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Promoting Nuclear Warhead Reductions: Regimes, Approaches and Technologies

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Abstract

After the Cold War, the United States and Russia recognized the urgent importance of reducing their large nuclear warhead stockpiles. Many technical and policy discussions as well as negotiations both formal and informal emerged to explore the possibility of transparent, verifiable, and irreversible nuclear warhead elimination. A verifiable nuclear warhead reduction regime involves highly sensitive national security information; complicated and intrusive verification technologies and techniques; carefully designed monitoring and dismantling procedures and substantial technical and financial resources. Thus, it is essential to consider and develop all potential policy regimes, verification approaches, and available or promising technologies. This report breaks nuclear warhead reductions into three tiers: regimes, verification approaches, and associated technologies and proposes that with existing technical capabilities, it is fully possible to design a verifiable regime with adequate confidence for irreversible nuclear warhead reduction.

List of abbreviations

MAD - Mutual Assured Destruction
ICBM - Intercontinental Ballistic Missile
SLBM - Submarine Launched Ballistic Missile
MIRV - Multiple Independently Targetable Reentry Vehicle
SALT - Strategic Arms Limitation Talks
INF - Intermediate-range Nuclear Forces
START - Strategic Arms Reduction Treaty
SORT - Strategic Offensive Reductions Treaty
PNIs - Presidential Nuclear Initiatives
NTM - National Technical Means
OSI - On-Site Inspection
PPCM – Portal and Perimeter Continuous Monitoring
RVOSI - Reentry Vehicle On-Site Inspection
IAEA – International Atomic Energy Agency
TLI – Treaty Limited Item
SDNV – Strategic Delivery Nuclear Vehicle
HEU – Highly Enriched Uranium
LEU – Low Enriched Uranium
RV – Reentry Vehicle
NPT – Nonproliferation Treaty
ALCM – Air Launched Cruise Missile
NWS – Nuclear Weapon State
NNWS – Non-Nuclear Weapon State
CTR – Cooperative Threat Reduction
DOE – Department of Energy
NNSA - National Nuclear Security Administration
MINATOM – Ministry of Atom
NFU – No First Use
STI – Stability, Transparency and Irreversibility
FMCT – Fissile Material Cutoff Treaty
NSA - Negative Security Assurance
PSA - Positive Security Assurance
NWFZ – Nuclear Weapon Free Zone
CBMs – Confidence Building Measures
RDDs - Radiological Dispersal Devices
SLCM - Sea-Launched Cruise Missile
TNW - Tactical Nuclear Weapons
DTRA - Defense Threat Reduction Agency
FMSF - Fissile Material Storage Facility
CTBT – Comprehensive Test Ban Treaty
FMCT - Fissile Material Cut-off Treaty
TTBT - Threshold Test Ban Treaty

PTBT - Partial Test Ban Treaty
PNET – Peaceful Nuclear Explosion Treaty
ABM – Anti-Ballistic Missile
DPRK - Democratic People's Republic of Korea
MPC&A - Material Protection, Control and Accountability
CFE - Conventional Armed Forces in Europe
CWC - Chemical Weapons Convention
NIS - Newly Independent States
GPS - Global Position System
EM - Electro-Magnetic
MOX - Metal Oxide
HE - High Explosive
AF&F - Arming, Fusing and Firing system
NRDC - Natural Resources Defense Council
WgPu - Weapon grade Plutonium
WgU - Weapon grade Uranium
NWIS - Nuclear Weapon Identification System
CIVET - Controlled Intrusiveness Verification Technique
TRADS - Trusted Radiation Attribute Demonstration System
IS/IB - Inspection System with Information Barrier
BNL – Brookhaven National Laboratory
ORNL – Oak Ridge National Laboratory
LANL – Los Alamos National Laboratory
LLNL – Lawrence Livermore National Laboratory
SNL – Sandia National Laboratory
PNNL – Pacific Northwest National Laboratory
RIS - Radiation Inspection System
SHA - Secure Hash Algorithm
TRIS - Trusted Radiation Inspection System
FMTTD - Fissile Material Transparency Technology Demonstration
AMS/IB - Attribute Measurement System with Information Barrier
AVNG - Attribute Verification System with Information Barrier for Plutonium with classified characteristics utilizing Neutron Multiplicity Counting And High-Resolution Gamma-ray Spectrometry
NMIS - Nuclear Materials Identification System
TID - Tamper-indicating Device
UNSCOM – United Nation Special Commission
C/S - Containment and Surveillance
CSA – Sanned Subassembly
INMM-xx – the xxth annual conference of the Institute of Nuclear Material Management

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Contents

1. Introduction

Even in the midst of the competitive development of their nuclear capabilities during the Cold War, the governments of the United States and the Soviet Union realized that nuclear war would be disastrous.[1] Indeed, in 1985, Presidents Reagan and Gorbachev declared, "A nuclear war cannot be won and must never be fought."[2] Although various efforts were made to avoid a nuclear confrontation, each side had developed and maintained huge nuclear forces, operational on hair-trigger alert, in an effort to gain advantage over the other.[3] There were many agreements between the United States and the Soviet Union for better communication in order to avoid nuclear conflict, including the Hotline Agreement of 1963 and its expansion in 1984, the Agreement on Measures to Reduce the Risks of Nuclear War in 1971, the Incidents at Sea Agreement in 1972, the Prevention of Nuclear War Agreement in 1973, the Agreement to Establish Nuclear Risk Reduction Centers in 1987, and the Agreement on Notifications of Launches of ICBMs and SLBMs in 1988. During the late 1980s and 1990s, the United States and the Soviet Union/Russia made substantial progress in nuclear arms reduction. Both countries sponsored and conducted significant nuclear disarmament treaties and activities, including Intermediate Nuclear Forces (INF) Treaty in 1988, the Presidential Nuclear Initiatives (PNIs) on the removal of large numbers of tactical nuclear weapon systems in 1991, the Strategic Arms Reduction Treaty (START) in 1994, and the Strategic Offensive Reduction Treaty (SORT, also known as the Moscow Treaty) in 2002.[4]

After the end of the Cold War, the governments of the United States and Russia pursued extended nuclear deterrence and first-use of nuclear weapons policy.[5] In its nuclear posture review, the Bush administration made clear that it had no intention of limiting the role of nuclear weapons to their "core function"—deterring nuclear attacks.[6] In 1993, Russia renounced its no-first-use policy. On April 21, 2000, Russian President Vladimir Putin signed a new military doctrine, The Russian Federation Military Doctrine, that allowed a nuclear "response to large-scale aggression utilizing conventional weapons in situations critical to the national security of the Russian Federation." It also explicitly stated for the first time that Russia "reserves the right" to use nuclear weapons in response to all attacks by "weapons of mass destruction."[7] Furthermore, the United States and Russia still maintained very dangerous launch-on-warning

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[1] McGeorge Bundy, *Danger and Survival: Choices about the Bomb in the First Fifty Years*, (Random House, Inc.: New York, first edition, 1988), pp. 588-596; "The effects of nuclear war", OTA-NS-89, (US Government Printing Office, Washington DC), May 1979; "Scientists' Declaration on the Nuclear Arms Race", Set forth by the Union of Concerned Scientists in August 1977, By the year's end, over 12,000 scientists and engineers had endorsed the Declaration, available at http://www.ucsusa.org/ucs/about/page.cfm?pageID=1012; and Richard Turco, "Nuclear Winter," in Catherine M. Kelleher, et al. eds., *Nuclear Deterrence: new risks, new opportunities* (Pergamon-Brassey's International Defense Publishers, Inc., first printing, 1986).

[2] Joint summit statements by President Ronald Reagan and Secretary-general Mikhail S. Gorbachev, Geneva, November 21, 1985

[3] William Langer Ury and Richard Smoke, "Beyond the Hotline: Controlling a Nuclear Crisis" A Report to US Arms Control and Disarmament Agency, Nuclear Negotiation Project, Harvard Law School, 1984; Dennis Paulson ed., "Voices of Survival in the Nuclear Age," (Capra Press, Santa Barbara), 1986; James E. Goodby and Harold Feiveson, "Ending the Threat of Nuclear Attack", The Center for International Security and Arms Control at Stanford, May 1997.

[4] The text of cited treaties can be found at http://www.state.gov/t/ac/trt/

[5] Committee on International Security and Arms Control, US National Academy of Science, *The Future of US Nuclear Weapons Policy* (National Academy Press: Washington D.C., 1997), pp.2, pp.14-15, pp.16-19, pp.26-27, pp.33-45, pp.73-75

[6] US DOD, "Findings of the Nuclear Posture Review", January 9, 2002, available at http://www.defenselink.mil/news/Jan2002/t01092002_t0109npr.html

[7] "Russia's Military Doctrine", available at http://www.armscontrol.org/act/2000_05/dc3ma00.asp

postures.[8] These developments run counter to the positive international nuclear disarmament trends of the late 1980s and 1990s.

Uncertainty regarding the size of US and Russian tactical nuclear warhead stockpiles,[9] and aggregate nuclear warheads,[10]—particularly what is in storage on the Russian side—presents huge obstacles to future nuclear disarmament. With the reduction of strategic weapon systems, the tactical nuclear stockpile will inevitably make deep reductions difficult.[11] In Russia, there is revived interest in the possible use of tactical to deter large conventional attacks. In the United States, there is renewed interest in using tactical nuclear weapons to destroy hardened and deep-buried targets of terrorists or hostile countries.[12]

With the development of precision guidance technology, the division between strategic and tactical nuclear weapon systems is becoming ambiguous. Therefore, future nuclear reductions must take into account all types of nuclear warheads, their uses, and delivery. Verifiable nuclear warhead elimination can open a new stage for the United States and Russia to conduct nuclear arms reduction toward a less dangerous world and also toward irreversible nuclear arms abolition in France, Britain, China and other *de facto* nuclear states.[13]

Elimination of nuclear warheads and their associated delivery vehicles can not only greatly reduce the overkill capabilities of both the United States and Russia, but can also limit the function of nuclear weapons to the core function of deterring nuclear attack.[14] Nuclear warhead elimination can also be very helpful in moving toward the final abolition of nuclear weapons.

It is also important to reduce operational strategic nuclear forces. Such a reduction limits the existing overkill capability by limiting and destroying the launch and delivery vehicles. However,

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[8] Bruce G. Blair, Harold A. Feiveson, and Frank N. von Hippel, "Taking Nuclear Weapons Off Hair Trigger Alert," *Scientific American*, November 1997

[9] The number of US and Russian tactical or non-strategic nuclear weapons differs in various estimations from NRDC's worldwide tactical nuclear weapon archive and data in Appendix 10B of SIPRI Yearbook 2002, to some personal estimations such as the estimated number in "Practical Steps for Addressing Non-strategic Nuclear Weapons" of William Potter and "Appendix A: Deep Cuts and De-alerting: A Russian Perspective" of Alexei Arbatov in "The Nuclear Turning Point: A Blueprint for Deep Cuts and De-Alerting of Nuclear Weapons"

[10]In 1992, the CIA estimated that Russia had 30,000 nuclear weapons, "plus or minus 5,000." (See "Testimony of Lawrence Gershwin before the House Defense Appropriations Subcommittee," 6 May 1992.). Subsequent statements by Russian Minister of Atomic Energy Victor Mikhailov that the Russian stockpile peaked at 45,000 warheads cast doubt on the CIA estimation and emphasized further the difficulty of estimating warhead stockpiles with national intelligence alone.

[11] Nikolai Sokov, "Tactical Nuclear Weapons Elimination: Next Step for Arms Control", Nonproliferation Review, vol. 4 (Winter 1997), pp.17-27; Joshua Handler, "The September 1991 PNIs and the Elimination, Storing and Security Aspects of TNWs", presentation for *Time to Control Tactical Nuclear Weapons*, United Nations, New York, September 24, 2001; and Alistair Millar, "The Pressing Need for Tactical Nuclear Weapons Control", *Arms Control Today*, May 2002.

[12] Harold A. Feiveson, ed., The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons, (Brookings Institution Press: Washington, D.C., 1999), pp.159-170, pp.319-321; William C. Potter, "Unsafe at Any Size", *Bulletin of the Atomic Scientists*, Vol. 53 (May/June 1997), pp.11-14; Philipp C. Bleek, "Report Says US Studying New Nuclear Capabilities", *Arms Control Today* **(**January/February 2002); Sidney Drell, James Goodby, Raymond Jeanloz, and Robert Peurifoy, "A Strategic Choice: New Bunker Busters Versus Nonproliferation", *Arms Control Today* **(**March 2003); Greg Mello, "New Bomb, No Mission," *Bulletin of the Atomic Scientists*, May/June 1997, pp. 28-32; Stephen M. Younger, "Nuclear Weapons in the Twenty-First Century," Los Alamos National Laboratory, LAUR-00-2850, Los Alamos, New Mexico, June 27, 2000; Robert W. Nelson, "Low-Yield Earth-Penetrating Nuclear Weapons", *Science and Global Security, 10:1–20, 2002*

[13] Committee on International Security and Arms Control, US National Academy of Science, *The Future of US Nuclear Weapons Policy* (National Academy Press: Washington D.C., 1997), pp.46-47, pp.66-67, pp.78, pp.82-83

[14] Committee on International Security and Arms Control, US National Academy of Science, *The Future of US Nuclear Weapons Policy* (National Academy Press: Washington D.C., 1997), pp.3-4; and Harold A. Feiveson, ed., *The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons*, (Brookings Institution Press: Washington, D.C., 1999), pp.31-45

there are no treaties, agreements, or initiatives—past or current—that promote the verifiable reduction and disposition of the mated nuclear warheads. Due to the flexible reversibility of uploading nuclear warheads to their corresponding delivery vehicles,[15] the large but uncertain number of nuclear warheads held in reserve poses a big problem to further nuclear arms reduction and the confidence of international nonproliferation regime. During the US Senate ratification of START I, concerns about rapid re-deployment of nuclear forces (mainly due to the uncertainty and reservation of large nuclear warheads not dismantled or disposed, and the huge quantity of fissile materials) resulted in the Biden amendment on ratifying the treaty.[16] In Russia, the Duma's reluctance to ratify the START II treaty also revealed concerns about the uploading capabilities of the US with its existing oversized nuclear stockpile.[17]

1.1 The past nuclear disarmament practice and experience

The effort for nuclear arms control has been pursued for nearly 60 years, since US representative Bernard Baruch first provided a suggestion to control military-related nuclear activities in June of 1946.[18] Although "the Baruch Plan" failed, it encouraged both the United Nations and the world to start thinking about nuclear arms control. Since then, the topic of nuclear arms control has gained popularity and acceptance with an increasing number of governments and individuals.

Past activity in nuclear arms control and reduction occurred mainly between the United States and USSR/Russia and focused on strategic nuclear delivery vehicles. The most successful practices limited or reduced the operational strategic nuclear capabilities of each side. A set of complicated and comprehensive counting rules for capping the number of nuclear weapon delivery vehicles was established. Verification technologies were also gradually developed, matured, and were accepted by both sides during the nuclear arms control process.

Strategic Arms Limitation Talks (SALT I), the first nuclear limitation agreement between the United States and the Soviet Union, was signed on May 26, 1972, in Moscow. Under this agreement, numerical limits were set on deployed Intercontinental Ballistic Missile (ICBM) silos and Submarine Launched Ballistic Missile (SLBM) launch tubes. The agreement limited the United States to 1,054 ICBM silos and 656 SLBM launch tubes, while the Soviet Union was limited to 1,607 ICBM silos and 740 SLBM launch tubes.[19] The verification of SALT I was mainly dependent on "National Technical Means" (NTM), such as photoreconnaissance satellites, electronic intercepts of missile flight test data, and other unilateral intelligence gathering, as well

[15] The START treaty nuclear warhead counting rules gave the possibility of expansion the nuclear capabilities by uploading the warheads to their mated delivery vehicles, and the treaty did not take any provisions to dismantle or dispose the nuclear warheads. The SORT treaty defines the total warheads each side can deploy for strategic purpose, it does not require any action on the delivery vehicles and the huge reserved nuclear warheads, left great space for warhead uploading to existing both countries' delivery vehicles.

[16] US Senate Executive Report 102-53 (US Government Printing Office: Washington DC, 18 Sep. 1992), Resolution of Ratification, pp.101

[17] Oleg Bukharin and Kenneth Luongo, "US-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals," Princeton University Report No. 314, April 1999

[18] The Baruch Plan, Presented to the Atomic Energy Commission of United Nations, June 14, 1946, available at http://www.atomicarchive.com/Docs/BaruchPlan.shtml

[19] For introduction and text of SALT I, see the reference at http://www.fas.org/nuke/control/salt1/intro.htm and http://www.fas.org/nuke/control/salt1/text/salt1.htm

as limited data exchange.[20] In a sense, SALT I could be considered a valuable nuclear arms reduction treaty. Although the treaty had numeric limits, both the United States and the Soviet Union were able to expand their nuclear forces by increasing the throw-weight of missiles, deploying Multiple Independently Targetable Reentry Vehicles (MIRVs) on ICBMs and SLBMs, deploying mobile ICBMs, and increasing bomber-based forces.

In the late 1980s and early 1990s, the United States and the Soviet Union/Russia successfully negotiated several nuclear arms reduction agreements, including INF and START. Both countries removed large parts of their nonstrategic nuclear weapon systems from deployment under PNIs.

The INF was the first real nuclear arms reduction treaty mandating the elimination of an entire class of nuclear forces—all ground-launched nuclear missiles with ranges between 500 and 5,500 kilometers. Under INF, the Soviet Union destroyed 1,846 intermediate-range nuclear missiles, and the United States eliminated 846 nuclear missiles.[21] The verification regime of INF had many unprecedented and intrusive methods, including

- the exchange of detailed data about intermediate-range nuclear forces;
- enhanced NTM (e.g., each side had the right to request open display of mobile ground-launched ballistic missiles at operating bases);[22]
- perimeter-portal monitoring of missile production facilities;[23] and
- On-Site Inspection (OSI).[24]

OSI, which had never before been accepted by the Soviets, became the main method for INF verification regime and provided significant practice and experience for late nuclear arms reduction.[25] OSI in INF included baseline inspections, elimination inspections, closeout inspections, and "quota" or "short-notice" inspections.[26] On-site inspections also provided for the use of radiation detectors to determine the number of warheads on a missile.[27]

During 1991 and 1992, the United States and the Soviet Union/Russia announced intentions to remove from deployment a large number of their tactical nuclear weapon systems and to eliminate many of these systems.[28] US non-strategic nuclear weapons were reduced from nearly 10,000 in 1991[29] to roughly 1,600 in 2001.[30] More than 11,000 nuclear warheads were

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[20] Bruce G. Blair and Garry D. Brewer, "Verifying SALT Agreement", Les Aspin and Fred M. Kaplan, "Verification in Perspective", and Stuart A. Cohen, "The Evolution of Soviet Views on SALT Verification: Implications for the Future" in William C. Potter eds., *Verification and SALT: the Challenge of Strategic Deception*, (Westview Press: Boulder, Colorado), 1980

[21] On-Site Inspection Agency: trust and verify, (prepared by DynMeridian, a DynCorp company, Alexandria, VA under contract no. OISO1-94-D-0006), pp.1-3

[22] Jeremy K. Leggett and Patricia M. Lewis, "Verifying a START Agreement: Impact of INF precedents"

[23] Ibid

[24] Harahan, Joseph P., *On-Site Inspections Under the INF Treaty, A History of the On-Site Inspection Agency and Treaty Implementation, 1988-1991,* (Treaty History Series, Government Printing Office, 1993)

[25] OTA-ISC-488, "Verification Technologies: Managing Research and Development for Cooperative Arms Control Monitoring Measures", May 1991

[26] Defense Threat Reduction Agency, Public Affairs Factsheet, "INF inspection status", available at http://www.dtra.mil/news/fact/nw_infosi.html

[27], "Radiation Detection Equipment for Monitoring the INF Treaty", INF Neutron Detector Fact Sheet, Cooperative Monitoring Center, Sandia National Laboratories, May, 2003

[28] SIPRI Yearbook 1992: World Armament and Disarmament (Oxford University Press: New York), pp.85-92

[29] Robert Norris and William Arkin, "Nuclear Notebook: US Nuclear Weapons Stockpile", *Bulletin of the Atomic Scientists*, June1991

[30] Hans Kristensen and Joshua Handler, "Appendix 6A. Tables of Nuclear Forces," SIPRI Yearbook 2001

eliminated in the Russian nuclear stockpile between 1992 and 2000.[31] Because the dismantlement and elimination of tactical nuclear weapons was based on unilateral assurance, without transparency or even simple verification measures, the analysis of unclassified or public reports yielded only limited confidence of tactical nuclear warhead elimination.[32] The exact portion of the tactical nuclear warhead stockpile that was dismantled or kept intact is unknown, and intact nuclear warheads could be readily re-deployed, possibly to gain some strategic advantage. Despite limited confidence and openness, the PNIs proved an alternative process of nuclear reduction and elimination through unilateral assurance. Various arguments proposed further action to eliminate the tactical nuclear warhead under the PNIs with some levels of transparency and verification for dismantling and destroying.[33]

START I was the most complicated and comprehensive nuclear arms control agreement ever negotiated, with 280 pages of treaty text, statements, annex, protocols, letters, and declarations.[34] This treaty permitted the United States and Russia to keep 1,600 deployed strategic delivery vehicles and 6,000 "accountable" warheads. It was the first nuclear arms control treaty to significantly reduce deployed strategic nuclear capabilities and to take the operational strategic nuclear warhead problems into consideration through the counting rules defined in Treaty Article III. Although START I did not solve the irreversibility of nuclear arms reduction and included loopholes in the rules for counting nuclear warheads, it opened a new era for nuclear arms reduction. START I presented feasible and practical ways of realizing verifiable reductions. The intrusive and cooperative verification and transparency measures of START I comprised the most comprehensive, well-devised, complicated, and costly treaty compliance monitoring regime. This regime included

- notifications (detailed data exchange on strategic nuclear forces related information);
- verification with NTM (any interference to impede verification of treaty compliance was not allowed);
- OSIs (covering 12 types such as baseline inspection, suspect-site inspections, reentry vehicle inspections, etc.);
- exhibitions;
- Perimeter-Portal Continuous Monitoring (PPCM) of mobile-ICBM production facilities; and
- cooperative measures (e.g., open display of mobile ICBMs under the reconnaissance satellite). [35]

The START I verification regime was effective and gave adequate confidence in treaty compliance.[36] The regime also provided valuable experience for deeper nuclear reductions. Although START II never came into force and START III was never formally negotiated, the

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[31] US Department of Defense, "Proliferation: Threat and Response", January 2001

[32] Joshua Handler, "The September 1991 PNIs and the Elimination, Storing and Security Aspects of TNWs", Presentation for *Time to Control Tactical Nuclear Weapons*, Seminar hosted by UNIDIR, CNS and PRIF, United Nations, New York, 24 September 2001.

[33] George Lewis and Andrea Gabbitas, " What should be done about Tactical Nuclear Weapons", Occasional Paper, The Atlantic Council of the United States, March 1999

[34] Amy F. Woolf, "Strategic Arms Reduction Treaties (START I & II): Verification and Compliance Issues", Foreign Affairs and National Defense Division, November 22, 1996

[35] "Strategic Arms Reduction Treaty (START): Analysis, Summery and Text", *Arms Control Today*, vol.21, no.9 (November, 1991), pp.1-24

[36] Congressional Record, "Capability of the United States to Monitoring Compliance with the START Treaty", (US Senate September 18, 1992)

research, technical cooperation, discussion, and considerations for the treaty of further nuclear warhead reduction was profoundly significant:[37] The United States and Russia agreed, at least in principle, to transparency and irreversible reductions in nuclear warheads.[38]

When George W. Bush took office in 2001, there was a significant change in the way the United States handled its nuclear arms reduction, particularly with the design of the SORT (which was less than two pages long[39]) and the plans of gaining permanent US nuclear advantage.[40] The Moscow Treaty reduces the total nuclear warheads operationally deployed on strategic delivery vehicles of the United States and Russia to roughly 1,700 to 2,200. It does not count warheads that were removed from service and placed in storage or warheads on delivery vehicles undergoing overhaul or repair. Thus, the United States can preserve a large "hedge" stockpile (categorized as "active reserve" and "inactive reserve") ready for "reconstituting" or "uploading" the intact nuclear warhead to appropriate delivery vehicles.[41] The treaty's limit for operationally deployed strategic nuclear forces was the one envisioned by the framework of START III; however, the treaty did not require the destruction of delivery vehicles, as previous START treaties did, or the destruction of warheads, as had been anticipated in START III.[42] This was a very different method of handling nuclear warheads compared with the US-Russia Summit initiatives in mid-1990s. Each party could determine for itself the composition and structure of its strategic offensive arms, allowing both sides to maintain missiles with multiple warheads. Comparatively, the START II treaty called for the elimination of all multiple-warhead ICBMs. SORT leaves both nations free to continue improving and modernizing their respective weapons stockpiles.[43] Furthermore, SORT has no verification provisions to assure nuclear reduction, leaving great uncertainty of the nuclear capabilities of both sides.[44]

1.2 The difference between nuclear warhead reduction and past nuclear arms reduction

In the history of nuclear arms control and reduction, verification has always been the most

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[37] See: Andrew J. Bieniawski, Paul B. Irwin (US Department of Energy), "Overview of the US – Russian Laboratory-to-Laboratory Warhead Dismantlement Transparency Program: A US Perspective," INMM-41; Robert Gromoll, "A Nuclear Warhead Control and Elimination Regime: Problems and Prospects,"INMM-38; "Verifiable Elimination of Nuclear Warheads: What Lies Behind Russian Proposals?" (Moscow: Center for Arms Control, Energy, and Environmental Studies, May 2002); and a lot of technical discussion reports on nuclear warhead transparency and dismantlement are available at Los Alamos Applied Monitoring Technology Laboratory website: http://amtl.iwapps.com/

[38] *Joint Statement on Strategic Stability and Nuclear Security*, Third Clinton-Yeltsin Summit, September 28, 1994 (Washington, DC); *Joint Statement on the Transparency and Irreversibility of the Process of reducing Nuclear Weapons*, Fourth Clinton-Yeltsin Summit, May 10, 1995, (Moscow, Russia); and *Joint Statement on Parameters on Future Reduction in Nuclear Forces,* Sixth Clinton-Yeltsin Summit, March 21, 1997 (Helsinki, Finland). The Joint Statements are available at http://www.ceip.org/files/projects/npp/resources/us-russiasummits.htm.

[39] The text of the SORT Treaty is available at http://www.whitehouse.gov/news/releases/2002/05/print/20020524-3.html

[40] See "Bush Plans Permanent US Nuclear Advantage Under Moscow Treaty", available at http://www.nrdc.org/nuclear/moscow/moscnuc.asp

[41] Hans M. Kristensen, "The Unruly Hedge: Cold War Thinking at the Crawford Summit", *Arms Control Today*, December 2001. Little is known about Russia's handling of its huge nuclear warhead stockpile, but Russian would most probably take the same action to preserve the intact nuclear warhead to upload or re-constitute its nuclear forces in crisis.

[42] Matt Rivers, "Fact Sheet: Comparison of US-Russia Nuclear Reduction Treaties", *Basic notes*, July 2002

[43] "The Moscow treaty", http://www.ucsusa.org/global_security/nuclear_weapons/page.cfm?pageID=1134; and "US – Soviet/Russian Nuclear Arms Control", *Arms Control Today*, June 2002

[44] "The Proposed 'Moscow Treaty' on Strategic Offensive Reductions", Presented before the Senate Foreign Relations Committee by Christopher E. Paine, July 23, 2002; and Nikolai Sokov, "The Russian Nuclear Arms Control Agenda After SORT", *Arms Control Today*, April 2003

important and most difficult part of negotiation. Other important issues include enhancing strategic stability and reducing incentives to initiate a full-scale nuclear war, whose attention is mainly on the nuclear projection capability.[45] The core focus of the past nuclear arms control treaties such as SALT, INF, and START was on verifiable limits for the number of nuclear delivery vehicles. Most of the verification procedures and technologies existed to confirm the numbers of delivery vehicles through complicated, hard-to-negotiate, and sometimes ambiguous counting rules, including detailed baseline and updated data exchange, NTM, on-site inspection, PPCM, and other measures used to collect and verify information about delivery vehicles and to gain confidence over the collected information. There were several reasons for the focus on delivery vehicles:

- Strategic nuclear delivery vehicles are huge in size and not easily concealed from reconnaissance satellites.
- The large delivery vehicles are more costly than their mated nuclear warhead (typically ten times as expensive).[46]
- Missiles or delivery vehicles are more significant than warheads alone for military operation.
- It is very difficult to produce and maintain large objects such as ICBMs in a covert facility (full-scale clandestine testing of ICBM was impossible).
- It would consume too much time and too many resources to reversibly deploy militarily significant strategic nuclear-capable deliveries without being noticed under multi-source advanced intelligence and information gathering measures.
- The technical details relevant to verification of delivery vehicles are generally less sensitive than those of nuclear warheads,[47]
- The risk of unauthorized or inadvertent launch of missiles was a concern.
- The technologies used to verify, monitor, and track the reduction and disposition of delivery vehicles were more mature and accessible than those applicable to verification of nuclear warheads.

Past strategic arms control agreements relied heavily on NTM for monitoring, particularly in the early stages. This unilateral capability remains the prominent measure for tracking future nuclear arms control activities associated with nuclear weapons. INF and START also placed a growing emphasis on cooperative measures and included extensive data exchange detailing the numbers and locations of treaty-limited delivery vehicles. INF and START contain good lessons

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[45] Frank von Hippel and Roald Z. Sagdeev, eds., *Reversing the Arms Race: How to Achieve and Verify Deep Reductions in Nuclear Weapons* (Gordon and Breach Science Publishers, 1990), pp. 9-57; and April Carter, *Success and Failure in Arms Control Negotiation,* SIPRI book from Oxford University Press, 1989, pp.105-133, pp.230-255. The SALT I (Interim Agreement) must be connected with the ABM treaty showed the concerns over the strategic stability of the United States and the Soviet Union.

