nuclear Weapons and the Secrecy-Certainty Spectrum

by

Eleanor Immerman

B.A., International Studies with Honors
University of Chicago, 2010

Submitted to the Institute for Data, Systems, and Society in Partial Fulfillment of the Requirements for the Degree

of

Master of Science in Technology Policy

at the

Massachusetts Institute of Technology

June 2016

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Director, Institute for Data, Systems, and Society
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Acknowledgements

Thanks most of all to my advisor, Scott, for being very flexible in what I study and having extremely useful insights and advice in helping to shape the interviews and research project. Thank you so much to Katia for joining the Moscow portion of this project—I greatly appreciate your research assistance and it was phenomenal working with you. Thank you to Aditi, Ruaridh, and Marc for encouragement and interesting conversations that helped with thinking about how to approach verification questions with a science, technology, and society lens. Thank you to my roommates, Meg, Brad, and Jodie, for excellent conversations, reminders of the wider context, and frequent coffee and breakfast breaks. Thank you to Rory, Addie, Marika, and Ashley for being amazing. Thank you to Daniel for being the best of all possible brothers. Thank you to the rest of my research group: Areg, TD, Jill, Jayson, Taylor, and Mareena. Thanks to MISTI for funding my research in Moscow and to the Technology Policy Program—especially Barb.

Thanks to Jonas, Josh, and the rest of the *Bulletin* group as well as Michelle and Scav 2007 for getting me interested in the sociology of nuclear weapons originally. Thank you so much to everyone I interviewed for this project—I greatly enjoyed meeting with all of you and it was fascinating to hear about your work in the field.

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ABSTRACT

Historically, arms control treaties have exclusively relied on indirect verification mechanisms. Increasingly, direct nuclear weapons verification proves relevant to future arms control treaties. I therefore explore the epistemology of direct nuclear weapons verification through interviews, reports, and publications on potential verification systems.

I argue that within Russia, most involved in the arms control non-governmental community, consider existing verification technologies sufficient. They are noticeably caught between contradictions in their work on disarmament verification and skeptical that their efforts will influence arms control dynamics. Within direct verification of nuclear weapons (DVNW) experiments, the few vulnerability tests and technology demonstrations that occur tend to disrupt prior assumptions about verification and longstanding research trajectories within the field, triggering epistemic crises within the verification field. Shifting political and technical constraints shape many of the ideas within DVNW. Narratives that frame secrecy and certainty as direct trade-offs appear to have developed in the United States with Field Test 34 and continue to generate an underlying skepticism towards any approaches that attempt to reconcile the aims of direct weapons verification.

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Introduction

When verifying the Russian SS-18 missile, a treaty inspector could look at warheads from behind a "conforming shroud," a piece of cloth, where perturbations in the cloth indicated an item of potential interest. The SS-18 was Russia's sole heavy intercontinental ballistic missile permitted under the START Treaty. The inspector counted ten objects in two rows, then two "objects"—assumed to be nuclear warheads—were carried away, and the inspector could measure the neutrons emitted two meters from the missile, and compare that to the background neutron level. This is the most invasive measure that has been permitted in any nuclear arms control treaty.[1]

Verification in arms control has long been indirect. Though warheads are ostensibly limited by the most recent arms control treaty, New START, these weapons are accounted for through counting rules based on delivery vehicles—submarines, missiles, and bombers—rather than by counting the weapons themselves. That is, counting rules associate a hypothetical number of nuclear weapons with each delivery vehicle. For instance, in the New START Treaty, heavy bombers are counted as one warhead, even though their capacity can be as high as 20 warheads.[2] Study of the possibility of directly verifying nuclear warheads or their components began in 1963. Yet possible measurements developed through this research have never been employed in a treaty context and appear not to be viable for a bilateral treaty.

About fifteen thousand nuclear weapons remain. Over 90% of these are in the Russian and U.S. arsenals. Both countries have expressed a willingness to reduce their nuclear arsenals further. Estimates of how far they might go vary, though the United States seem confident they

[1] U.S. interview subject 14.
[2] Hans M. Kristensen, "New START Treaty has new counting," Federation of American Scientists, https://fas.org/blogs/security/2010/03/newstart/.

can draw to down to fewer than 1000 deployed weapons.[3] In Russia, the calculation is more complex, conditioned on near neighbor dynamics, concerns regarding U.S. missile defense and efforts at prompt global strike, and Russia's conventional force weakness relative to NATO countries. Nonetheless, Russia has expressed an interest in further reductions, with caveats.[4] Beyond their deployed arsenals, both nations have thousands of weapons in strategic reserves and awaiting dismantlement. The strategic reserve serves two purposes. If deployed weapons become unreliable, these weapons can replace them. Secondly, the reserve is kept on the chance of a future arms race, in which both countries might expand their deployed forces. Weapons being dismantled are dismantled without verification.

Force parity appears to matter greatly to political and military leaders in both nations, for strategic and identity-driven reasons.[5] The importance of parity increases to both sides as the number of deployed weapons decline. At lower numbers, fewer weapons can easily off-set parity. Uncertainty about reserve stockpiles and dismantlement rates create ambiguity about parity. Verification has become increasingly relevant to the future of arms control. Several scholars have estimated that direct verification of warheads will be considered necessary when deployed weapons go below 1000.[6] Accordingly, I am keen to explore the technical and political constraints surrounding direct nuclear weapons verification. These constraints on how direct

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[3] Department of Defense, "Report on Nuclear Employment Strategy of the United States Specified in Section 491 of 10 U.S.C," (June 12, 2013), http://www.globalsecurity.org/wmd/library/policy/dod/us-nuclear-employment-strategy.pdf.

[4] Anatoly Diakov, Eugene Miasnikov, and Timur Kadyshev, "Nuclear Reductions after New START: Obstacles and Opportunities," *Arms Control Today* (May 3, 2011), https://www.armscontrol.org/act/2011_05/Miasnikov.

[5] Anne L. Clunan, *The Social Construction of Russia's Resurgence: Aspirations, Identity, and Security Interests* (Baltimore: Johns Hopkins University Press, 2009); Nick Ritchie, "Relinquishing Nuclear Weapons: Identities, Networks, and the British Bomb," *International Affairs* 86, no 2 (March 2010): 465-487.

[6] Steve Fetter, "Verifying Nuclear Disarmament," Henry L. Stimson Center Project on Eliminating Weapons of Mass Destruction (March 1998), http://drum.lib.umd.edu/bitstream/handle/1903/4023/1998-VerifyingNuclearDisarmament.pdf?sequence=1&isAllowed=y.

verification could occur vary in the United States and Russia, and how these dynamics relate remains unexplored.

In this thesis, I ask: what beliefs and narratives underlie past approaches to direct verification and how have these beliefs formed and evolved? How do Russian and American engineers and policy-makers consider the constraints surrounding verification and why have past approaches not been viable? Based on U.S. and Russian constraints, how can we define the treaty space for future arms control verification?

No existing literature pertains to these questions, although insights from science, technology, and society (STS) studies of experimentation and technology demonstration are useful for considering the studies—the Black Sea Experiments, the Fissile Material Technology Transparency Demonstration, and the U.K.-Norway Initiative—conducted in the context of direct verification of nuclear weapons (DVNW). Technology policy and STS accounts of Soviet and Russian arms control history are useful for exploring what plays into current perspectives on DVNW; histories of the nuclear arms control and nonproliferation regime are similarly helpful. Policy arguments and official reports on the possibilities for DVNW are helpful as artifacts to explore the progression of ideas within this realm.

I explore Russian and American perspectives on weapons verification, focusing on designers of verification systems and those whose views would influence treaty negotiations. Secondly, I explore the dynamics of the three major international collaborations focused on direct weapons verification via semi-structured interviews with Russian and American participants. Interviewees were selected from reading publications from these collaborations and identifying key actors involved in the design and testing of these systems, the administrative personnel who distinguish between direct verification research proposals, and Russians and

Americans involved in direct weapons verification experiments. Further, interviewees were asked to suggest further people for interviews. All except one Americans contacted agreed to be interviewed; about half of Russians contacted agreed to be interviewed. COUHES approved of this study and granted it an exemption.[7] Sample interview questions are included in the appendix to this thesis. Interviews ranged from forty minutes to three and a half hours. When the subject was amenable, interviews were recorded and transcribed. Otherwise, notes were taken throughout the interview.

Unclassified complete prototypes of verification systems are described in the *Annual Proceedings of the Institute of Nuclear Materials Management.* I therefore review these articles and unclassified reports on verifying dismantlement and disarmament from the United States and Russia. Significant archival resources are available for the three major international collaborations I discuss in this paper: the Black Sea Experiments, the Fissile Material Technology Transparency Demonstration, and the U.K.-Norway Initiative. While American and Russian perspectives are both essential to this project, resources are far more plentiful on the American side. I was able to interview fewer Russians and access less documentation, since most of their labs' research is classified. I therefore address a less expansive set of questions with regard to Russian beliefs and knowledge regarding direct weapons verification.

I argue that within Russia, most involved in the arms control non-governmental community believe existing verification technologies are sufficient. They were noticeably caught between contradictions in their work on disarmament verification, both dedicated to their work and skeptical that their efforts would influence arms control dynamics as well as viewing national policies as unsound, yet it would not make sense to contradict them. Within the context of DVNW experiments, the available evidence suggests that assumptions are rarely tested. The

[7] COUHES is MIT's internal review board for research involving human subjects.

few vulnerability tests and technology demonstrations that have occurred have tended to disrupt prior assumptions about verification and longstanding research trajectories within the field, triggering epistemic crises within the verification field. Shifting political and technical constraints tend to shape many of the ideas held by DVNW researchers. Recently, the U.S. National Nuclear Security Administration has shifted to a research model that they hope will operate outside these constraints. An important narrative that influences many beliefs is the secrecy-certainty trade-off. This appears to have emerged with Field Test 34 and continues to generate an underlying skepticism towards any approaches that attempt to reconcile the aims of direct weapons verification. A recurring theme is skepticism that a system will be convincing without revealing classified information to the inspector.

Debates on how to execute direct nuclear weapons verification occur in the context of a broader nuclear arms control and nonproliferation regime. I review these regimes, the history of treaty verification, and the jargon of the field in chapter one. Next, I explore Russia's non-governmental organization (NGO) community perspectives on past arms control efforts and how they conceive of the treaty space for future weapons reduction and dismantlement treaties. In chapter three, I explore large-scale interstate collaborations to experiment on or demonstrate potential direct weapons verification systems. For the fourth chapter, I consider the two primary epistemic communities involved in parsing technical verification in the United States: the national laboratories and the National Nuclear Security Administration. I argue that their core assumptions about how verification would proceed have given way to widespread uncertainty and a desire to develop "unconstrained" verification systems. Finally, I address the implications of this project for informing the development of direct nuclear weapons verification and the treaty space that would use such a system, and I suggest future directions for research on these topics.

Chapter 1: Background

Underlying questions of direct nuclear weapons verification are a set of dynamics surrounding the nuclear nonproliferation and arms control regimes. There is far too much content to cover in this thesis, though I will briefly give an overview of the core questions affecting verification. Most multilateral questions involving nonproliferation and arms control are addressed through fora stemming from the Nuclear Non-Proliferation Treaty (NPT). The NPT entered into force in 1970. It is widely regarded as the "cornerstone" of the nonproliferation and arms control regime.[8] The only states that are not signatories are India, Pakistan, Israel, and South Sudan. North Korea formally withdrew from the treaty in 2003.

Through the NPT and its subsequent interpretation, disarmament, nuclear energy, and nonproliferation are discursively tied. Parties to the treaty commit not to assist other nations in developing nuclear weapons programs (article I), to not accept such assistance (article II), to accept safeguards from the International Atomic Energy Agency to ensure they do not develop nuclear weapons programs if they are designated non-nuclear weapons states (NNWS) under the treaty (article III) and to "pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament" (article VI).[9] Parties' rights to develop nuclear energy programs are asserted (article IV), though questions abound about the extent to which this permits enrichment or reprocessing and how it is possible to have a nuclear energy program that limits the odds of proliferation.[10] The Treaty was left

[8] "Nuclear Nonproliferation Treaty," U.S. Department of State (2015), http://www.state.gov/t/isn/npt/; "2015 Review Conference of the Parties to the Treaty on the Nonproliferation of Nuclear Weapons (NPT)," United Nations (2015), http://www.un.org/en/conf/npt/2015/.

[9] "The Treaty on the Non-Proliferation of Nuclear Weapons," United Nations, http://www.un.org/en/conf/npt/2005/npttreaty.html.

[10] See for instance: Ambassador Jackie W. Sanders, "NPT Article IV," (Presentation at the Third Session of the Preparatory Committee for the 2005 Review Conference of the Treaty on the Non-Proliferation of Nuclear Weapons, April 29, 2004, New York City, New York), http://2001-2009.state.gov/t/isn/rls/rm/32292.htm; Fred

purposefully vague as to how disarmament would proceed, likely given doubt at the time that disarmament would ever be achievable or desirable.[11]

Injustice is a prevailing theme for many states party to the NPT. The treaty designates five states "nuclear weapon states" (NWS) and the remaining states are "non-nuclear weapon states" (NNWS). The five were China, the United States, the then-Soviet Union, France, and the United Kingdom, then the only nuclear weapons-possessing countries in the world. The five states double as the five permanent, veto-possessing, members of the United Nations Security Council, through which many nuclear-relevant decisions are made. NWS and NNWS abide by different rules under the NPT, and this generates a two-tiered status, which many NNWS see as unjust. This two-tiered system closely fits North-South divides. NATO allies of the United States, as well as Japan, South Korea, and Australia are covered via extended deterrence, under the U.S.' nuclear umbrella. Many of these nations therefore have somewhat ambivalent relationships with disarmament and are more likely to align with NWS allies in nonproliferation and disarmament assessments.

Accordingly, many NNWS have joined the Non-Aligned Movement (NAM). NAM is composed of 120 states, who view themselves as unaligned with major powers. All African countries, save South Sudan, are members of NAM, while just one country in Europe, Belarus, is a member. NAM acts as a voting bloc within the NPT regime, trying to rebalance power among members. Many NAM states condition their willingness to support nonproliferation efforts,

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McGoldrick, "Limiting Transfers of Enrichment and Reprocessing Technology: Issues, Constraints, Options," Harvard Kennedy School Belfer Center for Science and International Affairs (May 2011), http://belfercenter.ksg.harvard.edu/files/MTA-NSG-report-color.pdf; Nina Tannenwald, "Justice and Fairness in the Nuclear Nonproliferation Regime," *Ethics & International Affairs* 27, no. 3 (Fall 2013): 299-317.

[11] Conference Report: Nuclear Non-Proliferation: Planning for 2020 (forthcoming), December 14-18, 2015, Steyning, United Kingdom.

which are usually driven by NWS, on the NWS' progress on disarmament and arms control.[12] NNWS frequently express a sense that they were deceived by NWS and believed progress on disarmament would be faster and more definitive. However, some argue that these arguments are somewhat disingenuous given the original ambiguity in the NPT and are driven more by an aim to pressure the NWS to comply with article VI.

Nonetheless, these NNWS are keen to be more involved in disarmament and arms control efforts. Every five years, there is an NPT Review Conference, which involves assessments of progress in fulfilling the terms of the treaty. Non-NPT nuclear weapons possessing nations—India, Pakistan, North Korea, and Israel—are typically not involved in the conversation. Dynamics between all the nuclear-weapons possessing states (NWPS) affect their willingness to engage on these questions. It is widely assumed among NWS that arms control will begin as a bilateral process between the United States and Russia, though as their numbers of weapons decline, other NWPS will be drawn in.[13] However, several states disagree with this approach and the timeline, as well as how arms reductions will extend to more states.[14] Indeed, how to assess progress on article VI (disarmament) is uncertain. NWS tend to be partial to a gradual series of steps, including a comprehensive test ban, cutting off fissile material production, and building alternate security dynamics and structures. Their defense doctrines assume that nuclear weapons have a stabilizing effect on global affairs, whether or not this is valid, and they are therefore

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[12] Tannenwald; Harald Muller and George Perkovich, "Debating Disarmament: Bridging the Gap in the Nuclear Order," Carnegie Endowment for International Peace (February 14, 2012), http://carnegieendowment.org/2012/02/14/debating-disarmament-bridging-gap-in-nuclear-order.

[13] United Nations, "2010 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons," NPT/CONF.2010/50, http://www.un.org/ga/search/view_doc.asp?symbol=NPT/CONF.2010/50%20(VOL.I).

[14] For instance, many in Russia are convinced that China has more nuclear weapons than widely reported and should therefore be involved in reductions in the nearer future. See Alexei Arbatov, "Engaging China in Nuclear Arms Control," Carnegie Endowment for International Peace (October 2014), http://carnegieendowment.org/files/Arbatov_China_nuclear_Eng2014.pdf.

concerned with developing alternate stabilizing structures should disarmament proceed.[15] Structures such as the humanitarian initiative focus more on the destabilizing and unjust dimensions of nuclear weapons possession and call for more immediate reductions and progress. Accordingly, what differing state groupings view as progress differs sharply. The five NWS consider recent arms bilateral arms reductions in the United States and Russia as well as unilateral reductions in France and the United Kingdom, and all five collaborating to produce a glossary of terms related to nuclear weapons and verification significant progress within an incremental framework towards article VI goals.[16] However, within the Humanitarian Initiative, such efforts tend to be regarded as insufficient.

Since the United States and Russia possess the vast majority of existing nuclear weapons, near-term disarmament progress has been focused on bilateral U.S.-Russian arms control treaties. Of the estimated 15,375 nuclear weapons globally as of March 2016, the United States possesses about 6,970 and Russia has 7,300, according to unclassified estimates from Robert Norris and Hans Kristensen.[17] The discrepancy between the two is due to tactical nuclear weapons, which have never been addressed in an arms control reductions treaty. An overview of key events in nuclear arms control and verification history proves useful in contextualizing coming arms control efforts. Treaties are listed in terms of their date of signature, rather than entry into force. For the Comprehensive Test Ban Treaty, which is awaiting signatures from several states before entry into force, the date at which the treaty opened for signature is listed.