[46] Steve Fetter, "Verifying Nuclear Disarmament", Occasional Paper No. 29, The Henry L. Stimson Center, October 1996, pp.5

[47] The five declared NWS have accomplished most of the strategic delivery technologies though technical gaps do exist with US and Russia being the most advanced, China the most lagged. In civil use of space delivery technologies, which are quite similar to military-use, there are some technical co-operation (see information at website: http://www.sea-launch.com/ and http://www.spaceandtech.com/index_current.html). The US prepares to co-operate with Japan, South Korea and maybe in the future with Russia and some European countries, which can promote the space technology capabilities. But the designs and core technologies about nuclear warhead have long been kept as top secret between five countries except some co-operations between US and U.K. (The 1958 Agreement for Co-operation on the Uses of Atomic Energy for Mutual Defence Purposes between US and U.K. opened the way to a bilateral co-operation between Britain and America on nuclear weapon design information. See **"**Nuclear Co-operation" in BASIC Research Report: *Nuclear Futures: Western European Options for Nuclear Risk Reduction,* available at http://www.basicint.org/pubs/Research/1998nuclearfutures5.htm).

for future nuclear arms reductions, particularly on verification issues such as detailed data exchanges and subsequent inspections as well as the use of many monitoring technologies.

SORT is the first treaty to limit the actual number of operationally deployed strategic nuclear warheads of each side. Without transparency and intrusive verification, it is hard to promote nuclear warhead reduction since each country worries about the other's intentions and uploading and reconstitution capabilities. Both countries would surely imagine the worst-case scenario, leading to the preservation of large warhead stockpiles. The verification and monitoring requirements for nuclear warhead reduction are very different from those in past nuclear arms control. Although NTM is helpful in tracking some nuclear-related activities such as large-scale fissile material production, it is insufficient for verification of warhead reduction.[48] Cooperative verification and monitoring measures covering various technologies and procedures will play a more important role, particularly in recruiting countries with little or no NTM capabilities for nuclear arms reduction.

Verifiable nuclear warhead reduction is particularly important in order to establish a regime with sufficient confidence so that countries do not covertly transfer hundreds of nuclear warheads to a secret place for future use. With a huge existing nuclear stockpile, it is not difficult to re-cast a retired nuclear warhead into a new one.[49] Verification and monitoring must be comprehensive, advanced, and intrusive[50] and must cover fissile material production and disposition and nuclear warhead assembly, maintenance, deployment, refurbishment, as well as dismantling in order to gain confidence. A flawed nuclear reduction regime can be tolerated since it is of little military significance and incentive to hide parts of nuclear stockpile with existing large nuclear capabilities. But a seamless verification regime covering cradle-to-grave nuclear warheads along with high confidence in detecting covert nuclear weapon-related activities must be established before deep nuclear reduction occurs.[51] Therefore, the earlier the nuclear warhead reduction process begins, the better the regime's future position, regardless of failure or success of the early verification and monitoring experience of nuclear warheads.

Box 1. Fissile material and pit

[48] "Verification of Dismantlement of Nuclear Warheads and Controls on Nuclear Materials", JASON Report, JSR-92-331, January 1993, pp.3-6

[49] Nuclear warheads from Pershing II missiles being eliminated under the Intermediate-Range Nuclear Forces (INF) Treaty were converted into new nuclear bombs. See Robert S. Norris and William M. Arkin, **"**Beating swords into swords", *The Bulletin of the Atomic Scientists,* November 1990,Vol. 46, No. 10, pp.14-16

[50] Some arguments tend to use simple and mature technologies either from the fears of divulging national security with advanced, unfamiliar technical methods though they can provide higher confidence, or from the consideration about resources, and they prefer simple technologies for easy negotiation and accepted by policy-makers. See Jonathan S. Landay, "Nuclear Disarmament with Low-Tech Approach", *The Christian Science Monitor,* February 20, 1998 and William C. Potter & Fred L. Wehling, "Sustainability: A Vital Component of Nuclear Material Security in Russia", The *Nonproliferation Review,* Spring 2000, Volume 7, Number 1

[51] Harold A. Feiveson, ed., The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons, (Brookings Institution Press: Washington, D.C., 1999), pp.23 and Steve Fetter, "Verifying Nuclear Disarmament", Occasional Paper No. 29, The Henry L. Stimson Center, October 1996, pp.9

The working principle of nuclear weapon is to use the giant energy released by nuclear fission or fusion or both (the application to trigger the chain reaction of a heavy element like uranium-235 or plutonium-239, or the fusion of a light element like deuterium or tritium). Thus every nuclear weapon must contain fissile material.

(1) Fissile material: material containing a large number of fissionable nuclei, which can be induced to split by thermal or fast neutrons. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239, which give off multiple neutrons in the fission process.

(2) HEU and LEU: uranium enriched to 20% or more in isotopic uranium-235 is called high enriched uranium, and below that level, usually 2-4% in uranium-235, is called low enriched uranium.

(3) WgU: the concentration of uranium-235 is more that 90%.

(4) WgPu: the concentration of plutonium-239 is more than 90% and the concentration of plutonium-240 is less than 7%

(5) pit: the core fission component of a nuclear weapon's "primary", is used to constitute the main energy-releasing part of an atomic bomb or to trigger the fusion reaction of a thermonuclear weapon's "secondary. Pits are made of plutonium-239 or uranium-235.

Nuclear warhead verification faces a bigger challenge than delivery vehicle verification. Not only is there a technological difference (No mature, non-intrusive, simple, and agreed technologies for verifying warheads have been fully developed.), but also there are different political and proliferation issues. It is hard to tell whether bulk fissile material (see Box 1) is from warheads. For example, during the implementation of High-Enriched Uranium (HEU) Agreement, the United States admitted that it was impossible to verify whether the HEU was from dismantled nuclear warheads or from Russian HEU stockpile. Without operation of continuous-monitoring equipment installed in the blending facility, the United States would have no confidence that the Low-Enriched Uranium (LEU) was from HEU.[52]

The core issue of past nuclear arms reductions was increasing strategic stability (particularly in the early stage of US-USSR arms control bargain) and reducing the probability of both nuclear conflict and preemptive nuclear strike capabilities through elaborate controls and reductions of the nuclear delivery capacities. With the great progress achieved in the reduction of strategic nuclear delivery vehicles and unilateral non-strategic nuclear capabilities, the core focus of future nuclear arms reduction should be transferred to irreversible elimination of excessive nuclear warheads.

1.3 The imperative for nuclear warhead reduction

There is widespread support outside the United States and Russia for deep and irreversible nuclear arms reductions, and for the ultimate goal—specified in Article VI of the Non-Proliferation Treaty (NPT)—of complete nuclear disarmament.[53] In many parts of the

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[52] "Status of Transparency Measures for US Purchase of Russian Highly Enriched Uranium", GAO Report to the Honorable Richard G. Lugar, US Senate, GAO/RCED-99-194; and Edward F. Mastal, Janie B. Benton and JosephW. Glaser, "Implementation of US Transparency Monitoring under the US/Russian HEU Purchase Agreement". A strong reason for not imposing very intrusive verification regime for HEU Agreement is that Russian had no incentive to introduce new HEU for HEU Agreement and it is believed that Russian had stopped producing HEU for defense purpose.

[53] The five NWS have solemn promise to the international community to negotiate in good faith to achieve nuclear disarmament under their obligation to NPT. See Article VI of the NPT, to "pursue negotiations in good faith on

world, nuclear-weapon-free zones have been established. It is helpful to consolidate past progress in nuclear arms control and direct these positive trends toward realizing additional substantive accomplishment.

The uncertainty in the number of nuclear warheads will be a big obstacle to further nuclear reductions.[54] Because the United States and Russia have large numbers of deployed MIRVed missiles and strategic bombers, the "uploading" of nuclear warheads to these delivery vehicles can be readily realized without being detected. This provides an incentive for both sides to reconstitute their strategic nuclear forces quickly in anticipation of an imminent worsened relationship.[55] For example, both US and Russia have missiles carrying less than their full capacity of nuclear warheads.[56] In order to avoid rapid upload of warheads, there should be verification of future nuclear reductions and monitoring of the total number of nuclear warheads no matter where they are and how they are preserved. One way is to dismantle unnecessary warheads and disposition of the pits, and monitor production and refurbishing facilities. Otherwise, the nuclear reduction can be readily reversible at such time as both countries think it necessary, thus destroying the progress of past nuclear arms reduction.

Keeping large nuclear warhead stockpiles is expensive (leaving inadvertent or deteriorated security flaws to be utilized by elaborate villainy or resentful insiders, particularly in Russia), [57] and negatively affects future nuclear arms reduction. Losing even a single nuclear warhead that could be used by terrorists would be an unbearable disaster.

It is also illogical for the United States and Russia to keep large numbers of nuclear warheads (particularly the huge numbers of hedge and intact warheads plus strategic pit reservation), since a few hundred secure, reliable, survivable and deliverable strategic nuclear warheads are sufficient for deterrence.[58] It is impossible to go further towards the nuclear arms reduction if the United States insists on keeping a large nuclear warhead stockpile:

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effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament". The NWS pledged to negotiate nuclear disarmament, while the NNWS pledged not to acquire nuclear weapons. The NPT was signed in 1968 and entered into force in 1970. Its initial duration was 25 years. In 1995 it was extended indefinitely, with a review conference to be held every five years. Nearly every country in the world -- 187 in all -- is a signatory to the NPT, with four very notable exceptions: India, Israel and Pakistan, which possess nuclear weapons and Cuba, which does not. The NPT aimed to stop the spread of nuclear weapons by brokering a deal between the NWSs and the NNWSs.

[54] Committee on International Security and Arms Control, US National Academy of Science, *The Future of US Nuclear Weapons Policy* (National Academy Press: Washington D.C., 1997), pp.37-40, pp.60-62

[55] Testimony Submitted to the Senate Foreign Relations Committee For a Hearing on the Strategic Offensive Reductions Treaty between the United States and Russia, Rose Gottemoeller, Senior Associate, Carnegie Endowment for International Peace, September 12, 2002

[56] Under the START I counting rules, e.g., US 150 US heavy bombers that are capable of carrying ALCMs will be counted as carrying only 10 missiles each though they have the capacity to hold 20 missiles each; a part of Minuteman III ICBMs downloaded from 3 warheads to 1 warhead per missile; Russian SS-N-18 was attributed to 3 nuclear warheads though it can be MIRVed to at least 10 RVs. And the START I did not require elimination of all withdrawn missiles. SORT has no provisions to destroy the strategic delivery vehicles and the United States and Russia can keep the various kinds of strategic nuclear delivery vehicles whatever they want, thus the existing MIRVed ICBMs and SLBMs can be effectively kept in each side's strategic nuclear forces.

[57] "Jump-START: Retaking the Initiative to Reduce Post-Cold War Nuclear Dangers", Committee on Nuclear Policy, the Henry L. Stimson Center, Feb. 1999, pp.9-10

[58] Committee on International Security and Arms Control, US National Academy of Science, *The Future of US Nuclear Weapons Policy* (National Academy Press: Washington D.C., 1997), pp. 77-83

> There are almost 8,000 warheads in the active stockpile today. As the initial nuclear warhead reductions are implemented, some warheads will be transferred from the active to the inactive stockpile. . . . The active stockpile also includes the nonstrategic nuclear weapons. . . . Inactive stockpile warheads . . . serve a number of purposes ranging from reliable replacements that act as a hedge against the discovery of a problem with a large number of active warheads, to the more predictable replacement of warheads consumed by quality assurance and reliability testing. . . . These warheads or their components could also be used to provide new capabilities.[59]

As of 2002, the National Nuclear Security Administration (NNSA) Pantex plant stored 10,000 plutonium "pits"–the result of decades of nuclear weapon production, retirements, and arms control reductions. Many of these pits are considered excessive to national security needs and have been designated as surplus inventory awaiting disposition.[60]

Most importantly, nuclear warhead reduction can augment the progress of the past nuclear arms reduction and, pushing it in the direction of irreversibility, can reduce the nuclear threat to the international community.

Verifiable nuclear warhead reduction is significant because

- It is a critical element for future deep reduction of nuclear stockpile;
- It can greatly enhance confidence in and predictability of aggregate nuclear warhead stockpiles (covering deployed strategic, tactical, and non-deployed nuclear warheads), and the full understanding of mutual nuclear stockpile can greatly reduce suspicion, confrontation and worst-scenario-thinking and promote the motivations for deep reduction;
- It is helpful to improve the secure status of remaining nuclear warheads to prevent theft or accidental and unauthorized use;
- Nuclear warhead reductions can enhance the nonproliferation regime by shrinking the nuclear stockpile and production complex and reducing military dependence on nuclear weapons;
- Deep nuclear warhead reductions by the United States and Russia can first reduce the incentives of France, UK, and, particularly, China to expand nuclear forces and then draw them into the nuclear transparency and disarmament process;[61] and
- The reduction of nuclear warheads through transparent or verifiable dismantlement and disposition would make nuclear arms reconstitution far more difficult.

It is the right time to push the reduction of nuclear arms through reducing nuclear warheads. With increased political and technical acceptance, nuclear warhead reductions between the United States and Russia can finally bring France, UK, China, and *de facto* nuclear countries into the nuclear arms reduction to greatly reduce the nuclear danger to the world. It can reduce nuclear risk to nuclear and *de facto* nuclear countries through appropriately devised regimes and steady phased implementations with relevant and proper measures and technologies.

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[59] Nuclear Posture Review [Excerpts], Submitted to Congress on 31 December 2001

[60] William Chambers et al., “Remote Storage Monitoring at Defense Nuclear Sites”, Paper presented to INMM 42nd Annual Coference

[61] Harold A. Feiveson, ed., *The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons*, (Brookings Institution Press: Washington, D.C., 1999), pp.8-9

1.4 How to promote the nuclear warhead reduction

Nuclear arms control experts have suggested various proposals on strategic, non-strategic (tactical), and aggregate nuclear warhead reduction. Most of the necessary verification and monitoring technologies are already available.[62] With the appropriate political decisions, a nuclear warhead reduction regime could be developed from partial transparency to comprehensive reduction involving unilateral, bilateral, and multilateral decisions with the help of established and newly-developed verification, monitoring, and transparency approaches and technologies.

Much of the technical and political groundwork for nuclear warhead reductions was laid during the US-Russia Presidents' Summit in the mid-1990s. These reductions occurred in connection with preparations for START III, Department of Energy (DOE) - Ministry of Atom (MINATOM) lab-lab cooperation, the Cooperative Threat Reduction (CTR) program, and the Warhead Safety and Security Exchange Agreement.[63] With the technical progress and methodologies proved effective in such past nuclear reductions, the current nuclear warhead reduction can be broadly categorized into three-tier levels: (1) the reduction regime, (2) the verification and monitoring approaches, and (3) the verification and monitoring technologies.

Table 1-1 The three levels of nuclear warhead reduction

The reduction regime	**The verification and monitoring approaches**	**The verification and monitoring technologies**
(1) Unilateral, bilateral or multilateral assurance, (2) Unilateral, bilateral or multilateral transparency, (3) Bilateral or multilateral reduction agreement	(1) Declaration of nuclear warheads with several approaches: aggregate declaration, phased declaration and restricted data exchange, (2) OSI, (3) NTM and remote sensing in-situ, (4) PPCM, (5) Chain-of-custody (limited and comprehensive), (6) Cooperative monitoring, (7) Societal verification	(1) Nuclear radiation detection and measurement, (2) Non-nuclear detection and measurement, (3) Tags and seals, (4) Surveillance (video monitoring, airborne sampling and etc.), (5) Dismantlement and Disposition technologies, (6) Information security

Although nearly all essential elements for deep nuclear reduction already exist, there is still work to be done for warhead reductions in the international and domestic arenas both on national security considerations and on devising a practical reduction regime and process, as well as on technology preparation. To realize a verifiable, irreversible, and transparent regime of

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[62] See Harold A. Feiveson, ed., *The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons*, (Brookings Institution Press: Washington, D.C., 1999), pp. 15-30 and pp. 129-243; George Lewis and Andrea Gabbitas, " What should be done about Tactical Nuclear Weapons", Occasional Paper, The Atlantic Council of the United States, March 1999; and Committee on International Security and Arms Control, US National Academy of Science, *The Future of US Nuclear Weapons Policy* (National Academy Press: Washington D.C., 1997), pp.58-85.

[63] Robert Gromoll, "A Nuclear Warhead Control and Elimination Regime: Problems and Prospects"; Andrew J. Bieniawski and Paul B. Irwin "Overview of the US – Russian Laboratory-to-Laboratory Warhead Dismantlement Transparency Program: A US Perspective", Report at the 41st Annual INMM Conference, New Orleans, July 2000; and Oleg Bukharin and Kenneth Luongo, "US-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals", April 1999, PU/CEES Report No. 314. More technical discussions and methodologies for nuclear warhead reduction can be found at website http://amtl.iwapps.com/.

nuclear warhead reduction, one must establish a comprehensive accounting, verification, dismantling, and disposition system for all warheads and fissile materials including those deployed and nondeployed. This system should be set up as soon as possible during the early phases of such reduction regime since (1) the regime can be of little military significance if there is a flawed verification system; (2) mutual confidence and trust can be tested and proven; (3) various technologies can be developed and finally accepted by multi-sides; (4) crisis stability can be maintained and not breached with large invulnerable nuclear forces during the initial reduction course[64]; and (5) countries can be highly confident to eliminate nuclear warheads after years of cooperative work on confirming the dismantlement and disposition.

It would be impossible for a nuclear reduction regime to immediately provide for comprehensive and complicated verification, monitoring, and transparency measures in all nuclear and *de facto* nuclear weapon countries. The practical way to develop nuclear warhead reductions is to consider a suitable combination of these three measures for various countries and different nuclear arms reduction phases. For example, under SORT, it was instructive to adopt methods developed under the framework of START III for the United States and Russia to begin verifiable and monitored dismantling of nuclear warheads and acquire the experience, and confidence in feasibility. Second, it is important to begin negotiation and implementation of a formal agreement or additional protocol of SORT to verify the elimination of some classes of nuclear warheads or limits on the number of warheads. After this, the United States and Russia could go further toward more comprehensive and verifiable deep nuclear warhead reductions, down to a total of 1000 nuclear warheads. The rest of the nuclear countries can participate in the nuclear reduction process as observers and provide partial transparency and information exchange on their nuclear forces, aggregate warheads, and nuclear-weapon-related infrastructures. After the deep reduction of the warhead stockpiles of the United States and Russia is established (with the measures and technologies cooperatively developed and used), the comprehensive and verifiable nuclear warhead transparency and elimination procedure can be extended to include all declared nuclear and *de facto* nuclear countries.

2. The nuclear warhead reduction regime

In future nuclear arms control agreements, there will be a stronger focus on reducing nuclear warheads, aside from their delivery systems.[65] Many nuclear warhead reduction proposals have been put forward over the last decade.[66] Numerous suggestions have been made on nearly every aspect of nuclear warhead reduction, including verification, monitoring, and dismantlement.[67]

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[64] Harold A. Feiveson, ed., The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons, (Brookings Institution Press: Washington, D.C., 1999), pp.15-17, pp.21-26, pp.174-175

[65] "Technology R&D for Arms Control", Arms Control & Nonproliferation Technologies Project, Office of Nonproliferation Research and Engineering, DOE, Spring 2001, pp. 3-4

[66] See Bruce G. Blair, et al., "Toward True Security, A US Nuclear Posture for the Next Decade," Federation of American Scientists, Natural Resources Defense Council, Union of Concerned Scientists, June 2001; Harold A. Feiveson, ed., The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons, (Brookings Institution Press: Washington, D.C., 1999), pp.15-29, 129-158; Rebecca Johnson, "Engaging the Five Nuclear Powers in Disarmament Talks", Paper presented to the Sixth ISODARCO Beijing Seminar on Arms Control, October 29-Novermber 1, 1998, Shanghai, China; Craig Cerniello, "International Group Issues Call For Abolition of Nuclear Weapons", *Arms Control Today*, January/February 1998, pp.34; Eric R. Gerdes, Roger G. Johnston, and James E. Doyle, "A Proposed Approach for Monitoring Nuclear Warhead Dismantlement**",** *Science & Global Security*,2001, Volume 9 pp.113-141

[67] See Frank von Hippel and Roald Z. Sagdeev, eds., *Reversing the Arms Race: How to Achieve and Verify Deep Reductions in*

However, none of these proposals or suggestions were accepted or implemented by policy-makers in Russia or the United States. Little has been done with regard to formal nuclear warhead reduction by either country, let alone the other nuclear and *de facto* nuclear states. Although the United States and Russia have dismantled and partially eliminated all of their retired and some of their tactical nuclear warheads in past years,[68] there are not agreed transparency measures in place and no formal agreements on nuclear warhead reductions. Breakout scenarios and upload capacity will be the main strategic concerns with such agreements. Both the United States and Russia are able to reverse agreed reductions because their missiles are capable of carrying more than the number of the warheads dictated by SORT. For example, the Minuteman missiles that the United States plans to arm with a single warhead can carry three warheads. The Russian situation is the same. There are many considerations, from national security to economic acceptability, that might push warhead reductions forward.[69] If the nuclear states reach a consensus that warhead reductions can serve their national interests, they will surely adopt the policy to reduce and eliminate nuclear warheads.

In general, as with other nuclear arms control regimes, three types of regimes could be adopted for the nuclear warhead reductions: assurance, transparency, and a formal treaty or agreement. However, a nuclear warhead reduction regime would have unique characteristics because of the sensitivity of warhead design information and the level of intrusiveness needed to gain confidence in reduction. Different regimes might be needed for the different nuclear states at various stages of reduction to reduce nuclear warheads without eroding national security.

Table 2. Types of reduction regimes and their characteristics

Regime Type	**Examples**	**Characteristics**	**Warhead reduction phase**	**Advantages**	**Disadvantages**
Unilateral, Bilateral or multilateral assurance	(1) PNIs in 1991 (2) No-First-Use policy (3) NSAs and PSAs	(1) The regime can be both a political symbol and a real reduction activity through unilateral, reciprocal and multilateral formal or informal action. (2) Its significance is to develop a benign political environment and eliminate the hostility and mistrust for nuclear warhead	The political-oriented assurance can be adopted throughout the procedure of nuclear warhead reduction to facilitate real action. The activity-oriented assurance can be accepted at the early stage of nuclear warhead reduction without comprehensive and strict verification, proved though various	(1) Easy, unconditional to implement (2) No hard, complicated and long-term negotiation. (3) Less troublesome domestic politics decision process (4) Create an amicable international atmosphere feasibly	(1) Difficult to confirm or verify (2) Easy to reverse (3) More political pledge than practicing real action (4) Limited confidence to reduce the large number of nuclear warheads

Nuclear Weapons (Gordon and Breach Science Publishers, 1990); Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions*, SIPRI book from Oxford University Press, 2003; Trevor Findlay and Oliver Meier, eds., *Verification Yearbook 2002*, (VERTIC, London), December 2002

[68] Oleg Bukharin, "A Breakdown of Breakout: US and Russian Warhead Production Capabilities", *Arms Control Today*, October 2002; DOD and DOE, "Summary of Declassified Nuclear Stockpile Information – Declassified Stockpile Data 1945 to 1994", available at http://www.osti.gov/html/osti/opennet/document/press/pc26tab1.html; "*Dismantling the Bomb and Managing the Nuclear Materials*", September 1993, OTA-O-572, chap. 3 and 6; NRDC, "Nuclear Data – Table of US Nuclear Warheads, 1945-2002" and "Nuclear Data – Table of USSR/Russian Nuclear Warheads, 1949-2002".

[69] Jump-START: Retaking the Initiative to Reduce Post-Cold War Nuclear Dangers, Committee on Nuclear Policy, the Henry L. Stimson Center, Feb. 1999

		reduction.	sources and activities for evidence collection.	and pragmatically. (5) It can be adopted by all NWSs.	
Unilateral, bilateral or multilateral transparency	(1) nuclear weapon policy (2) US Pu production (3) UK Pu Production (4) US declassified Gov. Doc. about nuclear warhead stockpiles (4) STI discussions of US and Russia in 1994-95 (5) Mayak Transparency	(1) The regime is mainly policy-oriented. (2) Voluntary should be considered in the beginning. With the progress of nuclear warhead reduction, the transparency can be transformed from voluntary unilateral action to forcible multilateral. (3) The intrinsic sensitivity needs to be considered seriously. It is impossible to realize real action thorough transparency.	The policy-oriented transparency can be adopted throughout the procedure of nuclear warhead reduction to facilitate real action. The practice-oriented transparency must be taken step-by-step, well devised without negative impact on strategic stability and nonproliferation regime, and should exist and last during the whole process of nuclear warhead reduction.	(1) Very significant on reducing the miscalculation and risk of nuclear hostility and confrontation (2) Establish the nuclear confidence and predictability (3) Enhance the nonproliferation regime and prove the NWSs' obligation to abolish the nuclear weapons (4) It can be taken unilaterally and voluntarily (5) The transparent contents can be prepared in advance and at appropriate time to be publicized.	(1) No agreed consensus between NWSs (2) Lack of legal groundwork to exchange restricted data (3) Strategic instability risk (4) Lack of mature, comprehensive and trusted co-operative technologies to implement (5) Proliferation risk (6) The reluctant posture to accept.
Bilateral nuclear reduction agreement	(1) INF (2) START (3) SORT (4) HEU Agreement (5) Plutonium Disposition Agreement (6) Trilateral Initiative	(1) The regime would eliminate or dispose the excess nuclear warheads to assure the irreversible nuclear reduction (2) Exchange very sensitive data about nuclear warhead-related information (3) Adopt very intrusive verification measures and complicated administrative procedures (4) Provide unprecedented openness between the treaty parties (5) Eliminate the nuclear capable delivering vehicles (6) The treaty should have a legal base for restricted data exchange in advance	The nuclear assurance treaty can be adopted in the first place such as bilateral NFU treaty or de-targeting treaty with selective co-operative verification and monitoring methods. Bilateral reduction treaty can be signed at the early and middle stage of nuclear warhead reduction with flawed verification and monitoring measures, limited data exchange. With the in-depth reduction, more strict procedures and methods can be added to amended treaty.	(1) The real step toward irreversible nuclear reduction (2) Prove the decisive action of reducing nuclear warheads to NPT obligation (3) Set out technical and political preparation for further reduction (4) Provide a benign international nuclear disarmament environment (5) Very positive to reduce the function of nuclear weapons and nuclear risks (6) Enhance the NPT regime and reshape the nuclear policy.	(1) Hard to negotiate (2) Probably encounter the obstacles from domestic politics (3) Need a long time to prepare for technical and practically political solutions (4) Susceptive to international political environment (5) Unprecedented intrusiveness and sensitiveness will cause serious affection to reduction decision.
Multilateral nuclear reduction agreement with	FMCT NPT IAEA Safeguard	(1) Maximize the effect of irreversible nuclear reduction (2) Exchange very	To nuclear warhead reduction, multilateral action is the late stage. Some multilateral steps	(1) Fully improve the international relation and reduce the function of nuclear	(1) Very hard, difficult and time-consumed to negotiate

comprehensive verification and monitoring		sensitive and comprehensive data about nuclear warhead-related information (3) Adopt very intrusive verification measures and complicated administrative procedures (4) Provide unprecedented openness between the treaty parties with the involvement of international organization (5) Eliminate the nuclear capable delivering vehicles (6) The treaty should be strongly associated with full custodian of fissile materials.	can be brought in advance to reduce the nuclear capability or uncertainty such as multilateral nuclear weapon-related information exchange, FMCT, and the abolishment of certain category of nuclear weapon systems. Policy-oriented multilateral measures can also be taken first such as signing multilateral NFU treaty.	weapons (2) Greatly enhance the NPT regime (3) Comprehensive steps towards irreversible nuclear reduction and finally abolishes nuclear weapons (4) Helpful to global environment and resources, and collective security.	(2) Probably encounter the obstacles from domestic politics (3) Need a long time to prepare for technical and practically political solutions (4) Susceptive to international political environment (5) Unprecedented intrusiveness and sensitiveness inflicting serious affection to reduction decision.

2.1 Assurance

An "assurance" is a statement or other indication that inspires confidence.[70] In this context, it is an action, guarantee, or pledge taken unilaterally by a nuclear weapon state to provide confidence to another state in order to decrease the danger or threat originating from nuclear weapons. Assurances can be divided into two categories. The first type is the political pledge or guarantee by a nuclear weapon state to express an intention or benign attitude towards reducing the nuclear threat or danger; the second is a unilateral action by a nuclear weapon state to limit or reduce the threat or danger posed by nuclear weapons.

The first category has a long history. At the first United Nations Special Session on Disarmament (UNSSOD-1) in 1978, all five declared nuclear-weapon states (NWS) issued unilateral statements on negative security assurance (NSA) to assure non-nuclear-weapon states (NNWSs) against the use or threat of use of nuclear weapons.[71] Although each NWS embraced different nuclear policies and strategies, the NSAs provided additional confidence that the NWS would not use (or threaten to use) nuclear weapons against non-nuclear-weapon states.[72] The positive security assurance (PSA) is the commitment by the NWS to take action in support of a

[70] Excerpted from *American Heritage Talking Dictionary*. Copyright, 1997 The Learning Company, Inc.
[71] Thomas Bernauer, "Nuclear Issues on the Agenda of the Conference on Disarmament", UNIDIR/91/68, United Nations, New York, 1991, pp.6-9; International Organizations and Nonproliferation Project, "Nuclear-Weapon-Free Zones (NWFZs): Negative Security Assurances", Center for Nonproliferation Studies, Monterey Institute of International Studies, available at http://cns.miis.edu/pubs/reports/pdfs/9707nwfz.pdf.
[72] The US Bush administration now favors the "strategic ambiguity", undermining the past US commitment of NSAs (See "US Nuclear Policy: 'Negative Security Assurance'", Arms Control Association Fact Sheet, March 2002; "A New Strategic Framework: Detailing the Bush Approach to Nuclear Security", An *ACT* Interview with Undersecretary of State for Arms Control and International Security John R. Bolton, February 11, 2001; and James A. Russell and James J. Wirtz, "Negative Security Assurances and the Nuclear Posture Review", *Strategic Insight*, July 5, 2002).

NNWS in the event of a threat or an actual attack with nuclear weapons. The PSA was first introduced in the UN Security Council resolution 255 (June 19, 1968), restated in resolution 984 (April 11, 1995), and adopted by five NWS. The above security commitment or obligation offered by NWS not only promoted the establishment of Nuclear-Weapon-Free Zone,[73] strengthened the nuclear nonproliferation, helped prevent nuclear confrontation in certain areas, and decreased the operational utility of nuclear weapons, but also improved the international atmosphere towards collective security.[74]

The No-First-Use (NFU) policy is another political assurance to reduce the nuclear threat.[75] The NFU is very important for limiting the operational use of nuclear weapons, reducing dependence on nuclear weapons and restricting their role to deterrence. The adoption of NFU in a NWS's nuclear policy can effectively enhance the nonproliferation regime by reducing the incentives to acquire the nuclear weapons as usable weaponry. This not only benefits NNWS but also benefits NWS. The acceptance of NFU can promote the de-alerting and deactivation of nuclear weapons. The NFU policy is one of the strongest confidence-building measures that can diminish nuclear threat and danger if the policy becomes legally binding though multilateral NFU Agreement. After the Cold War, it is particularly important for all nuclear and *de facto* nuclear states to adopt the NFU policy. The NFU policy can be a helpful political tool to further nuclear arms reductions by the United States and Russia, and it also can create a suitable strategic environment for the rest of the nuclear states to join in the nuclear arms control process.[76] The NFU policy is not only a political symbol but also has its own intrinsic characteristics to be observed. A NWS that is consistent with its NFU nuclear policy would maintain very limited deployed and hedge stockpiles; adopt a counter-value nuclear strategy; not develop or deploy precise counter-force nuclear weapons; eliminate tactical nuclear weapons; maintain force at low alert levels; deploy highly survivable nuclear forces, and would not develop new types of nuclear weapons (such as those for attacking underground targets or for retaliating to the use of biological and chemical weapons).[77]

The de-targeting agreement[78] and other confidence-building measures (CBMs) such as the Hotline Agreement, the Agreement on Measures to Reduce the Risks of Nuclear War, and the

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[73] "Nuclear-Weapon-Free Zones (NWFZ) At a Glance", Arms Control Association Fact Sheet, July 2003.

[74] George Bunn, "The Legal Status of US Negative Security Assurances to Non-nuclear Weapon States", *The Nonproliferation Review,* Spring-Summer 1997; George Bunn and Roland M. Timerbaev, "Security Assurances to Non-Nuclear-Weapon States", *The Nonproliferation Review,* Fall 1993

[75] China has consistently and now the only nuclear state adhered to unconditional NFU policy –"not to be the first to use nuclear weapons at any time or under any circumstances" since it tested its first nuclear bomb in October 16, 1964, and presented a draft Treaty on the No-First-Use of Nuclear Weapons to the other four nuclear weapon states in January 1994 (See "VI. Actively Promoting International Arms Control and Disarmament", *China: Arms Control and Disarmament,* issued by Information Office of the State Council of the People's Republic of China, November 1995, Beijing). Russia withdrew from its NFU commitment in 1993.

[76] Lawrence Freedman, "No First Use"; Steven E. Miller, "The Utility of Nuclear Weapons and the Strategy of No-First-Use"; Pan Zhenqiang, "On China's No First Use of Nuclear Weapons"; John B. Rhinelander, "No First Use – It's Time is Not Foreseeable Whatever its Form"; Tom Milne, 'No First Use of Nuclear Weapons", Papers Presented to Pugwash Conferences on Science and World Affairs, November 15-17, 2002

[77] Wu Jun, "On No-First-Use Treaty", Paper Presented to The Sixth ISODARCO Beijing Seminar on Arms Control, October 29-Novermber 1, 1998, Shanghai, China; Hugh Beach, "Implementation of No First Use of Nuclear Weapons Strategy/Agreements", Paper Presented to Pugwash Conferences on Science and World Affairs, November 15-17, 2002

[78] For example, China signed de-targeting agreement with Russia in 1994 and non-targeting accord with US in 1998, respectively (See "China And Russia Issue Joint Statement," *Beijing Review*, 12-18 September 1994, pp.18; and Howard Diamond, "Sino-US Summit Yields Modest Advances in Arms Control Agenda", *Arms Control Today*, June/July 1998, pp. 23).

Prevention of Nuclear War Agreement gave NWS limited but valuable space and trust in order to avoid nuclear conflict. These measures can be considered complementary, since they can deal with the crisis and diminish tensions though mutual understanding, thus further pushing nuclear warhead reductions forward.

The second category not only has positive political effects on nuclear arms control and reduction, but also actually eliminates the existing threat imposed by nuclear weapons. On September 17, 1991, President George Bush announced that the United States would eliminate its ground-launched Tactical Nuclear Weapons (TNW) and remove all nuclear weapons from surface ships and attack submarines. Soviet Secretary-General Mikhail Gorbachev responded promptly and positively to the Bush initiative on October 5, reciprocating in kind with a few relatively minor modifications: The Soviet Union would eliminate all its nuclear artillery, nuclear mines, and nuclear warheads for tactical missiles, and withdraw nuclear warheads from air defense missiles, surface ships, and multi-purpose submarines. The reduced tactical nuclear warheads would be removed to central storage facilities or dismantled and eliminated except for a limited number of gravity bombs and long-range nuclear sea-launched cruise missiles (SLCM). The PNIs covered thousands of warheads and produced the single largest reduction of nuclear warheads.[79] As of 2001, both the United States and Russia had completed the withdrawal of TNW announced in the PNI. The United States dismantled over 80% of its tactical nuclear force and destroyed the warheads as announced; Russia eliminated over 60% of its entire inventory of TNWs.[80] The lack of a legally binding agreement or transparency measures has resulted in the absence of precise and creditable data on existing stockpiles, as well as the number of warheads to be put in central storage or dismantled. This will inevitably affect further nuclear arms reductions. However, the significance and positive affects of the 1991 PNI has been highly recognized by the UN and its members.[81] The assurances on the elimination of TNW made by both the United States and USSR/Russia was a momentous move toward nuclear warhead reductions without tedious bargains or rigid verification requirements. It proves that nuclear warhead reductions can be achieved through mutual or multilateral action-oriented assurances. Such assurances not only can reduce suspicion but also can enhance international stability and security.

Assurances have certain disadvantages. It is difficult to confirm or verify the real actions taken by a nuclear weapon state. It is easy to withdraw the pledge or guarantee. To the extent that it is more political symbol than real action, it is of limited significance. However, assurance can play a unique political role, providing confidence in the intent to reduce the nuclear threat and danger. Assurance can promote actual nuclear arms control and reduction to some degree. Assurance is easy to implement, without complicated long-term negotiation and a troublesome domestic

79 William C. Potter et al., eds., "Tactical nuclear weapons : options for control," Geneva: United Nations Institute for Disarmament Research, [2000], pp.8-12; and "Appendix 10B. Tactical nuclear weapons," Nicholas Zarimpas, ed., *SIPRI Yearbook 2002: Armaments, Disarmament and International Security (Oxford: Oxford University Press, 2002)*

80 Regina Lennox and Herbert Scoville Jr., "Briefing Book on Tactical Nuclear Weapons: New Challenges for a New Era", Center for Arms Control and Non-Proliferation, January 2003, available at http://www.armscontrolcenter.org/prolifproject/tnw/index.html; and Joshua Handler, "The September 1991 PNIs and the Elimination, Storing and Security Aspects of TNW," presentation for "Time to Control Tactical Nuclear Weapons," UNIDIR, September 24, 2001

81 "Reductions of non-strategic nuclear weapons", *The General Assembly, Recalling* its resolution *55/33* D of 20 November 2000, United Nations General Assembly, A/C. l/57/L.2/Rev.1, 23 October 2002

political battle. Assurances can be confirmed through reciprocal actions (such as mutual visits and data exchanges) with evidence collected by NTM or other sources. The first type of assurance is feasible throughout every step of nuclear arms control. The second type of assurance can be adopted in the early stages of nuclear warhead reductions and can pave the way for a comprehensive and verified nuclear warhead reduction. The most important value of both types is an expression of an intention towards reducing the nuclear danger, resulting in a more pragmatic way of taking action.

2.2 Transparency

The definition of transparency in nuclear arms control is ambiguous.[82] In international politics, the general meaning of transparency is "a condition in which information about governmental preferences, intentions, and capabilities is made available either to the public or other outsiders."[83] Thus, whatever the transparent process may be and through what ever international or domestic situation it is achieved, transparency is by nature a unilateral activity taken by a sovereign state.[84] In the arms control arena, transparency was introduced as a type of confidence-building measure that promotes openness and the exchange of military-related (directly or indirectly) intentions, capabilities, and activities.[85] CBMs should be established and brought into effect among more than one party. Transparency in traditional arms control has to be extended from unilateral to bilateral and multilateral, from voluntary or symbolic to obligatory and substantive. Transparency includes defense white papers (unilateral), visits to military bases, observation of certain military activities, and information exchanges and notifications (bilateral or multilateral). [86] Transparency will become more and more accepted and important in order to address international security problems, particularly in the area of nuclear arms control.[87] Nuclear transparency mainly provides (1) openness and information exchange of a NWS nuclear policy and doctrine and (2) nuclear-related capabilities and

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[82] Roger G. Johnston, "The Negative Consequences of Ambiguous 'Safeguards' Terminology," LAUR-03-3767, paper presented to 44th INMM Annual meeting, July 13-17, 2003, Phoenix, AZ

[83] Bernard I, Finel and Kristin M. Lord, eds., "Power and Conflict in the Age of Transparency," First Published 2000 by Palgrave™ New York, N.Y., pp.3, pp.138-140

[84] Morten B. Maerli and Roger G. Johnston, "Safeguarding This and Verifying That: Fuzzy Concepts, Confusing Terminology, and Their Detrimental Effects on Nuclear Husbandry", *The Nonproliferation Review*, Spring 2002, Volume 9, Number 1, pp.60

[85] "Part III: Nuclear Confidence Building: A Conceptual Approach" in David Mutimer, *Confidence Building and the Delegitimization of Nuclear Weapons: Canadian Contributions to Advancing Disarmament*, International Security Research and Outreach Programme International Security Bureau, March 2000; James Macintosh, "Confidence-Building in the Arms Control Process: A Transformation View", *Arms Control and Disarmament Studies*, No. 2 (Ottawa: Department of Foreign Affairs and International Trade, 1996); P. de Klerk, International Atomic Energy Agency (Austria), "Transparency, Confidence-Building and Verification and the Peaceful Use of Nuclear Energy".

[86] Transparency as one type of CBMs was applied to facilitate and strengthen European collective security environment in the Treaty on Conventional Armed Forces in Europe (CFE treaty) and the Open Skies Treaty. The principle and implementation of transparency measure are formulated in Vienna Document 1994 and 1999 of the Negotiations on Confidence- and Security-Building Measures adopted by the Organization for Security and Cooperation in Europe (OSCE). See Zdzislaw Lachowski, "Appendix 16A. The Vienna CSBMs in 1995", SIPRI Yearbook 1996, pp.740-744, "Appendix 14A. Confidence- and Security- Building Measures in Europe", SIPRI Yearbook 1996, pp.644-650; Heather Chestnutt and Steven Mataija, eds., "Towards Helsinki 1992: Arms control in Europe and the verification process", Center for International and Strategic Studies, York University, Toronto, Canada, pp.31-36, pp.205-228.

[87] National Institute for Public Policy, "Rationale and Requirements for US Nuclear Forces and Arms Control", Volume I, Executive Report, January 2001; Steve Fetter, "A Comprehensive Transparency Regime For Warheads and Fissile Materials"; Robert L. Rinne, "An Alternative Framework for the Control of Nuclear Materials"; Chad T. Olinger,et al., "Measurement Approaches to Support Future Warhead Arms Control Transparency"; Andrew Bieniawski, et al., "Overview of Transparency Under the US-Russian High-Enriched Uranium Purchase Agreement"; T. R. Koncher and Andrew J. Bieniawski, "Transparency Questions Looking for Technology Answers", available at http://amtl.iwapps.com/pdfs/

activities (especially those relating to nuclear weapons and fissile materials), including inventories, deployments, production, dismantlement, disposition, infrastructure, and R&D programs. In nuclear transparency, the desire for obligations rather than voluntary unilateral action has been voiced by international community and organizations in recent years.[88]

There is another definition of transparency used by US arms control experts refering to less formal measures designed to build confidence that agreed actions are being taken.[89] In reality, there is no black-and-white definition of transparency. In general, transparency means the openness or publicly accessible information about a state's intentions and capabilities.

In a nuclear warhead reduction regime, transparency means

- exchange of information related to nuclear warheads (aggregate inventories and inventories by type and status; warhead production, dismantlement, and disposition history records; warhead deployment, maintenance, and storage places; warhead production infrastructure; inventories of pits and other components of nuclear warhead and their storage places; inventories of fissile materials and their production, storage places, and infrastructures; nuclear weapon development and management programs; and any nuclear weapon related activities;
- public availability of non-sensitive information related to nuclear warheads;
- methods by which one can authenticate exchanged information through voluntary or reciprocal action such as issuing the evolution report periodically or visiting the relevant places;
- regimes for improving or enhancing the confidence of nuclear warhead reductions, for instance, co-operative monitoring of the dismantlement and disposition of nuclear warhead, the production rate of nuclear warheads, and the places related to nuclear weapon activities; and
- declarations regarding nuclear policy, strategy and targeting doctrine.

Like assurance, transparency can be policy-oriented or practice-oriented. Policy-oriented transparency includes statements regarding nuclear weapon policy, doctrine, and development history. Practice-oriented transparency is not easy to carry out voluntarily and unilaterally. It is particularly hard in weak NWS for this type of transparency to be comprehensive.[90] It has to be realized in stages, through careful negotiation.

During the late 1980s and the 1990s, the NWS began to accept and voluntarily take some very

[88] Article VI.6 and VI.15, Part I, The 2000 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons, New York, USA, 24 April - 19 May 2000: Final Document of the Conference; Supplementary memorandum submitted by Foreign and Commonwealth Office of UK to *NPT Review Conference*, 18 April 2000; Thanos P. Dokos, "The Future of the Global Consensus on Nuclear Non-proliferation: Can the NPT be Kept Together Without the Abolition of Nuclear Weapons", in Joachim Krause, Andreas Wenger (eds.), *Nuclear Weapons into the 21st Century: Current Trends and Future Prospects*, Wien, 2001; Rodney W. Jones and Nikolai N. Sokov, "After Helsinki, the hard work", Bulletin of the atomic Scientists, Vol. 53, No. 5, July/August 1997; "NPT Notes: News from Behind the Scenes", The 2000 NPT Review Conference (RevCon), 14 April - 19 May 2000, New York; Trevor Findlay, "On the threshold: the United Nations and global governance in the new millennium: weapons of mass destruction"

[89] "Technology R&D for Arms Control (Spring 2001)", Arms Control & Nonproliferation Technologies Project, Office of Nonproliferation Research and Engineering, DOE, pp.3; and James Morgan, "Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement", available at http://amtl.iwapps.com/pdfs/

[90] One reason that China is reluctant to be transparent about its nuclear arsenal is that China only has very weak and vulnerable nuclear forces.

limited and selective nuclear transparency measures to release nuclear weapon-related information.[91] Nuclear weapon policy, nuclear disarmament policy and attitude, and decision-making authority to launch the nuclear weapons are the most transparent part of NWS' nuclear regimes. All five NWS and India and Pakistan have issued their grand nuclear weapon and nuclear disarmament policy publicly, either through national defense white papers or other government documents.[92] But the detailed nuclear strategy and targeting doctrines are still very restricted although sometimes elements are inadvertently divulged.[93]

Nuclear testing and nuclear weapon development history are also becoming more and more openly acknowledged through declassified government documents, interviews with experts, and biographies of those who have been involved in the nuclear development programs.[94]

Since 1994, US Defense Threat Reduction Agency (DTRA), in cooperation with Russian MINATOM, built the Mayak Fissile Material Storage Facility (FMSF) Project, which will provide secure, monitored storage for 25,000 canisters of plutonium and HEU from dismantled Russian nuclear weapons.[95] Until now, there was no final consensus reached on transparency regime associated with FMSF. The United States and Russia had done a lot of technical work (e.g., the development of a weapon-grade fissile material attribute measurement system and the information barrier methodology and technology) to ensure transparency.[96] The transparency measures of FMSF are intended to confirm that the material in the facility is safe and secure; the material came from dismantled nuclear weapons; and the material was not being returned to nuclear weapons.[97]

In 1996, the United States made public its historic data on plutonium inventory and production,

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[91] For discussion of the typology of transparency measures adopted by NWS, see Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions,* SIPRI book from Oxford University Press, 2003, pp.39-47

92 The official declaration and estimation of grand nuclear policy of five NWSs, India and Pakistan can be found at websites. For the United States, Nuclear Posture Review: http://www.defenselink.mil/news/Jan2002/t01092002_t0109npr.html. For Russia, Russia's Military Doctrine, available at http://www.armscontrol.org/act/2000_05/dc3ma00.asp. For UK, Strategic Defence Review: http://www.mod.uk/issues/sdr/. For France, 1994 White Paper on Defence: http://www.basicint.org/pubs/Research/1998nuclearfutures4.htm. For China, White Paper on China's National Defense in 2002: http://english.peopledaily.com.cn/features/ndpaper2002/nd.html. For India, Paper laid on the table of the House on Evolution of India's nuclear policy: http://www.indianembassy.org/pic/nuclearpolicy.htm and http://www.armscontrol.org/act/1999_07-08/ffja99.asp. For Pakistan, http://www.armscontrol.org/act/1999_07-08/fzja99.asp

[93] For instance, the US news media exposed part of classified part of US NPR inducing the response and argument from international community (see "America as Nuclear Rogue," available at http://www.nytimes.com/2002/03/12/opinion/_12TUE1.html and "DoD News Briefing - Secretary Rumsfeld and Gen. Myers", http://www.defenselink.mil/news/Jul2002/t07222002_t0722sd.html)

94 See DOE/NV--209-REV 15, "United States Nuclear Tests, July 1945 through September 1992," available at http://www.nv.doe.gov/news&pubs/publications/historyreports/default.htm; Robert S. Norris and William M. Arkin, "NRDC Nuclear Notebook: Known Nuclear Tests Worldwide, 1945-98", Bulletin of the Atomic Scientists, Vol. 54, No.6November/December 1998; Victor Nikitovich Mikhailov, ed., Catalog of Worldwide Nuclear Testing, (Begell-House, Inc., New York), 1999; and Victor Nikitovich Mikhailov, "I am a Hawk", Institute of Strategic Stability, 1995

[95] US DTRA, "Fissile Material Storage Facility", available at http://www.dtra.mil/ctr/project/projrus/ctr_fissile_storage.html, updated: June 27, 2003

96 Thomas R. Rutherford and John H. McNeilly, "Measurements on Material to Be Stored at the Mayak Fissile Material Storage Facility," Proceedings of the 41st Annual Meeting of INMM; and many other technical reports about Mayak transparency available at http://amtl.iwapps.com/

[97] Matthew Bunn, "The Next Wave: Urgently Needed New Steps to Control Warheads and Fissile Materials" (Washington, D.C. and Cambridge, Mass: Carnegie Endowment for International Peace and Harvard Project on Managing the Atom, April 2000), pp. 37.

acquisition, and utilization.[98] In 2000, the UK issued a report of its plutonium for defense nuclear programs.[99] These are the most transparent actions taken by NWS on nuclear weapon-related issues.

During the implementation of START and INF, the United States and USSR/Russia adopted many arrangements to ensure transparency, focusing on the nuclear delivery vehicles, effective throw weight, and attributed nuclear warheads by a set of mutually agreed upon counting rules (not real warhead numbers.)[100] The UK and France also have revealed aspects of their nuclear force capabilities.[101]

In the field of nuclear warhead reduction, only the United States declassified and released information on its nuclear warhead stockpile.[102] During 1994-95, the United States and Russia held a series of official discussions known as the Safeguards, Transparency and Irreversibility (STI) talks. In 1995, the United States had proposed a draft agreement text on an exchange of information concerning nuclear warhead and fissile material inventories. The nearly completed text of the Cooperation Agreement provided the legal basis for exchanging classified nuclear data. The Clinton and Yeltsin Summit of March 1997 stated that the START III agreement (1) should include "measures relating to the transparency of strategic warhead inventories and the destruction of strategic nuclear warheads" and (2) should explore transparency measures related to sea-launched cruise missiles, tactical nuclear weapons, and nuclear materials. Although these negotiations were not completed,[103] they had provided valuable experience for future nuclear warhead reductions. Under the STI and START III discussions, arms control and technical experts from Russia and the United Stated made substantial and deep research on nuclear warhead dismantling and monitoring technologies with feasible, acceptable policy suggestions. Examples include the joint DOE-DOD Integrated Technology Implementation Plan and the US-Russia lab-lab program.

The main objective of warhead reduction is to promote the elimination of nuclear warheads and to guarantee the irreversibility of this elimination. Because of the sensitivity and proliferation risk associated with nuclear warhead transparency, the NWSs are reluctant to accept transparency about their nuclear weapon-related information and activities. Indeed, it would be

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[98] US Department of Energy (DOE), "The First 50 Years: United States Plutonium Production, Acquisition, and Utilization from 1944 through 1994", DOE/DP-0137, (DOE, Washington, DC, 1996), available at http://www.osti.gov/html/osti/opennet/document/pu50yrs/pu50y.html

[99] British Ministry of Defence (MOD), "A summary report on the role of historical accounting for fissile material in the nuclear disarmament process, and on plutonium for the united kingdom's defence nuclear program" and **"**Plutonium and Aldermaston - an historical account", available at http://www.mod.uk/publications/nuclear_weapons/accounting.htm and http://www.mod.uk/publications/nuclear_weapons/aldermaston.htm

[100] "Chapter 1. Trends in Nuclear Disarmament: The Drawbacks of the START I and START II Treaties", in A. S. Diakov ed., *Nuclear Arms Reduction: The Process and Problems*, Center for Arms Control, Energy and Environmental Studies at the Moscow Institute of Physics and Technology, Dolgoprudny, October, 1997; "Strategic Arms Reduction Treaties (START I & II): Verification and Compliance Issues", Amy F. Woolf, Foreign Affairs and National Defense Division, November 22, 1996; and Arms Control Association Fact Sheet, "US-Soviet/Russian Nuclear Arms Control", June 2002

[101] UK Ministry of Defence, "Strategic Defence Review", available at http://www.mod.uk/issues/sdr/; and NATO Office of Information and Press, "NATO Handbook", 1110 Brussels – Belgium, 2001, pp. 54

[102] US DOE and DOD, "Summary of Declassified Nuclear Stockpile Information: Declassified Stockpile Data 1945 to 1994", available at http://www.osti.gov/html/osti/opennet/document/press/pc26tab1.html and http://www.osti.gov/html/osti/opennet/document/press/pc26.html

[103] Harold A. Feiveson, ed., The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons, (Brookings Institution Press: Washington, D.C., 1999), pp.181- 190.

irresponsible to advocate complete transparency about nuclear warheads.[104] It is impossible for any NWS to accept absolute transparency on its nuclear warhead related information, capabilities, and infrastructures. Transparency should be increased step-by-step, and information that can be made transparent should be well thought-out. The transparency regime for nuclear warhead reductions still requires a lot of political and technical work,[105] which no doubt will last throughout the nuclear warhead reduction process.

Devised deliberately, a transparency regime for nuclear warhead reductions can have a positive effect towards substantial and irreversible nuclear reductions without compromising strategic stability or national security. This includes

- establishing bilateral or multilateral nuclear confidence and predictability,
- improving the security environment to avoid tensions and hostilities,
- avoiding nuclear arms competition due to the military misunderstanding,[106]
- encouraging adoption of a NFU policy by the NWS,
- acquiring the experience to draw all NWS and *de facto* NWS into the nuclear arms reduction process, and
- improving security and preventing diversion and theft of nuclear warheads through cooperative monitoring.

There are five points that must be emphasized: (1) The transparency regime should be help make possible further nuclear reductions. (2) The transparency regime should reinforce nonproliferation regime rather than crippling international security by bringing more risks to custodianship of nuclear warheads or fissile materials. (3) The transparency regime must be assured through a series of cooperative technical procedures instead of unilateral technology or NTM alone. (4) The transparency regime should be a phased process that takes into account the security positions of each state.

The transparency regime can begin with the United States and Russia's exchange of data on the total warheads numbers and the dismantling rate per year with a time schedule to eliminate the excess stockpile. Through US and Russian cooperative technical research and development, transparency measures can be explored for nuclear warhead deployment, refurbishment, production, retirement, dismantlement, and disposition. It is essential for other NWS to join the technical and policy discussion of transparent nuclear warhead reductions in order to prepare for their transparency. With the deep reductions in the aggregate number of US and Russian nuclear warheads, all NWS, including *de facto* nuclear states, could be transparent about their nuclear

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[104] For example, considering the vulnerable problems, the NWS would not be completely transparent about the precise location of its all nuclear forces at same time. Also some military plans of using nuclear weapon are impossible to be fully transparent.

[105] Many political and technical problems for nuclear warhead reduction transparency can be found in Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions,* SIPRI book from Oxford University Press, 2003; T. R. Koncher and Andrew J. Bieniawski, "Transparency Questions Looking for Technology Answers"; Oleg Bukharin and Kenneth Luongo, "US-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals," Princeton University Report No. 314, April 1999; and Oleg Bukharin and James Doyle, "Transparency and Predictability Measures for US and Russian Strategic Arms Reductions, " *Nonproliferation Review* 9, No.2 (Summer 2002)

[106] "Managing the global nuclear materials threat: policy recommendations": a report of the CSIS Project on Global Nuclear Materials Management, Washington DC, 2000, pp.52-64; Bernard I, Finel and Kristin M. Lord, eds., "Power and Conflict in the Age of Transparency," First Published 2000 by PALGRAVE™ New York, N.Y., pp.5-7, pp.143-144; Lisbeth Gronlund, "From Nuclear Deterrence to Reassurance: the Role of Confidence-Building Measures and Restrictions on Military Development," CISSM PRAC Paper No.8, December 1993

capabilities.

2.3 Formal agreement or treaty

An arms control agreement is the written or unwritten embodiment of the acceptance of one or more arms control measures by two or more nations.[107] More specifically, a nuclear arms control agreement[108] is a solemn covenant among sovereign states. Its aim is to address the basic security concerns associated with nuclear weapon-related issues of the involved parties. The agreement must provide for both relevant rights and pertinent obligations that can be reached through the process of formal inter-governmental negotiation. Nuclear arms control agreements can have various forms from treaties, conventions, protocols, or documents to guidelines, memoranda, declarations, or common understandings to statutes, charters, and binding decisions of international bodies. Only after it completes all domestic legislation procedures can a nuclear arms control treaty be regarded as entering into force and become legally binding under international and domestic law.[109] Due to the destructive power of nuclear weapons, it is important for a nuclear arms control agreement to have mechanisms to ensure the implementation of the treaty requirements and the settling of disputes over compliance. From the past experience, a nuclear arms control treaty will not be an ideal paragon. It always has flaws (e.g., technical or political limitations on verification), ambiguities, and gray areas that need clarification, particularly with the emergence of new technologies.[110]

Past nuclear arms control agreements were mainly the business of the United States and USSR/Russia to enhance mutual stability and reduce the risks of nuclear war, except for the NPT, Comprehensive Test Ban Treaty (CTBT), Fissile Material Cut-off Treaty (FMCT) and Nuclear-Weapon-Free Zones (NWFZ) treaties. In the near future, agreements will continue to focus on US and Russian nuclear reductions, including deployed strategic forces, aggregate strategic nuclear warheads, tactical nuclear weapon systems, total nuclear warheads, and fissile materials. It is also a top priority to enhance the nonproliferation regime. Much of the political and technical work should be done as early as possible, with proposals for multilateral nuclear arms control put forward, to facilitate future multilateral nuclear arms control.[111] Examples include uninterrupted disarmament, capping nuclear arsenals, and a multilateral NFU treaty.

However, successful multilateral nuclear arms control should have common grounds based upon

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[107] "Department of Defense Dictionary of Military and Associated Terms (Joint Pub 1-02), (Amended Through 5 June 2003), pp.47

[108] In this report agreement and treaty are used interchangeably (the terminological difference between treaty and agreement can be found in A. Chayes, et al, "International Legal Process"). The nuclear arms control agreement here covers the treaty for freezing, limiting, reducing, and eliminating certain category of nuclear weapons, establishing nuclear confidence-building measures, limiting or depressing the nuclear R&D capabilities, and nuclear nonproliferation; this is different from the normal typology of nuclear weapon-related treaty (see Committee on International Security and Arms Control, National Academy of Sciences, "*Nuclear Arms Control: Background and Issues*," National Academy Press, Washington, D.C., 1985).

[109] Based on arguments from Jozef Goldblat, "Arms Control: A Guide to Negotiations and Agreements," (SAGE Publications Ltd, London UK), first paperback edition, 1996, pp.3-6; and Arms Control Association, "Arms Control and National Security: An Introduction", (Washington, D.C: Arms Control Association, 1989), pp.12-13

[110] Gloria Duffy, Compliance and the Future of Arms Control, (Cambridge, Mass.: Ballinger), 1988, pp.2-6, 31-60

[111] Owen Greene, "Multilateralising the nuclear disarmament process: some next steps for the nuclear weapon states", INESAP Briefing Paper No.2, 1998; and Herbert Wulf and Michael Brzoska, "Reinvigorating Multilateral Arms Control", ISIS Europe, Briefing Paper No. 24, May 2001

feasible reality of the different requirements and interests of different countries.[112] For verified and irreversible nuclear warhead reduction (either bilateral or multilateral),

- the treaty would eliminate or dispose the excess nuclear warheads forever, thus assuring irreversible nuclear reductions or at least making it more difficult to re-arm nuclear forces quickly;
- there would be a comprehensive exchange of nuclear warhead-related information (i.e. deployed, retired, dismantled, and reserved nuclear warheads; nuclear weapon infrastructure; fissile materials; and historical records) to confirm the accuracy of declarations of existing nuclear warheads, fissile materials, and capabilities. Additionally, intrusive verification approaches would ensure there will be no undiscovered places for holding covert nuclear warheads and fissile nuclear materials, and administrative procedures must be established to confirm that the treaty parties are abiding by their obligations;
- the treaty would provide unprecedented openness (at least between the treaty parties and a supreme international organization such as IAEA) of NWS nuclear weapon-related information;
- the treaty would endure extensive, formidable, long-term, and controversial negotiation;
- the treaty would have a deep impact on international relations and stability;
- the treaty should be step-by-step and far-sighted to avoid any unstable elements inducing unexpected nuclear conflict;
- the treaty should be associated with the elimination of nuclear-capable delivery vehicles;
- the treaty should be strongly associated with the highest standards of protection, control, and accounting for fissile materials; and
- the treaty should have a legal basis for restricting data exchange in advance.