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[15] Todd S. Sechser, "Militarized Compellant Threats, 1918-2001," *Conflict Management and Peace Science* 28, no. 4 (2011), http://faculty.virginia.edu/tsechser/Sechser-CMPS-2011.pdf.

[16] "Statement by the People's Republic of China, France, the Russian Federation, the United Kingdom of Great Britain and Northern Ireland, and the United States of America to the 2015 Treaty on the Non-Proliferation of Nuclear Weapons Review Conference," (Nuclear Non-Proliferation Treaty Review Conference, May 2015), http://www.un.org/en/conf/npt/2015/statements/pdf/P5_en.pdf.

[17] Hans Kristensen and Robert Norris, "World Nuclear Weapon Stockpile," Ploughshares (March 2, 2016), http://www.ploughshares.org/world-nuclear-stockpile-report.

Dates	Arms Control and Disarmament Treaties	Experiments, Demonstrations, Collaborations
1963	Partial Test Ban Treaty	
1967		Field Test 34
1968	Nuclear Nonprolif. Treaty	
1970		
1972	SALT I Treaty, ABM Treaty	
1974	Threshold Test Ban Treaty	
1979	SALT II Treaty	
1987	INF Treaty	
1988		Joint Verification Experiments
1989		Black Sea Experiments
1991	START I Treaty	
1992		
1993	HEU-to-LEU Agreement	
1994		Lab-to-lab begins
1995		WSSX begins
1996	CTBT opens for signature	Trilateral Initiative begins
2000		FMTTD
2002		Trilateral Initiative ends
2005		WSSX ends
2007		UK-Norway begins
2010	New START Treaty	
2014		Lab-to-lab ends

As is clear from the timeline, collaboration between the United States and Russia expanded rapidly in the 1990s. Though there has been a Threshold Test Ban Treaty, which bans tests of weapons with yields greater than 150 kilotons, and a Partial Nuclear Test Ban Treaty, which prohibits all nuclear tests that are not underground, a comprehensive treaty has not gone into effect. These multilateral treaties are typically perceived as both arms control—limiting new types of nuclear weapons that would require above-ground testing—and nonproliferation measures—making it more difficult for new states to try to produce nuclear weapons, if their designs would require tests. Explicit arms control and disarming treaties exclusively exist between Russia, the Soviet Union, former Soviet republics, and the United States.

In past arms control treaties, nuclear radiation-based measurements have been minimally involved. Their role was primarily to measure the *absence* of nuclear weapons. Helium-3 bubble detectors have been included in the verification of the Intermediate-Range Nuclear Forces (INF) Treaty, START I Treaty, and New START. Such detectors rely on an isotope of helium, ^{3}He.[18] The detector is relatively unaffected by beta and gamma rays. However, when it encounters slow-moving "thermal" neutrons, it absorbs them and produces two isotopes of hydrogen, which can be measured efficiently. In the START and New START treaties, these detectors are used to measure the absence of neutron radiation for items that are declared to be *non-nuclear*.[19] Therefore, assuming these items have been accurately declared, no sensitive information is revealed. Under the INF Treaty, SS-20s, which could carry three nuclear warheads, had to be destroyed, while SS-25s, which carried just one warhead, were permitted under the treaty.[20] The rockets had a similar first stage and were therefore distinguished using the first measurements of *nuclear* items permitted under a treaty. The two missiles were distinguished through neutron measurements via ^{3}He detectors. Under the START I Treaty, ^{3}He detectors were used to verify that both air-launched cruise missiles that were declared to be non-nuclear and containers that

[18] Notably, tritium is usually involved in the triggering of nuclear weapons, so as production of nuclear weapons lapses, so does the supply of ^{3}He and ^{3}He has appreciated in price about twentyfold in recent years. See, for instance, Craig Tyler, "Running Low," *1663* (August 2014), https://www.lanl.gov/discover/publications/1663/2014-august/_assets/docs/1663_22_HE3.pdf.

[19] U.S. Department of State, "Annex on Inspection Activities to the Protocol to the Treaty Between the United States and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms," http://www.state.gov/documents/organization/141293.pdf; Edward Ifft, "Monitoring the INF and START Treaties," (Presentation to the American Physical Society, November 2, 2013).

[20] M.W. Johnson, J.E. Doyle, and C.L. Murphy, "Recovering START Institutional Knowledge." *Institute for Nuclear Material Management Annual Meeting Proceedings* 52 (2011), http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-11-03284

were declared not to contain nuclear fissile materials were accurately declared.[21] Under New START, ^{3}He detectors are used only to measure that objects declared to be non-nuclear warheads do not release more neutrons than background levels.[22]

Beyond arms control treaties, radiation-based measurements of sensitive materials have been involved in the HEU blend-down agreement. Through this agreement, 500 metric tons of highly enriched uranium, derived from dismantled Soviet-era warheads, were downblended with low enriched uranium to produce fuel for U.S. nuclear reactors. The deal extended from 1993 until the downblending was completed in 2013. Within the deal, the United States sought to verify that the HEU was truly derived from weapons. The U.S. inspectors were not allowed access to dismantled weapons components, although they could observe Russian scientists make measurements on objects asserted to be weapons components within containers.[23] Further, after the Russians had converted the materials to UF_6, the U.S. was allowed to continuously monitor the blend-down through a detection system that induced fission upstream of where the two uranium sources were blended, then detected fission fragments downstream of the blending site—in essence, tagging material through a radioactive process.[24] A U.S. participant in negotiating the verification measures describes the system as "transparency, not verification," given the absence of measurements of the highly enriched uranium.[25] Many of the approaches posed for direct weapons verification would be significantly more invasive than use of the ^{3}He

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[21] Defense Nuclear Agency, *Radiation Detection Equipment Comparative Evaluation Test Program: Volume I – Point Source Measurements,* by John H. McNeilly and Bernice D. Rothstein, August 1994, http://www.dtic.mil/dtic/tr/fulltext/u2/a283003.pdf.
[22] U.S. Department of State, "Annex on Inspection Activities to the Protocol to the Treaty Between the United States and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms," http://www.state.gov/documents/organization/141293.pdf.
[23] U.S. interview subject 3.
[24] Office of Nonproliferation Research and Engineering, *Technology R&D for Arms Control* (Spring 2001), http://fissilematerials.org/library/doe01b.pdf.
[25] U.S. interview subject 3.

detectors in the START and INF Treaties or use of the blend-down monitoring system via the HEU-to-LEU Agreement.

Within direct nuclear weapons verification, five terms are particularly relevant. An attribute measurement system is a verification system that relies on defining a general nuclear weapon in terms of characteristics it must possess, then checking whether a test object exceeds the minimum thresholds for each attribute. For instance, a common attribute assigns a minimum quantity of plutonium that a nuclear weapon must possess. Any test object would pass inspection if measurements suggested it possessed the minimum quantity of plutonium, without it mattering how far above the threshold the plutonium content was. Though initially attributes were designed to describe all possible or existing nuclear weapons, more recently researchers have explored whether different attribute systems could be defined for each class of nuclear weapons.

The other main type of verification system proposed has been template-based systems. A template measurement system relies on a "golden warhead," one that is accepted by both the host and inspector as a true warhead. Then, weapons of the same class of warheads are compared with this one. Again, characteristics that define this as a warhead are identified. However, in this case, the test object is supposed to match the golden warhead, within some error bars allowed. Template system designers need to think about the initialization problem, how to ensure that the golden warhead is a true warhead. Most approaches to this rely on randomly selecting a deployed warhead and assuming that both the selection being random and the warhead being deployed would suggest, with high probability, that it is a true warhead. As early as 1991, nuclear weapons verification experts proposed that warheads in storage could be tagged and sealed—a process which both the United States and Russia believe has integrity of – and these could then be randomly selected as golden warheads for verifying retired weapons in the future.[26] Template systems vary as to whether template measurements would be taken and then stored or whether the golden weapon would be compared to a test object in real time. In Russia, such systems are referred to as "passport systems."[27]

For both attribute and template systems, ensuring classified information is not revealed is a prominent concern. Accordingly, information barriers have been developed. An information barrier is any system that creates a separation between the specific measurements made on test objects and whether the test object is approved. It accepts measured sensitive information, and produces an unclassified output. Typically, these have been systems that are closed to the inspector, where a sensitive measurement is made and tested for the attribute or template requirements within a closed system, then a red or green light external to the system indicates to the inspector whether the test object is in compliance with particular characteristics. After one measurement is made using an information barrier, the system is typically considered a classified object, and can no longer be thoroughly dissected and tested. Several challenges stem from information barriers: how can these systems ensure that, if disrupted, no classified information would be revealed? What happens to them after a measurement: can they be reused and repeat authenticated? Under what conditions will an inspector trust a system that simply shows red and green lights, without more detail about the measurements? This raises the wider challenge associated with verification systems: both the host and the inspector must be comfortable with the system.

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[26] Natural Resources Defense Council, "Conclusions of the International Workshop on Verified Storage and Elimination and of Nuclear Weapons" (November 21, 1991).

[27] Richard L. Garwin, "Monitoring and Verification of Nuclear Weapons," (Presentation, Nuclear Weapons Issues in the 21st Century, November 3, 2013), https://fas.org/rlg/11_03_2013MonitoringandVerificationofNuclearWeapons.pdf.

Certification and authentication pertain to the inspector's and host's comfort that the verification system is accurately measuring what it aims to measure, with no extraneous functionality and no way to access classified information. Certification is a process that aims to ensure that the host is comfortable that no sensitive information will be revealed to the inspector. Authentication is a process designed to assure an inspector that the system measures what it claims to measure and only a true test object will pass inspection. Verification systems seek to achieve both certification and authentication simultaneously. Bifurcating the verification challenge into certification and authentication has been the dominant U.S. approach and tends to also be a theme in U.S.-Russian collaborations.

Chapter 2: Russian Perspectives on Verification

Russians with whom I spoke articulated a vision of verification where existing technology is sufficient, though largely irrelevant. They sought to draw a strong separation between political and technical matters, and argued few technical questions matter to verification. Rather, in their view, political constraints and trust between the United States and Russia most strongly shape what sort of future treaties could occur and the level of associated verification. A sense of futility coupled with decades of commitment to arms control was common.

Interviews

In July of 2015, I traveled to Moscow and was based at the international think tank, Carnegie-Moscow. I met with eight subjects, spoke on the phone with two, and corresponded with about a dozen further people. I worked with a research assistant based in Moscow, Katia Paramonova. Katia graduated from MIT's nuclear engineering undergraduate program in 2013 and is fluent in both English and Russian. Interviews were conducted in a combination of English and Russian. Subjects were a combination of civil society experts in arms control, Russian Academy of Sciences researchers, and members of Russia's nuclear weapons laboratories. Many had overlapping current or past roles advising the government on arms control issues. I chose whom to contact from my knowledge of the think tank community in Russia, reading articles in Russian and English on arms control and noting authors and sources, and contacting several American and ex-patriot Russian experts on arms control and seeking their advice. Members of the Russian nuclear weapons laboratories tended to reply to my emails, though only one was able to talk with me, a person familiar with the weapons work, though whose expertise is more on the materials accounting side. As noted by several interviewees, Federal Security Bureau personnel are based in all Russian nuclear weapons laboratories and military regiments. Their growing scrutiny means collaboration has become increasingly difficult, both domestically and internationally.[28] All interviewees had lost touch with most contacts in the Russian and U.S. nuclear laboratories in the last decade. Given the limited evidence available, tracing the trajectory of beliefs on verification is untenable, though it is possible to draw some insights on how Russian arms control experts see Russian-American collaboration in the areas of weapons verification, the future of verification, and arms control history. These conclusions are systematically biased because they rely on subjects willing to communicate with me, a U.S. citizen. To supplement the interviews, I have relied on Russian articles on arms control, histories of Soviet and post-Soviet decision-making, and articles from the *Institute of Nuclear Materials Management's Annual Proceedings*, where all unclassified complete verification systems have been described.

History of U.S.-Russian Collaborations on Arms Control

A brief historical overview of Russian and Russian-American collaborations on verification helps contextualize Russian perspectives and efforts on verification. The first exchanges between the United States and Russia over arms control began shortly after Eisenhower's "Atoms for Peace" speech. In this speech, Eisenhower advocated extending access to atomic power globally and sought to reframe nuclear technology outside the military context.[29] Stemming from this speech, the United States made several arms control proposals to the Soviet Union through their U.N. ambassadors. These proposals were variations on the United

[28] Russian interview subject 9.
[29] Dwight D. Eisenhower, "Atoms for Peace," (United Nations General Assembly, December 8, 1953), https://www.eisenhower.archives.gov/research/online_documents/atoms_for_peace.html.

States reducing their stockpile by weapons amounting to about 60 kilograms and the Soviet Union reducing by weapons amounting to about 40 kilograms of weapons-grade plutonium.[30]

Owing to uncertainty over whether such a reduction could be verified, the Arms Control and Disarmament Agency (ACDA) conducted Project Cloud Gap, a series of disarmament verification experiments. Of these, the 1967 Field Test 34 experiments have been declassified. The experiments impressed upon the ACDA the extent to which classified information could be revealed through even relatively nonintrusive inspections. Accordingly, governmental interest in direct arms control verification and discussions faded in the following decade. However, a transnational community advocating for arms control emerged.

Adler argues that an epistemic community composed of American scientists and civilian strategists developed notions of arms control and these diffused to the Soviet nuclear physics community and the American government.[31] This community formed from two subgroups whose differing logics suggested arms control would be stabilizing. One subgroup believed nuclear weapons were inherently destabilizing and arms control and reductions would help secure societies; the other believed the near future would rely on deterrence, and while nuclear weapons would be useful, arms control could mitigate the chances of dangerous misperceptions and strategic imbalances.[32] At RAND, a community of "futurists" modeled and strategized about nuclear war.[33] While many advocated nuclear superiority for stability, a prominent subgroup argued for the "necessity of stabilizing mutual deterrence by means of arms control technical

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[30] Frank von Hippel, "The 1969 ACDA Study on Warhead Dismantlement," *Science and Global Security* (2002), http://scienceandglobalsecurity.org/archive/sgs02vonhippel.pdf.
[31] Emanuel Adler, "The Emergence of Cooperation: National Epistemic Communities and the International Evolution of the Idea of Nuclear Arms Control," *International Organization* 46, no 1 (Winter 1992): 101-145.
[32] Adler, 111.
[33] Sharon Ghamari-Tabrizi, *The Worlds of Herman Kahn: The Intuitive Science of Thermonuclear War* (Harvard University Press: Cambridge, MA, 2005).

measures."[34] This community became close advisors of Eisenhower and then Kennedy, whom they convinced to form the Arms Control and Disarmament Agency.[35] The U.S. arms control community interacted with the Soviet community largely through Pugwash and other conferences.[36] The Soviet arms control community was composed primarily of Soviet physicists who had been extensively engaged in international scientific collaborations until Stalin ended this in the 1930s.[37] They were closely connected to Soviet elites, and advised the government to engage in bilateral arms control. Political elites within the two nations had divergent motivations: those in the Soviet Union were more interested in arms control to support strategic stability.[38] In the United States, much of the motivation for the early arms control treaties was to constrain Soviet capabilities; Nixon's advisors did not view the SALT and ABM treaties as particularly constraining U.S. plans.[39] Arms control seems to have been first seriously considered in the Soviet Union in the 1960s.[40]

Krushchev became critical of nuclear weapons' increasingly dominant role in national affairs and the drain on national resources. He observed, " 'What the hell do we want with tests? You cannot put a bomb in soup or make an overcoat out of it. Nevertheless we are compelled to test.' "[41] Krushchev's interest in arms control as a way to check the expansion of arsenals stemmed in part from his discussions with Leo Szilard.[42] Further, "Soviet physicists had since the 1940s enjoyed a certain degree of intellectual and political autonomy stemming from their

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[34] Adler, 113.
[35] Adler, 117.
[36] Kai-Henrik Barth, "Catalysts of Change: Scientists as Transnational Arms Control Advocates in the 1980s," in *Global Power Knowledge: Science and Technology in International Affairs*, Eds. John Krige and Kai-Henrik Barth (Chicago: University of Chicago Press, 2006): 11.
[37] Matthew Evangelista, *Unarmed Forces: The Transnational Movement to End the Cold War* (Cornell University Press: Ithaca, NY, 1999): 27.
[38] Adler, 135.
[39] Adler, 132.
[40] A.G. Savelev, Nikolay N. Detinov, and Gregory Varhall, *The Big Five: Arms Control Decision-Making in the Soviet Union* (Praeger Publishers, Inc: United States, 1995): 8.
[41] Cited in Evangelista, 82.
[42] Evangelista, 35.

involvement with nuclear weapons...[and] the structure of the Soviet political system gave them access to the top leadership."[43] Krushchev supported a Soviet-American Disarmament Study Group, a series of scientific exchanges that began with his last year in office and continued through the early Brezhnev years.[44] Several competing bureaucracies dealt with arms control issues. In the context of the SALT I negotiations, two groups of five were formed to ease coordination between the military, Twelfth Directorate (the unit directly responsible for handling the arsenal), the Ministry of Defense, the Ministry of Nuclear Engineering, and the Ministry of Foreign Affairs.[45] The two groups were known as the *petyorka*, groups of five.

The *petyorki* were divided into an upper and a lower branch. The senior *petyorka* included the head of the KGB, the Minister of Defense, the Minister of Foreign Affairs, and the Prime Minister of the Military-Industrial Commission (VPK). Initially, the President of the Academy of Sciences was a member of the group, though the Academy was "left out of both the negotiations and the decision-making mechanism."[46] He was dropped and the delegation solidified to become a permanent arms control structure, known as the "Big Five." The Big Five was chaired by a member of the Politburo. The lower *petyorka* developed arms control recommendations. All decisions required consensus from both of the *petyorki.* The upper *petyorka* tended to select and invite experts to brief them when arms control decisions were under consideration.[47] Though the groups met frequently in negotiating SALT I, they met just once or twice in the context of the SALT II negotiations, owing to a Soviet executive-level decision to keep the negotiating position of the country unchanged from the previous talks.[48] The

[43] Evangelista, 148.
[44] Evangelista, 144.
[45] Savalyev, Detinov, and Varhall,10-18.
[46] Savalyev, Detinov, and Varhall, 17.
[47] Savalyev, Detinov, and Varhall, 31.
[48] Savalyev, Detinov, and Varhall, 34.

two *petyorka* were operational throughout START I and START II, though Gorbachev violated precedent by unilaterally approving the Intermediate Range Nuclear Forces (INF) Treaty and the START treaties, without involvement from the *petyorka*.[49] Gorbachev's disregard for the *petyorka* set a precedent of top-down decision-making in nuclear arms control that continued and expanded with Yeltsin and Putin.[50] This trend dampened slightly under Medvedev, who formed the Russian International Affairs Council to seek external expertise.[51] Everyone I interviewed who brought up the *petyorka* or was asked about them expressed nostalgia for that approach to decision-making, where control was distributed among more than just the executive.[52] Gorbachev's approach to arms control tended to be more personally driven and less a function of committee views.