Nuclear arms control treaties have played an important role during the Cold War in modulating superpower competition over nuclear weapons. They have established norms for responsible states, facilitating the nonproliferation regime, reassuring domestic audiences and allies by means of cooperative threat reduction and reducing the risks associated with dangerous nuclear weapons.[113]

Nuclear arms control agreements, such as SALT and START, impose limits or agreed reductions on nuclear weaponry and nuclear-related military activities, while disarmament treaties, such as INF, Threshold Test Ban Treaty (TTBT), Partial Test Ban Treaty (PTBT), CTBT, and FMCT, provide for the elimination or prohibition of certain categories of weapons or nuclear weapon-related activities. Other agreements, such as Hotline Agreement, Agreement on Measures to Reduce the Risks of Nuclear War, Incidents at Sea Agreement, Prevention of Nuclear War Agreement, and Agreement to Establish Nuclear Risk Reduction Centers, establish

[112] James Schlesinger, "The Demise of Arms Control?" *The Washington Quarterly*, Spring/2000, Volume 23, Issues2, pp. 179–182; and Clifford E. Singer and Amy Sands, "Keys to Unblocking Multilateral Nuclear Arms Control"
[113] Michael Krepon and Larry Scheinman, "Arms Control Treaties and Confidence-Building Measures as Management Tools," in Chester A. Crocker, Fen Osler Hampson, and Pamela Aall eds., *Turbulent Peace: The Challenges of Managing International Conflict*, September 2001

mechanisms to improve nuclear confidence and trust in order to reduce the risk of nuclear war. The NPT is a very special treaty in which the nuclear weapon states' status quo shows some commitments of good faith to eliminate the nuclear weapons while inhibiting other non-nuclear weapon states to develop nuclear weapons.

During the Cold War, the negotiation and implementation of nuclear arms control treaties were of great importance for several reasons:

- to reduce the nuclear tension and head-head nuclear collision,
- to avoid a disastrous nuclear war,
- limit and reduce the cost and risk of the nuclear arms race spiral evolution,
- to enhance mutual understanding, trust, and confidence and to improve mutual relationship,
- to ensure the international security,
- to help shape and moderate nuclear weapon policy,
- to change the relationship from hostile to benign,
- to reinforce the nonproliferation regime,
- to strengthen the control of nuclear weapons and prevent a nuclear accident,
- to regulate the nuclear forces deployment,
- to freeze, limit, reduce or abolish certain categories of nuclear weapons or forces,
- to improve military stability and predictability, and
- to enhance crisis stability (e.g. to enhance strategic stability and reduce the incentive of preemptive nuclear strike, SALT I and Anti-Ballistic Missile (ABM) treaties were bound together signed).[114]

Although the probability of a massive nuclear war decreased dramatically after the Cold War, other problems associated with nuclear weapons still remain. Some problems have become even more serious, such as nuclear proliferation, the risk of theft and unauthorized use of nuclear weapons, and terrorist attempts to acquire nuclear weapons or radiological dispersal devices (RDDs).[115] Through a nuclear warhead reduction treaty, the NWS could cooperate more closely to prevent the diversion of the nuclear weapons. With limited nuclear warheads, the security of warheads can be improved with existing resources.[116]

The success of a nuclear arms control treaty often depends on long, hard, and iterative negotiation and bargaining that is frequently interrupted by international and domestic politics even if the treaty itself has gained widespread inside and outside support. While the treaty itself is the most serious and formal way to realize nuclear arms control, it cannot guarantee

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[114] Jozef Goldblat, "Arms Control: A Guide to Negotiations and Agreements," (SAGE Publications Ltd, London UK), first paperback edition, 1996, pp.5; and Arms Control Association, "Arms Control and National Security: An Introduction", (Washington, D.C: Arms Control Association, 1989), pp.10-15

[115] Charles D. Ferguson, "Reducing the Threat of RDDs," *IAEA Bulletin,* Volume 45, Number 1, June 2003, pp.12-15

[116] William Moon, "CTR Russian Weapons of Mass Destruction Security Program," paper presented to the NDIA Security Division Symposium and Exhibition, Reston, Virginia, June 27, 2002; Matthew Bunn, "Nuclear Warhead Security," in *The Next Wave: Urgently Needed New Steps to Control Warheads and Fissile Material* (Washington, D.C.: Carnegie Endowment for International Peace and Harvard Project on Managing the Atom, April 2000), pp. 37-38; and Charles L. Thornton, "The Nunn-Lugar Weapons Protection, Control, and Accounting Program: Securing Russia's Nuclear Warheads", Paper presented at the 43rd Annual Meeting of the Institute for Nuclear Materials Management, June 2002, Orlando, Florida. More discussion about the security of nuclear warhead, see CNS website on "Securing Nuclear Warheads and Materials: Warhead Security Upgrades, available at http://www.nti.org/e_research/cnwm/securing/warhead.asp.

irreversible nuclear disarmament. The treaty parties can retreat from the for reasons from national security considerations to power-seeking ambitions (i.e., the Democratic People's Republic of Korea (DPRK) quitting the NPT and US withdrawing from ABM Treaty.) After Westphalia, the sovereignty of a state is the most important notion in international relation—it is difficult to effectively bind a state firmly to a treaty.[117] If political antagonism or distrust between the involved countries stands in the way, it would be impossible to reach even a simple nuclear arms control treaty, let alone a nuclear warhead reduction treaty.[118]

Therefore, in order to establish a nuclear warhead reduction treaty there must be several prerequisites: (1) construction of a positive and active international nuclear arms reduction environment (e.g., a formal multilateral NFU treaty can greatly reduce the incentives of using nuclear weapons, therefore expressing amicable political desire towards nuclear arms reduction),;(2) full understanding and development of the technologies used in the verification, monitoring, elimination, and other areas of nuclear warhead reduction; and (3) far-sighted design of nuclear warhead reduction schedules and strategic stability considerations.

There are a few practical ways to go beyond SORT for nuclear warhead reduction. First, the US and Russia can begin negotiating the elimination of strategic nuclear warheads under the SORT framework while pushing forward monitoring measures to verify the elimination of tactical nuclear warheads under the 1991 PNIs. Second, the United States and Russia can reduce the total number of nuclear warheads to an agreed level that can draw the rest of the nuclear and *de facto* nuclear states into the nuclear reduction negotiation. Third, a multilateral nuclear reduction negotiation must occur.

Because of (1) the small size of nuclear warheads[119] is the makes it easy to hide a few hundred, (2) the uncertainty about aggregate numbers of nuclear warheads,[120] including how many have been produced, refurbished, reserved, retired, and dismantled, (3) the uncertainty over past production of fissile materials,[121] (4) large and dispersed nuclear warhead infrastructures,[122] (5)

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[117] "ABM treaty withdraw: neither necessary nor prudent", An ACA Press Conference, *Arms Control Today*, January/February 2002, pp.12-21; Sergei Kortunov, "Washington Withdraws from the ABM Treaty," International Affairs: A Russian Journal, No. 4, 2002

[118] Colin S. Gray, "Arms control does not control arms", *Orbis*, Summer/1993, Vol. 37, Issue 3

[119] A hypothesized primary of a thermonuclear warhead has the outside radius less than 25 cm (see Frank Von Hippel and Roald Z. Sagdeev, eds., "Reversing the Arms Race: How to Achieve and Verify Deep Reductions in the Nuclear Arsenals" (Science and Global Security Monograph Series, Vol 1), (Gordon & Breach Science Publishers),June 1990, pp.299).

[120] For example, Lawrence Gershwin (CIA national intelligence officer for strategic programs) testified in 1992 that Russia had 30,000 nuclear warheads, "plus or minus 5,000", while a statements by Russian Minister of Atomic Energy Victor Mikhailov revealed that the Russian stockpiled 45,000 warheads in 1986. (see "Testimony of Lawrence Gershwin before the House Defense Appropriations Subcommittee," May 6, 1992, and William J. Broad, "Russian Says Soviet Atom Arsenal Was Larger Than West Estimated," *New York Times*, Sept. 26, 1993, p. A1).

[121] Even for US, the best accountable quantity data had 2.8MT Plutonium due to inventory difference, though there is no evidence to show any security breach or diverted use of the fissile material (see "The First 50 Years: United States Plutonium Production, Acquisition, and Utilization from 1944 through 1994"). Ten percent of the inventory difference is enough to produce 70 pits for nuclear warheads (assume the 2.8MT Plutonium attribute WgPu, and one pit contains 4kg WgPu, see Frank Von Hippel and Roald Z. Sagdeev, eds., "Reversing the Arms Race: How to Achieve and Verify Deep Reductions in the Nuclear Arsenals" (Science and Global Security Monograph Series, Vol. 1), (Gordon & Breach Science Publishers),June 1990, pp.267, 296-299). The inventory of HEU probably has large accountable difference; and Other NWSs' fissile materials accounting data is believed not better than that of US

[122] For both US and Russia, there are more than a dozen separate places expanding large areas for nuclear warhead deployment, interim and long-term storage, maintenance, and reserve (see Oleg Bukharin, "Downsizing Russia's Nuclear Warhead Production Infrastructure", *The Nonproliferation Review*, Spring 2001, Volume 8, Number 1, pp.116-130; Office of Arms Control and Nonproliferation, DOE, "Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead

mixed functions of nuclear warhead facilities,[123] and (6) high sensitivity of nuclear warhead-related activities, it is important to address the verification and compliance problems for a nuclear warhead reduction treaty, particularly at the deep reduction stage. However, technical and political difficulties will surely arise.

Compliance with an arms control treaty depends on the faithful behavior of involved parties so that they may abide by their agreed obligations during the treaty implementation process. It cannot be totally based on the treaty itself. An appropriate international institution should be constructed for effective and successful compliance with treaty obligations.[124] The issues of compliance raised large numbers of controversial disputes during the Cold War. The disputes over how to make the treaty member compliant with its obligation, how to enforce the compliance effectively, and how to minimize the military significance of treaty violations remained to be solved.[125] Therefore it is important to design a nuclear warhead reduction treaty that it is detectable, distinguished, and difficult for treaty parties to violate in practice.

Along with compliance issues, nuclear arms control or reduction treaties should also deal with the problem of verification. Unlike past verification measures that relied on complicated NTM technologies and simple agreed technologies, the nuclear warhead reduction verification will require the exchange of nuclear weapon-related information. This would thoroughly and genuinely lay the ground for reductions and use intrusive, advanced, and highly sensitive technologies to confirm the elimination of nuclear warheads. Verification would also require establishing comprehensive monitoring procedures for every nuclear weapon-related facility. Warhead reduction verification requires highly cooperative work and transparency between treaty members. A better way to facilitate future nuclear warhead reduction verification measures is to expand the nuclear warhead verification technology and policy cooperation beyond the existing US-Russia cooperative work under past CTR and START III frameworks for warhead dismantlement transparency.[126] If possible, the reduction technology cooperation should also include the rest of the nuclear and *de facto* nuclear states by allowing access to non-sensitive information.

With the development of advanced military technologies and capabilities and with further

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Dismantlement", May 19, 1997, pp.29-39; and William M. Arkin, Robert S. Norris and Joshua Handler, "Taking Stock: worldwide nuclear deployments 1998," (Washington, D.C.: Natural Resources Defense Council), March 1998, pp.14-38)

[123] See Pantex Mission Statement, available at http://www.pantex.com/ds/pxgend1.htm; and Office of Arms Control and Nonproliferation, DOE, "Transparency and Verification Options: An Initial Analysis of Approaches for Monitoring Warhead Dismantlement", May 19, 1997, pp.29-39

[124] Harald Müller, "Compliance Politics: A Critical Analysis of Multilateral Arms Control Treaty Enforcement", *The Nonproliferation Review,* Summer 2000, Volume 7, Number 2, pp.77-90

125 Robin Ranger and Dov S. Zakheim, "Arms Control Demands Compliance", Orbis, Spring, 1990, Vol. 34, Issue 2, pp.333-349. For more detailed discussion of the compliance issues and its affection, see Gloria Duffy, Compliance and the Future of Arms Control (Cambridge, Mass.: Ballinger, 1988); and Michael Krepon and Mary Umberger, eds., Verification and Compliance (Cambridge, Mass.: Ballinger, 1988).

[126] Oleg Bukharin and Kenneth Luongo, "US-Russian Warhead Dismantlement Transparency: The Status, Problems, and Proposals," Princeton University Report No. 314, April 1999; Federation of American Scientists, "Conclusions from the Russian-US Workshop on Dismantlement Transparency," November 9-10, 1998, available at http://www.fas.org/nwp/pubs/workshop.html; and Andrew J. Bieniawski, Paul B. Irwin (US Department of Energy), "Overview of the US – Russian Laboratory-to-Laboratory Warhead Dismantlement Transparency Program: A US Perspective", Report at the 41st Annual INMM Conference, New Orleans, July 2000. And a lot of technical and policy discussion reports on nuclear warhead transparency and dismantlement available at Los Alamos Applied Monitoring Technology Laboratory website - http://amtl.iwapps.com/

nuclear force reductions, the line between strategic and tactical is becoming more ambiguous.[127] In this case, the core element of the nuclear warhead reduction treaty should include counting total nuclear warheads (tactical, strategic, and reserved) with high confidence that there are no concealed warheads. This would diminish the capability to produce new warheads quickly and at the same time dismantle and dispose of reduced warheads. Furthermore, the nuclear warhead reduction treaty must be associated with fissile materials, having high confidence that all fissile materials are under verification and monitoring.

3. Verification and monitoring approaches

Verification includes measures and procedures to confirm that agreed treaty activities are executed as required and that the treaty parties are complying with the provisions of the agreement.[128] These measures and procedures are recognized by many governments and arms control experts as the essential ingredients in the arms control process. The central concern in any arms control treaty is the ability of signatory states to verify compliance by their treaty partners. The basic and common purpose of all verification procedures for arms control treaties is to raise the political risk, the technical difficulty, and the economic cost of noncompliance.[129] Successful implementation of an arms control agreement relies heavily on verification[130] for several reasons: (1) to deter any intent of violation and prove violations through monitoring, detection, and evidence-collecting methods, (2) to build the highest confidence possible among treaty members, (3) to protect the security of parties through early warning or discovery of violations, (4) to reduce the incentives for violation by raising the costs of cheating through careful designed verification procedures, and (5) to enhance the implementation of the treaty by enforcement measures.[131]

Due to the destructive nature of nuclear weapons, verification of nuclear arms control agreements should be highly effective in providing early detection of any militarily significant violations. However, no arms control treaty can be fully verified. Every treaty carries some risk that certain non-compliant activities may go unnoticed, either entirely or until they actually become a problem.[132] Arms control treaties cannot guarantee one hundred percent confidence in compliance and execution. There is always some existing inadvertent or technological limitation that leaves room for elaborate deception, especially if a state has the will and the means to carry out the violation. Thus, during INF and START negotiations, the United States argued that it should require "effective" rather than "adequate" verification[133] for a nuclear arms treaty.[134] In

[127] See Qiao Liang and Wang Xiangsui, "Unrestricted Warfare," (Beijing: PLA Literature and Arts Publishing House), February 1999

[128] Steve Fetter and Stanislav N. Rodionov, "Verifying START", in Francesco Calogero et al. eds., *Verification: Monitoring Disarmament,* (Westview Press: Boulder, Colorado), 1991, pp.96; and "Technology R&D for Arms Control (Spring 2001)", Arms Control & Nonproliferation Technologies Project, Office of Nonproliferation Research and Engineering, DOE, pp.3

[129] Steve Fetter and Thomas Garwin, "Tags," in Richard Kokoski and Sergey Koulik, eds., *Verification of Conventional Arms Control in Europe: Technological Constraints and Opportunities* (Boulder, CO: Westview Press, 1990), pp. 139

[130] UK Ministry of Defence, "Strategic Defence Review", available at http://www.mod.uk/issues/sdr/

[131] William F. Rowell, "Arms Control Verification: Guide to Policy Issues for the 1980s", (Ballinger Pub Co: Cambridge, MA), February 1986, pp.14-19; Andrzej Karkoszka, "Strategic Disarmament: Verification and National Security", SIPRI, (Publisher: Taylor & Francis, Incorporated), January 1, 1978, pp.33-37; and Steve Fetter and Stanislav N. Rodionov, "Verifying START", in Francesco Calogero, et al., eds., *Verification: Monitoring Disarmament,* (Westview Press: Boulder, Colorado), 1991, pp.96-97

[132] "Strategic Arms Reduction Treaties (START I & II): Verification and Compliance Issues", Amy F. Woolf, Foreign Affairs and National Defense Division, November 22, 1996

[133] For definition of "adequate verification", see Committee on Foreign Relations, United States Senate, *The SALT II Treaty,*

1988 Ambassador Paul Nitze defined "effective verification":

> What do we mean by "effective" verification? We mean that we want to be sure that if the other side moves beyond the limits of the Treaty in any militarily significant way, we would be able to detect such violation in time to respond effectively and thereby deny the other side the benefit of the violation.

In 1992 Secretary of State James Baker went on to explain:

> If the other side attempts to move beyond the limits of the Treaty in any militarily significant way, we would be able to detect such a violation well before it becomes a threat to national security so that we are able to respond. Additionally, the verification regime should enable us to detect patterns of marginal violations that do not present immediate risk to US security. However, no verification regime can be expected to provide firm guarantees that all violations will be detected immediately.

In his definition, Nitze argued that no verification regime could perfectly detect all cheating actions. Instead, verification is effective if it can detect one side's violation in time to allow the other side to minimize the impact of the violation. Baker strengthened this argument that verification should also be able to discover minor violations before they become militarily significant.[135]

Verifying limits on nuclear warheads is substantially more difficult than verifying limits on delivery vehicles.[136] While both countries established confidence that nuclear capable delivery vehicles were eliminated under past nuclear arms reduction treaties, the United States and USSR/Russia have had no actual practice of verifying nuclear warhead reductions, whether the warheads are removed, stored, dismantled or eliminated.[137]

An effective verification system that ensures with high confidence that no signatory holds the covert treaty-prohibited weapons in order to gain some military advantages in the future is essential to a nuclear arms reduction treaty.[138] But for a nuclear arms reduction treaty, the difficulty lies in deciding exactly what is necessary for effective verification,[139] particularly for nuclear warhead reduction verification that will face many political and technical challenges, including (1) proper balance of intrusiveness, confidence, and sensitivity, and (2) feasibility, practicability, acceptability, and capability (violation-detecting ability) of required technologies and confidence thereby achieved. Due to these challenges, there is no objective or quantifiable answer to the question, "How much verification is enough?" Instead, evaluation of the

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Hearings, 96th Cong., 1st session, 1979, pp.237, 288

[134] Arms Control Association, "Arms Control and National Security: An Introduction", (Washington, D.C: Arms Control Association, 1989), pp.140

[135] David Hafemeister, **"**Summing Up: Questions and Answers on the Comprehensive Test Ban Treaty", in Matthew McKinzie, ed., "The Comprehensive Test Ban Treaty: Issues and Answers", Peace Studies Program, Cornell University, Occasional Papers #21, June, 1997

[136] Committee on International Security and Arms Control, US National Academy of Science, *The Future of US Nuclear Weapons Policy* (National Academy Press: Washington D.C., 1997), pp.37

[137] Rose Gottemoeller, "Nuclear Arms Control After Moscow"

[138] Joseph Rotblat, "A Nuclear Weapon-Free World Leading to a War-Free World", presentation to "*1996: Disarmament at a Critical Juncture*", a conference sponsored by the NGO Committee on Disarmament at the United Nations on 25 April 1996

[139] Jeremy K. Leggett and Patricia M. Lewis, "Verifying a START agreement: Impact of INF precedents", *Survival*, Sep./Oct. 1988, pp.409-428

prospective nuclear warhead reduction verification mechanism must be a complex economic, political, military, and diplomatic judgment.[140]

Arms control verification and monitoring is a process both for the detection and the deterrence of cheating. When the potential violator recognizes the high risk of being caught or the possibility of unsuccessful shrouding of a covert arsenal, the requirements for deterrence of noncompliance can be less rigorous than those of assuring oneself that cheating is totally impossible.[141]

There are several questions that should be considered, including what goal could be achieved or advantages obtained by cheating, what methods can be used to achieve the goal or advantage, the probability of detection, and the result or outcome of detecting the violation. There are several general principles of an effective verification system of a nuclear warhead reduction treaty:

- Making the noncompliance activities costly and time-consuming, thus reducing the incentives for violation and greatly increasing the resources needed for cheating
- Improving the probability of violation discovery to maximize the compliance behavior by adopting agreed advanced technology and introducing the cooperative technology as much as possible
- Enhancing the quick response and enforcement capabilities of the treaty, thus minimizing the expected benefits of cheating
- Establishing integrated dispute settlement measures to prevent minor violations from escalating
- Clarifying the concepts, definitions, and verification framework clearly and definitely
- Exchanging detailed relevant information to form the verification base in advance

After the Cold War, international relations between the major powers have become less hostile. The incentive for acquiring military advantage through noncompliance activities has been greatly, but not completely, reduced. With the development of modern technologies—particularly innovative satellite, information, and sensor technologies—it has become increasingly difficult for a treaty party to carry out non-compliant activities for long periods of time without being noticed.[142] After long years of nuclear arms control and reduction efforts (through verification procedures, NTM, and intelligence analysis), more and more nuclear weapon-related information has been opened either to the public or between states.[143]

The verification system for nuclear warhead reductions can draw useful experience and practice from those of past nuclear reduction treaties such as INF and START, while having unique

[140] Office of Technology Assessment, Congress of US, "Verification technologies: Measuring for monitoring compliance with the START treaty (Summary)", OTA-ISC-479, December 1990, pp.7
[141] Ibid, pp.6
[142] For example, IAEA and many NGOs use commercial satellite image to facilitate the discovery of undeclared fissile materials production and refinement, reactor operation and other nuclear activities (for detailed discussion, see Bhupendra Jasani and Gotthard Stein, eds., "Commercial Satellite Imagery: A Tactic in Nuclear Weapon Deterrence", (Springer: Chichester, UK), 2002).
[143] Through the CTR, MPC&A, and Lab-Lab programs, and HEU Agreement, INF, START and Trilateral Initiative, the United States and Russia had unprecedented access to each other's nuclear and missile facilities and understood the cradle-to-grave process of nuclear warhead much more than before.

characteristics:

- Highly intrusive and high-tech methods employed to detect, authenticate and confirm the existence of nuclear warheads
- Heavy reliance on past and existing records of production, dismantlement, and production of the total nuclear warheads
- Strong association with the fissile materials stockpile and its uncertainty
- Intentions of the signature state to comply with the nuclear warhead reduction obligations,
- Capability to prevent the non-compliant member from gaining militarily significant benefit
- Comprehensive and integrated combination of multiple and defense-in-depth verification procedures to maximize the reliability that no possible violations occurs[144]
- Reliable chain-of-knowledge on nuclear weapons at all stages of their life-cycles to avoid any diversions
- Potential treaty-required warhead dismantlement and disposition, probably co-existent with the legal warhead maintenance, refurbishment, and production, mostly at the same site, causing the discrimination of both activities (without breaching national security) to face great technical challenges

The verification system for nuclear warhead reductions has a two-fold purpose: (1) to authenticate nuclear warheads, e.g., acquire the distinguishable characteristics of specific nuclear warhead types and (2) to establish the continuous knowledge of reduced nuclear warheads and total nuclear stockpile in the deep reduction period.

INF was a breakthrough in uses of verification technology and methods that included on-site inspection,[145] comprehensive data exchange, PPCM, and simple radiation measurements. It was very important to develop cooperative verification methods that both parties would agree to since the cooperative verification technologies and methods could be well understood by both sides—either by policymakers or technical experts. The START verification measures have expanded upon the lessons of INF and made the confirmation of treaty implementation more effective.[146]

Verification of a nuclear warhead reduction treaty would also heavily rely upon a combination of technical and human capabilities. These include imagery, signals intelligence, human intelligence, open-source information, and verification provisions of the treaty. Those

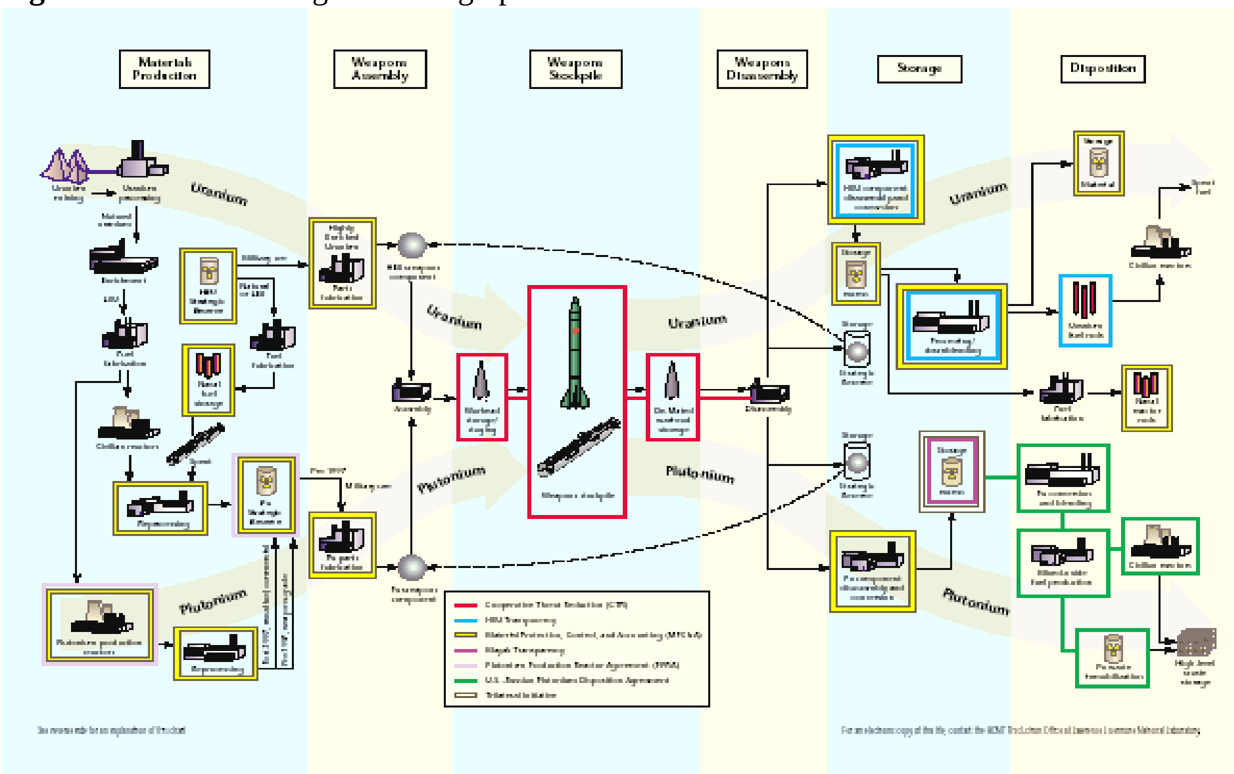
[144] According to past nuclear arms control compliance practice and experience, violations are seldom "unambiguously clear" (white or black), so there is the strong reasons to incorporate as much verifiability as possible in every arms control treaty (see Steve Symms and David Sullivan, "Soviet violations of existing arms control treaties may make future treaties ineffective", in Rudolf Avenhaus and Reiner K. Huber, eds., *Quantitative Assessment in Arms Control: Mathematical Modeling and Simulation in the Analysis of Arms Control Problems,* (Plenum Press: New York), 1984, pp.413-444)

[145] OTA-ISC-488, "Verification Technologies: Managing Research and Development for Cooperative Arms Control Monitoring Measures", May 1991, pp.2

[146] Unlike SALT I and ABM treaty's implementation in 1970s and early 1980s, both the United States and USSR raising numerous questions about each other's compliant behaviors, the implementation of INF and START were carried out basically smoothly without many disputes over the compliance issues (for example, see Bureau of Verification and Compliance, US Department of State, "Adherence to and Compliance with Arms Control and Nonproliferation Agreements and Commitments," Washington, DC, 2001).

verification provisions are composed of various monitoring measures such as NTM, OSI, PPCM, chain-of-custody, and cooperative monitoring. The verification measures should be interlocked in order to maximize the efficiency and guarantee the credibility of the reductions. All these verification measures should be applied from the original production to the final disposal of nuclear warheads as delineated in Figure 1. Across the whole process, fissile materials have been the subject of agreements or cooperative programs between the United States and Russia (e.g., HEU agreement, CTR and Material Protection, Control and Accountability (MPC&A) program, Plutonium disposition agreement and Mayak Transparency), but little has been done regarding the nuclear warhead. At every stage of the nuclear weapon lifecycle, great technical and political challenges must be solved in order to verify nuclear warhead reduction.

Figure 1. The cradle-to-grave flow graph of a nuclear warhead



Source: Office of Nonproliferation Research and Engineering, DOE/NNSA, Arms Control and Nonproliferation Project, spring 2001, "Technology R & D for Arms Control"

3.1 Data exchange and declaration

The first step in any nuclear arms control treaty should be the exchange of information that ranges from TLIs-related data such as number, type, and necessary distinguishing characteristics to production, deploying, storage, and eliminating facilities and other essential information. Nearly all data that is exchanged would become the baseline for succeeding verification and monitoring.[147] INF and START are very good examples of comprehensive data exchanges for nuclear arms control.[148] Both treaties provided successful models for future nuclear arms

[147] OSIA, On-Site Inspection Agency: trust and verify, (prepared by DynMeridian, a DynCorp company, Alexandria, VA under contract no. OISO1-94-D-0006), pp.3-4
[148] INF and START had established very detailed list, illumination and update of information exchanged in accordance with the

reduction on data exchange problems.

The credible, authentic, reliable, and accurate data exchange is crucial to successful implementation of a nuclear arms control treaty for several reasons: (1) to constitute the substantial base for the treaty's implementation by revealing the actual nuclear arms capabilities and status, (2) to eliminate the uncertainty and skepticism of the ongoing nuclear arms control by faithful declaration of treaty-limited or reduced nuclear items and relevant facilities (transparency and openness), (3) to reduce the likelihood of disputes or allegations of noncompliance by showing distinguishing characteristics between prohibited and allowed nuclear items, and (4) to decrease the cost and time of confirmation for large quantities of TLIs and facilities over the large territory.

A data exchange must protect sensitive information. The data exchange for nuclear warhead reductions can be divided into two categories: (1) direct warhead related information, which covers existing and historical data on nuclear warhead inventories by type, status, and location, as well as the distinguishing characteristics used to authenticate the warhead and (2) indirect warhead related information, which covers information on fissile materials, facilities and nuclear capable delivery vehicles. The comprehensive exchange of these data can effectively provide the base for subsequent verification and can greatly reduce the breakout risk by early detection and warning.

In order to gain high confidence in nuclear warhead reductions and to minimize the possibility of covert nuclear stockpiles, the exchange of nuclear warhead information must be comprehensive. A well-planned exchange schedule and procedures should be designed to release the information step by step. For example, the NWS and *de facto* NWS can first collect the data and compile it in an encrypted table. Then according to request, the information exchange can be partial and confidential between NWS. When the time is appropriate, all the information can be exchanged and made public.

Confirmation of the declared or exchanged data is the most difficult part. Even the most sophisticated technologies and vast intelligence cannot provide accurate data of another country's weapon inventories. Thus it is critical to encourage treaty members to declare and exchange authentic and credible data on their own weapon inventories and other related information.

The exchange of data requires not only political decisions, but also the resolution of difficult technical and political problems, particularly for those NWS that have large nuclear arsenals.

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treaties requiring the declaration of missile's production, final assembly, storage, testing, and deployment places or facilities, also the numbers and types of the treaty-concerned missiles at each declared places or facilities (see the Protocol on inspections of INF and START I). For INF, the data exchange focused on prohibited missiles, caring little about the mated nuclear warhead. For START, the data exchange focused the numbers and types of strategic nuclear-capable delivery vehicles and "accounted" nuclear warhead: for example, an initial data exchange took place in 1990. A second data exchange was carried out in December 1994, within 30 days of the date START I entered into force; additional exchanges would occur every 6 months for the life of the treaty. The data exchange together with other institutions such as notification, inspection and monitoring created military transparency and openness heretofore unthinkable. They are also the critical prerequisite for real nuclear arms reduction (see Secretary Baker, "T*he start treaty: foundation of a safer world"*, Statement before the Senate Foreign Relations Committee, Washington, DC, June 23, 1992).

Until now, no mature and effective technologies and procedures have been developed for proving the completeness of a NWS's nuclear weapon arsenal. Despite the work of the United States and Russia toward verifying the transparent nuclear warhead reduction,[149] there is still a long way to go to remove the technical and political obstacles.

Table 3. Data exchange categories for nuclear warheads

Category (direct-related and indirect-related)[150]		Significance	Exchange mode and stage	Confirmation measures
Warhead direct-related information for exchange or declarations	Total existing inventories by aggregation, type, status (deployed, reserved, maintained, refurbished dismantled), and locations	Establish the baseline for nuclear warhead reduction and minimize the probability of holding a covert nuclear arsenal	Step by step, deliberate design of declaration schedule to release the data without compromising the national security, international strategic stability and non-proliferation regime. At first, the data can be exchanged between NWSs and then publicized.	OSI with high resolution and sensitive detection equipment, continuity of knowledge for the concerned (at first) or total (during the deep reduction) nuclear warhead with full scope monitoring, tag and seal
	Historical inventories data archives on total numbers, production, retirement, dismantlement and disposition by years			
	The detailed list of each single nuclear warhead by serial number, production date, type, statues, location and final destiny date (tested, accidental wrecked, back to fissile materials stockpile, kept as pit or rebuilt into another weapons).			
	(Providing or mutual measuring) Distinguished characteristics of each type and its variations of nuclear warhead (type and mode template)			
	Any updated above information			
Fissile materials (indirect-related)	Total existing inventories by aggregation mass, isotopic-grade, chemical and physical forms, and locations	Reduce the uncertainty and skepticism of nuclear warhead stockpile, block the back door for future possible nuclear warhead expansion	The NWSs should selectively exchange the national account of fissile materials as early as possible between each other and then reveal the data to the public. The comprehensive data can be included in FMCT	OSI with high resolution and sensitive detection equipment, continuity of knowledge all fissile materials with full scope monitoring, tag and seal
	Historical inventories data archives on total production, isotopic-grade, consumption and location by years, national historical fissile materials account data			
	The detailed list of container or items holding the fissile materials with serial number, package date, mass, isotopic-grade, chemical and physical forms, and locations.			
	Any updated above information			
Facilities and locations (indirect-related)	Operational deployed field	Set up the continuous knowledge of nuclear warhead;	The NWS should be more transparent about all these facilities, which	NTM, OSI, surveillance, and past intelligence archives
	Interim and long-term storage places			
	Production, maintenance, dismantlement and disposition facilities			

[149] Richard L. Garwin, "Technologies and procedures for verifying warhead status and dismantlement" and Oleg Bukharin, "Russian and US technology development in support of nuclear warhead and material transparency initiatives", in Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions,* SIPRI book from Oxford University Press, 2003, pp.151-180

[150] This column is based on Steve Fetter, "Stockpile declarations", in Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions,* SIPRI book from Oxford University Press, 2003, pp. 137-143, and has some expansions.

	The facility descriptions The capabilities of nuclear warhead production, maintenance, refurbishment and dismantlement Any updated above information	enhance the confidence of no hidden activities taking place.	have no direct impact on national security considerations and can make the list for future verification.	
Nuclear capable delivery vehicles	Total existing inventories by aggregation, type, status (deployed or reserved), nuclear capabilities (throw weight or warhead actually and able to carry) and locations Historical inventories data archives on total numbers, production, retirement, dismantlement and disposition by years The detailed list of each single delivery vehicle by type, production date, statues, and location. The production, maintenance and storage facilities and their locations Any updated above information	Reduce the incentive for maintaining the unnecessary excess or hidden nuclear warhead and fissile materials stockpiles, control operational nuclear capabilities	Step by step, careful declaration schedules to release the data without compromising the national security and international strategic stability.	NTM, OSI, tag and seal, and past nuclear arms control collective data archives

The authentication of the information in Table 3 will pose technical challenges relating to warhead and fissile material detection and discrimination[151], the reduction of fissile material inventory differences, and proof of no hidden stockpiles.

Declaration and data exchange can be offered unilaterally, provided through reciprocation, or included in the formal treaty provisions. Since nuclear warhead data is highly sensitive, questions about what information should be released and what measures can facilitate and authenticate the data exchange need to be resolved first. Some general principles on the exchange or declaration of nuclear warhead information: (1) It should be a phased procedure in which the United States and Russia can first exchange data or declare their total nuclear warhead stockpiles. When it is appropriate (for example, after the US and Russia agree to deep reductions in the number of nuclear warheads), the United States and Russia can declare more detailed data, and the rest of the NWSs can declare or exchange their total numbers of nuclear warheads. Fissile material stockpiles and associated facilities and their locations should also be declared. Nuclear warhead and fissile material inventory data should be archived in an agreed-upon form as early as possible. (2) Care must be given when selecting information to exchange so as not to introduce possible instabilities or proliferation risks. (3) Cooperative monitoring and detection technologies should be developed to verify and authenticate the declared or exchanged data effectively and reliably.

The authenticity of the declaration or data exchange is the most important basis for future nuclear warhead reduction. It would be possible for a nuclear-weapon state to conceal a small nuclear arsenal (up to few hundred nuclear warheads for the United States or Russia) without being discovered for an extended period of time, especially if it is preparing to deceive in the

[151] Steve Fetter, "Stockpile declarations", in Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions,* SIPRI book from Oxford University Press, 2003, pp.137-138

first place. It is also virtually impossible for an inspection to find a small covert nuclear stockpile, unless one knows exactly where to look.

3.2 OSI

OSI is regarded as one of the most effective methods for verifying the reduction and elimination of nuclear weapon systems for several reasons:

- OSI is the direct and immediate way to confirm the accuracy of initial and updated declarations and data exchanges.
- Multiple, complementary, and defence-in-depth OSI arrangement can improve the confidence that there will be no treaty violations.[152]
- On-site surveying, monitoring, and observation of production, deployment site, and elimination procedures of certain treaty-concerned items can reduce the risk of breakout scenarios by proving no conversion, deployment, or production of treaty-prohibited items.
- Through direct contact, OSI can enhance mutual understanding of the treaty implementation process and, by finding flaws of the treaty, can better facilitate treaty implementation[153] and improve the basis for further verification.

No verification system will provide an adequate level of assurance without some on-site inspection. For nearly sixty years of nuclear arms control process, OSI was the focus of negotiation for verifying the treaty implementation. Most of the nuclear arms control treaties, including the TTBT, CTBT, Peaceful Nuclear Explosion Treaty (PNET), INF, and START, has used OSI for verification.[154] During the Cold War period of deep political mistrust and militarily hostile postures, there was the fear that intrusive OSI would divulge military secrets and infringe national sovereignty and security. This prevented OSI from becoming an effective tool for verifying early nuclear arms treaties like SALT I and ABM.[155] The application of OSI to the nuclear arms control process was very limited until the breakthrough INF treaty.

According to its purpose, OSI can be divided into five general categories: (1) to confirm treaty-related data during the baseline inspection period and thereafter, (2) to verify no noncompliant activities are taking place at treaty-declared facilities or sites, (3) to prove that the required elimination or conversion of certain treaty-limited or prohibited items is being carried out in accordance with agreed procedures, (4) to discover possible violations at undeclared sites, and (5) to help resolve ambiguities.[156]

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[152] For example, for INF and START, baseline inspection was carried out promptly after treaty's entering into force (e.g., START I baseline inspections began on March 1, 1995, and concluded in July 1995. The United States visited 65 locations in the former Soviet Union during this period. Inspectors from Belarus, Ukraine, Kazakhstan, and Russia visited 36 sites in the United States during the same time frame; short-notice and suspect site inspections at various locations were an effective deterrence to clandestine production, deployment, storage or maintenance of treaty-prohibited items.)

[153] During the baseline inspection of INF, both US and Russia had found out several errors or inaccuracy of declared data and corrected them through the consultation, assuring the following smooth execution of the treaty. The same case had also happened in the implementation of START and CFE (see George L. Rueckert, "On-site inspection in theory and practice: A primer on modern arms control regimes", (Praeger Publisher), 1998, pp.86-87).

[154] George L. Rueckert, "On-site inspection in theory and practice: A primer on modern arms control regimes", (Praeger Publisher), 1998, pp.10-30

[155] Ibid

[156] Ibid pp.80

Deigned to satisfy the specific verification target, OSI can have over 20 distinct types of inspections including baseline, elimination, closeout, short-notice, perimeter portal monitoring, designated-site, reentry vehicle on-site, and invitational.[157] INF has used the first five types,[158] while START has twelve types of OSI including baseline, new facility, data update, suspect site, reentry vehicle, post dispersal, conversion and elimination, closeout, formerly declared facility, technical characteristics exhibition, distinguishability, and heavy bomber baseline.[159] START I entered into force in December 1994 and implementation has proceeded relatively smoothly, with the United States conducting more than 150 inspections in the former Soviet Union and hosting around 60 inspections at US facilities within only two years.[160]

However, the START OSI regime is not an "anytime, anywhere" regime. Thus, there is always the possibility of hidden weapons or covert facilities that may be missed, although the intelligence community remains confident that any pattern of such activity would eventually be detected.

Various OSI measures aimed at various stages of nuclear weapon development can be combined into an interlocking chain to deter the noncompliance activities and to maximize the detecting efficiency. OSI can gain direct evidence by "taking a close look", thus determining whether treaty obligations are being kept.[161] At the same time, OSI is a useful way to increase overall transparency by establishing essential CBMs.

OSI would be one of the most important measures for the verification of nuclear warhead reductions. The combination of multiple and defense-in-depth OSI measures is essential to avoid suspicion and to improve confidence that objects are (or are not) nuclear warheads. The broadly applied fields of OSI for nuclear warhead reduction verification can be summarized follows: (1) to directly target nuclear warheads that by applying multiple OSI measures to every stage of the nuclear warhead lifespan, (2) to use OSI as a barrier to block additional nuclear warheads, and (3) to discover undeclared activities or hidden nuclear stockpiles through on site inspections.

The OSI of nuclear warhead reduction verification has its own characteristics:

- The technologies and equipment used by OSI are much more intrusive and sensitive than those of INF or START. If intrusive and highly sensitive technologies and equipment are not allowed in the OSI verification arrangement, then the overall efficiency and confidence gained will be greatly reduced.
- Large aerial surveys like those provided for in the Open Skies and Conventional Armed Forces in Europe (CFE) treaties are used to deter or detect covert nuclear activities.

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[157] OTA-ISC-479, "Verification Technologies: Measures for Monitoring Compliance with the START Treaty - Summary", December 1990, pp.9

[158] Joseph P. Harahan, "On-site Inspections Under the INF Treaty", US Government Printing Office, 1993, pp.9-10

[159] George L. Rueckert, "On-site inspection in theory and practice: A primer on modern arms control regimes", (Praeger Publisher), 1998, pp.28-29

[160] Amy F. Woolf, "Strategic Arms Reduction Treaties (START I & II): Verification and Compliance Issues", Foreign Affairs and National Defense Division, November 22, 1996

[161] Mohamed ElBaradei, "Inspections Are the Key", Essay, published in the *Washington Post,* Page A 25. 21 October 2002

- More intense challenges and suspect site inspections compared to those of the Chemical Weapons Convention (CWC) will ensure no militarily significant violations have occurred and give early warning if any violations are found.
- When entering into deep reductions, “anywhere, anytime” OSI should be employed to deter violations.
- Capabilities to expose covert nuclear activities or hidden nuclear stockpiles will be another key task, particularly when entering deep and multilateral nuclear warhead reductions.

Setting up workable and effective OSI verification mechanisms for nuclear warhead reductions requires several requirements to be satisfied first: (1) mutual trust and benign political postures for negotiating warhead-related OSI,[162] (2) authentic and detailed information that includes nuclear warhead-related declarations and data exchange forming the basis for subsequent OSI activities, (3) the cooperative development of detection and monitoring equipments forming the technical basis for OSI verification, and (4) a legal basis for international access to the former highly-restricted areas.

Several OSI measures are important for warhead reduction verification that covers the whole lifespan in which nuclear warheads are produced, deployed, maintained, refurbished, retired, stored, dismantled, and disposed, including fissile materials and any nuclear activity facilities or sites:

- Baseline and updated data inspection: The only way to establish an accurate treaty-concerned database is that the treaty signatories should provide credible and correct information exchange and declaration in the first place. Appropriate verification measures can then confirm the authenticity of the provided data. Baseline and updated data inspections are the most important ways to complete the task. With this extensive and formidable information (along with the very sensitive and highly classified information of the past), the data confirmation of on-site inspection can achieve first-hand direct proof of the correctness of the provided data and form the basis for further reductions. Through the scrutiny of past records, the consistency and accuracy of the provided information can be proven. The case in which South Africa had abolished its nuclear weapons along with the following validation of IAEA that South Africa had destroyed all its nuclear stockpiles[163] showed that data and records examination could confirm declarations of past activities.
- Short-notice, challenge and suspect site inspections: The most worrisome problems

[162] During UNSCOM and IAEA inspection in Iraq after the first Gulf War, Iraq had employed a wide range of deception and denial methods, leaving the inspections in a very tensional, confrontational and frustrated situation. Though the inspectors had discovered many records and evidence to show that Iraq’s declaration was misleading and inaccurate, they did not find conclusive evidence that Iraq had produced MAD while they had the unequivocal right to conduct “anytime, anywhere” inspections at highly-restricted areas. The fact illuminated three-fold matters: (1) the co-operative actions taken by both inspected and inspecting sides are the lubricant to facilitate the inspections, (2) the highly intrusive inspection and the right to access to any suspect sites can be valid ways to find out illegal activities, (3) it is still difficult for OSI to uncover and get the firm evidence of noncompliance if the inspected state take deliberate deception and well preparation in advance (see Tim Trevan, “Ongoing Monitoring and Verification in Iraq”, *Arms Control Today*, (May 1994), pp.4.)

[163] Adolf von Baeckmann, Gary Dillon and Demetrius Perricos, **“**Nuclear verification in South Africa”, IAEA Bulletin Volume 37, Number 1

are covert diversion or production of nuclear warheads at declared facilities, and hidden nuclear stockpiles or activities at undeclared facilities. OSIs can be a great deterrent to secret nuclear activities. A few additional nuclear warheads would not be militarily significant; covert nuclear stockpiles would have to be at least comparable to allowed nuclear stockpiles in order to gain the military advantage even during a period of deep reductions (assuming at deep reduction period the remaining nuclear forces of NWSs are highly invulnerable). The large secret nuclear activities of over a few hundred nuclear warheads over a long period time will be at high risk for detection by a combination of short-notice, challenge and suspect site inspections with multiple modern advanced technologies.

- Aerial surveying[164] and on-site environmental sampling: This kind of inspection is very useful in revealing clandestine nuclear activities. Since nuclear activities have radiation emissions by nature, the sites or facilities to maintain or store over several hundred nuclear warheads have many characteristics[165] (several nuclear warheads can be dispersed over separate places, which increase the risk by employing more people and equipments). Large groups of people are needed to manage the nuclear activity over an extended period of time. The intrusive aerial inspection will be an effective tool to detect nuclear warhead-related activities through highly sensitive nuclear or non-nuclear detectors.
- OSI on nuclear capable delivery vehicles, such as those in INF and START but more widely and intensely, would further reduce the incentives for keeping a covert nuclear stockpile.

Because of the highly sensitive nature of nuclear warheads (relating to either direct detailed data such as numbers, locations, status, and distinguishable characteristics, or indirect information such as fissile materials and facilities), OSIs that confirm nuclear warhead reductions will have to resolve a great number of intractable technical and political problems. A verifiable nuclear warhead reduction regime must incorporate several types of OSIs to achieve adequate confidence of compliance.

3.3 NTM and remote sensing

A 1983 US State Department publication defined National Technical Means as nationally controlled assets for monitoring compliance with the provisions of an arms control agreement. National technical means include photographic reconnaissance satellites, aircraft-based systems (i.e., radars and optical systems), and sea and ground-based systems such as radars and antennas for collecting telemetry.[166]

NTM played an important role in the past nuclear arms control verification. They were, in fact,

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[164] OTA-ISC-480, "*Verification Technologies: Cooperative Aerial Surveillance in International Agreements*", describes the significance and application of aerial investigation under open skies.

[165] The basic characteristics of a nuclear facility can be found in Richard Kokoski, "Technology and the Proliferation of Nuclear Weapons", SIPRI 1995; Tom Pedroni, "Hanford Federal Nuclear Facility", available at http://www.environmentaleducationohio.org/Case%20Studies/hanford.html; NTI, "Iraq Nuclear Facilities", available at http://www.nti.org/e_research/e1_iraq_N_facilities.html and many books and reports about the characteristics of mining, reprocessing for fissile materials and nuclear reactor.

[166] US House of Representatives, Committee on Foreign Relations, Executive Report 102-22, (US Government Printing Office: Washington DC), November 1991, pp.43

the major method of verifying compliance with nuclear arms control agreements (SALT I, ABM and NPT) prior to the INF and START treaties. Because of the individually possessed high technologies, secret-sources, and freely accessing nature of NTM-originated information, the NTM is a unilateral estimation about other country's decisions or intentions. Therefore it is both preferred over and more highly disputed than the NTM-information-based assessment and actions.

In the past, the NTM proved effective in strategic nuclear arms control and nonproliferation regimes for monitoring large objects such as strategic ballistic missiles, nuclear reactors, strategic submarines and bombers, and reprocessing plants With the development of advanced high-resolution satellites and data processing technologies, NTM has become increasingly competent in detecting small-sized objects and activities and locating suspicious sites. It can be a great challenge to put the diverse pieces of information together to form an accurate assessment, reducing the false-alert probability and increasing the credibility of NTM methods.[167]

The resolution of military reconnaissance satellites such as the improved version of KH-11 (now in operation) can reach 0.15 m.[168] Although high-resolution satellites cannot see covered or buried objects, their imagery is critical in characterizing certain militarily significant activities and in providing 3D or multi-spectral imagery to analyze the detailed characteristics of suspicious sites and to design the efficient verification procedure.[169] The United States has developed the most advanced satellite imagery and sensing technologies, which have been utilized in its military reconnaissance space programs and deployed in various reconnaissance systems.[170] Russia and France also have made great progress in military reconnaissance satellite technologies[171] in order to improve the capability for detecting militarily significant activities and possible treaty violations.[172] Many of the verification roles in the past nuclear arms control process were established through the military reconnaissance satellites.

In addition to military reconnaissance satellites and national intelligence, today's advanced and

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[167] During early 1980s, the Reagan administration made the judgment that Soviet Union had great superiority over US on the nuclear capabilities, particularly the intercontinental ballistic missiles, thus decided to develop the SDI to compensate the overwhelming USSR's total throw-weight (see Thomas J. Ward, "Endowed with a Sense of History", J*ournal of unification studies*, VOL. III, 1999-2000; Benjamin B. Fischer "A Cold War Conundrum"). Another well known misusing intelligence incidents was US intelligence believed that several chemical agents violating CWC were loaded aboard a Chinese ship named Yinghe in 1993 and US forced to inspect the vessel. However, the final inspection of the ship at a port in Abu Dhabi proved that no prohibited chemical agents were on boarding the vessel (see the declaration about Yinghe, by Ministry of Foreign Affairs of P.R. China on September 4th, 1993).

[168] William E. Burrows, "Imaging Space Reconnaissance Operations during the Cold War: Cause, Effect and Legacy", available at http://webster.hibo.no/asf/Cold_War/report1/williame.html; and FAS Space Policy Project website: http://www.fas.org/spp/index.html

[169] Craig Covault and Cape Canaveral, "Secret NRO Recons Eye Iraqi Threats", *Aviation Week & Space Technology*, September 16 2002, available at http://www.aviationnow.com/content/publication/awst/20020916/aw23.htm

[170] Douglas Pasternak, "Lack of Intelligence: America's secret spy satellites are costing you billions, but they can't even get off the launch pad", *US News and World Report*, August 11, 2003, available at http://www.usnews.com/usnews/issue/030811/usnews/11nro.htm

[171] C. Covault, "USAF Eyes Advanced Russian Military Reconnaissance Imagery", *Aviation Week and Space Technology*, May 23 1994, p. 53; Ian Black & Tony Paterson, "France and Germany in new romance"; "Interview with General de brigade aerienne Daniel Gavoty, Head of the Space Bureau: French Joint Chiefs of Staff," Interview & Translation by Taylor Dinerman for the October 15, 2002 issue of SpaceEquity.com; and "High-resolution imaging instrument for the French Helios II military reconnaissance satellite", available at http://www.alcatel.com/space/pdf/observation/heliosgb.pdf

[172] OTA-ISC-480, "*Verification Technologies: Cooperative Aerial Surveillance in International Agreements"*

publicly-accessible commercial satellites have sufficient capability for many verification tasks.[173] The approximate requirements of reconnaissance satellite for verification application are shown in Table 4. The capability and development of commercial or civilian reconnaissance satellite technologies are shown in Table 5. The commercialization of advanced satellite imagery has promoted the analysis and monitoring of known nuclear sites by hundreds of organizations and experts involved in nuclear arms control. It is becoming an effective deterrent against covert nuclear activities. With the development of detection technologies such as advanced synthesized aperture radar, ground penetration radar, and infrared or multi-spectral sensing, the multiple information fusion of NTMs will be a powerful tool to merge a comprehensive image of the concerned areas.

Table 4. Approximately required imagery resolution for detecting, identifying, describing and analyzing different targets (in meters)

Target [a]	**Detection** [b]	**General Identification** [c]	**Precise Identification** [d]	**Description** [e]	**Technical Analysis** [f]
Nuclear weapons components	2.5	1.5	0.30	0.03	0.015
Vehicles	1.5	0.6	0.30	0.06	0.045
Rockets and artillery	1.0	0.6	0.15	0.05	0.015
Missile sites (SSM/SAM)	3.0	1.5	0.60	0.30	0.045
Aircraft	4.5	1.5	1.00	0.15	0.045
Airfield facilities	6.0	4.5	3.00	0.30	0.150
Surface ships	7.5-15.0	4.5	0.60	0.30	0.045
Surfaced submarines	7.5-30.0	4.5-6.0	1.50	1.00	0.030
Command and control headquarters	3.0	1.5	1.00	0.15	0.090
Roads	6.0-9.0	6.0	1.80	0.60	0.400
Bridges	6.0	4.5	1.50	1.00	0.300
Supply dumps	1.5-3.0	0.6	0.30	0.03	0.030
a. Chart indicates minimum resolution in meters at which targets can be detected, identified, described, or analyzed. b. Detection: Locating a class of units, objects, or activity of military interests.					

[173] For detailed discussion of commercial satellite utilization in nuclear arms control and other verification regime, see Bhupendra Jasani and Gotthard Stein, eds., "Commercial Satellite Imagery: A Tactic in Nuclear Weapon Deterrence", (Springer: Chichester, UK), 2002; and Yahya A. Dehqanzada and Ann M. Florini, "Secrets for Sale: How Commercial satellite Imagery Will Change the World", Carnegie Endowment for International Peace, 2000.

c. General Identification: Determining a target type generally.

d. Precise Identification: Discrimination within target type of known types.

e. Description: Size/dimension, configuration/layout, components construction, equipment count, and etc.

f. Technical analysis: Detailed analysis of specific equipment.

Sources: Senate Committee on Commerce, Science, and Transportation, *NASA Authorization for Fiscal Year 1978*, pp.1642-1643; *Reconnaissance Hand Book* (McDonnell-Douglas Corporation, 1982), pp.125, and Ann M. Florini, "The Open Skies: Third Party Imaging Satellites and US Security", International Security, Vol.13, No.2 (Fall 1988), pp.98

Besides the use of high-resolution satellites as the main tool for verification or finding suspicious activities, high-altitude aerial reconnaissance; electronic signal sensing; global atmospheric, seismic, radionuclide, hydroacoustic and infrasonic monitoring; and human intelligence are other important ways to gather information for revealing the covert campaigns and early warnings of other countries' dangerous action. During the Cold War, the United States and USSR had established specific organizations such as National Reconnaissance Office (NRO), National Security Agency (NSA), and Glavnoe Razvedivatelnoe Upravlenie (GRU), and developed numerous diverse technologies to acquire, intercept, interpret, and analyze the pieces of gathered information and then merge them into a clear and meaningful picture.[174] NTM has been used heavily and continuously to obtain the intelligence and information of military activities, technical developments, nuclear testing, strategic arms monitoring, and arms control treaty compliance confirmation.

Table 5. Some specifics and capabilities of selected commercial and civilian imaging satellites

[174] There are many books and reports on intelligence gathering and its use in fusing the pieces of information into a clear assessment such as Donald P. Steury, "Intentions and Capabilities: Estimates on Soviet Strategic Forces, 1950-1983", Center for the study of intelligence, CIA, Washington DC, 1996; Graham Allison and Philip Zelikow, "*Essence of Decision: Explaining the Cuban Missile Crisis (SECOND EDITION)*", (Addison Wesley Longman, 1999); and etc.

north america

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
Landsat 3	1978 (1983)	NASA/NOAA	30RBV/80MS	185/185	18	retired
Landsat 4	1982	EOSAT/Sp. Imaging	30MS/80MS	185/185	16	operational[a]
Landsat 5	1984	EOSAT/Sp. Imaging	30MS/80MS	185/185	16	operational
Landsat 6	1993 (1993)	EOSAT	15PAN/30MS	185/185	16	failed
Landsat 7	1999	USGS	15PAN/30MS	185/185	16	operational
IKONOS 1	1999 (1999)	Space Imaging	0.82-1PAN/4MS	13/13	3 to 5	failed
IKONOS 2	1999	Space Imaging	0.82-1PAN/4MS	13/13	3 to 5	operational
EarlyBird	1997 (1997)	Earth Watch	3PAN/15MS	3/15	1 to 5	failed
QuickBird 1	2000	Earth Watch	1PAN/4MS	22/22	1 to 5	planned
QuickBird 2	2000	Earth Watch	1PAN/4MS	22/22	1 to 5	planned
OrbView 3	2000	Orbimage	4MS/8HS	8/8	3	planned
OrbView 4	2000	Orbimage	1PAN/4MS/8HS[b]	8/8/5	3	planned
MEMO	2001	STDC	6PAN/30HS	30/30	1 to 7	planned
Resource21	2001	Boeing	10PAN	200	7	planned
RADAR 1	2002	RDL	1SAR	4	1	planned
RADARSAT-1	1995	CSA	8SAR	50-500	3 to 24	operational
RADARSAT-2	2002	MDA	3SAR	50-500	3 to 24	planned

a. Data transmission from the 80-meter sensor failed in August 1993.
b. Orbimage will be able to sell only 24-meter hyperspectral images to nongovernmental entities.

southeast asia and south america

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
JERS-1	1992 (1998)	Japan	18MS/18SAR	75/75	44	retired
ADEOS 1	1996 (1997)	Japan	8PAN/16MS	80/80	41	failed
ALOS-1	2003	Japan	2.5PAN/10MS/10SAR	70/70/70	46	planned
Info-Collection	2003	Japan	1PAN/3-SAR	N/A	N/A	planning
Kompsat-1	1999	South Korea	10PAN/20MS	40/40	2 to 3	operational
Kompsat-2	2003	South Korea	1PAN/4MS	N/A	2 to 3	planned
Rocsat 2	2002	Taiwan	2PAN	N/A	1	planning
CBMD	2003	China	4SAR	700	N/A	operational
CBERS I	1999	China/Brazil	20MS/80-160HS	120/120	26	planned
CBERS II	2001	China/Brazil	20MS/80-160HS	120/120	26	planning
CBERS III	N/A	China/Brazil	5PAN/10MS	N/A	N/A	planning
CBERS IV	N/A	China/Brazil	5PAN/10MS	N/A	N/A	planning
SABIA	2003	Brazil/Argentina	6MS	400	N/A	

australia

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
Ares	2003	Australia	10PAN/30HS	15/15	6 to 7	planned

russia

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
SPIN-2[a]	Periodic[b]	Russia	2PAN/10PAN	180/200	N/A	N/A
RESURS-F	Periodic[c]	Russia	5-8MS/15-30MS	N/A	N/A	N/A
RESURS-DK	2000	Russia	2PAN/3MS/15SAR	N/A	N/A	N/A

a. SPIN-2 is the product of KVR-1000 and TK-350 cameras on board the Kometa spacecraft.
b. SPIN-2 satellites are presently launched about once each year and have a mission life of 45 days.
c. RESURS-F satellites are launched throughout the year and have a mission life of 25 days.

middle east

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
EROS-A1	2000	WIS	1.8PAN	13	2 to 3	planned
EROS-A2	2000	WIS	1.8PAN	13	2 to 3	planned
EROS-B1	2001	WIS	0.8PAN	13	2 to 3	planned

western europe

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
SPOT 1/2	1986/90	Spot Image	10PAN/20MS	60/60	1 to 4	operational[a]
SPOT 3	1993 (1996)	Spot Image	10PAN/20MS	60/60	1 to 4	failed
SPOT 4	1998	Spot Image	10PAN/20MS	60/60	1 to 4	operational
SPOT 5	2002	Spot Image	2.5PAN/10MS	60/60	1 to 4	planned
ERS-1	1991	ESA	30-50 SAR	100-500	3 to 35	operational
ERS-2	1995	ESA	30-50 SAR	100-500	3 to 35	operational
ENVISAT 1	2000	ESA	30 SAR	100	3 to 35	planned
ENVISAT 2	2003	ESA	N/A	N/A	N/A	planning

a. Although still operational, SPOT 1 was withdrawn from active service at the end of 1990.

south asia

Satellite	Launch (end of service)	Operator	Capability (meters)	Swath Width (kilometers)	Revisit Time (days)	Status
IRS-1C	1995	India	5PAN/23MS	70/150	5 to 24	operational
IRS-1D	1997	India	5PAN/23MS	70/150	5 to 24	operational
IRS-P5[a]	2000	India	2.5PAN	30	5 to 24	planned
IRS-P6[b]	2001	India	5PC/23MS	750/750	5-24	planning
CartoSat-2	2003	India	1PAN	N/A	N/A	planning
Badr-C	2000	Pakistan	10MS	205	N/A	planned

a. IRS-P5 is also known as CartoSat-1.
b. IRS-P6 is also known as Resource Sat-1.