A close relationship between Gorbachev and two scientists, Evgenii Velikhov and Roald Sagdeev, helped advance arms control under his leadership. Velikhov first became politically involved when Brezhnev sent him to attend a Papal Academy of Sciences meeting on the nuclear arms race, on behalf of the Soviet Union.[53] At the time, Velikhov was a professor, whose research interests focused on plasma physics and computer science. He served as Vice President of the Soviet Academy of the Sciences and presently is the President of the Kurchatov Institute of Atomic Energy. Through travel to the United States in the summer of 1962, Velikhov established contact with several American scientists.[54] He was allowed to attend Pugwash conferences and there encountered many other scientists and activists focused on nuclear arms

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[49] Russian interviewees 4 and 8.
[50] Russian interview subjects 8, 9, 4.
[51] Russian interview subject 9.
[52] Russian interview subjects 4, 8.
[53] Evangelista, 158.
[54] David E. Hoffman, *The Dead Hand: The Untold Story of the Cold War Arms Race and its Dangerous Legacy* (Doubleday: New York, 2009): 210.

control.[55] Velikhov "swept aside bureaucratic obstacles... [he] was Gorbachev's top science and arms control advisor and Yeltsin's top advisor for both, [he is] also fairly close to Putin."[56] Roald Sagdeev was a plasma physicist and the head of the Space Research Institute. He also served as an arms control advisor to Gorbachev. While Gorbachev was in power, Velikhov and Sagdeev "could open the door with their foot and could tell him something, including what was discussed at the Pugwash meetings."[57]

In 1986, Gorbachev unilaterally announced a nuclear test moratorium. The two nations had negotiated a threshold nuclear weapons test ban treaty in 1974, though the U.S. Congress was debating ratification, expressing concerns regarding verification. At the time, the U.S. Congress passed resolutions to pressure President Ronald Reagan to retreat from an arms race with the Soviet Union, through forcing compliance with the SALT I Treaty and extending debate of the test ban treaty.[58] In discussing the possibility of a threshold treaty transitioning into the development of a comprehensive test ban treaty, Tom Cochran, Stan Norris, and Bill Arkin, all at the National Resources Defense Council (NRDC), wondered about the possibility of involving "ordinary citizen scientists" and "revers[ing] the process and be[ing] ready with technical verification support as negotiations were concluding."[59] In previous arms control treaties, negotiations preceded discussion of verification. The three proposed the idea of two seismic verification experiments to be conducted at the Nevada Test Site in the United States and a comparably prominent test site in the Soviet Union. Acquainted with Evgeny Velikhov from a

[55] U.S. interview subject 16.
[56] U.S. interview subject 3.
[57] Russian interview subject 2.
[58] John Isaacs, "Congress and the Arms Control Paradox," *Bulletin of the Atomic Scientists* 41, no 1 (January 1985): 9.
[59] Michael Krepon, "Joint Verification Experiments," *Arms Control Wonk* (January 11, 2011), http://www.armscontrolwonk.com/archive/402990/joint-verification-experiments/.

test ban conference in 1986, Cochran posed the idea to Velikhov, who was keen to join.[60] The collaboration became known as the Joint Verification Experiments.

As the experiments approached, opposition from the Twelfth Directorate (the branch of the Soviet military responsible for the integrity of its nuclear arsenal) mounted. Owing to Velikhov and Sagdeev's close ties with Gorbachev and the changes associated with *perestroika*, Gorbachev was open to Soviet participation in the Joint Verification Experiments (JVE). The NRDC received similar backlash about the experiments from executive figures in the United States. Cochran presented the JVE to Paul Nitze, President Reagan's arms control advisor as well as John Whitehead, a high-level figure in the State department. Whitehead replied with a letter skeptical of the experiments, arguing that it was possible the NRDC could come to different conclusions than the U.S. government, and " 'There is obvious potential here for confusion.' "[61]

Gorbachev asked that Velikhov host a meeting with members of the Politburo to determine whether the Joint Verification Experiments could occur.[62] The discussion was "inconclusive" in Velikhov's view, though Gorbachev granted him authority to "follow the line of discussion of the meeting," which Velikhov interpreted as approval: the experiments could go forward.[63] Through the Joint Verification Experiments, seismic stations were deployed to monitor chemical explosions adjacent to the Semipalatansk and Nevada Test Sites in 1988.[64] These experiments were designed to simulate the detection of nuclear weapons tests and show that a ban on testing could be verified. The political implications of the experiments were

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[60] Thomas B. Cochran, "The Black Sea Experiment" (presentation, "From Reykjavik to New START: Science Diplomacy for Nuclear Security in the 21st Century," The National Academy of Sciences and the U.S. Institute of Peace, January 19, 2011), http://docs.nrdc.org/nuclear/files/nuc_11020401a.pdf.
[61] Kai-Henrik Barth, "Catalysts of Change: Scientists as Transnational Arms Control Advocates in the 1980s," in *Global Power Knowledge: Science and Technology in International Affairs,* eds., John Krige and Kai-Henrik Barth (Chicago: University of Chicago Press, 2006), 23.
[62] Hoffman, 257.
[63] Hoffman, 257.
[64] Cochran.

significant enough that several congressmen attended. To satisfy the Soviet military, the condition was imposed that the Americans would have to turn off their sensors if the Soviets decided to test an actual nuclear weapon, a condition that suggested that despite the unilateral moratorium, the Soviet Union may have been continuing to test.[65]

The Joint Verification Experiments were regarded by multiple interviewees as important in developing relations between non-governmental Soviet and American scientists and comfort in approaching each other's nuclear facilities. Both sides in the Joint Verification Experiments were limited to non-intrusive measurement systems, though they were allowed samples of dirt from each test site, which allowed for broad-based insights about yield and composition of past warheads tested. In the JVE, participants sought to differentiate between the effectiveness of hydrodynamic systems, favored by the American nuclear laboratories, and seismic equipment.[66] A subsequent review found the American Corrtex system marginally more accurate than the Soviet system, though not meaningfully so.[67] Certainly, though, the Joint Verification Experiments convinced participants that yield could be closely approximated from the non-intrusive sensors used.[68]

Following the Joint Verification Experiments, Cochran and Velikhov settled on detection of nuclear weapons at sea as a next collaboration. A Soviet debate about the distance at which nuclear weapons could be detected in cruise missiles meant Sagdeev was partial to exploring the range of neutron detectors, largely in order to disprove a theory that they could be detected at a

[65] U.S. interview subject 16; Hoffman, 257.
[66] Sandra Blakeslee, "Soviets Prepare for Verification at Nevada Site," *New York Times* August 15, 1988, http://www.nytimes.com/1988/08/15/world/soviets-prepare-for-verification-at-nevada-site.html In fact, under pressure from Los Alamos, the State Department delayed visas until the Soviets agreed to witness a demonstration of the U.S.' favored CORRTEX system.
[67] Lynn R. Sikes and Goran Ekstrom, "Comparison of Seismic and Hydrodynamic Yield Determinations for the Soviet Joint Verification Experiment of 1988," *Proceedings of the National Academy of the Sciences* 86 (May 1989), http://www.pnas.org/content/86/10/3456.full.pdf.
[68] Sikes and Ekstrom.

distance of more than a kilometer.[69] Velikhov was similarly interested in resolving the disputes within the Soviet Union about the effectiveness and range of radiation detectors. They settled on a set of experiments called the Black Sea Experiments (BSE), addressed in the next chapter.

Extensive collaborations developed between the United States and Russia on arms control and nonproliferation after the Black Sea Experiments and expanded in the wake of the Soviet Union's collapse. The Soviet Ministry of Foreign Affairs, the NRDC, and the Federation of American Scientists co-organized a series of meetings on eliminating and storing nuclear weapons, starting in the late 1980s.[70] Siegfried Hecker, then director of Los Alamos National Laboratory, traveled to Russia in 1992 and met with his counterparts from Russian nuclear weapons laboratories. Out of these meetings, the lab-to-lab program emerged. Collaboration was largely focused in the areas of materials accounting and control, fundamental science, and conversion of defense facilities.[71] A smaller-scale piece of the collaboration dealt with direct weapons verification. This was intertwined with the Warhead Safety and Security Exchange (WSSX), a specialized agreement that extended from 1995 to 2005. Most of the lab-to-lab projects were funded by the United States, though included comparable participation from facilities in both countries. Many of the warhead dismantlement projects addressed through the Trilateral Initiative, a six-year collaboration between Russia, the United States, and the International Atomic Energy Agency, were subsumed under WSSX when the Trilateral Initiative ended in 2002. In 2013, the United States and Russia signed an agreement to continue collaboration. However, with the souring in relations related to Russia's military presence in the Ukraine and the claimed INF violation, lab-to-lab ties fizzled a year later.

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[69] Cochran.

[70] U.S. interview subject 16.

[71] Alla Kassianova, "U.S.-Russia Nuclear Lab-to-Lab Cooperation: Looking Back on a Quarter Century of Constructive Relations," *Ponars Eurasia* 425 (March 2016), http://www.ponarseurasia.org/memo/us-russia-nuclear-lab-lab-cooperation.

Interviewees diverge in how they recount the tension in U.S.-Russian relations, most Americans tending to focus on recent events, while many Russians trace this as a gradual process, beginning with the aftermath of the Soviet Union's collapse and the subsequent move towards unequal dynamics between the two former superpowers. Given tensions between the United States and Russia, interviewees found near term prospects for arms control dim. Most Russian interviewees traced these tensions as starting with the expansion of NATO in 1999 to include former Warsaw Pact states.[72] Several reiterated the narrative that NATO expansion occurred despite U.S. promises that such expansion would not occur, though Gorbachev discounts this account.[73] Russians have found discursive characterizations of Russia particularly insulting in recent years.[74] The 2015 controversy over whether Russia violated the Intermediate Nuclear Forces Treaty has further stressed relations.[75] Further, renegotiating post-Soviet dynamics has proved very difficult.

Gerovitch describes the collapse of the Soviet Union as a "trauma of losing the superpower status" and one from which Russia has still not recovered: it is still searching and lacks a "unifying 'national idea.' "[76] This accords closely with interviewees' nostalgia for the

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[72] Former U.S. Secretary of Defense William Perry characterizes START II as a " 'casualty of NATO expansion,' " in Angela Stent, *The Limits of Partnership: U.S.-Russian Relations in the 21st Century* (Princeton University Press: Princeton, 2014): 29. Stent argues, though, that Putin sought to join NATO, though was rebuffed by the George W. Bush administration (74).

[73] See, for instance: Steven Pifer, "Did NATO Promise not to Enlarge? Gorbachev says 'No,' " Brookings (November 6, 2014), http://www.brookings.edu/blogs/up-front/posts/2014/11/06-nato-no-promise-enlarge-gorbachev-pifer; Mary Elise Sarotte, "A Broken Promise?: What the West really told Moscow about NATO Expansion," *Foreign Affairs* (September/October 2014), https://www.foreignaffairs.com/articles/russia-fsu/2014-08-11/broken-promise.

[74] For instance, an interviewee noted that Obama cited the top three threats to the world at a U.N. General Assembly meeting as ISIS, Russia, and ebola. Further, Kerry's critique of Russia during the Nuclear Nonproliferation Treaty Review Conference "spoiled the environment," according to Russian interview subject 6.

[75] Pavel Podvig, "Sorting Fact from Fiction on Russian Missile Claims," *The Bulletin of the Atomic Scientists* (June 22, 2015), http://thebulletin.org/sorting-fact-fiction-russian-missile-claims8414.

[76] Slava Gerovitch, *Soviet Space Mythologies: Public Images, Private Memories, and the Making of a Cultural Identity*, (University of Pittsburgh Press, Pittsburgh, 2015): 155. In part of the effort at recovery, then-President Medvedev formed a Presidential Commission of the Russian Federation to Counter Attempts to Falsify History to the Detriment of Russia's Interests.

Soviet era and opposition to the shifting relations of the United States and Russia. Most 1990s and early 2000s arms control projects were sponsored and primarily designed by the United States. It was an unequal partnership, that the Russian arms control community has found increasingly untenable. Rosatom has explicitly noted that future collaboration must be between the two nations operating as equals, with each paying for their own portions of the project.[77] In practice, though, Rosatom is reluctant to dedicate funds to ventures similar to past lab-to-lab projects.

Several smaller projects endure, including efforts towards a bilateral plutonium disposition agreement. Wider cooperation between the two countries is stalled. Even close ties from over twenty years of collaboration have been constrained by current dynamics; at times, members of either country have been prevented from communicating with their counterparts.[78] In this context, the arms control think tank community is highly skeptical of possibilities for the coming decade.

The leadership in Russia is presently not especially receptive to arms control measures. "Right now there is no Gorbachev. If there was a person like Gorbachev, then there could be a Velikhov."[79] Interviewees were consistent in arguing that arms control—and Russian policy in general—has been top-down. When the leader supports arms control, the field advances rapidly, independent of the status of existing technical verification measures.[80] This accorded with the view of several Americans, that policy figures had more relative power in Russia and could impose verification conclusions, by which the scientists would have to abide.[81] However, this

[77] Russian interview subject 6.
[78] U.S. interview subject 10.
[79] Russian interview subject 2.
[80] Russian interview subjects 9, 4, 2.
[81] U.S. interview subject 12.

claim should be further explored—it is presently purely anecdotal, though it accords closely with societal narratives of Russian culture and history.

Interviewees were strikingly aligned in their nostalgia for Soviet arms control decision-making. In particular, they supported the *petyorka* approach. One noted, "before the government used to listen to us, but now they are too smart, so they make decisions without us, but we still work."[82] This statement is characteristic of the tensions surrounding expertise, authority, and scientific advice. Interviewees characterized the end of the Soviet era and early Russia as requiring authoritarian rule, noting that the present leadership exhibits greater authoritarianism while it is now less necessary.[83] In the 1990s, amid the economic crisis stemming from the collapse of the Soviet Union, fissile material went missing and some classified information appears to have been shared with Japan. Some of the present careful scrutiny is reactive, meant to overcome the laxness of the 1990s, but it has also had a chilling effect on informal cooperation.[84] Interviewees noted that past leadership actively sought arms control expertise from the think tank community and nuclear laboratories, though the current regime tends to ignore such resources. Nonetheless, the arms control think tank communities continue to receive grants from the Ministry of Foreign Affairs and Rosatom to support their work, suggesting there is still an interest that they continue this work.[85]

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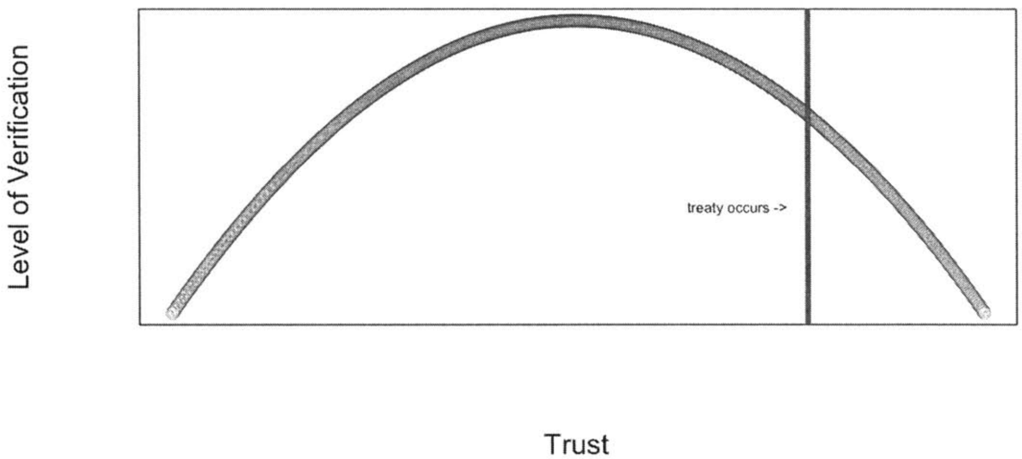
[82] Russian interview subject 7.
[83] Russian interview subject 7.
[84] The James Martin Center for Nonproliferation Studies keeps a database of Global Incidents and Trafficking involving nuclear materials. They note that the IAEA has cited 15 confirmed cases from 1993-2002 of HEU or separated plutonium possession and further observe that more recent cases have mostly been focused in the Black Sea region. See, for instance: "CNS Global Incidents and Trafficking Database: Tracking Publicly Reported Incidents Involving Nuclear and other Radioactive Materials," James Martin Center for Nonproliferation Studies (March 2016), http://www.nti.org/analysis/reports/cns-global-incidents-and-trafficking-database/. Russian interview subject 9 discussed the Japan case.
[85] Russian interview subjects 4, 6, 9.

Russian Perspectives on Verification

The Russian arms control think tank community overwhelmingly argues for less intrusive verification methods, guided by six core arguments:

1. The level of verification required is a product of the level of trust between the countries and the point at which countries trusted one another enough to engage in arms control treaties would require a lower level of verification.



2. Verification is associated with a particular treaty: it serves to fulfill the aims of that treaty. It is a purely political goal that need not be developed independently of treaties;
3. Past treaties reflected a Russian-American power differential and were therefore excessively intrusive due to American preferences;
4. Arms will only be reduced if both sides view them as unnecessary and not valuable, so there would be no need to closely verify reductions if "true" reductions were occurring[86];
5. Existing methods are sufficient. There is no need to develop new, more complex and intrusive approaches to arms control.
6. We must protect classified information, even though both sides know this information.