Sources: Yahya A. Dehqanzada and Ann M. Florini, “Secrets for Sale: How Commercial satellite Imagery Will Change the World”, Carnegie Endowment for International Peace, 2000, pp.38-39

NTM is a very important method for verification, particularly for large objects or facilities dispersed over a wide geographic area persistently. NTM also has its disadvantages in nuclear warhead reduction verification:

- Very few countries possess advanced NTM, particularly high-resolution photoreconnaissance satellites. It is hard to convince treaty members without an advanced NTM technology to accept verification or compliance inspection by another treaty member who owns it. One way is to share the original data gathered by NTM, but this would raise the questions of security and secrecy.
- The information gathered from NTM is often unavailable to the public or even to another treaty member because of secrecy.[175] It is too sensitive to carry out nuclear warhead reduction verification by the alleged information just from NTM alone. How to persuade the treaty members to justify the information gathered by NTMs and how to disclose the information maximally remain to be solved as both technical and

[175] While US accused Iraq’s violation of relevant UN resolutions in 2002, it reluctantly provided alleged evidence gathered through its NTM.

political problems.

- NTM is unable to detect, distinguish, and authenticate among real and fake warheads or different types of nuclear warheads.
- NTM can be spoofed by well-planned deception such as making use of bad weather, shrouds, or underground facilities.

For nuclear warheads, the case is more serious. In verification provisions of INF and START treaties, there was no interference or concealment that can be applied to NTM in order to facilitate the verification process. Those targeted at large-size objects include ballistic missiles, strategic submarines and bombers, and well-known facilities with enough information exchanged in advance, or telemetry data of missile flight test. However it is impossible to expose queues of nuclear warheads towards the high-resolution reconnaissance satellite. The most probable utilizations of NTMs in nuclear warhead reduction verification are to monitor nuclear warhead and fissile material-related facilities, sites, and activities; to provide large-area information; and to find suspicious or covert militarily significant nuclear activities. These include large-scale nuclear warhead or fissile material storage, maintenance, and production.

NTM is a supplemental tool and part of a comprehensive verification system to nuclear warhead reduction verification regime.[176] The cooperative procedure and technologies will play the major role. Data from multiple sources must be fused into a meaningful picture. Design of multilateral monitoring systems would serve US interests and would increase the confidence of countries without NTM resources, and would make sure that all parties in an agreement are compliant with the treaty.

3.4 Chain-of-custody

Chain-of-custody is one of the most important verification methods for nuclear warhead reduction. Nuclear warhead reduction aims at irreversible nuclear disarmament. Because of the specific characteristics of nuclear warheads[177], this would require continuous knowledge and tracking of movements from their original location to final disposal. Assured prevention of diversion or substitution for every reduced or existing nuclear warhead is important for a nuclear warhead reduction verification regime.[178] During the nuclear warhead reduction, it is of great importance to keep the Continuity of Knowledge at the starting point to the final disposition for reduced nuclear warhead, thus a layered monitoring and tracking system should be set up to

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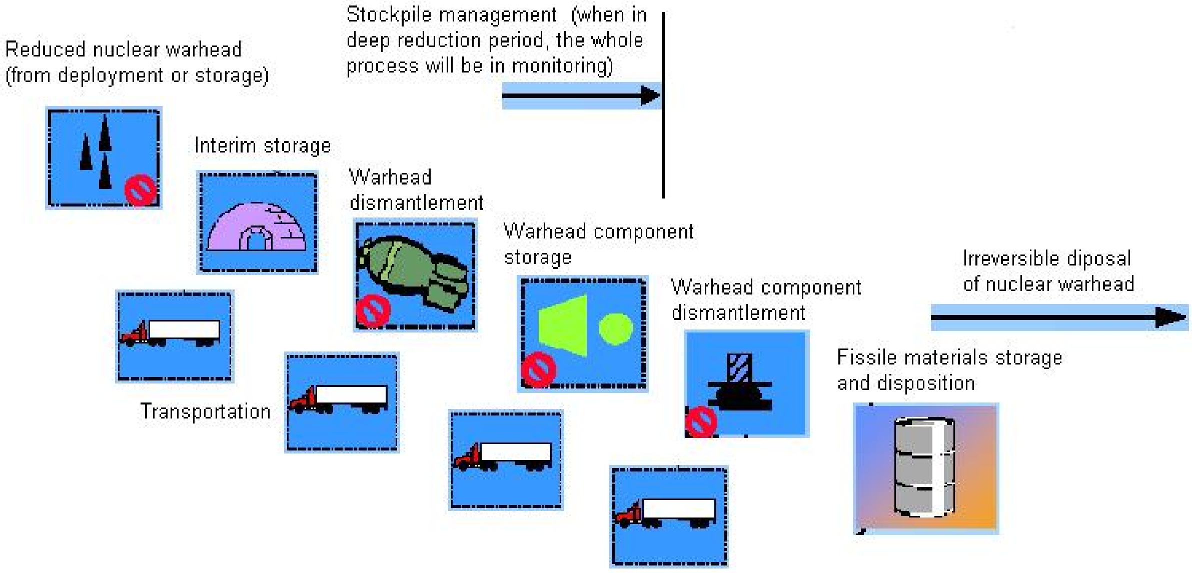
[176] "Verification of Dismantlement of Nuclear Warheads and Controls on Nuclear Materials", JASON Report, JSR-92-331, January 1993, pp.3

[177] For example, the relative small size, highly secret and diverse configurations, proliferation risk, the easiness to reconstitute an atomic bomb with available fissile materials (for those NWSs who have enough design, test, producing and maintenance experience and practice in nuclear weapons, it can be realized quickly and facilely without any difficulties), the highly-restricted data of warhead numbers, possible uploading to generate military significance (with intact warhead), and long developing, producing, deploying, and dismantling history, plus the association with fissile materials.

[178] "Verification of Nuclear Disarmament: A presentation by the United Kingdom", Strides along the road of Practical Step 13, A presentation to accompany the UK Working Paper Verification of Nuclear Disarmament: First interim report on studies into the verification of nuclear warheads and their components, British Crown Copyright, 2003; Eric R. Gerdes, Roger G. Johnston and James E. Doyle, "A Proposed Approach for Monitoring Nuclear Warhead Dismantlement", *Science and Global Security*, Vol. 9, 2001, pp.113-141; G. Kiernan, M. Percival, L. Bratcher, "Transparency in Nuclear Warhead Dismantlement - Limited Chain of Custody and Warhead Signatures," paper presented at the 37th Annual Institute of Nuclear Materials Conference, Naples, Fla., July 28 – August 1, 1996; and the Introduction Provision of "A summary report by the ministry of defence on the study conducted by the Atomic Weapons Establishment Aldermaston into the united kingdom's capabilities to verify the reduction and elimination of nuclear weapons", available at http://www.mod.uk/publications/nuclear_weapons/verification.htm

implement the task.

Figure 2. The key points to maintain the continuous knowledge of reduced nuclear warhead by chain-of-custody



Sources: "Verification of Nuclear Disarmament: A presentation by the United Kingdom", Strides along the road of Practical Step 13, A presentation to accompany the UK Working Paper Verification of Nuclear Disarmament: First interim report on studies into the verification of nuclear warheads and their components, British Crown Copyright, 2003; James E. Doyle and Sharon L. Seitz, "Applied Monitoring and Transparency Initiatives for Nuclear Weapon and Fissile Material Reduction", LA-UR-01-3607

The chain-of-custody method for nuclear warhead reduction verification includes the use of photography (optical pictures, x-ray, or ☐-ray images), video or visual surveillance, tags and seals, nuclear warhead authentication (nuclear or non-nuclear detection and confirmation), and information processing (encryption and decryption, data compression, data transmission and relay, etc.). All of these technologies will be integrated into a seamless network in order to increase the confidence of nuclear warhead reduction. This would also assure that the limit on the number of deployed nuclear warheads would not be breached. The chain-of-custody can be divided into two categories: (1) limited chain-of-custody aiming at a specific facility or reduction procedure and (2) full-range chain-of-custody that keeps continuous knowledge of the whole reduction process and total nuclear warhead numbers.

IAEA has designed and utilized chain-of-custody widely in its safeguarding nuclear materials including facility and material containment/surveillance (visual check, video, tags and seals), nuclear material protection, control and accountability, and nuclear detection.[179] The chain-of-custody for nuclear facilities and activities has proven effective in preventing the diversion of known or declared nuclear materials, allowing them to be monitored.[180]

[179] Pierre Goldschmidt, "The IAEA safeguards system moves into the 21st century", Supplement to the IAEA Bulletin, vol. 41, NO. 4/december 1999; "IAEA Safeguards: Stemming the Spread of Nuclear Weapons", IAEA 2001 Annual Report "Nuclear Security & Safeguards,"IAEA Bulletin, Vol. 43, No. 4, 2001; IAEA Annual Report 2001, pp.95-103; "The IAEA Safeguards System: Ready for the 21st Century", IAEA; and INFCIRC/153 (Corrected)
[180] Michael Farnitano, et al., "Reengineering the Development of Safeguards Equipment: Process Change Driven by Experience", INMM-42

In fact, a chain-of-custody for every nuclear warhead has been established by each NWS for its own nuclear warhead production, dismantlement, maintenance, and refurbishment. But imposing bilateral, multilateral, or even international monitoring over the nuclear warhead stockpile is quite different from that of domestic execution for both political and technical reasons. The technologies used by a country to monitor its own nuclear warheads need not prevent the collection of sensitive information. It can be quite complicated to assure the confidence of nuclear warhead reduction on the condition of not divulging the sensitive information.

There also are difficulties in establishing either limited or full-range chain-of-custody. Of course, the full-range is more intricate and troublesome, but the intrinsic natures of the two kinds of chain-of-custody are the same. Difficulties include: (1) the difficulty of avoiding compromising sensitive information and national security while providing high confidence of the non-diversion of nuclear warheads; (2) the co-existing process of both reduction and stockpile management that makes either limited or full-range monitoring and tracking procedures more complicated and time-, labor-, cost-consuming; (3) the integration of the most advanced technologies and their durability and reliability;[181] and (4) the possible acceptance of such chain-of-custody by the nuclear countries.

The US and Russian arms control experts have done much work in discussing, developing, and integrating possible advanced technologies into a flawless chain-of-custody over nuclear warhead reduction.[182] US weapon labs have demonstrated several limited chain-of-custody systems such as an Integrated Monitoring and Surveillance System designed for ORNL, Integrated Monitoring and Review System, Integrated Facility Monitoring System and Magazine Transparency System developed by LANL, Material Monitoring System and Cargo Monitoring System developed by SNL, and etc.[183] There is also cooperation among the United States and Russia to develop the limited chain-of-custody technologies targeting specific nuclear facilities or processes.[184] All of these limited chain-of custody systems have some capability to integrate advanced nuclear and non-nuclear sensors and detections; multiple tamper indication

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[181] The video surveillance system based upon DCM-14 and other instruments, which is widely used by IAEA in international nuclear safeguards area, has to resolve the reliability problem in order to facilitate its utilization (see M. Aparo, G. Hadfi and J. Whichello, “Implementation of Digital Image Surveillance: Problems and Solutions”; and J.S. Kraus, et al., “LIFE CYCLE RELIABILITY FOR IAEA INSTRUMENTS”, INMM-43).

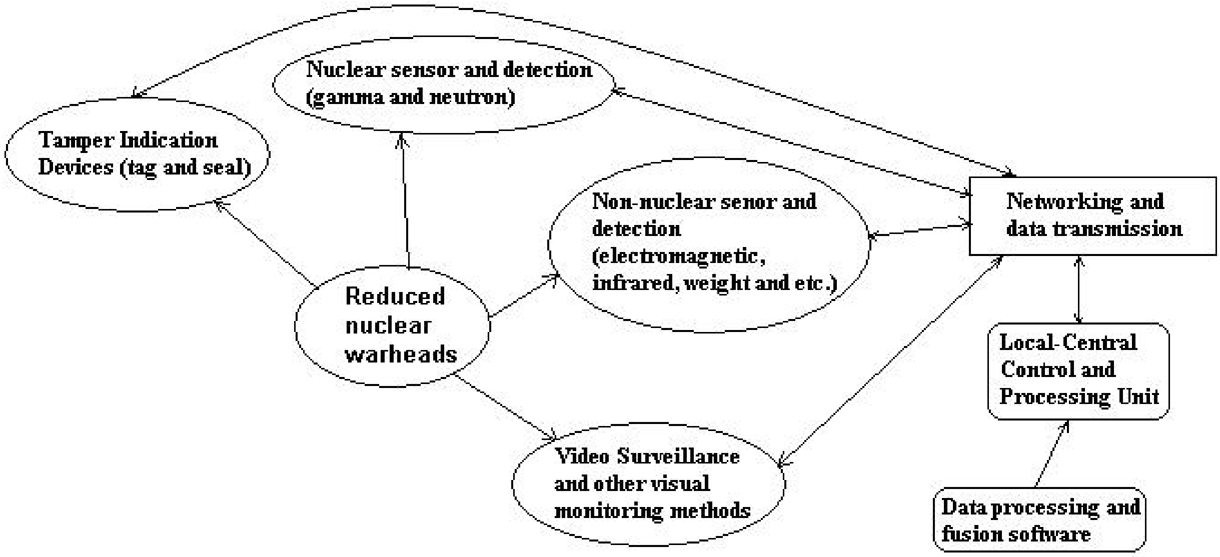
[182] Department of Defense,"CTR Overview," Feb. 10, 1995, p. 8;

[183] Dale Kotter, et al., “Integrated Sensor Systems for Packaged SNM Monitoring and Surveillance”; available at http://amtl.iwapps.com/pdfs/1998/00000222.PDF; James K. Halbig, et al., “Integrating Surveillance and Radiation Detection Technologies”, available at http://amtl.iwapps.com/pdfs/1999/00000310.pdf; James E. Doyle and Roger G. Johnston, “Report to the Joint DOD/DOE Integrated Technology Implementation Plan Steering Committee on the Integrated Facility Monitoring System (IFMS) and Magazine Transparency System (MTS)”, LA-UR-00-1671; Lawrence Desonier, “SNL Material Monitoring System: Sensor Configurations and Latest Applications”, available at http://amtl.iwapps.com/pdfs/2000/00000198.pdf; Robert Kinzel, et al., “Update of Project Straight-Line, a Comprehensive Nuclear Material Monitoring System”, available at http://amtl.iwapps.com/pdfs/1997/0059.PDF; William Pregent and Suzanne Kelly, “Tracking and Monitoring Nuclear Materials During Transit”, available at http://amtl.iwapps.com/pdfs/1999/00000177.pdf; Douglas Smathers and Dennis Mangan, “Non-Intrusive Long-Term Monitoring Approaches”, available at http://amtl.iwapps.com/pdfs/1998/00000221.PDF

[184] Greg Mann, et al., “Weapon Storage Technology Demonstration Facility”, available at http://amtl.iwapps.com/pdfs/2000/00000182.pdf; Vladimir A. Bychkov, et al., “Image Processing for Arms Control Monitoring at Nuclear Facilities”, available at http://amtl.iwapps.com/pdfs/2000/00000255.pdf; Chris A. Pickett, et al., “Automated Systems for Unattended Weight and Item Monitoring at Kurchatov Instutute in Moscow, Russia”, available at http://amtl.iwapps.com/pdfs/1999/00000005.pdf;

devices; video surveillance; and computer network with complicated data transmission, processing, encryption, and fusion.

Figure 3. Prototype limited chain-of-custody system



During the execution of the CTR program, chain-of-custody had been successfully implemented to denuclearize the Soviet successor states. This included the transfer of over 2,000 weapons and their components to Russia, safe storage of fissionable material, and the transfer of 600 kg of HEU from Kazakhstan to the United States.[185] During INF and START reductions, chain-of-custody had been carried out in order to assure the destruction of agreed nuclear-capable missiles by monitoring the transportation, dismantlement and disposition of reduced or prohibited missiles from deployed sites to destruction sites.[186] All of these activities provide valuable experience for future implementation of chain-of-custody in nuclear warhead reduction.

Although it has many political and technical difficulties, the chain-of-custody will inevitably constitute the basic element of a nuclear warhead reduction verification regime. The most beneficial part of the chain-of-custody method to nuclear warhead reduction is that the high confidence monitoring and accessing procedure could be involved at every step of the reduction. In theory and practice, chain-of-custody is a crucial tool to ensure irreversible nuclear warhead reduction.

3.5 PPCM

Perimeter and Portal Continuous Monitoring (PPCM) is categorized as one type of OSI for verifying arms control treaties;[187] it is also a useful tool to protect controlled items and resources

[185] Detailed discussion can be found at website - http://www.nti.org/db/nisprofs/russia/forasst/ctr/chaincus.htm, http://www.dtra.mil/ctr/02object.html, http://www.defenselink.mil/pubs/ctr/reduces.html, Chapter 7 - *Cooperative Threat Reduction* of "1997 Annual Defense Report", DOD and James E. Goodby, "Dismantling the Nuclear Weapons: Legacy of the Cold War"
[186] Trevor Findlay, "Verification at low/zero levels of Nuclear Weapons: What will it take?"
[187] OTA-ISC-479, "Verification Technologies: Measures for Monitoring Compliance with the START Treaty - Summary",

such as nuclear materials, weapon systems, etc. The purpose of PPCM is to guarantee that only agreed items move into and out of monitored places. It is a very special OSI method for arms control verification, that allows the permanent or long-term existence of inspection on the related sites under the terms of a treaty and can be regarded as limited chain-of-custody method. In nuclear arms control treaties, it is an effective means to ensure that no non-compliant activities take place across the fenced border.

PPCM has been successfully implemented under several nuclear arms control agreements including INF and START, US-Russia CTR and MPC&A programs. The confidence established through monitoring the items into and out of the PPCM sites (either component production plants or materials protection areas) is provided on the grounds that there are no treaty violations or diversions of nuclear materials that have occurred through the portal and perimeter.

During the verification implementation process of INF, the United States and USSR had set up the PPCM system at each other's specific missile components production plant or missile final assembly plant. The United States constructed the PPCM system with the resident American officers at Votkinsk Machine Building Plant in the USSR. Reciprocally, USSR inspectors monitored the Hercules Plant No. 1 (now called Alliant Plant No. 1) in Magna, Utah.[188] Both PPCM systems utilized observation, physical measurement methods, perimeter fences, intrusion detectors, and video monitoring for objects coming into and exiting the plant. Specifically, at Votkinsk, the United States adopted the radiographic imaging system (CargoScan) to check that the canisters on the railcars exiting the plant did not hold prohibited SS-20 missiles.[189] The PPCM system for INF increased confidence that both the United States and USSR/Russia had complied with the INF treaty obligations. The INF was the first nuclear arms control agreement to introduce the PPCM for treaty verification.

Like INF, during the verification implementation process of START, both the United States and Russia agreed to conduct PPCM at each other's designated missile production or assembly plant.[190] The two former Soviet missile assembly plants were the Votkinsk Machine Building Plant in Russia for SS-25 ICBM assembly and a plant in Pavlohrad, Ukraine for SS-24 ICBM assembly. With those measures undertaken by the INF treaty, the US inspectors were permitted to observe and physically measure all vehicles exiting the Votkinsk and Pavlohrad plants. Inspectors were also permitted to inspect the interior of vehicles large enough to contain an item of continuous monitoring. Unlike operations under INF, START did not allow for non-destructive radiographic imaging. Monitors still measured the size of missile containers and visually inspected each canister. Additionally, each SS-25 and SS-27 missile exiting the facility had a unique identifier inscribed upon it. The Russians could carry out PPCM at a Thiokol Corporation facility in Promontory, Utah, which is the former Peacekeeper missile final

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December 1990, pp.9

[188] For detailed implementation procedure of INF Continuous Portal Monitoring Inspections, see Harahan, Joseph P., *On-Site Inspections Under the INF Treaty, A History of the On-Site Inspection Agency and Treaty Implementation, 1988-1991,* (Treaty History Series, Government Printing Office, 1993), pp.67-98

[189] The treaty-allowed SS-25 missile canister, which was also assembled at the same plant, was large enough to hold treaty-banned SS-20 missiles.

[190] 104th Congress 2d Session, Report 104-246, "Capability of the United States to Monitor Compliance with the START II Treaty", March 27, 1996

assembly site; however, they have never exercised their right to do so.[191] The PPCM implementation for START verification was executed smoothly with a successful negotiation on the inspection procedures and instrumentations.[192]

The multifaceted MPC&A program, a co-operation of US DOE, Russian MINATOM, and NIS (Newly Independent States), to improve the security and control of nuclear materials, had made efforts to introduce and enhance the PPCM systems at nuclear material processing or storage sites.[193] Under CTR programs, US DOD/DTRA had provided security systems consisting of security fencing and sensor equipment in order to improve Russian nuclear weapons security status at the Russian Ministry of Defense weapons storage sites[194].

In fact, the PPCM system had been so widely used by domestic military sites,[195] including guards, intrusion detectors, and video surveillance for monitoring that no diversion, stealing or intrusion has occurred. But for nuclear arms control verification and monitoring, these highly sensitive facilities for missile production and nuclear materials storage sites must be under bilateral or multilateral inspection. The inspecting and inspected parties have to resolve the contradiction between assuring compliance and not divulging sensitive information.

Manufacturing warhead nuclear components is the most critical and difficult step in the nuclear weapon production cycle. It is impossible without highly specialized equipment and skills, and it must be conducted in safe and secure facilities that require considerable time and resources to establish components. Limits on new production of nuclear warheads and greater transparency of warhead production complexes are likely to be important elements of future deep stockpile reductions.[196] The containment/surveillance of nuclear warhead-related facilities such as those for production, maintenance, and refurbishment can catch diversion or cheating and give early warning of a dramatic increase in nuclear warhead-related activities. Thus, the establishment of PPCM around nuclear warhead-related facilities is a very important method for verifying compliance with a nuclear warhead reduction agreement.

For nuclear warhead reduction verification, PPCM systems established around sites such as storage, dismantlement, production, refurbishment, and maintenance facilities would face great technical challenges in validating that no diversion or cheating happens. The perimeter monitoring for nuclear warhead-related facilities can adopt multiple intrusion detection methods to increase the security of the facility. Portal monitoring is difficult because it has to distinguish

[191] DTRA Factsheet, "Continuous Portal Monitoring in the Former Soviet Union", available at http://www.dtra.mil/news/fact/nw_cpm_fsu.html; and "Continuous Portal Monitoring Under the Strategic Arms Reduction Treaty (START)", available at http://www.dtra.mil/news/fact/nw_cpm.html

[192] US State Department, "Adherence To and Compliance With Arms Control Agreements", Annual Report, 1996-2001

[193] DOE nuclear material security task force, "Partner for Nuclear Security: United States/Former Soviet Union Program of Cooperation on Nuclear Material Protection, Control, and Accounting", December 1997

[194] DTRA Factsheet, "Cooperative Threat Reduction Program", available at http://www.dtra.mil/news/fact/nw_ctr.html; and Charles L. Thornton, "The Nunn-Lugar Weapons Protection, Control, and Accounting Program: Securing Russia's Nuclear Warheads", *Presented at the 43rd Annual Meeting of the Institute for Nuclear Materials Management*, 26 June 2002, Orlando, Florida

[195] "Perimeter Protection Products Get Renewed Look", available at http://www.securitymagazine.com/; "The Next Generation Perimeter Security Systems", available at http://www.americanaimpex.com/perimeter_detection.htm; and Marcelo Medina, "A Layered Framework for Placement of Distributed Intrusion Detection Devices", George Washington University, Washington, D.C.

[196] Oleg Bukharin, "Transparency of Reductions in Pit Manufacturing Capacity", INMM-43

the incoming and outgoing nuclear warhead and corresponding components and determine whether they are allowed or prohibited. US and Russian experts have strived to reach the goal of authenticating the specific type or category of nuclear warhead; however, all technical means available require considerable sensitive information for reasonable confidence. Although many measures have been developed to protect sensitive information while validating nuclear warheads, there are still a substantial number of technical problems to be resolved. The PPCM system around nuclear warhead-related facilities will also create a significant impact on the normal operation of the facility.[197]

The PPCM system for nuclear warhead facilities has unique characteristics different from those used in the past for nuclear capable delivery reduction, nuclear material surveillance/containment (such as the US/Russia MPC&A program), and domestic critical resources or military bases protection:

It would be extremely intrusive to apply to a nuclear warhead facility, because the system must reliably detect small-sized nuclear warheads and their components at the portal in order to assure no diversion or illegal movement of nuclear warheads. The tension between confident detection and the protection of sensitive information must be managed.

Inspection would continue indefinitely until high confidence is achieved that no nuclear activities will occur in the monitored facility. Even for closed nuclear warhead facilities, PPCM systems would still be in use to make sure that activities do not resume until it is confirmed that the facilities can be no longer used for nuclear warhead activities.

The probable goal for near future nuclear warhead reduction is to limit and reduce the total number of nuclear warheads rather than to ban a specific type of nuclear warhead.[198] Therefore, the co-existence of allowed operations for nuclear warheads (allowed stockpile stewardship) and monitoring of the dismantling of reduced nuclear warheads in the same facility not only has an unprecedented impact over the facility operation for stockpile stewardship, but also makes the implementation of PPCM intricate and hard to negotiate. It is, then, a prerequisite that a list of the exact number of total nuclear warheads by types should be exchanged in advance.

PPCM can effectively block the illegal movement of nuclear warheads in and out of the monitored facility with advanced nuclear and non-nuclear detecting technologies and appropriately designed monitoring procedures while at the same time not breaching national-security information. This will then make the nuclear rearmament more difficult since reconstitution would require building a covert facility in order to accomplish the

[197] US Pantex plant is now responsible for DOE warhead stockpile management. If it were used for nuclear warhead reduction (dismantlement) activities with establishment of PPCM around its perimeter and leaving only very limited portal for items in-and-out, the allowed warhead activities would be inevitably affected.

[198] Under the instance of US, it has a huge stockpile stewardship program to keep the security, safety and reliability of its nuclear stockpile consisting of seven primary nuclear warhead types (the original type and its developed variants) (see "The Stockpile Stewardship and Management Program: Maintaining Confidence in the Safety and Reliability of the Enduring US Nuclear Weapon Stockpile", US Department of Energy, Office of Defense Programs, May 1995, available at http://www.fas.org/nuke/guide/usa/doctrine/doe/st01.htm), it seems impossible for US to totally give up all nuclear warheads of a specific type in fear of single-point failure. This status would bring many troubles and complex to verify the reduction of nuclear warhead, particularly the allowed operations and reduced procedures would probably appear in the same facility.

production and maintenance of nuclear warheads.

3.6 Cooperative monitoring

Cooperative monitoring for arms control is the method for bilateral or multilateral parties of an arms control treaty to jointly monitor the treaty implementation and to share the information through monitoring or detecting instruments. CM involves two parts: (1) the utilization of co-developed monitoring systems to scrutinize the on-going activities of the arms control treaty obligation (All the technologies used in the cooperative monitoring should be permitted, acknowledged, and shared by all treaty members in advance or before their application in the monitoring activities.) and (2) the collective collection, analysis, and sharing of the obtained information among the parties to the treaty. The treaty parties should have the equal right to possess the data and information acquired by the monitoring system; though final judgment may be different, the transparent original data can be very helpful for open discussion of treaty compliance.[199]

There is a wide range of measures and technologies available to form different levels and options for arms control cooperative monitoring.[200] Measures include remote collective monitoring; cooperative aerial inspection; PPCM; wide-area military activity monitoring; [201] technologies including various individual nuclear (neutron, gamma, x-ray and etc.) or nonnuclear (weight, infrared, microwave, seismic, magnetic, acceleration, and etc.) detectors; integrated or combined sensor modules; data encryption/decryption, transmission, and processing; information networks; wired or wireless communication links; video or optical picture recording, processing, and analysis; commercial satellite imagery analysis; etc.[202] All of these technologies have to be demonstrated and authenticated carefully to ensure that they are appropriate for the agreed-upon monitoring objective and will not divulge sensitive information or compromise national security.

Cooperative monitoring can be executed efficiently by monitoring strategy and to determine specific activities; which part of the facility, and to what level can be jointly monitored by use of applicable systems, and the exchange of data and specific characteristics on monitored items.

Unlike the verification that relied mainly on nationally-owned measures during the Cold War, cooperative monitoring is becoming a regular feature of future international arms control agreements.[203] During the implementation of the CFE and Open Skies Treaty, NATO and the

[199] "Verification in all its aspects, including the role of the United Nations in the field of verification", the report of the Secretary-general to the UN General Assembly, A/50/377, September 22, 1995, pp.74
[200] Arian Pregenzer, "The Cooperative Monitoring Center: Achieving Cooperative Security Objectives through Technical Collaborations", in J. Marshall Beier et al., "Verification, Compliance and Confidence Building: the Global and Regional Interface", pp.89-91
[201] Waheguru Pal Singh Sidhu and Jing-Dong Yuan, "Cooperative Monitoring for Confidence Building: A Case Study of the Sino-Indian Border Areas", (Cooperative Monitoring Center Occasional Paper #13, SNL), pp.17-19 and Appendix G
[202] The Cooperative Monitoring Center of SNL has developed many innovative cooperative monitoring technologies and prototype systems for experiment and demonstration aiming at different objectives for international or regional security. Nearly all these technologies and systems can be exported abroad and shared internationally. See the website of CMC at http://www.cmc.sandia.gov/; and Gerald M. Steinberg, "The role of satellites in cooperative monitoring"
[203] OTA-ISC-488, "Verification Technologies: Managing Research and Development for Cooperative Arms Control Monitoring Measures", May 1991

USSR/Russia exchanged and verified a large amount of conventional military information using cooperative monitoring methods.[204] In the INF and START verification procedures, both the United States and USSR/Russia utilized cooperative monitoring such as technical characteristics exhibition, baseline inspections, and PPCM.

For cooperative monitoring of nuclear materials and storage of nuclear warheads, US DOE labs and Russian MINATOM labs have made great progress in the last few years by jointly developing and demonstrating feasible cooperative methods and technologies.[205] During the negotiation of the Mayak Transparency, Trilateral Initiatives, and Plutonium Disposition, many US, Russian, and IAEA technical experts preferred using the cooperative monitoring method to prevent the illegal movement of fissile materials and to enhance mutual trust and confidence.[206]

The cooperative monitoring approach nuclear warhead reduction verification is a high priority for several reasons:

- It is relatively easily accepted by NWS, because these cooperatively developed systems and technologies have no unwanted or hidden functions that would breach sensitive information during the monitoring process. In particular, the monitoring system is composed of commercially available devices whose functions are well understood by the monitored party or have been proven by past nuclear arms control treaties.
- To the country with very limited national technical means, the cooperative monitoring method would become a very useful tool to verify the other party's compliance and to increase confidence in nuclear warhead reductions
- It is a very useful way to increase the transparency of nuclear warhead reductions. Cooperative monitoring can greatly improve confidence in treaty compliance and improve relations among treaty members by reducing suspicions and uncertainties during treaty implementation.

Cooperative monitoring technologies and systems should be robust enough to prevent cheating, counterfeiting, or substitution since the technologies and systems (including the monitoring layout or procedures used by cooperative monitoring) are transparent to all the treaty parties. Cooperative monitoring cannot make the final decision of treaty compliance without the help of other verification measures such as NTM or OSI. Because of the ultra sensitivity of nuclear warhead-related facilities and activities, it is impossible to use cooperative monitoring to cover every detail of nuclear warhead reduction process. However, the cooperative monitoring measure should be applied throughout the key points from the cradle-to-grave of nuclear warheads in

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[204] "World Armaments and Disarmament", SIPRI Yearbook 1993, pp.606-617, 632-634 and Appendix 12C; Amy E. Smithson, "Open Skies ready for takeoff"; and J. Altmann, "Cooperative Monitoring of Limits on Tanks and Heavy Trucks using Acoustic and Seismic Signals - Experiments and Analysis", 5th Battlefield Acoustics Symposium, Ft. Meade MD, USA, 23-25 September 1997

[205] C. Dennis Croessmann, et al., "SNL/VNIIEF Sotroage Monitoring Collaboration", available at http://amtl.iwapps.com/pdfs/1999/00000133.pdf; Robert L. Martinez, et al., "American-Russian Remote Monitoring Transparency Program Accomplishments During the Past Year", available at http://amtl.iwapps.com/pdfs/1997/0190.PDF; and Thomas Lockner, et al., "Progress towards Complimentary Cooperative Monitoring Facilities at the Savannah River Site, USA and VNIIEF, RF", available at http://amtl.iwapps.com/pdfs/2000/00000183.pdf

[206] Matthew Bunn, "Introduction: Monitoring Nuclear Stockpiles and Reductions", available at http://204.71.60.38/e_research/cnwm/monitoring/index.asp, last updated by Matthew Bunn on October 28, 2002

order to maximize mutual trust in reduction.

3.7 Societal verification[207]

Societal verification is a system of monitoring compliance with treaties and detecting attempted or existing violations by means of an individual citizen's or a group of citizens' voluntary efforts other than treaty-specified or national intelligence means. Societal verification is diverse: (1) "Citizen's reporting" is the main form, encouraging citizens of the treaty signatories to report to an appropriate international authority any information about violations in their countries. (2) "Whistle blowing" finds clues of noncompliance by analyzing available public information. Scientists, highly-skilled experts, and workers who could be involved in treaty violations can be reminded of their loyalty to humankind and, through domestic or international laws, encouraged to report any violations of international arms control treaties. (3) Non-governmental organizations can play a role in monitoring arms control implementation and noncompliance tracking.[208]

The right of individuals to disclose violations of treaty obligations to the international community is becoming increasingly recognized and can be a meaningful addition to more traditional verification methods. Societal verification can reveal otherwise unknown violation activities. Even in a dictatorial regime, the government cannot absolutely guarantee that persons with knowledge of clandestine activities would not expose the information to the international community. For example, in 1991, the son-in-law of Iraqi President Saddam Hussein, General Hussein Kamal Hassan, disclosed Iraqi calutron purchases and other clandestine nuclear and biological weapon activities; Russian chemist Vil Mirzajanow reported the secret chemical weapon activities of the former Soviet Union; and German Nobel Peace Prize Laureate, Carl von Ossietzky, a journalist and writer in the 1920s and 1930s, disclosed secret military cooperation between the German army and the Soviet authorities, violating international agreements concerning disarmament measures in the 1919 Versailles Peace Treaty.

Societal verification can influence policy and, in some cases, the ethics of the scientific and engineering community. For example, in 1987, the Committee on the Military Use of Biological Research of the Council for Responsible Genetics led by M.I.T. biologist Jonathan King organized a petition campaign and collected more than 1,000 signatures of scientists who pledged they would not participate in biological weapons work. A proposed code for scientists and

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[207] This section is based on the following reference: Joseph Rotblat, "Societal Verification," in Joseph Rotblat, Jack Steinberger, and Bhalchandra Udgaonkar, eds., *A Nuclear-Weapon-Free World: Desirable? Feasible,* (Westview Press) 1993, pp.103-118; Dieter Deiseroth, "Societal Verification: Wave of the Future?", in *Verification Yearbook 2000,* pp.265-280; Oliver Meier and Clare Tenner, "Non-governmental monitoring of international agreements", in *Verification Yearbook 2001,* pp.208-227; Trevor Findlay, "The Verification and Compliance Regime for a Nuclear Weapon-Free World", Briefing on UK Nuclear Weapons Policy, No. 2, November 1999; The Canberra Commission on the Elimination of Nuclear Weapons, "Verification in a Nuclear Weapon Free World"; Trevor Findlay, "Verification at low/zero levels of Nuclear Weapons: What will it take?", paper presented to *IAEA Regional Seminar on the Protocol Additional to Nuclear Safeguards Agreements,* Lima, Peru, 4 - 7 December 2001; Tim McCarthy, "Intelligence in arms control and disarmament", in *Verification Yearbook 2000,* pp.250-263; and Lester G. Paldy, "A Code of Ethics on Arms R&D for Scientists and Engineers", paper presented to the Sixth ISODARCO Beijing Seminar on Arms Control, October 29-Novermber 1, 1998

[208] For instance, SIPRI played an important role in organizing the verification systems of CWC; the Internationa Committee of the Red Cross had made great efforts in promoting the Ottawa Convetion banning anti-personnel landmines and etc. (see Oliver Meier and Clare Tenner, "Non-governmental monitoring of international agreements", in *Verification Yearbook 2001,* pp.210)

engineers can be stated:

> Scientists, engineers, and scientific and technical professionals should not participate in any research and development or scientific or technical support activity in violation of international arms control agreements to which their nations are signatories.

The effect of societal verification would be greatly reinforced if production and use of weapons of mass destruction constituted a personal crime under international law. Under this circumstance, there would be a strong incentive for individuals not to participate in or support state weapons of mass destruction programs and an incentive for whistle blowing particularly by persons who might otherwise be implicated in illegal activity.

Access to relevant information is crucial for societal verification. Thus, to promote freedom of information (records in the possession of public agencies and departments of the executive branch are accessible to citizens), would exert effective deterrence to clandestine activities. Those requiring access to the publicly available information should no longer be demanded to prove that they are qualified to obtain the data and have a special need for it. Instead, the "need to know" standard must be replaced by a "right to know" doctrine. The government or head of the relevant public agency must be required to justify the legally protected need for secrecy (for instance, properly classified documents, internal personal rules and practices, confidential business data, internal government communications, personal privacy, and law enforcement).

But societal verification has its intrinsic disadvantages: (1) Citizens' reporting and whistle blowing are often suppressed, fragmented, unpredictable, unreliable, and ineffective (Warnings could be either out of date or too late, coming after the violation becomes militarily significant.). (2) Limited access to information and locations, particularly secret official information and militarily significant bases, prevents societal verification from acquiring consistent and consolidated proof of violation activities. (3) The lack of advanced technology and resources can result in limited capabilities for monitoring the activities of a treaty's practice and reporting. (4) The bias from different political foci may induce a misleading conclusion. In some cases, it can be manipulated and used by governments.

To make social verification more effective, the following steps are helpful: (1) The legal right of all citizens and citizen groups to engage in societal verification needs to be guaranteed by each international agreement and by the legal system of each state party. (2) Explicit legal protection against reprisal and criminal prosecution should be established for all persons reporting violations or attempted violations of an international agreement. (3) The right to raise funds for citizens' verification purposes, within and outside the country, must be guaranteed so that citizens groups can obtain financial resources for their work. (4) Regulations concerning freedom of information and openness in science should be promulgated.

The tide of globalization and the revolution of information technology can enhance non-proliferation and arms control regime positively through quick and wide dissemination of information, promoting transparency, and empowerment of anti-WMD efforts. Governments are finding it increasingly difficult to control the flow of information in and out of their territory, providing a boost for democracy, advocacy, and unofficial monitoring. Societal verification, so long regarded as utopian and naïve, will be facilitated by such developments.

4. The nuclear warhead reduction verification and monitoring technologies

The life cycle of a nuclear weapon includes four phases: (1) research, development and testing; (2) production and assembly of components; (3) operational deployment and maintenance; and (4) retirement, dismantlement, and disposition of components and materials. A comprehensive nuclear warhead verification regime should cover the above four procedures with high confidence, especially during the deep reduction period. The various verification or monitoring systems should be developed across a broad technological spectrum, to provide a large number of verification options and thereby increase the chance that nuclear warhead reductions can be verified with high confidence.

As early as 1967, the US government began to study the feasible monitoring methods and technologies to verify the destruction of nuclear warheads and to conduct field tests that evaluated the extent, effectiveness, and practicality of warhead elimination verification. The government also identified operational, technical, classification, safety and security problems during the destruction procedures.[209] Because of technological limitations (such as simple gamma-ray and neutron detection),[210] poor data analysis, and other procedural limitations, confidence in verifying the elimination of nuclear weapons was relatively low (Table 5). With the development of modern technologies, particularly the application of advanced radiation detection technologies and data analysis methods, confidence in nuclear warhead authentication has greatly improved. For example, it is now possible to distinguish genuine warheads from fake nuclear warheads with high confidence, and it is also possible to distinguish among warheads of different types.[211] It should be noted, however, that this higher confidence is obtained only with more expensive and intrusive technologies and with a greater degree of transparency between the treaty parties.[212]

Table 5. The credibility of nuclear weapons' detection during Field Test FT-34

Access level	Percentage of fake nuclear warheads detected	
	By ordinary inspectors	By weapon experts
Access level 1: external inspection, no radiation instruments, materials assay	0	15
Access level 2: looking in warhead access doors and running Geiger	20	25

[209] US Arms Control and Disarmament Agency, "Field Test FT-34: Demonstrated Destruction of Nuclear Weapons (U)", Final Report – Volume 1, January 1969

[210] During the Field Test FT-34 conducted by US ACDA in 1967, the chemical analysis was used to determine the fissile materials assay instead of nowadays-prevailing high-resolution gamma-ray spectrum or neutron multiplicity counting (Ibid).

[211] Richard L. Garwin, "Technologies and procedures for verifying warhead status and dismantlement", in Nicholas Zarimpas, ed., *Transparency in Nuclear Warheads and Materials: the Political and Technical Dimensions,* SIPRI book from Oxford University Press, 2003, pp.156-157

[212] "Confidence, Security & Verification: the Challenge of Global Nuclear Weapons Arms Control", Atomic Weapons Establishment, Aldermaston, 2000, pp.9

counters over their surfaces		
Access level 3: using neutron counters and gamma spectrometers	20	25
Access level 4: inspection of X-ray plates of the warheads	55	60

Sources: Frank von Hippel, "The 1969 ACDA Study on Warhead Dismantlement", Occasional Paper, *Science & Global Security*

The technologies for verifying nuclear warhead reductions can be divided into four categories:

- Warhead authentication technologies, ranging from nuclear detection (e.g., high-resolution gamma energy spectrum, neutron multiplicity counting, active neutron induced coincidence counting, gamma ray imaging, and nuclear archaeology) to non-nuclear methods (e.g., calorimetry, electro-magnetic (EM) coil, x-ray scanning and radiography, acoustic resonance or response, thermal flow, and millimeter wave);
- Warhead continuous knowledge tracking technologies, including simple nuclear radiation detection, tags and seals, video and image surveillance, global position system (GPS), information transmission and processing, data encryption and decryption, and advanced nuclear and non-nuclear micro and effective detectors;
- Physical protection technologies such as various intrusion detectors (e.g., microwave, infrared, optical, and motion); and
- Warhead dismantlement and disposition technologies including hydro-cutting, pit-stuffing, immobilization, and metal oxide (MOX) conversion.

Verification of nuclear warhead reductions cannot be considered merely a technical challenge or a political process; it must be treated as an interaction of technology and politics to persuade parties to agree to and abide by treaty obligations. The technology could be a very strong force that can fulfill or block nuclear arms control agreements and a powerful tool to settle disputes over compliance issues. For example, during the negotiation and implementation of INF and START, because of comprehensive technical capabilities such as high-resolution reconnaissance satellite to assure "effective verification," the treaties were executed relatively smoothly with high confidence compared with the many censures over compliance issues during the SALT and ABM period. During the CTBT negotiations—and now with the preparation of the verification provisions—the lack of the full combination of appropriate and effective technologies is a barrier to treaty implementation. While advanced technologies provide unprecedented opportunities for verifying nuclear warhead reductions, they also face various challenges such as the trade-off between confidence, intrusiveness, acceptability, and cost.

Both the United States and Russia have developed many technologies to monitor the elimination of nuclear weapons, either for domestic use or in the context of an international agreement.[213] In

[213] For example, US DOE ORNL had developed NMIS (NWIS) many years ago (since 1984), which was first used in domestic safeguards and now has wide application in nuclear arms control particularly in nuclear warhead authentication (see T. E. Valentine, J. T. Mihalczo, et al., "NWIS Signatures for Identification of Weapons Components at the Oak Ridge Y-12 Plant"). US DOE BNL had done a lot of work on its CIVET system, which was proved to be very useful in template measurement for nuclear warhead (see Walter R. Kane, James R. Lemley and Leon Forman, "The Application of High-Resolution Gamma-Ray Spectrometry (HRGS) to Nuclear Safeguards, Nonproliferation, and Arms Control Activities"). US DOE SNL had illustrated its TRADS for nuclear warhead and materials authentication (see Dean J. Mitchell and Keith M. Tolk, "Trusted Radiation Attribute Demonstration System"). And US DOE LANL and LLNL successfully established and demonstrated AMS/IB system to measure the attributes of nuclear warhead or fissile materials before a Russia delegation (see FMTTD website: http://www-safeguards.lanl.gov/FMTT/index_main.htm). The Russians also utilized "passport" system in its domestic nuclear safeguards and now can be converted to nuclear warhead verification utilization (see Thomas R. Rutherford, John H. McNeilly and Matthew A. Hartline, "Implementation of Transparency Technologies at the Mayak Fissile Material Storage Facility",

recent years, under various US-Russia agreements over fissile materials (HEU Purchase Agreement, Mayak Transparency, Plutonium Disposition Agreement, Plutonium Production Reactor Agreement, Trilateral Initiative with IAEA) and the CTR and lab-lab programs, many of the technologies, methods, processes and protocols have been collaboratively developed to solve the problems encountered in the nuclear warhead reduction.[214]

Unlike past nuclear arms control practices aiming at operational nuclear forces in which verification depended on mature technologies[215] (particularly for OSI application), NTM, and monitoring procedures, the verification of nuclear warhead reduction relies more heavily on advanced and intrusive technologies and procedures. This is because of the characteristics of nuclear warheads, such as their small-size, high proliferation risk, national security concerns, and safety and hazard problems. Innovative and feasible technologies would push irreversible nuclear warhead reductions forward.

While confidence in verifying nuclear warhead reductions requires the unprecedented application of intrusive and advanced technologies, the problems of protecting sensitive information and minimizing proliferation risk should be resolved in advance to ensure the acceptability and implementation of a nuclear warhead reduction regime. Many proposals and new concepts include the utilization of information barriers and managed access. There are still numerous technical and verification procedure problems required to do more in-depth research.

The development of technology can finally accomplish the verification task for nuclear warhead reduction; this requires the closer and broader cooperation of technical experts from all over the world to push nuclear warhead reductions forward.

4.1 Nuclear detection and measurement technologies

Nearly all strategic thermonuclear weapons have two stages: primary and secondary (Figure 4). The primary, composed of a pit, high explosive (HE), neutron generator, D-T gas, an arming, fusing and firing system (AF&F), and structural materials, is the trigger that provides enough energy to ignite fusion reactions in the secondary. Thus, the main purpose of irreversible nuclear warhead reduction verification is to confirm the elimination of the primary. Of the primary components, the pit is the most important and most difficult to produce and the most expensive focus of verification efforts for irreversible nuclear warhead reduction.

Figure 4. The configuration sketch of a modern two-stage nuclear warhead

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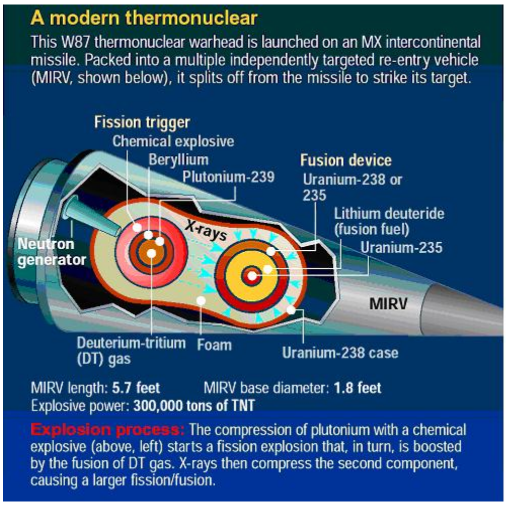
INMM-42)

[214] Andrew J. Bieniawski and Paul B. Irwin "Overview of the US – Russian Laboratory-to-Laboratory Warhead Dismantlement Transparency Program: A US Perspective", Presentation to the 41st Annual INMM Conference, New Orleans, July 2000; K. N. Danilenko, et al., "A Gamma-Ray Camera for Inspection Control"; Rena Whiteson, et al., "A Prototype Inspection System with Information Barrier for the Trilateral Initiative"; Vitaly P. Dubinin and James E. Doyle, "Item Certification for Arms Reduction Agreements: Technological and Procedural Approaches"; and Thomas R. Rutherford and John H. McNeilly, "Measurements on Material to be Stored at the Mayak Fissile Material Storage Facility"

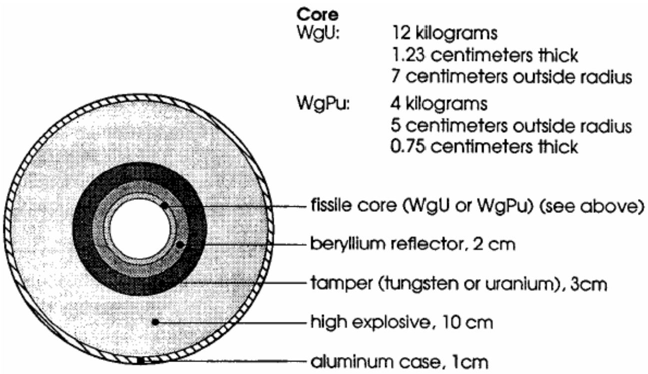
[215] For example, not only Russians but also Americans preferred to use low-tech approaches in past nuclear disarmament (see Jonathan S. Landay, "Nuclear Disarmament With Low-Tech Approach", *The Christian Science Monitor*, February 20, 1998)



Sources: Report of the Select Committee on US National Security and Military/Commercial Concerns with the People's Republic of China (Cox Report), May 1999, pp.78

The pit of a modern nuclear warhead is composed of fissile core (weapon-grade uranium or plutonium, Table 6), beryllium reflector, and tamper (tungsten or uranium). The hypothetical boosted warhead primary model is shown in Figure 5. Since the fissile core is made up of WgU or WgPu, it has an intrinsic and detectable radiation signature. Thus, radiation measurement is the main technology to detect and authenticate nuclear warheads. In 1989, the Natural Resources Defense Council (NRDC) of the United States and the Soviet Academy of Science cooperatively carried out a meaningful measurement campaign against a real Soviet nuclear-armed SLCM aboard the Soviet cruiser "Slava" on the Black Sea. The results of the measurement proved it is possible to measure nuclear warhead with high-sensitivity gamma and neutron detectors at a distance.[216]

Figure 5. The hypothetical boosted warhead primary model



Sources: Steve Fetter, et al., "Detecting Nuclear Warheads," *Science & Global Security*, 1990, Volume 1, pp. 227

Table 6. The isotopic composition of WgPu and WgU (percent)

[216] Steve Fetter, et al., "Measurements of Gamma Rays from a Soviet Cruise Missile", and S.T. Belyaev, et al., "The Use of Helicopter-borne Neutron Detectors to Detect Nuclear Warheads in USSR-US Black Sea Experiment", in Frank von Hippel and Roald Z. Sagdeev, eds., *Reversing the Arms Race: How to Achieve and Verify Deep Reductions in Nuclear Weapons* (Gordon and Breach Science Publishers, 1990), pp.379-404

	Pu-239	Pu-240	Pu-241	Pu-242	Pu-238
WgPu	93.5	6.0	0.44	0.015	0.005
	U-235	U-238	U-234		
WgU	93.5	5.5	1		

Source: Steve Fetter, et al., "Fissile Materials and Weapon Models", in Frank von Hippel and Roald Z. Sagdeev, eds., *Reversing the Arms Race: How to Achieve and Verify Deep Reductions in Nuclear Weapons* (Gordon and Breach Science Publishers, 1990), pp.295 and 297. It should noticed that the isotopic composition of weapon grade plutonium (WgPu) and weapon grade uranium (WgU) is the average estimation, the real value of the composition of fissile materials in pit can be varied a little; and it is possible to make the bomb with high-purity Pu-239 or U-235 though it is very costly.

The detection of a nuclear warhead can be divided into three categories:

- passive detection, which can deduce valuable information or acquire the fingerprint of the specifically configured nuclear warhead through measuring the escaped spontaneous radiation (gamma rays and neutrons) from the fissile core of nuclear warheads and their reaction with the surrounding materials;
- active or induced detection, which measures the induced response of nuclear warhead materials to interrogation with neutrons, gamma rays, or high-energy x-rays; and
- radiography using high-energy x-rays.

No matter what category of technology is used, it should solve the most difficult problems in nuclear warhead reduction verification and authenticate the specific type of nuclear warhead.

Because each type of nuclear warhead primary has a specific configuration, it has a unique radiation pattern that can be detected and recorded by radiation measuring systems. There are two types of methods (either active or passive): (1) the measurement of full-energy gamma spectrum with high-purity germanium detectors and associated data gathering and analysis systems and (2) the measurement of time-correlated neutron multiplicity events with multiple arrayed neutron detectors. Both are major ways to detect and authenticate nuclear warheads.

In INF verification, radiation measurements were used to distinguish between treaty-allowed one-warhead SS-25 and banned three-warhead SS-20, by making use of the fact that the neutrons emitting from multiple warheads are at a higher intensity and in a different pattern than those from single warheads.[217] In START I, radiation detectors and radiation sources could be used to confirm that an ALCM was nuclear or non-nuclear and prove that the container did not conceal the presence of radiation by neutron counter or Geiger counter.[218] This is the simplest application of nuclear radiation detection in arms control verification and its purpose is only to confirm, by counting the total number of neutrons or gamma rays, if the nuclear radiation exists or what the relative intensity of the radiation is.

For nuclear warhead reduction verification, radiation detection would be much more intrusive than that used in INF and START. For example, to verify nuclear warhead reductions, one

217 "Radiation Detection Equipment for Monitoring the INF Treaty", Cooperative Monitoring Center of DOE SNL, *INF Neutron Detector Fact Sheet,* Aug 10, 1999

218 "Annex 4 - Procedures for inspections of heavy bombers, former heavy bombers, long-range ALCMs, and their facilities", The inspection protocol annexes of START I, available at http://www.state.gov/www/global/arms/starthtm/start/inanxtoc.html#AnxTOC

should have the capability to authenticate specific types of warheads. The most advanced high-resolution gamma energy spectrum measurement, complicated neutron multiplicity counting, substantial data analysis and innovative computational methods would have to be used in order ensure high confidence in verification of nuclear warhead reduction.

Although nuclear warheads emit detectable neutrons and gamma rays, it is very complicated to authenticate a specific type of nuclear warhead. First, there are many factors that determine the detectable radiation emission from nuclear warheads, such as the mass, density, geometry, and isotopic and chemical composition of the fissile core and the materials surrounding it. Second, many factors affect nuclear warhead detection capabilities, including shielding containers, distance from nuclear warheads, size and efficiency of nuclear detectors, background radiation, settings of measurement devices (e.g., radiation pulse shaping, threshold, deadtime), and data analysis methods (e.g., gamma peak fitting and coincidence correlation). All of these technical problems should be well understood before the relevant equipment is applied to detecting nuclear warheads. US DOE national labs have done a substantial amount of work to develop the nuclear detection technologies and associated data analysis methods to authenticate nuclear warheads. They have also developed several prototype systems for nuclear warhead verification such as nuclear weapon identification system (NWIS) from ORNL, controlled intrusiveness verification technique (CIVET) from BNL, trusted radiation attribute demonstration system (TRADS) from SNL, inspection system with information barrier (IS/IB) from LANL, and Pu-300/600/900 from LLNL&LANL (Figure 6).

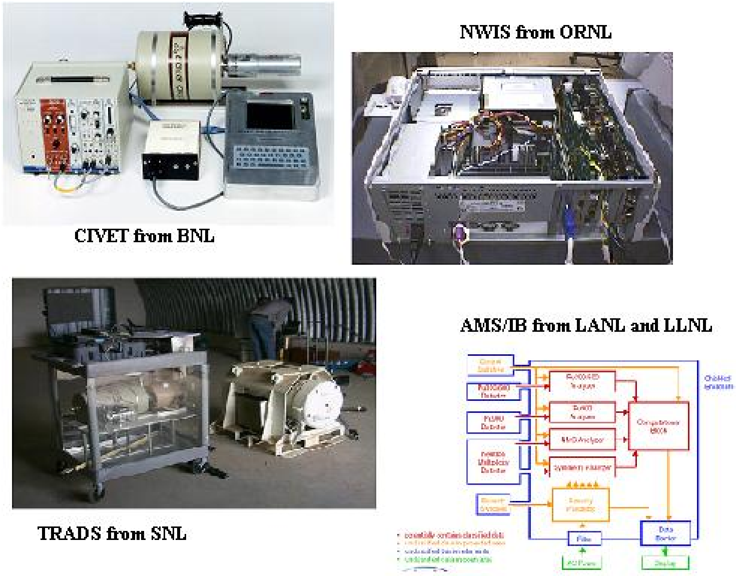
Until now, for several reasons, most of the technical nuclear warhead research on detection and authentication has been aimed at plutonium-based pits. First, all of the strategic thermonuclear warhead primaries in the existing US nuclear stockpile are plutonium-based. The situation in Russia is probably the same, because the critical mass of plutonium is less than that of uranium, decreasing the weight and size of primary. Second, plutonium pits are easier to detect than uranium, because plutonium emits more intense gamma rays and more neutrons (mainly due to the spontaneous fission of Pu-240).[219] Therefore, it is harder to shield or conceal plutonium-based warheads. For this reason, however, it is important to find an effective technical solution to measure uranium-based nuclear warheads. Today the active methods can detect HEU efficiently,[220] but there are still some problems left to be resolved.

There is no doubt that nuclear radiation measurement is the most important and central technology used in nuclear warhead reduction verification. But the technology itself needs to be developed to satisfy the requirements of a feasible verification system by solving the problems of intrusiveness, protection of sensitive information, confidence in the credibility of measurements, reliability, and cost.

[219] Thomas B. Gosnell, “Uranium Measurements and Attributes”, Presentation to the 41st Annual INMM Conference, New Orleans, July 2000

[220] For example, the NMIS developed by ORNL can effectively measure the enrichment and mass of HEU contained in weapon component (see J. T. Mihalczo, et al., “NMIS plus Gamma Spectroscopy for Attributes of HEU, Pu, and HE Detection”, INMM-43; and L. G. Chiang, et al., “Verification of Uranium Mass and Enrichments of Highly Enriched Uranium (HEU) Using the Nuclear Materials Identification System (NMIS)”, INMM-41).

Figure 6. The picture of several prototype systems for nuclear warhead verification



Sources: Peter B. Zuhoski, Joseph P. Indusi and Peter E. Vanier, Brookhaven National Laboratory, “Building a Dedicated Information Barrier System for Warhead and Sensitive Item Verification”; T. E. Valentine, L. G. Chiang and J. T. Mihalczo, “Preliminary Evaluation of NMIS for Interrogation of Pu and HEU in AT400-R Containers at Mayak”; Dean J. Mitchell and Keith M. Tolk, Sandia National Laboratories, “Trusted Radiation Attribute Demonstration System”; and Duncan MacArthur, Los Alamos National Laboratory, “Attribute Measurement System with Information Barrier (AMS/IB): Conceptual Description”

Not all of the activities to verify nuclear warhead reductions need the most advanced nuclear detection technologies; in some cases, simple radiation measurements would be enough. The type of measurement technologies needed for various nuclear warhead reduction procedures or scenarios is shown in Table 7.

Table 7. The intrusive and advance level of nuclear detection technologies for different reduction applications

Reduction application scenario	Applied nuclear detection technologies	Level of intrusiveness	Level of advance
The scenarios to authenticate nuclear warhead or pit	The individual or combined utilization of the following technologies: (1) High-resolution gamma spectrum measurement (2) Sophisticated neutron coincidence incidents measurement (3) Active detection method to measure the specific signature of nuclear warhead or weapon components (4) Precise radiation photography	Very high intrusiveness. Need to measure the accurate and detailed nuclear radiation information of nuclear warhead Requiring information barrier or filter and managed access to protect sensitive data.	Very complicated and the most advanced. Requiring sophisticated instruments or systems, and large data analysis capabilities.
The scenarios to prevent theft,	(1) Total gamma or neutron counting,	Low to medium	Simple and

security and diversion of nuclear warhead (the continuous knowledge of nuclear warhead)	Geiger counter (2) Radiation pattern measurement (3) Rough radiation photography	intrusiveness	mature radiation measurement technologies

4.2 Non-nuclear detection and measurement technologies

Due to the intrusiveness of nuclear radiation detection and high sensitivity of nuclear warheads, many complementary non-nuclear detection and measurement technologies have been developed. Most of these non-nuclear technologies utilize the inherent signatures of warheads such as specific configuration, thermal flow from fissile core, density, material mechanical properties, total mass, mass distribution, geometry and geometric orientation, and electromagnetic properties. There are several important criteria in using the appropriate non-nuclear technologies for verifying nuclear warheads:

- The nuclear warhead should have the distinguished property to be explored by non-nuclear detecting technologies.
- The unique or specific fingerprint of nuclear warhead (type) can be acquired by measurement.
- The non-nuclear technologies should be no more complicated and intrusive than the nuclear ones.
- The non-nuclear measurement should be meaningful, i.e., the directly-measured or induced results have definite rules (either linear relation between the measured attribute and result or all the resulted data fall in a certain area)
- It should be safe and non-destructive.