Arguments were circular at times and displayed striking comfort with underlying contradictions. On occasion, claims aligned with arguments that have been rhetorically useful to the Russian government, though are not necessarily literally believed.[87] Several were more convinced of trust as a measure to ensure treaty enforcement, rather than verification. They noted

[86] "True" here refers to the argument that recent nuclear arms control treaties have not meaningfully constrained (or required the destruction of) weapons and have never explicitly verified weapons.
[87] Comments from Russian interview subjects 2, 4, 5, 6, and 9 all raised instances.

that the United States and Russia would likely only be open to joining a treaty if there were a base level of trust between the two nations—and this level of trust would mean each side would be less intent on verifying the other.[88] In this view, if a treaty were possible, it would only be as constraining as each side could trust the other to comply with, and verification serves a secondary, confidence-building role.

While the official American position is to research arms control independently of the conditions under which it would occur,[89] Russian researchers have tended to consider the most likely contexts for future arms control. Importantly, many expressed skepticism of U.S. intentions with regard to missile defense and the Comprehensive Test Ban Treaty; they were skeptical that missile defense plans would be curbed were the Iranian nuclear issue favorably resolved.[90] Given distrust between the United States and Russia, few Russian interviewees thought arms control likely in the coming decade. Indeed, many were ambivalent over whether working on these issues had value or relevance. One commented, "I'm a train that has built up momentum and keeps on rolling, wherever the tracks lead it to… I'm involved in some projects… but none of it has any real relation to arms control."[91] He argued he was destined to work towards disarmament, though also assumed his work did nothing to make disarmament more likely. Given the present tensions, he argued that many options had disappeared and should not be considered or researched in the current environment, since they were no longer realistic options.

All were careful to distinguish between political and technical questions. Graham explores this tendency in the context of the tendency of Russian scientists not to commercialize

[88] Russian interview subjects 2, 5, 7.
[89] U.S. interview subjects 6, 15, 7.
[90] Russian interview subjects 1, 6.
[91] Russian interview subject 2.

technology, noting that they consider this an unethical venture, so draw sharp boundaries on their work.[92] Most characterized treaties as operating in a political space. Though technical experts' opinions are considered, their views are often discounted.[93] They argued the pursuit of certainty plays a political role, but is not technically relevant: existing technologies are sufficient.[94] One interviewee argued that verification is "only a political problem; even technically, it's not really difficult or dangerous."[95] Another contended, "There's no uncertainty in these measurements. Uncertainty is some deception in the mind of American experts."[96] The physicist who made this claim has written articles expressing uncertainty in nuclear fissile material measurements. Rather, this comment should probably be read figuratively as arguing: uncertainty serves a political role in arms control and for the purposes of verification; existing measurement techniques are sufficient for the level of certainty required. All Russians interviewed defined themselves as technical experts and therefore unqualified to discuss political dimensions. Indeed, all were careful to say that the government was surely correct whenever their views were in opposition, though they did overwhelmingly express opposition to Putin's approach to arms control.[97] This carefulness accords closely with characterizations of the public relationship between truth and obligation in the Soviet Union. Gerovitch charts how the language of cybernetics and political *newspeak* were intertwined in the Soviet Union, both serving powerful ideological roles.[98] He argues, "politics affected science through the subtle mechanism of

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[92] Loren R. Graham, "Money vs. Freedom: The Russian Contradiction," *Questia* (September/October 1999), https://www.questia.com/magazine/1P3-45298851/money-vs-freedom-the-russian-contradiction.
[93] Russian interview subjects 4, 6.
[94] Russian interview subjects 8, 3, 2, 1.
[95] Russian interview subject 8.
[96] Russian interview subject 2.
[97] Russian interview subject 4, 9.
[98] Slava Gerovitch, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics* (The MIT Press: Cambridge, MA, 2002).

discursive domination rather than through the brute force of administrative control."[99] Scientists were given relative flexibility in their studies so long as they demonstrated discursive subordination to the governing ideology. Under the cult of the al-Asads in pre-Arab Spring Syria, Wedeen addresses how the ruling family is discussed. Citizens would often express statements in support of the al-Asads so exaggerated as to be unbelievable. In this way, they both abided by the implicit regulations of adoration of the leaders while also subtly satirizing them.[100] A similar phenomenon appeared to be at play in some of the commentary of interviewees. They would couple claims about arms control with expressions of deference to the current Russian executive that invalidated their original arguments.

Russian arms control experts overwhelmingly argued that verification is purely a function of a treaty. In early arms control treaties, verification was exclusively performed through national technical means (NTM). NTM includes satellite imagery, telemetric information, and radar-derived information. Both nations were initially partial to this approach, though American support was likely curbed by the 1989 JASON report arguing NTM were insufficient for arms control verification. Harking back to this form of verification, several interviewees argued NTM were sufficient, since verification's primary role is as a ceremonial goodwill measure to build trust.[101] As one interviewee argued, "The verification isn't there for verification's sake exactly – it was established to implement a treaty. Everything depends on the treaty."[102] In this and similar articulations, existing verification is sufficient because verification is a facet of a treaty that works to build trust, though does not have independent goals. One of the assumptions that plays

[99] Gerovitch 2002, 6, 28.
[100] Lisa Wedeen, *Ambiguities of Domination: Politics, Rhetoric, and Symbols in Contemporary Syria* (Chicago: The University of Chicago Press, 1999).
[101] Russian interview subjects 8, 9, 3.
[102] Russian interview subject 8. He also noted, though, that verification measures are occasionally vestigial in treaties. For instance, telemetric information has no role as a constraint in the New START Treaty, though the U.S. Congress argued for its inclusion, since it had been a function of past treaties.

into this view is that arms reductions are both important for international security and unlikely to happen independent of a recoding of the role and value of nuclear weapons. The assumption is that such a reevaluation would make verification unnecessary, though is dependent on a uniform understanding of the valuation of nuclear weapons. That is, most deterrence logics include parity as a key feature in supporting stability.[103] If nations believed they could reliably dismantle a subset of their weapons – and that parity were key – then they may be very concerned about verification.

When pressed on particular verification techniques, Russian interviewees expressed strong support for existing information barriers. They argued that they were highly reliable and – most importantly – do not disclose sensitive information.[104] In particular, they were partial to the AVNG system developed by VNIIEF and the analogous array of Attribute Measurement System with Information Barrier generations. A veteran of the Russian national laboratories argued that only fissile material mattered because it was the only feature that could imaginably be covered by a treaty.[105] Most interviewees were unfamiliar with systems besides these two. Arguments about what ought to be verified were often historically based: a threshold for isotopics can and should be verified because it was in the HEU-to-LEU agreement.[106] This argument was somewhat circular: we will only verify fissile materials extracted from weapons because we only know how to verify them and we should not study other methods of verification alongside fissile materials because we already know how to verify fissile materials.[107] One interviewee observed, though, that if an entire class of warheads were to be eliminated, these should be verified using a

[103] See, for instance, Robert Jervis, *The Meaning of the Nuclear Revolution* (Ithaca, NY: Cornell University Press, 1989) and Daryl G. Press, *Calculating Credibility: How Leaders Assess Military Threats* (Ithaca, NY: Cornell University Press, 2005).
[104] Russian interview subject 5.
[105] Russian interview subject 3.
[106] Russian interview subjects 2, 5.
[107] Russian interview subjects 3, 5.

template approach: "make sure the golden warhead is real, then use gamma and neutron radiation, [in a] template system."[108] A caveat, though:

> *The key element of a nuclear weapon is the fissile materials. So if the process will be aimed at fissile materials, then the verification process can reach agreement. But if, as usual, the Americans come, they peer into every crack and cranny to find everything. You need to understand, it's impossible.*[109]

In short, secrecy is key, thresholds are sufficient for verification, partly because verification is primarily aimed at transparency, and the Americans are overly intrusive and were able to achieve overly intrusive treaties in the past, though the dynamic should be equalized between the two countries.

Russians with whom I spoke tended to find the current official perspective on sensitive information unsupportable, though they also found it problematic to oppose the perspective. All framed nuclear weapons verification and past arms control in terms of ensuring that sensitive information not be revealed. When questioned what the dangers of revealing sensitive information were, the following argument was characteristic:

> *I believe that for a long time, really, there are no secrets in this* [nuclear weapons] *area. But there are traditional security measures... No, it's pointless. There will be no change. These questions will not be discussed because they are not in the competences of the* [technical] *experts.*[110]

A special commission for classification determines which aspects of nuclear weapons are classified.[111] Two interviewees observed that they could not account for why isotopic information should be so closely protected by the committee, though this designation meant that

[108] Russian interview subject 2.
[109] Russian interview subject 2.
[110] Russian interview subject 4.
[111] Both American and Russian experts cite the importance to the committee of ensuring Russian fissile material isotopics are not released and this, in particular, has not been subject to negotiation. In verifying the megatons to megawatts agreement, American inspectors were only allowed to take measurements on the fissile material after it had been extracted, converted to UF_6, and initially downblended. An American academic with whom I spoke noted, though, that the sense that Russian isotopics are unknown is a myth: Americans are allowed to roam through Russian facilities and the dust in these facilities can be tested to reveal the isotopics.

it was a reality that isotopics were very sensitive information.[112] Though they found the status quo untenable, they viewed this question as outside their domains of expertise.

Most interviewees were working towards a future they thought elusive and one which they thought their efforts would likely not influence. Articulating a strong separation between science and policy, they characterized the late 1980s and the 1990s as a golden era of arms control. Its achievements, defined by the alignment of a leader and advisors keen on arms control—Gorbachev, Velikhov, and Sagdeev—the new thinking of *perestroika,* and the collapse of the Soviet Union enabling greater alignment with the United States, were no longer imaginable. Interviewees embraced contradictions, both opposing the current Russian regime and finding it impossible to do so. In terms of direct nuclear weapons verification, despite doubt that it could be achievable, Russians expressed a preference for jointly designed, simple systems that served primarily a confidence-building role. Interviewees raised many historical claims that should be further explored about which factors ultimately play into arms control and verification.

Two themes were most apparent in these interviews: a sense of futility about arms control efforts and circular logics of sufficiency. Both themes appeared to be mostly a function of political dynamics shaping technical perspectives and torn allegiances. Interviewees were both strongly devoted to arms control and felt an obligation to support their national leadership, leading to contradictions in their views on verification. The circular logic of sufficiency saw existing technical approaches as sufficient because verification is purely ceremonial. While the technical views of Russian researchers on nuclear measurements are comparable to their American counterparts, this overarching sense of futility shaped what interviewees thought verification would mean and therefore limited some technical preparation.

[112] Russian interview subjects 2, 5.

Appendix to Chapter 2: U.S.-Russian Technical Collaboration on DVNW Systems

Beyond general perspectives on arms control and U.S.-Russian dynamics, several specific collaborations on verification systems help explain Russian constraints and preferences in the area of direct nuclear weapons verification. Russian verification systems are designed exclusively through the national nuclear laboratories, VNIIEF (the All-Russia Research Institute of Experimental Physics, located at Sarov), VNIIA (the All-Russia Research Institute of Automatics, located in Moscow), and VNIITF (the All-Russia Scientific Research Institute for Technical Physics, in Chelyabinsk). Additionally, nuclear arms control experts in the Russian Academy of Sciences and non-governmental experts in civil society research systems and how they could fit into an arms control regime. Many of these civil society experts have taken part in the Russian-U.S. laboratory-to-laboratory program or have secondary roles in the Russian government. Any system designed independently in Russia is classified, though systems that were designed in Russia with influence or assistance from the U.S. nuclear laboratories are written about in publicly accessible sources.

Both Russians and Americans interviewed emphasized that Russia had comparable expertise in nuclear measurements to the United States, though presently lacks the manufacturing capacity to domestically produce ^{3}He detectors or germanium crystals for high purity germanium detectors. Germanium detectors are the type of gamma ray detector with the greatest energy resolution, and thus of interest for various verification systems. Particular isotopes emit characteristic energy gamma rays and distinguishing these peaks allows for the identification of the quantities of particular isotopes contained in a substance. Though Russian nuclear laboratories appear to have wide-ranging experience on developing information barriers, attribute, and template verification systems, the only four that are discussed in the public domain emerged from Russian-U.S. collaboration.

Bilateral cooperation united each of the Russian nuclear weapons laboratories with one or two American laboratories. The most extensive project was the development and testing of the Attribute Verification System with Information Barrier for Plutonium with Classified Characteristics Utilizing Neutron Multiplicity Counting and High-Resolution Gamma Ray Spectrometry (AVNG). Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and VNIIEF co-designed AVNG through the Trilateral Initiative. Evoking the series of AMS/IBs designed primarily by LANL, AVNG incorporated an information barrier and assessed the threshold compliance of three attributes: the presence of plutonium, the plutonium 240:239 ratio, and a minimum mass of plutonium.[113] Following the end of the Trilateral Initiative, WSSX adopted the project.[114] Though jointly designed, the system was unilaterally constructed, at Sarov in Russia. Participants from both nations tend to argue that joint development of a system bolsters inspectors' and hosts' capacity to certify and authenticate the system, though they tend to find joint construction unnecessary.[115]

Differences between AVNG and American systems were focused on the information barrier. Initially, the system relied on PTS-DOS, a Russian operating system that used "erasable

[113] Dmitry Budnikov, et al, "Progress of the AVNG System—Attribute Verification System with Information Barriers for Mass and Isotopics Measurements," *Annual Proceedings of the Institute of Nuclear Materials Management* (2005), http://www.inmm.org/source/proceedings/files/2005/pdffiles/papers/236%20197.pdf
[114] Michele R. Smith, "Introduction to the Attribute Verification—Neutron/Gamma (AVNG) Program, *Annual Proceedings of the Institute of Nuclear Materials Management* (2010), http://www.inmm.org/source/proceedings/files/2010/305.pdf
[115] Russian interview subjects 2, 8, and 5. Duncan MacArthur, Alexander Livke, et. al, "The Attribute Measurement Technique," *Annual Proceedings of the Institute of Nuclear Materials Management* (2010), http://www.inmm.org/source/proceedings/files/2010/210.pdf

programmable read-only memory."[116] This eventually shifted to eCOS, a software system with open sourcecode, which proved more comfortable to American participants.[117] Participants from both sides have collaboratively written about how the simultaneous challenges of authentication and certification played out in AVNG's information barrier. All data were kept in volatile memory, so that it would be immediately lost if power were cut, which would happen automatically if the internals of the system were accessed.[118] Both Americans and Russians advocated ultimately designing a system such as AVNG, that can operate in both a classified and unclassified mode.[119] That is, the information barrier would be equipped with a key that the host country could use to shift between unclassified and classified modes. In the unclassified mode, the information barrier could be breached and the system would still function, without the power cutting. However, they noted that a problem remained, the inspector could not be certain the same attributes were being measured in both modes.[120] A further problem is known as the last access problem. When granted the opportunity to test a system, the host or inspector may believe in its integrity, though this belief is compromised once the other is allowed to test the system. The host or inspector only trusts the system when she is the last actor to access the system. VNIIEF carried out a small-scale demonstration of the AVNG system for their American counterparts in 2009.

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[116] A.B.Modenov, et al, "A Prototype Structure of AVNG with Information Barriers," *Annual Proceedings of the Institute of Nuclear Materials Management* (2001), http://www.inmm.org/source/proceedings/files/2001/PDFS/00000220.PDF

[117] Alexander Modenov, et al., "AVNG System Software—Attribute Verification System with Information Barriers for Mass and Isotopic Measurements," *Annual Proceedings of the Institute of Nuclear Materials Management* (2005), http://www.inmm.org/source/proceedings/files/2005/pdffiles/papers/235%20162.pdf

[118] D.G. Langner, et al., "Progress Towards Criteria for a Second-Generation Prototype Inspection System with Information Barrier for the Trilateral Initiative," *Annual Proceedings of the Institute of Nuclear Materials Management* (2000), http://www.inmm.org/source/proceedings/files/2000/PDFs/00000035.pdf.

[119] MacArthur and Livke, et al.

[120] MacArthur and Livke, et al.

Despite limited access, American viewers sought to test the credibility of the system. While the system was tested on several reference objects – and American observers were allowed to select within several of these – Americans were restricted to an adjoining conference room, with a telephone connected to the room where Russians were testing the system. They were allowed to later review the video footage. In an effort to determine the credibility of the system, Americans gave several identifiers – including a luggage tag – to their Russian counterparts on the morning of the demonstration – and saw them in the video feed. Further, they called the Russians during the demonstration with instructions, including smiling and waving at the camera.[121] All time stamps correlated. On the final day of the experiments, unusual scenarios were tested, including opening the door to the electronics, when the system was operating in classified mode.[122] The AVNG behaved according to protocol in all tests. Yet, a follow up paper notes, the "display of red and green lights does not do a great deal to inspire monitor confidence."[123] Familiarity with the system did little to bolster credibility that it was the known system, working as intended. Indeed, some observers concluded that pure transparency may instead be the best approach.[124] In their view, nothing short of direct measurement and sense data could be sufficiently convincing.

Besides AVNG, the U.S.-Russian collaborations on developing and testing complete direct weapons verification systems were relatively modest, at least in terms of their discussion in the public domain. Oak Ridge and VNIIEF collaborated to examine the nuclear materials inspection system (NMIS). The system was original designed by Oak Ridge National Laboratory

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[121] Jonathan Thron, Sergey Razinkov, et al., "AVNG Authentication Features," *Annual Proceedings of the Institute of Nuclear Materials Management* (2010), http://www.inmm.org/source/proceedings/files/2010/487.pdf.
[122] Sergey Kondratov, et al., "AVNG System Demonstration," *Annual Proceedings of the Institute of Nuclear Materials Management* (2010), http://www.inmm.org/source/proceedings/files/2010/324.pdf.
[123] MacArthur and Livke, et al.
[124] MacArthur and Livke, et al.

(ORNL); under the lab-to-lab contract, both VNIIEF and ORNL manufactured sample NMISs for joint testing on eight unclassified plutonium samples.[125] The results mention modest success, though say little regarding the viability of the system.[126] VNIIA and Brookhaven National Laboratory (BNL) collaborated on a test of Brookhaven's CIVET system. Through this collaboration, the two agreed on byte-by-byte code comparison with a known valid copy of the software to establish credibility of the test software.[127] VNIIA concluded that the gamma spectrometer represented a potential vulnerability, given its plethora of components that would need to be individually verified.[128] They focused on human factors that could affect measurements, including inspectors or hosts wearing components that could alter electromagnetic signals.[129] Accordingly, they advocated simplifying the measurement system and closely checking all inspectors and hosts before any measurement. Their conclusion was unenthusiastic: "it is reasonable to retain some of these concepts [underlying CIVET]" in a future verification system.[130] They highlight a range of possible challenges that could undermine CIVET, noting that information security remains unresolved. A final collaboration paired Sandia National Laboratory (SNL) with VNIITF, to develop the multi-attribute measurement system (MAMS). MAMS is an attribute-based system that aims to detect fissile material and high explosives. It allows for operation in both a secure and an open mode and the information barrier is secured via tamper-indicating devices. Through the collaboration, VNIITF and Sandia settled

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[125] J.K. Mattingly, "Plutonium Attribute Estimation from Passive NMIS Measurements at VNIIEF," Oak Ridge National Laboratory Report (January 2002), http://web.ornl.gov/~webworks/cppr/y2001/rpt/112914.pdf; V.P. Dubinin, et al., "VNIIEF-ORNL Joint Plutonium Measurements with NMIS and Results of Plutonium Attributes Preliminary Evaluations," Y-12 National Security Complex Report (June 25, 2001), http://www.osti.gov/scitech/servlets/purl/782883.
[126] Dubinin, et al.
[127] Peter E. Vanier, Andrey Sviridov, et al., "Study of the CIVET Design of a Trusted Processor for Non-Intrusive Measurements," *Annual Proceedings of the Institute of Nuclear Materials Management* (2001), http://www.inmm.org/source/proceedings/files/2001/PDFS/00000333.PDF.
[128] Vanier, Sviridov, et al.
[129] Vanier, Sviridov, et al.
[130] Vanier, Sviridov, et al.

on several changes to better measure high explosives and fissile material in a second MAMS prototype, which appears never to have been completed.[131] Collaborative efforts to explore non-nuclear signatures met skepticism about their viability.[132]

From the experience of collaborating on system design, American and Russian national laboratory scientists have some commonalities in their thinking about the implications for a viable verification system. Encrypting data generates skepticism from several core individuals in the early design of verification systems, particularly on the Russian side.[133] One person noted a mistake involving encrypting telemetric data in the verification of START I that contributed to a sense of encryption as obfuscation, though not actually securing information.[134] In particular, within the arms control world, there is uncertainty about the two nations' decryption capabilities, though there are concerns that these are or soon will be sufficient to decrypt any ostensibly encrypted classified data. An American engineer noted that the systems he and colleagues designed were motivated by their particular biases on what made for a more secure system, and he happened to believe more in hardware-based systems, while many Russians were drawn to software as more controllable.[135]

Most interviewees from both Russia and America explored the idea of joint design. Members of each of the laboratories tend to be overwhelmingly skeptical towards systems they have not designed. Some argued joint design, development, and testing were key to a system being viable; all subsets were also occasionally posed. Joint design contributes to familiarity and

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[131] Igor Kostenko, et al., "Multi-aspect System for Measurement of Attributes of Fissile Materials and Explosives," *Annual Proceedings of the Institute of Nuclear Material Management* (2007), http://www.inmm.org/source/proceedings/files/2007/data/papers/430.pdf.
[132] John L. Smoot, Victor V. Bairak, et al., "Non-Nuclear Technologies: Potential Application to Support Fissile Material Safety and Security," *Annual Proceedings of the Institute of Nuclear Materials Management* (2000), http://www.inmm.org/source/proceedings/files/2000/PDFs/00000179.PDF.
[133] U.S. interview subject 12.
[134] Russian interview subject 4.
[135] U.S. interview subject 12.

ownership of a system, and therefore comfort with its capabilities and a greater likelihood of detecting modifications to the system. Joint development furthers this familiarity, though introduces challenges if a system is calibrated to a specific class of weapon. Several dozen papers have explored the logistics and logical challenges of testing or jointly testing a direct nuclear weapons verification system. Russian interviewees were overwhelmingly confident in existing tag and seal systems, which are used to mark materials that have been inspected and ensure they are not modified post-inspection. Americans were divided, though many were skeptical of tags and seals, pointing to an extensive red teaming study that suggested all tags and seals could be spoofed as of 1999.[136] Even the Russians that were aware of the American vulnerability test saw the IAEA successfully using tags and seals as evidence for their viability: they found the scenarios of vulnerability tests too contrived.

Many expressed a preference for using commercially available materials.[137] This could help the system with field deployability and – depending on the origins of these materials – could support certification. The Second Generation AMS/IB was built as an experiment in how much of the system could be designed with COTS equipment. Several advocated modular, though simple, design, so components could be independently verified and replaced.[138] On the matter of the information barrier, Luke observes that these collaborations led to remarkably consistent designs.[139] He argues, it "is the opinion of the author that this is not so much a function of the cooperative development but a function of the nature of the information that needed to be protected," and confirms the sentiment that Russian researchers tended to be more comfortable

[136] Roger G. Johnston, "Tamper-Indicating Seals for Nuclear Disarmament and Hazardous Waste Management," Los Alamos National Laboratory Report, http://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-99-4821.
[137] D.G. Langner, et al.
[138] Thron, Razinkov, et al.
[139] S.J. Luke, "AVNG as a Test Case for Cooperative Design," *Annual Proceedings of the Institute of Nuclear Materials Management* (2010), http://www.inmm.org/source/proceedings/files/2010/327.pdf.

with software-based systems.[140] In this view, the constraints surrounding information barriers mean that individual biases and aims will be overshadowed.

A primary disagreement was over whether the host or inspector should be responsible for the construction of the verification system (an independent question to the original design of the system) and how to allow each side to verify the system after used or verified by the other side. Of particular concern is what happens to the verification system after it has been used to make a classified measurement.

Complicating these beliefs about constraints on direct verification systems was the underlying sociotechnical context. The downturn in U.S.-Russian relations contributed to the dim views on the potential for direct weapons verification. Interviewees both expressed beliefs regarding constraints, yet were skeptical of the relevance of their beliefs, given the current administration's limited receptivity to arms control elites' perspectives.

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[140] Luke.

Chapter 3: Collaboration and Demonstrations on Direct Verification of Nuclear Weapons

Security constraints and limited interest and funding in DVNW experimentation means that such experiments have been rare. Yet, the few that have occurred have had prominent results and appear to closely fit with shifts in direct verification research trajectories. There have been three major international collaborations on direct nuclear weapons verification involving experiments or demonstrations. Two—the Black Sea Experiments (BSE) and the Fissile Material Technology Transparency Demonstration (FMTTD)—involved U.S.-Russian collaboration. The third, the U.K.-Norway Initiative, involved a series of simulations and collaborative experiments to explore how a non-nuclear weapons state might become involved with arms control.

Such experiments and demonstrations operate at odds with how credibility is more typically constructed in technical fields. Early modern scientists stressed the importance of witnessing experiments to establish their credibility.[141] The identities of witnesses were essential: it was the domain knowledge of the witnesses and their ostensible moral status that allowed them to determine the merits of an experiment.[142] They lent their authority to support the scientific merit of the experiment. Most scientific fields have shifted from a witness-based approach to knowledge production. Rather, a core set of values (even if these may not be directly followed) defines scientific experiments and are used to evaluate their credibility. Interestingly, when this order breaks down, scientific fields tend to turn to respected elites for adjudication.[143] Within nuclear disarmament verification, personal ties remain strikingly powerful. Partly, access tends to be limited so many witnesses appear to use personal impressions as a proxy for experimental

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[141] Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, NJ: Princeton University Press, 1985).
[142] Shapin and Schaffer; H.M. Collins, "Public Experiments and Displays of Virtuosity: the Core-Set Revisited," *Social Studies of Science* 18 no 4 (November 1988): 729.
[143] Sheila Jasanoff, *The Fifth Branch: Science Advisors as Policymakers* (Cambridge, MA: Harvard University Press, 1990).

credibility. Further, most DVNW experiments have tended to be technical tests or demonstrations. With technical testing and demonstrations, witnesses are usually granted reduced access to the experiment *and* the witnesses tend to less frequently possess domain knowledge.[144] This raises a paradoxical notion: witnesses are "expected to draw firm conclusions from experiments that normally require expert interpretation."[145] Modern witnesses to scientific experiments are typically members of the public. They are unlikely to be equipped to skeptically evaluate demonstrations or technical tests. In particular, "the public is used to seeing demonstrations which reflect scientific consensus, not experiments within a disputed area… The public sees experiments, but in a restricted way."[146] Using the public or another audience with reduced access partly helps with more simply conveying a message. Interestingly, "proximity to the seat of creation of scientific facts usually has the effect of creating *uncertainty*."[147] In this sense, a non-specialized witness is an ideal subject for a demonstration or technical test that is motivated to produce a particular result.

Demonstrations and technical tests differ from idealized experiments in that they are meant to be persuasive. Pinch notes, "Something is at stake… expectations are built around a certain outcome."[148] Technical tests and demonstrations are conducted after prior uncertainty or doubt is reconciled.[149] They are often framed as ways to show or prove an approach or technical artifact is viable. Collins argues there is also a component of "illusion:" observers appear to be given enough information to independently assess a demonstration's outcome, as if it were an

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[144] Collins, 725.
[145] Collins, 725.
[146] Collins, 739.
[147] Collins, 725-726.
[148] Trevor Pinch, " 'Testing—One, Two, Three… Testing!': Toward a Sociology of Testing," *Science, Technology, & Human Values* 18, no 1 (January 1993): 26.
[149] Collins, 728.

experiment, though information is limited so as to shape the conclusions drawn.[150] Additionally, non-scientific factors tend to weigh heavily on how demonstrations are received. For instance, simplified visual data tend to be particularly persuasive and many assessments of credibility seem to reflect more an assessment of the "virtuosity" of the demonstrator rather than the viability of the technology.[151] The three DVNW experiments/demonstrations fit this paradigm closely: each was meant to be politically persuasive. Further, each test had self-fulfilling components. Through their execution, they were meant to be instances of the aims they posited were achievable.

Operating within a semi-classified domain complicates the picture, exacerbating the tendency for witnesses to receive insufficient information for sound technical judgment. Engineers from the national nuclear laboratories in the United States and Russia have asserted boundary claims to limit the extent to which outsiders judgments bear on direct weapons verification. A similar phenomenon was noted by MacKenzie with respect to intercontinental ballistic missile accuracy: "it is impossible for critical scientists to do experiments that would back up doubts about the reported accuracy of intercontinental ballistic missiles because neither finance nor test facilities are available to non-governmental personnel."[152] In asserting boundaries, the national laboratories sought to undermine the Black Sea Experiments, which occurred without their participation. Within FMTTD, efforts to ensure witnesses did not encounter sensitive information constrained their access and meant that the demonstration could not be convincing. The U.K.-Norway Initiative was more exploratory and less scripted. Its

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[150] Collins, 743.

[151] Collins, 730; David P. McCabe and Alan D. Castel, "Seeing is Believing: The Effect of Brain Images on Judgments of Scientific Reasoning," *Cognition* 107, no 1 (April 2008): 343-352.

[152] Mackenzie, cited in Collins, 740, 741.

discoveries and the representation of these suggest tension about how individual interactions influence ostensibly technical outcomes.

The Black Sea Experiments had several overlapping technical and political goals. The demonstrators aimed to expand non-governmental scientists' capacity to influence arms control policy. Further, they sought to expand Soviet-American collaboration on verification. The experiments were a collaboration between the Natural Resources Defense Council, the Soviet Academy of the Sciences, and the Kurchatov Institute. A more specific goal was to determine the viability of verifying a ban on submarine-launched cruise missiles. Roald Sagdeev sought to disprove a claim that radiation detectors would work at distances of multiple kilometers.[153]

All experiments were carried out on a single warhead on a Soviet cruiser, the *Slava.* Despite objections from the director of a Soviet nuclear weapons design laboratory, Gorbachev decided that a true weapon would be available for study.[154] One medium-range cruise missile containing a nuclear warhead was left on the ship for the study. The missile launcher was unshielded and left on the deck of the ship, making the warhead easier to detect. Americans from the NRDC conducted high-resolution gamma spectrometry of the weapon; Soviet scientists conducted lower resolution gamma spectrometry. The Soviet scientists further ran an experiment on the distance at which neutrons emitted by the weapon could be detected. Gamma rays are high-energy photons that are emitted by radioactive sources. Different isotopes emit gamma rays at different characteristic energy levels and information about the isotopic content and mass of a sample can therefore be determined from a gamma spectrum. Complicating interpretation, though, any materials between the material of interest and the detector may attenuate the signal, to an extent varying by material composition. The detectors used were passive: they waited for

[153] Cochran, 2.
[154] Cochran, 3.

gamma ray interactions to occur within the detector and then amplified and analyzed these signals. The Soviet Academy of Sciences gamma ray measurement is typically ignored, as it used a lower resolution detector than used by the NRDC. Secondarily, the Kurchatov Institute tested the distance at which neutrons released from spontaneous fission of ^{240}Pu could be detected. They flew *Sovietnik* helicopters tens of meters away from the *Slava* and compared the neutron signatures to background levels. The *Sovietniks* were able to detect the nuclear warhead on the *Slava* up to seventy meters from the ship.

The BSE functioned as both a set of experiments and a demonstration. Members of the Soviet military and the chief arms control negotiator attended, as did several members of the KGB.[155] Three U.S. Congressmen, two staffers of other congressmen, and several U.S. reporters and academics also witnessed the experiments.[156] During the experiments, an "agitated Soviet official… accused the Americans of exceeding their time limit, and demanded they surrender the tape cassette containing their data."[157] To the observers, the organizers of the experiments sought to showcase the possibility of Soviet-U.S. collaboration on verification research and the capacity to measure a weapon without deriving overly sensitive information. One of the Congressmen in attendance, Representative John Spratt, concluded, "I don't think one should be swept away… Passive detection is only one element in a verification and detection scheme, not foolproof by any means."[158] Spratt was unconvinced by the demonstration, holding a prior belief that passive detection could be spoofed. Other witness reactions were not documented.

Significant backlash from the U.S. and Soviet security establishments followed the experiment. From the gamma spectra revealed, the NRDC scientists learned that U-232 was

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[155] Cochran.
[156] Cochran.
[157] Bill Keller, "Rare Test by U.S. Scientists of Soviet Missile at Sea," *New York Times* (July 6, 1989), http://www.nytimes.com/1989/07/06/world/rare-test-by-us-scientists-of-soviet-missile-at-sea.html.
[158] Keller.

present in the weapons, indicating that some of the uranium had come from reprocessed spent fuel, presumably from Soviet production reactors.[159] Experimenters were further surprised by the lack of shielding around the weapon and the unexpectedly high level of enrichment of the uranium.[160] Yet, they saw these results as innocuous, not revealing any sensitive information about the weapon. Weapons scientists from Livermore National Laboratory disagreed. They interpreted the gamma spectrum and argued that they could derive sensitive design information, including that it was a "two-stage oralloy burner," which the NRDC scientists found "interesting" though harmless.[161] The "United States Government dismissed the exercise as irrelevant," distancing themselves from the experiment, [162] partly owing to a Reagan Administration preference to maintain tactical nuclear weapons at sea.[163]

Russian and American interviewees were closely aligned in their perceptions of the Black Sea Experiments and its implications. They described the security establishments of both countries as shaken by the level of sensitive information that could be derived from the experiments.[164] No subsequent experiment has been conducted allowing members of one nation to measure gamma or neutron signals from a nuclear weapon of another nation. Indeed, several argued that it was the Black Sea Experiments occurred at a moment swept up in perestroika and newfound optimism. Considering similar experiments again is presently anathema to Russian and U.S. national laboratories. For most public discussions, the gamma spectrum from the Black Sea Experiments stands in for verification data. The experiment is viewed as irreproducible,

[159] Steve Fetter and Frank von Hippel, "The Black Sea Experiment: US and Soviet Reports from a Cooperative Verification Experiment," http://faculty.publicpolicy.umd.edu/sites/default/files/fetter/files/1990-SAGS-DNW-BlackSea.pdf.
[160] Fetter and von Hippel. Some members of the U.S. national laboratories are convinced the test object was not a true weapon. They argue both that the gamma spectrum revealed overly sensitive information and that, even so, this could have come from a spoofed weapon.
[161] Cochran, 4.
[162] Keller.
[163] U.S. interview subject 16.
[164] Russian interview subjects 3, 5, 8; U.S. interview subjects 2, 12, 16.

given the political context and security concerns about weapon design information. A decade later, in the context of the Trilateral Initiative, Americans demonstrated a possible verification system to their Russian counterparts.

Through the Fissile Material Technology Transparency Demonstration, Americans sought to persuade their Russian counterparts to consider an attribute measurement system in conjunction with an information barrier as an option to solve the verification challenge. They sought to prove that such a system could protect sensitive information and was authenticatable.[165] However, the authentication goal was subservient to the protection of classified information.[166] The Americans did not hope to prove that the demonstrated system was optimal or efficient. Rather, they hoped to persuade the Russian attendees that such systems merited study. The Americans assessed threshold compliance with six attributes in the first generation of the Attribute Measurement System with an Information Barrier (AMS/IB).

Though many of the Russians attendees had significant non-destructive assay expertise, there were restrictions on their access to the demonstration equipment, constraining their ability to interpret results. Unclassified sources were used for the demonstration, carefully selected such that at least one would pass each attribute threshold and at least one would fail each.[167] To independently validate the system, Russian attendees suggested measuring the unclassified samples with their own instruments. According to the official U.S. report, "[t]his suggestion proved unrealizable during the demonstration owing to the security posture that was imposed, but in recognition of the Russian idea, arrangements were made for a 'placeholder' measurement

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[165] "Technical Overview of Fissile Material Transparency Technology Demonstration: Executive Summary," Los Alamos National Laboratory, http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/exec_sum.pdf.
[166] Duncan W. MacArthur, "Attribute Measurement System with Information Barrier (AMS/IB)—Conceptual Description," Los Alamos National Laboratory, http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/ams_ib_fin.pdf.
[167] M.W. Johnson, "Sources and Thresholds in the Fissile Material Transparency Technology Demonstration," Los Alamos National Laboratory, http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/sources_file_cab_%20paper_bjohnson.pdf.

in which standard (albeit US-supplied) nuclear instrumentation was used to display properties of the unclassified material, with the measurement performed by US personnel but controlled [overseen and advised] by Russian personnel."[168] Despite working with unclassified sources, the Russian observers were prevented from inspecting the sources. The outputs they could view were measurement readings when the sources were calibrated or the AMS/IB used in unclassified mode, though there was no evidence about whether these measurements were valid. Secure-mode measurements using the AMS/IB were meant to suggest certification and authentication were achievable. Yet, the only outputs Russian observers could see were a series of red and green lights indicating compliance or non-compliance with the six attributes. As such, few found they had enough information to assess the system designers' claims: access was too restricted to prove the desired result.

This accords with Collins' arguments regarding how witnesses tend to interact with demonstrations: they were presented with limited information, then urged to draw conclusions in concert with the demonstration's aim. Possessing significant domain knowledge and an underlying skepticism that sensitive information could be protected in an authenticatable system, many of the Russians who attended the demonstration were unconvinced.[169] As one American attendee commented, the witnesses "couldn't touch the equipment or container... [the demonstration raised] interesting things to think about... [but they had] no way of knowing that's truly what you measured."[170] Beyond demonstrations, exploratory collaborations have started to emerge. The most extensive of these is a collaboration between the United Kingdom and

[168] M.W. Johnson, "An Example of a Measure for Increased Confidence in Authentication," (Presentation, Fissile Material Technology Transparency Demonstration, 2000), http://www.lanl.gov/orgs/n/n1/FMTTD/presentations/pdf_docs/dart_paper_johnson.pdf.
[169] U.S. interview subject 15.
[170] U.S. interview subject 15.

Norway. It began with the United Kingdom offering to collaborate with any country on disarmament verification in the 2005 NPT Review Conference. Norway accepted the offer.

The U.K.-Norway Initiative (UKNI) covers an expansive set of collaborations between the two countries as well as several open-invitation initiatives. The collaboration began in 2007 and is still in progress. Interviews of participants were not obtained for this thesis, though DVNW sociology would greatly benefit from study of the UKNI. As such, relatively brief comments can be made about the Initiative. The Initiative was more exploratory than the other two demonstrations. It sought to explore the issues that would emerge when NWS and NNWS collaborate on direct weapons verification.

In particular, UKNI consider the interpersonal dynamics involved in inspections. Norway and the United Kingdom rotated impersonating NWSs and NNWSs who had alliances or adversarial relations: the Kingdom of Torland (host) and the Republic of Luvania (inspector). In Norway's role as a NWS, it built an "atomic weapons laboratory" for the dismantlement exercises. When the United Kingdom was playing an adversarial host country, its ostensible primary motivation was concern about security. Accordingly, facility personnel carefully prepared answers to a wide range of postulated questions, so as not to accidentally reveal any sensitive information. These mechanical answers proved difficult to interpret for the inspectors. Many were very skeptical of the answers, seeing them as formulaic and therefore believing they were potentially dishonest.[171] The dynamics between individual inspectors and hosts proved prominent in shaping confidence in the inspections. Yet, the official report concludes that the level of trust between verification parties "should not be relevant" to the level of confidence

[171] United Kingdom-Norway Initiative, "The United Kingdom-Norway Initiative: Further Research into Managed Access of Inspectors During Warhead Dismantlement Verification," http://ukni.info/mdocs-posts/20120426_2010_ukni_man_access_exercise/; Side conversation at "Nuclear Verification at Low Numbers: A Scoping Workshop," Princeton University, December 10-11, 2015.

inspired by an inspection.[172] The experimenters both studied and tried to deny the importance of psychological effects.

In the Black Sea Experiments and the Fissile Material Technology Transparency Demonstration, two very controlled demonstrations yielded unexpected results. The first showed that even a spoofable signature revealed considerable detail regarding a test object. The second demonstrated the gap between developing a prototype of a system and convincing, certifiable field deployment. The United Kingdom-Norway Initiative explored new terrain within the nonproliferation and arms control regime, bringing a NNWS into a technical arms control collaboration. All three experiments demonstrated the challenge of restricting a skeptical witness' access as well as the importance of psychological effects and experimenter-witness relations.

[172] United Kingdom-Norway Initiative, "Trust in Verification Technology: A Case Study: The U.K.-Norway Information Barrier," http://ukni.info/mdocs-posts/revcon2015-ibnon_paper__trust_in_verification_technology/.

Chapter 4: American Perspectives on Verification

A recent episode in U.S.-U.K. collaboration illustrates a shift in how the laboratory engineers and members of the National Nuclear Security Administration are reconceptualizing the nuclear weapons verification challenge. Widely regarded as one of the most viable verification systems designed, the Trusted Radiation Attribute Demonstration Systems (TRADS) was developed by Sandia National Laboratory. It relies on a high purity germanium detector to measure two attributes: a declared minimal quantity of plutonium and the ratio of ^{240}Pu to ^{239}Pu isotopes, which should be less than 0.1 to be consistent with weapons-usable plutonium.[173] The system is an attribute measurement system that emerged as an iteration of the Radiation Inspection System (RIS) template system and an associated attribute model, the RIS-plus.[174] TRADS and its closely associated template-matching system, TRIS, were both used as part of U.K.-U.S. collaborative measurement efforts in 2013 and 2014.[175] In an effort to reduce the likelihood that classified information would be leaked, U.K. Atomic Weapons Establishment (AWE) employees were prepared with canned answers so that they would not accidentally reveal sensitive information. These answers seemed formulaic to American observers, as though information were being concealed.[176] Yet, each side checked and rechecked the TRIS and TRADS to be used on a WMD component to ensure it both accurately measured what it claimed to measure and denied inspectors sensitive information. The U.K. was serving as the host

[173] ^{240}Pu acts as a source of extra radiation, heat, and spontaneous neutrons. The latter can, in some (but not U.S.), weapons designs compromise the yield. For these reasons, it is typically avoided in weapons. For specifications on TRADS, see: Dean J. Mitchell and Keith M. Tolk, "Trusted Radiation Attribute Demonstration System," *Annual Proceedings of the Institute of Nuclear Materials Management* (2000), http://www.inmm.org/source/proceedings/files/2000/PDFs/00000142.pdf.
[174] Bruce Geelhood, et al., "Review of Two U.S. Information Barrier Implementations," *Annual Proceedings of the Institute of Nuclear Materials Management* (2001), http://www.inmm.org/source/proceedings/files/2001/PDFS/00000276.PDF.
[175] National Nuclear Security Administration, U.K. Ministry of Defence, Atomic Weapons Establishment, "Joint U.S.-U.K. Report on Technical Cooperation for Arms Control," (2015), http://www.nnsa.energy.gov/sites/default/files/Joint_USUK_Report_FINAL.PDF.
[176] Personal communications with British participant in the measurement, December 2015.

country, so the so-called 'trusted processor' was in its possession, though the U.S. was granted several chances to check the authenticity of the system. It was a system they had designed and worked with for over a decade. The 'trusted processor' was deemed to be reliable by the Americans. The American inspectors conducted a measurement on a sealed container, with TRADS operating in "secure mode," meaning as if it was on a true warhead component, where any breach of the 'trusted processor' or measurement device would shut down the system. The container passed, indicating it was authentic The British suggested another measurement, this time with the container open, in the unclassified mode. There was nothing in the container. Still, the empty container "passed." The system considered it an authentic weapon. The British had reconfigured TRADS to measure a container ten meters away. Despite close familiarity with the system and repeated chances to check for modifications, the Americans had been fooled.

For the first forty years of direct nuclear weapons verification research, secrecy trumped measurement certainty for researchers and those guiding their agendas. In the last decade, along with greater attention to the practicalities of verification, growing interest in certainty in conjunction with a sense of failure about the whole venture has led to reconsideration of many core assumptions about verification and a renewed interest in template-based systems. All existing U.S. approaches seem to adopt the framing of the original challenge. However, they transfer the item to be verified, yielding a somewhat circular research history. For instance, an information barrier yields a new piece of classified equipment and a new verification challenge: verifying software that cannot be directly inspected.

Arms Control Research Bureaucratic Structure

The structure of the National Nuclear Security Administration (NNSA) and the National Laboratories helps clarify some of the dynamics of historical verification research efforts. Two overarching offices in the NNSA, known as NA-24 and NA-22, support verification research in the national laboratories. Research into verification was first funded owing to an amendment to the 1972 SALT I Treaty.[177] Senator Henry Jackson was deeply skeptical of the SALT I Accords, viewing them as destabilizing for U.S.-Soviet parity and unlikely to be verifiable.[178] He managed to pass an amendment for the treaty, stipulating conditions for deeming future agreements fair and requiring "the establishment of a robust verification technology research program."[179] The national laboratories first explored verification prior to this, starting in the mid-1960s. Los Alamos and Sandia collaborated on a project to monitor nuclear tests.[180] Verification for potential arms control treaties emerged gradually in the following decade, with Brookhaven and Sandia leading. Other laboratories followed suit starting in 1972.[181]

The National Nuclear Security Administration (NNSA) was formed in 2000 as a branch of the Department of Energy, to more closely oversee nuclear weapons issues within one organization. Within the NNSA, the Defense Nuclear Nonproliferation (NA-20) office houses verification work. NA-22 is the nonproliferation research and development group, tasked with basic research and development on verification topics. In the NNSA's perspective, NA-22 works

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177 U.S. interview subject 7.
178 Michael Krepon, "The Jackson Amendment," *Arms Control Wonk* (August 6, 2009), http://www.armscontrolwonk.com/archive/402414/the-jackson-amendment/.
179 U.S. interview subject 7; Krepon 2009.
180 Sandia National Laboratory, "A Bold Heritage: Sandia National Laboratory's Roots lie in World War II's Manhattan Project, which built the world's first atomic bombs," http://www.sandia.gov/about/history/.
181 L.M. Brenner and S.C.T. McDowell, "U.S. Safeguards History and the Evolution of Safeguards Research and Development," *Annual Proceedings of the Institute of Nuclear Materials Management* (1989), https://inis.iaea.org/search/searchsinglerecord.aspx?recordsFor=SingleRecord&RN=21008254.

on "really unique and novel ideas that may not have any guarantee of success."[182] It operates outside the scope of treaties, pursuing basic research. Proposals from the national laboratories as well as academic and think tank groups are evaluated starting in the fall; winners are selected in late spring.[183] An external group of "wisemen" – all male subject matter experts – consults NA-22 on the projects.[184] The office tends to be most interested in research on technologies that could apply to multiple projects, though do not have an explicit application in mind. There has been some tension between the laboratories and the NNSA about how to set the verification research agendas, with the laboratories arguing for their greater expertise in radiation measurements and the NNSA's relative focus on treaty policy dimensions.[185] In the last five years, the National Nuclear Security Administration has responded to criticism about a disconnect between the NNSA and the laboratories by selecting several former members of the labs for NA-22 and NA-24 leadership roles. NA-24 is the nonproliferation and international security office. During the 1990s, the precursors to NA-22 and NA-24 collaborated on verification proof-of-concept projects.[186] In the 2000s, NA-22 and NA-24 drifted to funding less overlapping research. In the last five years, the two divisions have again collaborated on proof-of-concept applied projects.[187]

After exploratory projects funded by NA-22, some technologies are transferred to NA-24 for further prototyping. NA-24 is more applied, working on potential treaty verification issues. Through research it funds, the laboratories explore how verification technology could be fielded. However, NA-24 funding is affected by whether there is a treaty in the works. NA-24 can only

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[182] U.S. interview subject 7.
[183] U.S. interview subject 6.
[184] U.S. interview subject 6.
[185] U.S. interview subject 14.
[186] U.S. interview subject 14.
[187] U.S. interview subjects 13, 14, 15.

afford to red team (thoroughly assess and try to exploit vulnerabilities of) a system when funding is specifically allocated in the context of a treaty. At times, the State Department or Defense Threat Reduction Agency will step in to sponsor arms control efforts.[188] In addition to funding research, NA-24 is involved in negotiating arms control agreements.

Publicly available data for NA-22 and NA-24 funding is highly inconsistent. More consistent has been qualitative commentary regarding verification funding. In the 1990s, funding for verification research was 2-3 times current levels, not accounting for inflation.[189] Under the George W. Bush administration, funding for verification and arms control was severely cut and the NNSA was discouraged from researching direct nuclear weapons verification.[190] Amidst the budget tension of the George W. Bush era, some NNSA work was reframed as counterterrorism work, oriented towards detecting explosives.[191] Anecdotally, most members of the national laboratories mentioned several people who had left the verification field or retired owing to the difficulty of securing funding for verification projects.

Emergence of Verification Research Narratives

Project Cloud Gap appears to be the first instance of a study of verification. It was held as a response to a series of U.S. proposals to the Soviet Union to each reduce their nuclear stockpiles and account for the fissile material generated. Project Cloud Gap generally explored the possibilities for arms control and disarmament verification. The culminating experiment was Field Test 34, whose documents have been declassified.

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188 U.S. interview subject 15.
189 U.S. interview subject 14.
190 U.S. interview subject 14, 15, 7. A widely cited comment from Linton Brooks, then head of the NNSA, implored employees to continue preparing for future arms control, though confine their efforts to the "space between the rug and the bottom of the floor."
191 U.S. interview subject 3.

Based on Field Test 34, a narrative emerged that perceived verification as a struggle between certainty and secrecy, with secrecy the more important component. Conducted despite the protests of the Atomic Energy Commission, Field Test 34 evaluated six metrics: the number of test items inspectors validly and invalidly determined to be true and spoof weapons, the number of classified pieces of information inspectors detected, and the number of classified pieces of information that could have been detected, had inspectors been capable.[192] Inspectors were divided into groups at four levels of access to the weapons, ranging from visual observation of just the containers at a distance to a range of neutron and gamma assays and visual inspection of the weapon. While accuracy at distinguishing weapons from spoofs increased linearly from 49% at the lowest level of access to 81% at the most invasive, the number of pieces of classified information detected increased exponentially, from 34 to 112.[193] Roughly 56% of the exposed pieces of classified information were detected, as inspectors were not experts in this realm.[194] Classified data were counted without distinction as to the importance of these data. This set up the experimenters for monolithic conclusions about classified data, not distinguishing levels or types of classified data. The final report for Field Test 34 describes the aims as "conflicting… being convincing, … safeguarding sensitive design information, and … practicability."[195] This aim of "safeguarding sensitive design information" appears to have broadened through and post Project Cloud Gap, incorporating any classified or sensitive information, not just data related to weapons design. The report argues, "It appeared that to convince inspectors that bona fide nuclear weapons were being destroyed some classified information would be revealed," though

[192] United States Arms Control and Disarmament Agency, "Final Report—Volume 1: Field Test FT-34: Demonstrated Destruction of Nuclear Weapons," (January 1969), http://fas.org/nuke/guide/usa/cloudgap/ft-34.pdf.
[193] United States Arms Control and Disarmament Agency, "Final Report Field Test FT-34: Annex F: Analysis and Results," (January 1969), http://fas.org/nuke/guide/usa/cloudgap/ft-34v3-annexf.pdf.
[194] "Final Report Field Test FT-34: Annex F."
[195] "Final Report—Volume 1: Field Test FT-34: Demonstrated Destruction of Nuclear Weapons," 27.

the test also sought to explore the associated constraints.[196] All participants concluded that the construction of a dedicated verification and dismantlement facility would help limit inspectors' exposure to classified information.

In a somewhat sarcastic conclusion, the Atomic Energy Commission (AEC) expressed a sense of futility at the whole process. Noting that the AEC had initially viewed the experiment as having "doubtful value," they argued that maximal access did not yield certainty that the weapons were authentic, yet exposed significant classified information; while with minimal access, inspectors could not draw meaningful conclusions about the weapons and were still exposed to classified information.[197] They argued, "It does not appear possible to gain positive assurance of correct identification of real weapons… short of firing the devices, which we do not regard as either an acceptable or sensible technique."[198] This statement suggests a perception of certainty as an elusive point, rather than a spectrum. All information sought to be certain that a proffered weapon is authentic cannot feasibly be obtained—and the report argues that the costs of classified information being revealed are too severe. The results of Field Test 34 were surprising and scary to the ACDA. Classified information proved much more vulnerable than anticipated—and no threshold of access seemed safe or sufficient.

In the two decades after Field Test 34, a focus on preserving the integrity of classified information contributed to an institutional preference for reliance on national technical means (NTM) within the Department of Energy.[199] National technical means include reliance on satellite imagery and telemetry detection. NTM can be used to derive information remotely,

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[196] "Final Report—Volume 1: Field Test FT-34: Demonstrated Destruction of Nuclear Weapons," 31.
[197] "Memorandum for Chairman Seaborg, Commissioner Ramey, Commissioner Tape, and Commissioner Johnson," Atomic Energy Commission (November 21, 1967), http://fas.org/nuke/guide/usa/cloudgap/aec-memo112167.pdf.
[198] "Memorandum for Chairman Seaborg, Commissioner Ramey, Commissioner Tape, and Commissioner Johnson."
[199] James Fuller, "Verification on the Road to Zero: Issues for Nuclear Warhead Dismantlement," *Arms Control Today* (December 5, 2010), https://www.armscontrol.org/act/2010_12/%20Fuller.

without on-site inspections. Most logics that relied on NTM for verification were exclusively focused on verifying delivery vehicles, unable to directly verify weapons. The effort to rely solely on national technical means was rejected through the Robinson Committee report and a JASON report in 1989.[200] Both described NTM as insufficient on their own, and emphasized the necessity of on-site inspections for any confidence in arms control treaty compliance. These reports appear to have refocused attention on direct weapons verification systems for testing treaty compliance.

Despite the case for national technical means being undermined, the narrative of secrecy versus certainty persisted. Consistently, this view is articulated in official verification reports.[201] In particular, articulating certainty as a direct trade-off for secrecy has become the norm to such an extent that researchers struggle to conceptualize verification techniques that depart from this formulation.

A debate about the relative merits of template and attribute system reflects the perception of secrecy and certainty that emanated from Field Test 34. Most of the debate occurred in the mid-to-late 1990s and was resolved by 2000. The debate resolved in favor of attributes owing in large part to the approach's greater concern for secrecy than certainty. As the 2001 report assessing the viability of all previous verification systems argued, "Most of the current negotiations seem to be headed toward the attribute approach because it does not require the retention of classified data obtained during an inspection measurement."[202] This perspective

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[200] S. Drell, et al., *Verification Technology: Unclassified Version* JASON (October 1990), http://fas.org/irp/agency/dod/jason/verif.pdf.
[201] See, for instance, *Technology R&D for Arms Control* or *Verification Technology: Unclassified Version.*
[202] Office of Nonproliferation Research and Engineering, *Technology R&D for Arms Control,* eds., David Spears, Arden Dougan, and Giorgiana M. Alonzo (U.S. Department of Energy, Spring 2001), http://fissilematerials.org/library/doe01b.pdf.

assumes that a template matching system would require storage of a classified template and would also face an initialization problem: identifying a viable "golden warhead."[203]

Some were convinced the International Atomic Energy Agency would conduct inspections on nuclear arms reductions. As such, to them, classification was supreme. This was due to the NPT's restriction on sharing proliferation-sensitive information and because the IAEA's inclusion meant inspectors would not necessarily be from NWS. The opposition to revealing sensitive information generalized into an opposition to revealing any information.[204] Since then, though, many involved have started to reconsider this absolutist perspective on secrecy.[205]

The other group in the attributes-templates debate assumed that any inspectors would be familiar with nuclear weapons and unlikely to derive novel, sensitive information from inspections. Accordingly, this group tended to favor template-based systems as they were concerned that individual classes of weapons be differentiated. This group, in conversation, tends to similarly perceive many of the challenges associated with the implementation of a template approach that the other group cites. However, they tended to bracket these questions—initialization and template storage—in the 1990s. More recently, several members of the laboratories have begun to address some of these sub-challenges. Members of the NNSA tended to favor the attribute-based perspective, and this was reflected in greater funding for attribute-based systems.[206] Some template systems continued to receive funding, though.

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[203] W.R. Kane, et al., "On Attributes and Templates for Identification of Nuclear Weapons in Arms Control," *Annual Proceedings of the Institute of Nuclear Materials Management* (2000), http://www.inmm.org/source/proceedings/files/2000/PDFs/00000032.pdf.
[204] U.S. interview subjects 7, 15.
[205] Ibid.
[206] U.S. interview subjects 15, 7.

Despite different conclusions as to the type of system that should be applied to verification, all of these approaches understood the verification challenge in very compatible ways. As Gusfield notes, "Every perspective is a way of *not* seeing as well as a way of seeing."[207] For the laboratories, rather than proceeding from an effort to define verification and what it should entail, all tended to ask instead what the value of classified information was, and derive what verification should mean from here. It is not that the labs and NNSA's particular conceptualization of verification is illogical or unreasonable. Rather, in the words of Bloor, " 'logically' possible alternatives were deflected by prevalent beliefs."[208] Latour notes how beliefs about uncertain ideas tend to shape the language used to describe them and in turn, the "operation of information construction... transforms any set of equally probable statements into a set of *unequally* probable statements."[209] Here, framing all systems in terms of trade-offs between certainty and secrecy means that when a prospective system appears to satisfy one dimension, the resultant assumption is that it inadequately addresses the other constraint. It also meant that systems that could both generate certainty and secure information were unfathomable.

Indeed, approaches from think tanks and academia that diverge from the core NNSA and laboratories perspective have tended to encounter striking criticism from the laboratories. A recurring critique argues that nuclear weapons are so sensitive and poorly understood by those without security clearances, that they do not understand vulnerabilities in their designs and could not properly design procedures for handling weapons.[210] This fits with Gieryn's insights

[207] Gusfield, 187.
[208] Bloor, referenced in Latour and Woolgar, 158
[209] Latour and Woolgar, 241
[210] U.S. interview subject 12.

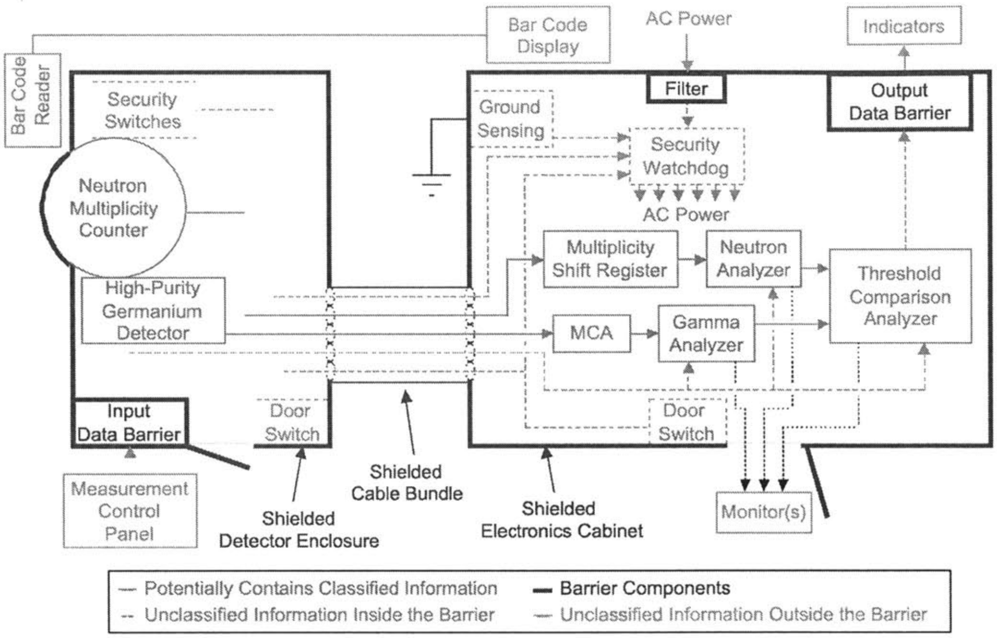
regarding epistemic communities closely bounding their fields and trying to limit the authority of outsiders to comment on their domain.[211]

Information Barriers

The prevailing perspective in the late 1990s saw classification as nonnegotiable. Information Barriers were popularized via the Trilateral Initiative. Indeed, one interviewee argued that the Trilateral Initiative—and, in particular, the Fissile Material Technology Transparency Demonstration, the core demonstration of the Initiative—was meant to convince Russians to consider information barriers.[212]

Information barriers were first used in the U.S.-designed Corrtex system, which was included in the Joint Verification Experiments.[213] Information barriers were first studied "in a coordinated manner" in the United States as of 1997.[214] In the Trilateral Initiative formulation, information barriers (IB) tended to be a combination of physical barriers and electronics to shield information. The "fundamental thought was that any measurement would yield restricted data… that's not necessarily true, but that was the going thought at the time."[215] A figure of the information barrier included in the AVNG helps illustrate the core features of an IB.

[211] Thomas F. Gieryn, "Boundary Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists," *American Sociological Review* 48, no 6 (December 1983): 781-795, http://woodhous.arizona.edu/geog596m13/Gieryn_1983.pdf.
[212] U.S. interview subject 12. The report, *Technology R&D for Arms Control* agrees with this account.
[213] According to an expert involved with the experiments, under pressure from Los Alamos, the Soviets' visas to visit the Nevada Test Site were delayed until they agreed to tack on a visit to Los Alamos to see a demonstration of the Corrtex system, per U.S. interview subject 16.
[214] *Technology R&D for Arms Control*, 6; Diana G. Langner, et al., "Attribute Measurement System Prototypes and Equipment in the United States," *Annual Proceedings of the Institute of Nuclear Materials Management* (2001), http://www.inmm.org/source/proceedings/files/2001/PDFS/00000347.PDF.
[215] U.S. interview subject 7.



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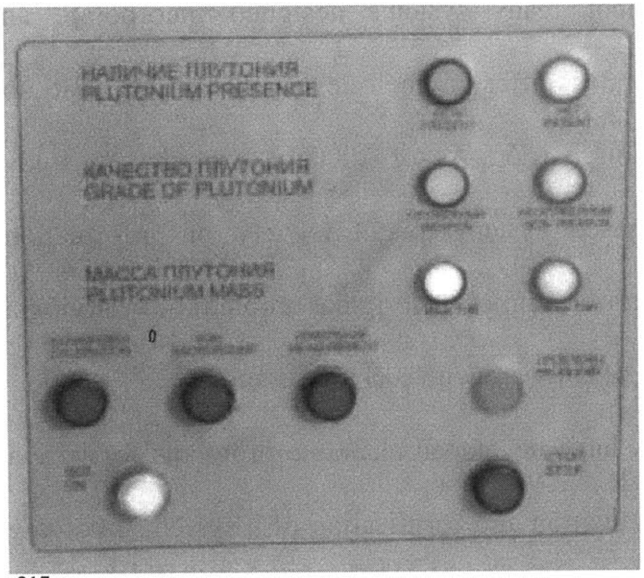
Sections of the system are delineated based on whether classified information may pass through them. All classified information is contained within a combination of physical and electronic barriers, designed not to store any information should the system be disrupted. Then, the inspector simply sees an external, unclassified display, such as the one below, from the AVNG. When operating in classified mode, only the external controls are visible to the inspector.

216 Image from Diana G. Langner, et al., "Attribute Verification Systems with Information Barriers for Classified Forms of Plutonium in the Trilateral Initiative," International Atomic Energy Agency Publications, http://www-pub.iaea.org/MTCD/publications/PDF/ss-2001/PDF%20files/Session%2017/Paper%2017-02.pdf.



[217]

Theoretically, in response to any breach of the system, the power should cut out and no information should be attainable. Measurements tend to be conducted within a "protective shell" using read-only memory, compared to a value included in the associated template or attribute characterization, and then for each feature, a light external to the system turns either red or green to indicate whether the test object is in compliance.[218] Such a system raises significant questions of trust and verification. Some systems have both classified and unclassified settings in which they can operate, to allow inspectors more opportunities to test whether the claims about what is being measured are accurate. Yet, in most tests, observers express doubts that an inspector would be convinced of the validity of the results. Typically, this argument is made in terms of needing more information to be persuasive, expressing an underlying doubt that certainty can be achieved without compromising secrecy.

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[217] Image from Sergey Razinkov, et al., "The Design and Implementation of the AVNG Measurement System," *Annual Proceedings of the Institute of Nuclear Materials Management* (2010), http://www.inmm.org/source/proceedings/files/2010/302.pdf.
[218] Duncan W. MacArthur and James K. Wolford Jr., "Information Barriers and Authentication," *Annual Proceedings of the Institute of Nuclear Materials Management* 2001), http://www.inmm.org/source/proceedings/files/2001/PDFS/00000147.PDF.

Most of the 13 vulnerability-assessment ready systems designed incorporate an information barrier. Russia and the United States differ in their level of comfort that no information can be revealed via an information barrier. As of 2000, a Brookhaven study concluded that both attribute and template-based systems ought to rely on information barriers.[219] However, verifying an information barrier mimics the original problem of verifying a nuclear weapon, transforming it into verification of software with sensitive details.

The national laboratories and the NNSA have developed elaborate protocols for how a host and inspector nation would navigate authentication and certification of a system involving an information barrier. The consensus in the 1990s and early 2000s was that the host country would supply any verification system that would make a measurement on a classified object.[220] More recently, this assumption has been reconsidered by a small minority.[221] Once a measurement has occurred using the verification system, most argue that the system itself becomes a classified object. It can no longer be removed from the host country's possession. This approach reflects an underlying discomfort with information barriers. Even though nearly universally arms control experts assert that IBs can protect the integrity of classified information, it seems they fear that it may be possible to derive information from a used information barrier. Only members of the NNSA disputed the notion that information barriers could not be re-authenticated. They argued that a "golden copy" of the software controlling an information barrier could be retained and electronics could be visually inspected to determine whether the

[219] Kane, et al.
[220] See, for instance: Keith Tolk, et al., "Authentication Task Force – Hardware Task Group," *Annual Proceedings of the Institute of Nuclear Materials Management* (2001); Dennis L. Mangan and Echkard Haas, "Information Security and Authentication – A Trilateral Initiative Challenge," *Annual Proceedings of the Institute of Nuclear Materials Management* (2001); R.T. Kouzes, et al., "A Case Study for Authentication of Monitoring Equipment," *Annual Proceedings of the Institute of Nuclear Materials Management* (2002).
[221] U.S. interview subjects 2, 6, 15.

chip set and motherboard were the same.[222] Importantly, though, visual inspections of electronics can be spoofed.[223] The golden copy of the software would be compared to the software in the verification system, though with limited access given that the system would now have interacted with classified data. The re-certification and re-authentication of the used information barrier evokes the original verification problem: it is now a classified object that must be verified. It even uses the same terminology—a "golden copy" of the software instead of a "golden weapon." Several interviewees partial to templates mention the re-certification challenge of information barriers, though this was a noticeably reluctant—and speculative—topic among those partial to attribute systems that include information barriers. One interviewee suggested a modular information barrier, where components could be individually verified and then replaced to ensure the system would be usable for future measurements.[224] Such an approach amounts to template matching of attribute components, subdividing into many verification challenges.

Assumptionless Verification

The certainty displayed in 1990s verification debates has given way to an epistemic crumbling and widespread doubt about how to approach the challenge. Based on the limited vulnerability testing – which regularly seems to disrupt prevailing assumptions – many have become convinced that all systems are spoofable and are reconsidering how to even approach verification. One interviewee commented, "I used to be an attribute person, now I'm starting to like templates more."[225] Several others noted that they had begun to reject the dichotomy

[222] U.S. interview subject 15.
[223] For instance, the U.S. National Security Agency has developed an internal list, called the NSA catalog, of ways to hack and compromise a wide range of electronics. See for instance, Jacob Appelbaum, Judith Horchert, and Christian Stocker, "Shopping for Spy Gear: Catalog Advertises NSA Toolbox," *Der Spiegel* (December 29, 2013), http://www.spiegel.de/international/world/catalog-reveals-nsa-has-back-doors-for-numerous-devices-a-940994.html.
[224] U.S. interview subject 15.
[225] U.S. interview subject 6.

between attributes and templates: they are just "two ends of a spectrum… more related than we originally thought. Hundreds of attributes starts to look like a crude template."[226] The notion that attributes and templates were not necessarily disjoint was posed by members of the laboratories in the early 2000s, though has only become a widespread belief, and permeated the NNSA, in the last five years.[227] As another commented, attributes are not very effective at proving something is truly a nuclear weapon. For most existing sets of attributes, nuclear weapons states can make non-weapon objects that possess these attributes.[228] This observation reflects the shift from thinking of verification more along the lines of confidence building to a more recent focus on authenticating verification systems and attempting to define a spectrum of confidence in verification measurements.[229] JASON has argued that all verification systems can be defeated and verification should instead seek to make violations "costly, cumbersome, and generally unattractive."[230] In the 1990s, JASON posited that verification was paradoxical, as depicted in the figure below.

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[226] U.S. interview subject 12. U.S. interview subjects 15, 13, and 7 expressed similar sentiments.
[227] James R. Lemley, et al., "Template Applications for Monitoring Warhead Dismantlement," *Annual Proceedings of the Institute of Nuclear Materials Management* (2001), http://www.inmm.org/source/proceedings/files/2001/PDFS/00000334.PDF.
[228] U.S. interview subject 12.
[229] U.S. interview subjects 3, 7, 9, 15.
[230] S. Drell, et al., 39-40.

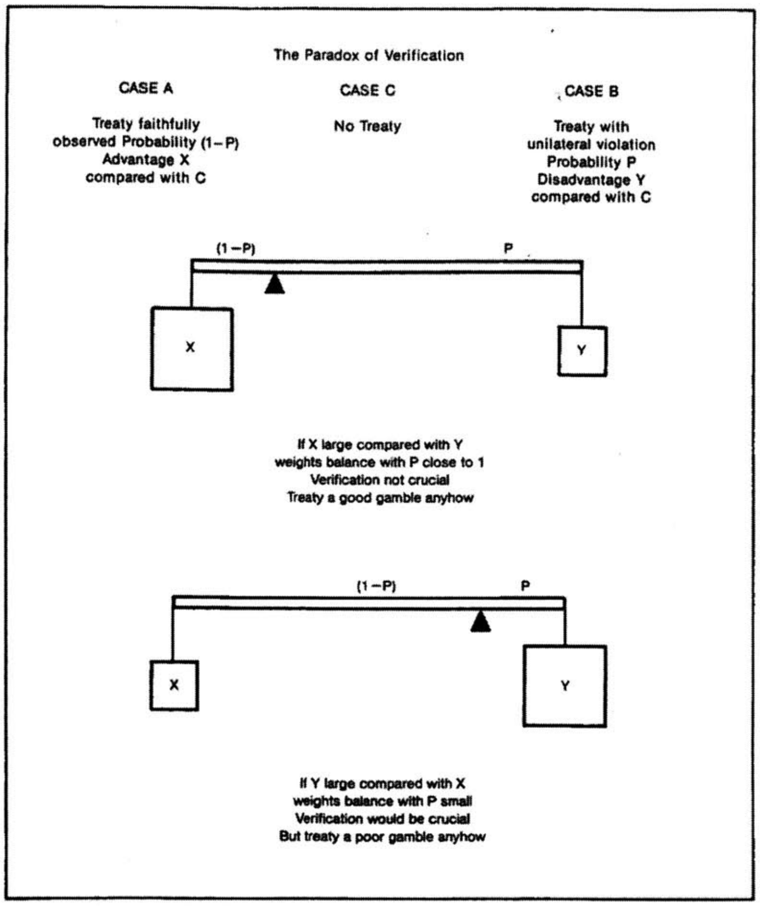

Figure 3-2. Moral: Strict verification is needed only for bad treaties. A good treaty can be useful even if verification is highly imperfect. [231]

Such a perspective fits very closely with Russian views that verification does not play into whether a party complies with a treaty.

The relationship with protecting classified information has also shifted. Some argued that it may be necessary to release some classified information, for instance that hosts should "release enough to convince monitoring parties what they're seeing is real."[232] Even the IAEA has argued for releasing some information recently, such as operational information and masses of fissile

[231] They argue here that if the benefits established through a treaty are significant, then verification is minimally relevant, since these benefits will already be derived even if the treaty partner violates a term. The image seems to imply a belief that these two options span the set of possible treaty outcomes and that a party derives benefits from a treaty regardless of whether its counterpart is in compliance with the treaty. Accordingly, per this perspective, JASON suggests in this report that there is a paradoxical dimension to verification, suggesting verification is key only for "bad" treaties. The report does not explore aims beyond the threshold of a treaty being useful. All is phrased as a direct trade-off, as opposed to a maximization of benefits problem. See S. Drell, et al., 35.

[232] U.S. interview subjects 3, 7, 12, 16.

material.[233] This shift in perspective shows that despite efforts to authenticate both attribute and template-based systems, interviewees assume releasing some information is important for demonstrating credibility. That is, they are now convinced that only classified information conveys credibility. They are treating revealing classified information much like a transparency measure or confidence building tool. Increasingly, "templates have become of interest again, because sharing classified information is seen as less horrible than it once was."[234] Such interviewees are quick to note, though, that we should "exhaust all possibilities not to release information."[235] In this perspective, sharing is necessary and inevitable, builds credibility, and should be minimized.

There was widespread ambivalence about the value of retaining classified information. Several concurred that "sharing is inevitable… we both know how it works."[236] In this view, inspections would be bilateral and neither the United States nor Russia would learn information that would modify their designs for nuclear weapons. Some distinguished between operational information—how weapons are handled and moved—versus design information, arguing that operational information could be released though design information was still sensitive, both between NWS and NNWS and between the United States and Russia.[237] Several interviewees set classification and the certainty spectrum up in direct opposition: "any useful radiation measurement from a nuclear weapon can be used to generate classified information," though noted that classification was not necessary for most, and maybe all, of this data.[238] The sense that some classified information may not be meaningfully classified shifts what DVNW should

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[233] U.S. interview subject 7.
[234] U.S. interview subject 12.
[235] U.S. interview subject 7.
[236] U.S. interview subject 12.
[237] U.S. interview subject 7.
[238] U.S. interview subjects 12, 13, 15.

entail, though still presents verification almost exclusively in terms of secrecy and certainty, directly opposed. The balance has shifted slightly in favor of certainty, now viewed as a spectrum. Coupled with this shift in how classified information should be treated, is a general collapse of many of the prior approaches to addressing verification.

In advance of deployment, verification technologies would be red-teamed. This is essentially a form of extensively attempting to defeat the technology. Most systems are tested in one-time demonstrations, which an interviewee noted is not generalizable to long-term verification campaigns.[239] Given the cost of red-teaming, it is exceedingly rare independent of a treaty under negotiation.[240] There is some internal peer review, though a pronounced lack of independent peer review. The same people are consistently involved in the internal reviews, perpetuating their core assumptions.[241] During the START I era, tags and seals were extensively red-teamed in advance of their deployment. This testing found that all systems could be defeated by a Los Alamos vulnerability assessment team in 1999.[242] Nonetheless, interviewees in both the United States and Russia broadly expressed trust in the tags and seal systems, some noting that the IAEA has been successfully using these technologies for years.[243]

The NNSA has recently developed a policy of attempting to approach verification with no perspective on how it would actually proceed. Partly, this stems from a notion that many technologies that were rejected twenty years ago may again be relevant since external technical advances change the costs and viability of these systems.[244] At present, NA-24 is conducting a review of what aspects are necessary to verify weapons, trying to avoid being informed by prior

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239 U.S. interview subject 12.
240 U.S. interview subject 14.
241 U.S. interview subjects 7, 12, 15.
242 Johnston.
243 U.S. interview subjects 7, 15; Russian interview subject 5.
244 U.S. interview subject 15.

NNSA-sponsored research.[245] Indeed, the study tries to avoid reference to either template or attribute approaches, instead trying to speak of relevant "characteristics." Current verification research funded by NA-22 tries "not to make assumptions about what will happen in a bilateral process... we're looking at everything."[246] Similarly, NA-24-funded research seeks breadth and tries to explore the possibilities for verification independent of constraints that may play into U.S.-Russian arms control efforts.[247] These efforts align closely with Jasanoff's writing on a "view from nowhere, an effort to combat human tendencies towards subjectivity by trying to decide blindly."[248] The breakdown in faith within the NNSA in early views on verification coupled with the unexpected results from the few vulnerability tests there are of systems and more information revealed than expected in verification experiments means that many verification researchers are consciously trying to abandon the constraints they have developed on how to approach verification and to rebuild thinking on verification.

While two decades ago, the focus was on certification, simultaneous certification and authentication as well as authentication on its own have become topics of interest to the NNSA and members of the U.S. nuclear weapons laboratories lately. Recent efforts from Los Alamos and Pacific Northwest National Laboratories have explored confidence as a spectrum and which efforts could improve inspectors' confidence in verification measurements. Los Alamos has further started to explore non-technical spoof efforts, such as "sleight of hand."[249] Drawing from the psychological literature on how humans can be deceived by illusionists, they explore change

[245] U.S. interview subjects 15, 6.
[246] U.S. interview subject 6.
[247] "Nuclear Verification at Low Numbers: A Scoping Workshop."
[248] See, for instance, Sheila Jasanoff, *Designs on Nature: Science and Democracy in Europe and the United States* (Princeton, NJ: Princeton University Press, 2005).
[249] Danielle K. Hauck, et. al., "Defining the Questions: A Research Agenda for Nontraditional Authentication in Arms Control," *Annual Proceedings of the Institute of Nuclear Materials Management* (2010), http://www.inmm.org/source/proceedings/files/2010/209.pdf.

blindness and the possibility of measurement system components being switched without inspectors' noticing.[250]

With the perspective that confidence is a spectrum and no system will be robust, many in the laboratories and NNSA also cede some control. Now, a prominent question is, "how much confidence do you need? Is this verification as a CBM [confidence building measure] or really tight verification?"[251] Several interviewees viewed the technical and political dimensions of verification as distinct, and a confidence interval as externally imposed by political, social, and economic conditions; then, the laboratories could respond with the appropriate technical system fitting those specifications.[252] In many ways this perspective is aligned with Russian thinking on the topic: that non-technical constraints may overwhelm the technical.

Speaking more specifically about constraints on a direct nuclear weapons verification system, interviewees highlighted simplicity, manufacturing concerns, and trust. The negotiation history of arms control treaties were a prominent reason for the simplicity requirement. As an interviewee noted, nothing "fancier" than a helium-3 detector has passed muster in a treaty, and these are "relatively easy" to image and ensure there is no extraneous functionality.[253] Further, arms control negotiations are prone to operating in the context of precedents.[254] Secondly, anyone red teaming verification systems prefers that the system be relatively simple, so they can be more confident when evaluating vulnerabilities.[255] Presently, Russian manufacturing capabilities are more limited than the United States in verification equipment; accordingly simplicity of the systems ensures both countries are capable of producing any required materials.

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[250] Hauck, et al.
[251] U.S. interview subjects 15, 12.
[252] U.S. interview subject 12.
[253] U.S. interview subject 12.
[254] U.S. interview subjects 2, 8, 16; Russian interview subjects 5, 6, 9.
[255] U.S. interview subjects 12, 14, 15. Worth exploring, though, is the ways in which systems can be simple or complex and the implications for certifying such systems and their political viability in treaties.

Interviewees spoke of trust in terms of believing in the credibility of equipment used in the verification system. As evidenced by past inspection efforts as well as role-playing collaborative verification experiments, dynamics between inspectors and hosts can quickly turn adversarial.[256] Beyond specific constraints on direct nuclear weapons verification systems, there remain some broader challenges to arms control and verification.

Besides verifying declared stockpiles, there could be treaty violations that are not even available for verification. For instance, the question of how to ensure a country does not stash 100 weapons in a cave is such an intimidating question that few have seriously thought about how to approach this.[257] An offhand approach lacking completeness received surprisingly wide support at a conference of veterans of technical verification work.[258] A widespread phenomenon among both NWS and NNWS is that some declarations are trusted; others raise skepticism. An underlying challenge for preventing cheating in nuclear reductions is verifying nations' original declarations about their stockpiles. Yet, these appear to be broadly trusted even though fissile material declarations are doubted.[259] It is not fully clear why there is this discrepancy in trust, although it is technically easier to quantify weapons than fissile material production.

Direct nuclear weapons verification is presently facing an epistemic crisis. Initially, it was explored through a lens of secrecy of classified information and certainty as direct trade-offs. The prevailing perspectives were centered on using only means that would not expose information. No metrics for evaluating a verification system have been established. Core assumptions went largely untested. Through the few instances of peer review and vulnerability

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[256] U.S. interview subject 15.
[257] U.S. interview subject 12.
[258] The idea was NWS could identify some areas of the country that were off-limits, pertaining to classified non-nuclear military matters. Then, the rest of the country would be fair game for the IAEA to thoroughly inspect and ascertain whether there were any hidden weapons. Posed at "Nuclear Verification at Low Numbers: A Scoping Workshop," not for attribution.
[259] "Nuclear Verification at Low Numbers: A Scoping Workshop."

testing, these assumptions have been upended. A sense of futility, that all systems are vulnerable and most of these projects may be in vain, is in vogue among many members of the weapons laboratories. There has also been a tendency within the field to reframe verification in a way that almost defines away the original challenge, and then assumes its resolution. For instance, an information barrier is almost universally posed as a solution to verifying a weapon without exposing classified information. Then, verification of the information barrier is bracketed. Increasingly, though, members of the laboratories and the NNSA are thinking about the limitations of past approaches to verification and are open to alternative methods. The secrecy-certainty narrative is starting to erode.

Chapter 5: Conclusion

A series of prior technical and political questions shape how researchers consider direct nuclear weapons verification. How much certainty is necessary? Is certainty really a goal of the associated treaty or is confidence-building more relevant?

Interestingly, addressing these questions as prior to developing a verification system has dominated thinking about direct verification, rather than other possible perspectives, such as thinking in terms of what is necessary to demonstrate a test object is a true weapon and no materials have been diverted or trying to develop a verification system flexible to fit multiple goals. As is clear from past subnational debates of arms control treaties, there are widely divergent views about the aims and role for verification, and therefore what an associated system would entail. The dominant Russians arms control elite approach has been to consider verification as a purely political formula, where existing technologies are sufficient and can be applied once the aims of verification are settled. In the United States, verification elites have shifted from a singular aim of protecting sensitive information to an expressed aim of pure objectivity, which they define as considering verification separately from the context in which it may apply.

An early narrative of secrecy being in direct opposition to certainty—and secrecy being singularly important—shaped much of the twentieth century U.S. thinking on direct verification. However, the latter point has given way to uncertainty about the extent to which secrecy matters. Still, a tendency to view secrecy and certainty as oppositional endures. This is revealed particularly through reactions to red teaming of prospective verification systems. The information barrier emerged in the late 1990s as a possible approach to overcome the secrecy-certainty challenge. Yet, then, the problem of verifying the information barrier appears and essentially replicates the original verification challenge. Instead, the information barrier played into the notion of secrecy and certainty forming a polarized spectrum. While U.S. researchers have tended to view all prospective systems as vulnerable, they are uncertain what the treaty requirements for a system would be. Russians I met with tended to view verification as having a more ceremonial role—bolstering trust within a treaty, though unable to affect treaty compliance.

Originally motivating this thesis was a question about the viability of zero knowledge and zero disclosure systems for direct nuclear weapons verification. Such systems have been posed in the last five years, primarily by academics outside the national laboratories. They rely on a branch of theoretical mathematics that allows for proving a theorem is probabilistically true without revealing any more information than the theorem's validity. Arms control applications of zero knowledge are set up through either electronic or physical cryptography of nuclear measurements. A small, growing population within the national laboratories has started to explore zero knowledge approaches. Yet, the wider community in the United States appears very skeptical. Few in Russia have considered zero knowledge systems. Based on the interviews conducted through this thesis, the U.S. skepticism seems to stem from efforts to bound who can work on arms control issues, zero knowledge not fitting into the secrecy-certainty narrative, and the new epistemic doubt, whereby many believe a system that is both certifiable and authenticable is not possible. The widespread doubt in all systems and the move to reject all assumptions about DVNW offers an opening, though. Past approaches have presented prototypes of systems and then discovered their shortcomings through vulnerability testing. Designers of zero knowledge DVNW approaches instead tend to frame their approaches as proofs. If such proofs prove persuasive they would be positive demonstrations of why these systems could work, rather than the more traditional approach of considering systems viable until vulnerability tested. Narratives of DVNW are in the midst of shifting.

Other constraints on verification systems prove more difficult to evaluate. I have collected a range of constraints in this thesis that interviewees and historical evidence suggest will shape the treaty space. Yet, this is a pilot study of verification narratives and approaches within the national laboratories. Many of these claims should be more fully explored. In particular, there is suggestive evidence that high-level support for arms control can dramatically shift the equation. Many of the technical claims interviewees made seemed also in large part to be shaped by the sociotechnical context. It would be greatly beneficial to do a more comprehensive study of all verification systems considered, designed, and built as well as all participants in crafting, considering, and testing these systems. Key questions about the treaty space for future arms control and the relationship between declining numbers and the level of verification remain open. In particular, an important question to address is how, when, and which perspectives and narratives interact to shape arms control treaties and verification. I am particularly interested in exploring the construction of credibility in the nuclear arms control regime and further exploring the experiments addressed in the third chapter.

Anonymity was used in this study, though probably was unnecessary, at least for the U.S. participants. Anonymity likely undermined credibility of the argument, as readers cannot determine the relevance of particular interviewees to comment on a topic. Further, interviewees seemed unconcerned whether they would be quoted by name or granted anonymity, and they appear to have enough institutional flexibility to express their views. A possible future approach would be to have non-anonymized interviews, though give interviewees the option to speak without being identified whenever they choose to do so.

The nuclear nonproliferation and arms control regime comprises a close-knit community. Many have been in the field for decades, interacting with their counterparts overseas despite tensions between the nations. Near-term prospects for U.S.-Russian arms reductions and direct verification post-New START may be dim. However, alternate trajectories towards Article VI commitments are in progress. Recent shifts in direct verification narratives and design bode well for their readiness for future treaties. Higher level questions of what a treaty means, what would be required for significant reductions, and how to build a secure world remain open—and not wholly connected.

Appendix

Several Sample Interview Questions

1. What's your involvement with verification research?
2. How did you get into the field?
3. Several questions based on articles written by the interviewee and any involvement in experiments or designing verification systems. For instance, how does [system] address authentication? When were times the design changed in significant ways? What played into these changes? What ideas or hypotheses play into this system?
4. Beyond [your project], what research on verification is going on at [your laboratory]?
5. How have existing verification systems been red teamed or vulnerability tested?
6. What are the relative roles of NA-22 and NA-24 in your work? Are there any other agencies external to your laboratory that are involved in your research?
7. How are NA-22 and NA-24 structured? What are their relative roles on DVNW? Which other agencies are involved in this project? Before the current NA-22 and NA-24 structure, how was verification research overseen at the NNSA? How was verification studied pre-2000?
8. How has the mandate and type of verification work changed administration-to-administration?
9. What projects are the various national laboratories involved with on verification research?
10. Absent funding constraints, how would you approach designing verification systems?
11. How are you thinking about the timeline for DVNW and the type of technologies that would be required? How is the NNSA thinking about it? How about other colleagues in the U.S./Russian laboratories?
12. What are the characteristics of a verification system that would make it viable for a bilateral treaty? How well do existing systems satisfy these constraints?
13. In verifying a weapon, what is important to verify? How should a weapon be verified?
14. Why have attribute-based systems been so prominent, given your comment in [article] that they would be insufficient on their own?
15. What is the current thinking on repeat authentication of verification systems and how does this fit into host-inspector dynamics?
16. How do you consider whether to focus on active or passive techniques or which measurement devices to include in a verification system?
17. Which systems (hypothetical or existing) do you think are most realistic for verification? How does this vary in (U.K., U.S., Russia, China)?
18. How has thinking on DVNW shifted over the course of your time in the field?
19. How did information barriers become a component of verification systems? What are the challenges/strengths associated with them?
20. What is the balance of technical and political objectives in these goals?
21. Which technologies do the United States and Russia use to evaluate their own weapons?
22. How did the national nuclear laboratories first get involved in direct verification research?
23. What was the basis for Field Test 34? What was the reaction to the conclusions? Why did the study choose the parameters and metrics it chose?

24. How was DVNW research studied in the 1970s and 1980s?
25. How did the laboratories and both governments react to the Black Sea Experiments?
26. What were the goals and results of the Trilateral Initiative?
27. During the HEU-to-LEU downblending agreement, what was verified and how was this negotiated?
28. How were the systems used for the Pantex system chosen? What were the implications of the experiments?
29. In which publications do researchers describe potential verification systems?
30. Can you talk about the ebb and flow of U.S.-Russian collaboration? How did it start? Why did the lab-to-lab program end?
31. How is the government engaging with China on these issues? What is involved in the track II dialogue with China, and with Russia?
32. How did ^{3}He detectors get included in past arms control treaties? What else was considered and why were these chosen? What were the arguments made regarding intrusiveness and treaty aims that played into including the detectors? What other technologies have come up in treaty negotiations and been seriously considered?
33. How have the laboratories and NNSA (and Russian analogues) been involved in advising or participating in negotiation of arms control treaties?
34. What's the breakdown of system types being studied in Russia and China?
35. What can you say about non-nuclear signatures? What roles could they have in a verification regime? What have been the conclusions from studying them?
36. How do you think about spoof weapons when designing a verification system?
37. What types of noncompliance do you consider or think likely?
38. Can you tell me about the different roles in weapons verification at VNIIA, VNIIEF, and VNIITF? How are the three laboratories overseen? How are research agendas determined?
39. When did Russia start getting involved in DVNW research?
40. How are the verification research agendas determined for these laboratories? How is funding allocated and what are the relative allocations for projects currently being pursued? Can you talk about the continuity in funding, based on past projects?
41. Whom would you suggest I contact? How is best to contact them? Are there resources beyond the ones I've mentioned that I should explore?
42. How realistic are zero knowledge or zero disclosure verification systems? What has the laboratories' reaction to them been?

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