Among the large number of non-nuclear detection technologies, the following candidates show promise for verifying nuclear warheads: (1) electromagnetic coil technology, (2) thermal measurement, (3) acoustic resonance spectroscopy, (4) x-ray scan, (5) infrared image, (6) radiation pattern image, (7) precision gravitational measurement.

Electromagnetic (EM) coil technology[221] is being developed to acquire the unique electromagnetic fingerprint of weapon components stored inside sealed metal containers. The EM signature of the weapon components in a container can be clearly distinguished as the measurement responds to all targeted conductive materials and depends on many parameters. Parameters include electromagnetic properties, mass distribution, configuration, and geometric orientation. The inability to reverse-engineer the sensitive information through EM coil's measuring data and short measuring time provides the technology's attractive application in nuclear warhead reduction verification. The US DOE PNNL has established a prototype system and has launched two measurement campaigns at the Pantex Plant against plutonium pits. The results of these tests showed that EM coil methods could determine both the specific response from the combination of targeted materials and measures such as diverse containers (various size and thickness) o4 different contents (aluminum, pit) and the various shapes of content (plate, hemisphere, ball) by imposing coil excitation frequency. These specific responses could

[221] This paragraph is based on Ronald L. Hocky, "Electromagnetic Coil Technology for Arms Control Applications", INMM-42; and R. L. Hocky and J. L. Fuller, "Electromagnetic Coil (EM Coil) Measurement Technique to Verify Presence of Metal/Absence of Oxide Attribute", Presentation to IAEA Symposium, October 2001, Vienna

categorize the measured objects. Thus, EM coil technology has the potential application of discerning between different nuclear warhead types. The EM coil method can also be used to discriminate between plutonium metal, plutonium oxide and mixtures of these two materials inside a sealed container instead of using the questionable 871 keV gamma line.

The principle of acoustic resonance technology[222] is that under the excitation of input acoustic waves, an object has a multitude of resonance responses corresponding to the object's vibration modes and determined by the multiple inherent characteristics of the testing item including material composition, mass and mass distribution, density, dimension, and internal structure. The recorded resonance response can be compared to the pre-acquired template for identifying the tested item type. The measured amplitude-frequency characteristics can be reliably distinguished among different contents in a sealed container. This technology still has several problems that need to be resolved for nuclear warhead verification. One problem is the feasible acquisition and application of standard templates of various nuclear warhead types. This includes the standard deviation of measurement, the consistency of measuring the same nuclear warhead type with minor variations in mass, geometry, or container, and the implications of varying environmental conditions such as temperature or humidity. Safety concerns over using acoustic energy against nuclear warheads are another problem. Lastly, there is the problem of how to protect sensitive information.

Thermal measurement[223] for nuclear warheads exploits the fact that weapon-grade plutonium or uranium emits thermal energy continuously because of radioactive decay. The heat signature can be readily measured with highly sensitive thermopiles and can determine the mass of the measured warhead or pit (with calibration, isotopic composition, and other information of measured fissile materials in advance). With the multi-point placement of heat sensors, the heat emission pattern could be acquired to get a rough picture of measured object. The thermal measurement method can be treated only as a complementary approach for nuclear warhead verification because the method can be easily deceived by substituting warhead with other heat emitters such as a ^{252}Cf source, the method needs to be carefully calibrated in advance and cannot be effective without other information about the nuclear warhead such as isotopic composition, and it would take a relatively long time for the heat exchange to come into equilibrium.

X-ray scan is a very mature technology, which has been widely used in item checking. For instance, an x-ray imaging system was employed at the Russian Votkinsk missile plant to distinguish SS-25 and SS-20 missiles by INF Treaty. The x-ray scan can get contour pictures of high-density material inside sealed container in a short time; this can be a very helpful supplement in determining interior content to see if it is a real nuclear warhead by measuring the

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222 This paragraph is based on Appendix B.1 in "Investigating the Feasibility of Detecting, Identifying, and Tracking Treaty Limited Items", prepared for DSWA by Futron Corporation on June 15, 1997; and John L. Smoot, Gordon B. Dudderet al., "Non-Nuclear Technologies: Potential Application to Support Fissile Material Safety and Security".

223 For detailed technical discussion on thermal measurement of fissile materials, see David S. Bracken, et al., "Use of Solid-State Heat Flow Sensors for Transparency Measurements"; and Clifford R. Rudy, "Determination of Average U-235 Enrichment and Mass of Uranium Metal Without Gamma-Ray Spectroscopy"; both reports are available at http://amtl.iwapps.com/; and R Likes, "Principles of Calorimetric Assay", in Doug Reilly, Norbert Ensslh and Hastings Smith Jr., eds., "Passive Nondestructive Assay of Nuclear Materials", March 1991, Prepared for Office of Nuclear Regulatory Research, US Nuclear Regulatory Commission

shape and size of a radiation object. But the direct use of x-ray scan on a nuclear warhead is too intrusive, so its use for nuclear warhead verification is still to be determined. Some technical solutions can be considered to mitigate the intrusiveness problem. Solutions include application of image pattern matching to give only a “yes” or “no” answer (this would, however, create the new question of how to acquire the original template), blurring the edge of acquired pictures, or scanning only a small area of the warhead. All of these solutions need to be evaluated with practical tests.

Like x-ray scanning, infrared imaging technology verfies the interior content by detecting the heat produced from spontaneous decay of fissile materials in a nuclear. Its poor resolution makes the technology suitable for non-intrusive detection of nuclear warheads while at the same time it can be easily spoofed by heat-emitted warhead simulators.

One kind of radiation pattern image technology[224] exposes a special film under the radioactive environment produced by fissile materials in nuclear warhead to image radiation source information. It can produce a two-dimensional image with a resolution of one square centimeter. The image resolution can be controlled by adjusting film reader settings or changing film design in order to protect sensitive information. Another kind of radiation pattern image technology uses multiple-array radiation detectors to count the emitted gamma rays from fissile materials in nuclear warheads, thus acquiring the image of the radiation source. It can provide an approximately one centimeter spatial resolution. The resolution can also be controlled by adjusting the data analysis software or changing the detector-array design. The radiation pattern image technology is more powerful against plutonium-based than uranium-based warheads.

Precision gravitational measurement[225] explores the fact of gravitational anomalies produced by testing objects. Compared to electromagnetic and nuclear forces, the gravitational force is so weak that the measurement must employ high-sensitivity instruments to detect the response from total mass and specific mass distribution signatures of testing objects. Several prototype systems were developed in the past, including Superconducting Gravity Gradiometer, Spin Resonance Gravity Gradiometer, Draper Floated Gravity Gradiometer, and Bell Aerospace Textron Gravity Gradient Instrument. Although these systems employ different ways of measuring gravity forces or gradients, they can produce the unique gravitational characteristics of measured objects, which categorize the specific type of testing items. The advantages of this technology are that it is relatively unspoofable, non-intrusive, passive, and of a well-understood theoretical basis, while the disadvantages are that it is relatively high-cost, sensitive to interference, and of immature technical status for verification application.

4.3 Template and attribute approaches

Under an imperative for verifying nuclear stockpile reduction, two approaches referred to as

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[224] This paragraph is based on Steve Miller, et al., “Use of Optically Stimulated Luminescence Imaging Plates and Reader for Arms Control Applications”, INMM-42; K. N. Danilenko, et al., “A Gamma-Ray Camera for Inspection Control”; K.P. Ziock, et al., “A Germanium Based Coded Aperture Gamma-ray Imager”, INMM-41; G.J. Schmid, et al., “Gamma-ray Imaging with a Segmented HPGe Detector”, INMM-41

[225] This paragraph is based on Appendix B.5 in “Investigating the Feasibility of Detecting, Identifying, and Tracking Treaty Limited Items”, prepared for DSWA by Futron Corporation on June 15, 1997

template and attribute were developed by US arms control technical experts to confirm the existence of nuclear warheads or certain amounts of weapon-originated fissile materials. These two approaches were developed to address the two most urgent questions in nuclear warhead verification: (1) The monitoring party should be assured that the nuclear warhead reduction is being executed with technical confirmation and that no fake nuclear assemblies are accounted for. (2) The monitored party should be guaranteed that any sensitive information cannot be divulged during the verification process. The attribute and template should be comprehensive enough to make cheating impossible or of unbearable cost. From the stand of reverse-engineering,[226] the most valuable measurement is to acquire sole quantity or result, which is of the highest confidence to confirm an item and also the most sensitive.

The template approach compares real-time measuring data with an established signature spectrum, similar to the DNA sequence for a species. The attribute approach is the single- or multiple-characteristics determination procedure that deduces a quantitative outcome by measuring data and comparing the result with a pre-agreed threshold, similar to the combination of height and weight that defines a class of people.

The template approach can explore both nuclear and non-nuclear if the signature spectrum of the measured object is able to uniquely determine the individual or a class of the measured object. The basic principle of the template approach for nuclear warhead verification is this: Due to the specific complex configuration and radiation field pattern determined by the mass and mass distribution; physical (alpha or delta phase for plutonium) and chemical (metal or oxide) form; geometry and isotopes of fissile materials; and the composition, dimension, and relative location of other components in nuclear warheads, the signature of a specific nuclear warhead type can be acquired by recording the inherent radiation characteristics or exclusive response induced from input excitation (electromagnetic and acoustic). Warheads of the same type would also produce the same measuring template data in a certain allowable error range. The template approach needs to solve several problems before its application for nuclear warhead verification:

- The template should have the capability to cover all warheads of the same type excluding the fake warheads and other types of warheads; thus, the template should be complex and comprehensive enough to exclusively define the type of nuclear warhead and have an appropriate error bound.
- Since the template data set contains highly sensitive information (especially the high-resolution full energy gamma spectrum), the storage and authentication of template data set should be secure and reliable with very high confidence.
- For the cradle-to-grave procedure of a specific nuclear warhead type, more than one template should be established, since at different stages, nuclear warheads emerge with different forms, e.g., deployed nuclear warheads (casing, primary, secondary, AF&F system, and neutron generator), dismantled nuclear warheads, fissile materials,

[226] The reverse-engineering of information can be divided into three types: (1) TYPE-I (First Principle Simulation), to directly reverse-simulate the original design or configuration with the measured data through theoretical calculation, (2) TYPE-II (Experimental Approaching), with the acquired measurement data and the available knowledge of original design or configuration, to approach the original copy gradually through constituting an experimental device and carrying out the tests under same condition, (3) TYPE-III (Deduced Analysis), with multiple uncompleted data set and the available knowledge of original design or configuration, to deduce or analyze the original copy.

and destructed components.

The simple template approach was used during INF verification, which compared the neutron radiation intensity pattern emitted from the canistered missiles of nuclear to the “benchmark” value obtained from the initial measurement of SS-25 and SS-20, and determined if the canister contained the banned SS-20 missiles.[227] The measured neutron emission was not sensitive and could only roughly determine the relative location of the radiation source.

The template approach can, with high confidence, distinguish the different types of nuclear warheads (especially if the configuration, mass, or physical diversity is large enough) and determine their unique signatures. During the nuclear warhead confirmation measurement campaign in the Pantex Plant in 1997, the Radiation Inspection System (RIS) developed by SNL showed very good matching results by comparing the measured data and the pre-acquired template with a low-resolution NaI detector (Table 8). [228]

Table 8. Average χ_m^2 for Comparisons of Measurements with Empirical Templates

		Template															
Source	**#**	**Back**	**PA**	**PA***	**PB**	**PC**	**PD**	**PE**	**PF**	**PG**	**FB**	**FC**	**FD**	**FE**	**FF**	**SB**	**SF**
PA	1	1285	**.6**	30	86	102	98	89	140	98	1039	75	414	680	782	5223	789
PA	2	1247	**1.7**	26	78	101	96	86	136	97	940	69	378	635	766	4565	765
PA	3	1298	**1.3**	31	85	97	92	86	141	92	1057	75	436	702	814	5056	817
PA	4	1320	**.9**	34	93	105	100	92	143	100	1123	84	457	728	817	5544	827
PA*	1	1034	47	**.7**	61	120	118	83	130	111	572	25	180	394	560	3391	547
PA*	2	1021	42	**1.1**	60	122	119	83	124	112	550	29	169	375	536	3417	524
PA*	3	1030	43	**.9**	65	120	118	87	135	111	569	25	171	379	533	3594	524
PB	1	1009	121	107	**1.2**	93	91	15	27	81	558	91	319	547	794	1380	760
PB	2	1008	117	101	**1.0**	95	93	14	25	84	548	86	304	528	771	1427	740
PB	3	1000	119	103	**1.0**	95	93	14	25	83	542	88	305	526	770	1364	739

[227] “Radiation Detection Equipment for Monitoring the INF Treaty”, Cooperative Monitoring Center of DOE SNL, *INF Neutron Detector Fact Sheet,* Aug 10, 1999

[228] “Technology R&D for Arms Control (Spring 2001)”, Arms Control & Nonproliferation Technologies Project, Office of Nonproliferation Research and Engineering, DOE, pp.4-5

PB	4	996	117	101	**.9**	95	93	15	25	83	541	89	305	528	772	1361	740
PC	1	2023	497	740	698	**.7**	**1.0**	263	398	7.8	2126	808	1777	1762	1860	4010	1846
PD	1	2016	496	733	681	**1.2**	**.8**	253	385	5.8	2112	794	1763	1755	1857	3985	1842
PE	1	1328	179	195	32	84	82	**.8**	25	70	923	177	605	863	1108	1994	1081
PF	1	1284	172	190	36	128	124	20	**.7**	112	858	203	566	821	1071	1836	1045
PG	1	2003	492	710	623	9.0	6.8	221	342	**.5**	1982	761	1665	1719	1862	3527	1843
FB	1	317	129	84	116	156	156	131	139	152	**.8**	92	32	7.7	42	400	27
FB	2	312	129	82	113	154	153	128	137	150	**.9**	90	31	8.2	45	381	29
FB	3	312	123	83	113	152	151	128	135	149	**.8**	91	32	8.5	45	386	29
FC	1	973	110	29	84	123	124	99	181	115	496	**.8**	140	336	491	3102	480
FD	1	540	113	51	90	139	139	111	142	134	63	43	**.9**	34	128	1217	113
FE	1	557	157	99	145	189	188	161	183	184	11	102	26	**.6**	46	790	33
FF	1	511	211	154	205	260	257	223	227	254	55	174	86	31	**1.0**	1477	6
SB	1	123	134	112	125	142	141	130	130	140	52	118	88	64	66	**.8**	57
SB	2	118	136	113	125	142	142	130	130	140	54	118	89	66	66	**1.3**	58
SB	3	130	135	114	128	144	143	133	134	142	53	120	90	65	65	**.8**	57
SB	4	121	135	113	126	143	142	131	131	141	54	119	90	66	66	**1.5**	58
SF	1	414	189	139	181	229	227	197	199	225	27	156	77	22	6.4	861	**.5**

PX represents different kinds of pit, PX* represents the pit inside standard "AL-R8" container, FX represents various types of full functional warhead, SB is the secondary in B-type canister and SF is the secondary in F-type canister

Sources: Richard L. Garwin, "Technologies and Procedures to Verify Warhead Status and Dismantlement", SIPRI Workshop, Paris, 02/08-09/2001

The confusion of PC and PD is probably because the two pits were from the same major type but different modification.

With the help of information barrier technology, a template measurement system can provide only Y/N output that can demonstrate whether the measured object either did or did not belong to the claimed class. The key point of the template approach is the template data set, which has two problems to resolve: (1) The data set should be assured to be genuine and credible. (2) The data set should be protected and secured without any doubts. The credibility of the template data set can be guaranteed through administrative management and data acquisition procedure control against different kinds of nuclear warhead. This can be done by having both the inspecting and inspected sides (such as on-deployed-site or on-stored-site measurement on typical warhead species) to achieve the template and its tolerance bound. Then the data set and a random selection of nuclear warheads of the same kind can be compared. The security and authentication of the template can be accomplished by utilization of secure hash algorithm (SHA-1) in a keyed-hash protocol.[229] The template approach is the only practical way to verify that two or more nuclear warheads or their components are of the same type.[230]

US DOE national labs had established several prototypes of template verification systems for nuclear warheads or fissile materials including RIS and trusted radiation inspection system (TRIS) developed by SNL[231], CIVET developed by BNL[232], Ranger and Ranger-plus developed by LANL, and NWIS developed by ORNL[233]. These systems were proven to be very effective in discriminating different types of intact nuclear warheads, pits, and secondaries during the measurement campaign against US nuclear weapons, and their components at Pantex Plant and LANL from 1997 to 1999[234].

Another useful verification method is the attribute approach, which is very helpful for arms control scenarios under the following condition: the object has an inherent unique or distinguished attribute[235] to be measured along with a set of attributes that can uniquely determine the object. The more attributes measured, the higher the confidence in verification. In past nuclear arms control verification activities, the measurement of attributes was the prevailing method. For example, during the implementation of START I verification, inspectors had the right to use radiation detection equipment to confirm that the ALCM is non-nuclear. They also had the right to use a weighing device to confirm the launch weight of an ICBM or SLBM of a new type and the right to use rulers or scales to measure the dimensions of an object that is outside a container or launch canister.[236] With the help of visual inspection, the attributes measurement of START I can achieve the purpose of verifying large-size treaty-limited items such as ballistic missiles or heavy bombers, and distinguish the nuclear-armed ALCMs from non-nuclear-armed ALCMs. Nearly all of the on-site attribute measurements utilized simple or mature technologies. The agreed measured attributes were obvious (many technical characteristics were exchanged in advance) and could determine the object with the help of eying the external appearance of monitored items.

The principle of the attribute approach for nuclear warhead verification is based on the assumption that a set of characteristics represented by unclassified, measurable, and quantitative values is adequate to distinguish nuclear weapons from non-weapon configurations of nuclear

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[229] Kevin D. Seager, et al., "Trusted Radiation Identification System", INMM-42
[230] "Technology R&D for Arms Control (Spring 2001)", Arms Control & Nonproliferation Technologies Project, Office of Nonproliferation Research and Engineering, DOE, pp.4
[231] Ibid pp.5 and note 238
[232] Walter R. Kane, James R. Lemley and Leon Forman, "The Application of High-Resolution Gamma-Ray Spectrometry (HRGS) to Nuclear Safeguards, Nonproliferation, and Arms Control Activities"
[233] J. A. Mullens, T. E. Valentine and J. T. Mihalczo, "Pattern Recognition Algorithms for Comparing NWIS Signatures for Weapons Components"
[234] Michael J. Newman, "Warhead Radiation Signatures: Report on the Nov-Dec 1997 Pantex Demonstration Measurements"; and John T. Mihalczo, Timothy E. Valentine and James A. Mullens, "Successful Blind Testing of NWIS for Pits at Los Alamos National Laboratory"
[235] For example, radiation measurement can effectively discern the nuclear from non-nuclear materials.
[236] Annexes to the inspection protocol of START I, available at http://www.state.gov/www/global/arms/starthtm/start/inanxtoc.html#AnxTOC

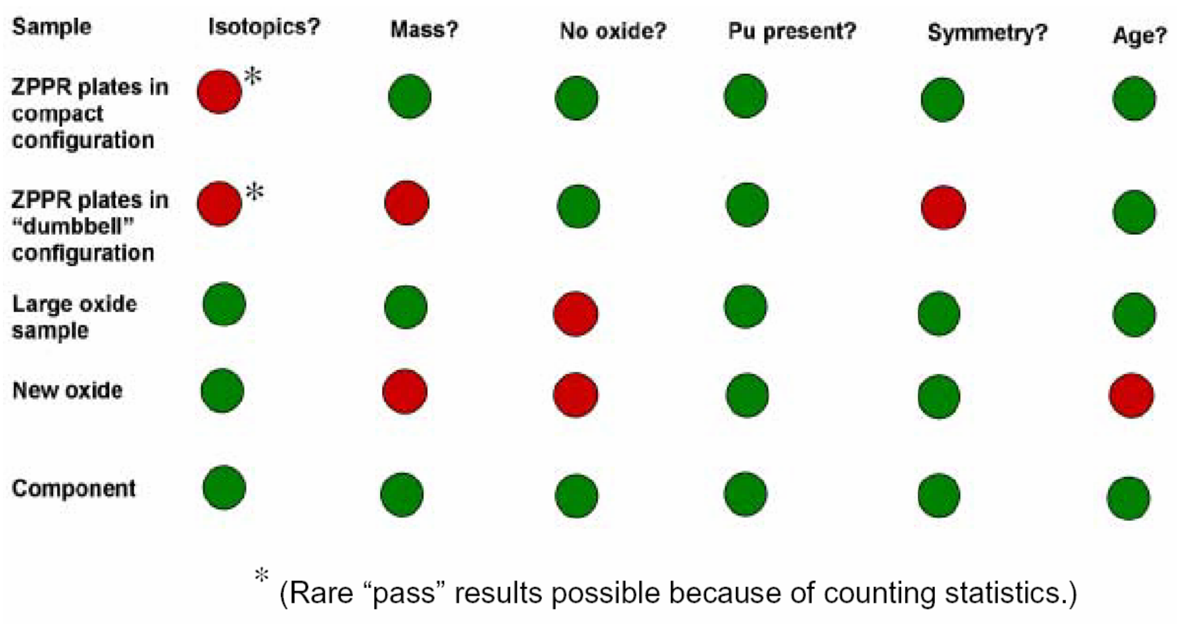
materials. The attribute approach for arms control application has the following basic characteristics:[237]

- Both inspecting and inspected parties should define a set of quantitative attribute threshold and an acceptance-rejection algorithm capable of concluding whether the weapon is genuine based on the set of measured attributes.
- The set of quantitative attribute values should be sufficient to distinguish nuclear warhead from normal fissile materials or fake warheads.
- The quantitative attributes should be unclassified. It is impossible to deduce the sensitive information from the values.
- The verification result (Y/N output) is accomplished by comparing the measurement data with agreed quantitative values, or agreed ranges of values.
- The verification measurement is aimed at single items.

The attribute approach for nuclear warheads can also explore both nuclear and non-nuclear technologies. But, apparently, the nuclear detection is more competitive because of the distinct characteristics and measurability of fissile materials in nuclear warheads. For verification implementation of the Mayak Transparency and Trilateral Initiative, US technical experts with their Russian peers had suggested six attributes (Table 9) to confirm the existence of plutonium-based nuclear weapons. The demonstrated measurement of these six attributes against some forms of plutonium material and even a real US plutonium-based pit were very successful during the fissile material transparency technology demonstration (FMTTD) campaign held at LANL in August 2000 (Figure 7). But in principle, the six attributes could only define the certain amount of weapon-grade plutonium metal, which had a symmetrical shape and was chemically purified before the assumed date. If the objective is to verify the existence of a nuclear warhead, it should have additional attributes. For example, for an integrated boosted nuclear warhead, it should have attributes such as the existence of certain amount of HEU and deuterium or tritium. The attribute approach is more appropriate for fissile materials verification than for direct application to nuclear warheads unless the sets of attributes can definitely determine the nuclear warhead.

Figure 7. The measurement results of FMTTD against different sources of Plutonium

[237] W. R. Kane, et al., "On Attributes and Templates for Identification of Nuclear Weapons in Arms Control"



ZPPR represents Zero-Power Plutonium reactor.

Sources: "Sources and Thresholds for the US Demonstration of an Attribute Measurement System With Information Barrier", Presentation by M. W. Johnson, available at http://www-safeguards.lanl.gov/FMTT/presentations/index_pres.htm

During the execution of attribute measurement, the measurement involves the original sensitive gamma and neutron data of nuclear warheads along with the calculation results of mass quantities, isotopic ratio and other information of nuclear warheads. Therefore, there is concern by inspected parties over how to protect these original and interim data. The attribute approach for nuclear warhead verification must be combined with information barrier technology to prevent the leakage of sensitive information. Credibility of final results (Y/N indicator) is also a concern for the inspecting party. Therefore, the measurement system for nuclear warhead verification must be authenticated thoroughly.[238] It is important that these two problems be considered before constructing an attribute-measuring system.

Table 9. The suggested six attributes for plutonium-based warhead or fissile materials, also the unclassified quantitative thresholds and measurement principles

Attribute	Threshold	Measurement principles
Presence of Pu	5σ > Background statistical counts at selected gamma-ray energies	Looking for several intense plutonium gamma-ray lines such as 345 keV peaks (Pu300), 646 keV and 659 keV peaks (Pu600) with HRGS
Isotopics ratio	$^{240}Pu/^{239}Pu < 0.1$	Calculating the Plutonium gamma-ray characteristic line pulse-height distribution in 630–670 keV region to determine the ratio of ^{240}Pu to ^{239}Pu by Pu 600 algorithm with HRGS, thus to confirm if it is weapon-grade

[238] Richard Kouzes, et al., "Authentication Procedures", INMM-43

Pu mass	> 500 grams (assume that the weapon-grade plutonium in a single warhead is above 500 grams)	Recording the count rates for non-coincident, doubly coincident, and triply coincident events (singles, doubles, and triples counts) in NMC detector and using the three kinds of counts to calculate the ^{240}Pu-effective mass, together with the isotopic ratio obtained from the Pu600 analyzer, the ^{240}Pu-effective mass can be used to calculate the Pu mass
Absence of Oxide	< 10% Pu oxide	Utilizing that the 870.7keV peak was not present with an area exceeding five standard deviations above the background continuum and alpha (a neutron multiplicity parameter) is greater than 0.5 to indicate there is no presence of plutonium oxide.
Age of Pu	Separated prior to Jan 1, 1997	Measuring the value of ^{241}Am/^{241}Pu ratio, which is a well-known function of time, through peak area calculation of ^{241}Am, ^{237}U and ^{239}Pu by Pu300 with HRGS
Symmetry	< ±15% of average counts	Recording the total and average neutron counts of 8 individual ^{3}He neutron detectors from 8 groups in NMC, and then comparing 8 sets of average counts

Sources: Thomas R. Rutherford and John H. McNeilly, "Measurements on Material to be Stored at the Mayak Fissile Material Storage Facility" and Larry R. Avens, James E. Doyle and Mark F. Mullen, "The Fissile Material Transparency Technology Demonstration", Presented at INMM 42nd Annual Meeting

The US DOE national labs had developed several prototypes of attribute measurement systems such as TRADS developed by SNL,[239] Attribute Measurement System with Information Barrier (AMS/IB) and Attribute Verification System with Information Barrier for Plutonium with Classified Characteristics utilizing Neutron Multiplicity Counting And High-Resolution Gamma-ray Spectrometry (AVNG) developed by LANL and LLNL[240], and Nuclear Materials Identification System (NMIS) developed by ORNL. These attribute measurement systems were proven to be effective and reliable for measuring the appropriate attributes of fissile materials.

Both template and attribute approaches can become powerful tools for nuclear warhead reduction verification. But these two methods have different characteristics (Table 10) and different utilization scenarios during warhead reduction verification procedures. The template approach is appropriate for checking intact nuclear warheads and pits before dismantlement and disposition, while the attribute approach is suitable for verifying fissile materials that originate from nuclear weapons. It is also possible to use the attribute approach to confirm the existence of integrated warheads if the continuity knowledge of warheads is robust enough and has high confidence.

Table 10. The characteristics of template and attribute approach for nuclear warhead verification

	Pros	Cons

[239] Dean J. Mitchell and Keith M. Tolk, "Trusted Radiation Attribute Demonstration System", INMM-41
[240] D. G. Langner, et al., "Progress Towards Criteria for a Second-Generation Prototype Inspection System with Information Barrier for the Trilateral Initiative"; and Larry R. Avens, James E. Doyle and Mark F. Mullen, "The Fissile Material Transparency Technology Demonstration", Presented at INMM 42nd Annual Meeting

Template approach	1. It can acquire and record distinguished radiation or other warhead signatures, thus it is suitable for discriminating different nuclear warhead types and their fissile components, and particularly useful in verifying the scenario of banning certain type of nuclear warheads.[241] 2. Given comprehensive sets of template, well-designed matching criteria and appropriate error bound, it can provide the proof with high confidence that certain type of nuclear warhead is under monitoring. 3. No threshold is required, thus there is no need to deduce any high-risk sensitive interim results with original data, and avoiding the complicated analysis software and algorithm. 4. It is very difficult to reproduce the identical comprehensive characteristic spectrum with fake nuclear warhead or component, thus the approach has strong capability against spoofing or cheating. 5. The template data can be used to calculate the relevant attributes if required.	1. It has to establish comprehensive sets of all existing warhead types and their fissile components' templates, which contain the most sensitive information of nuclear warhead. 2.The acquirement, authentication and information physical protection of comprehensive sets of standard template are quite difficult to carry out with full confidence 3. The minor change of measuring objects can cause the unmatching result, so the template developed until now can distinguish only major types of nuclear warhead (such as B61 vs. W87) instead of type modifications (such as B61/4 vs. B61/11)[242]. 4. The selection of data set, matching criteria and error bound need to be well understood and designed to categorize the nuclear warhead. 5. The matched characteristics or signatures may be irrelevant to targeted verification regime.[243]
Attribute approach	1. The agreed and stored threshold values are unclassified, thus attribute measurement system including hardware, software, and data storage can be fully transparent and ready for authentication check, which maximally eliminate the possibility of "hidden switch". 2. The attribute can be universally applied to various nuclear warhead types and their components with the same set of attributes, thus facilitating the verification implementation. 3. The set of attributes can be specifically designed and flexibly adjusted against different arms control agreement such as those in the negotiation of Mayak Transparency, Plutonium Disposition, and Trilateral Initiatives.[244]	1. The attributes alone are nearly impossible to distinguish the nuclear warhead types and their components, which limits its application on nuclear warhead verification. 2. With the limited attributes and thresholds which is far-reaching the sensitive actual attribute value, the measurement can be easily spoofed with warhead substitutes which have the same attributes. 3. In order to verify the existence of nuclear warhead, a more comprehensive set of attributes needs to be developed, which would highly raise the complexity and cost of measurement. 4. In order to gain the acceptance and avoid working out the sensitive data, the negotiation of appropriate attributes and their comparing quantities may be time-consumed and the threshold may have too large

[241] For example, an accord could be reached to ban the HEU primary, thus greatly facilitating the nuclear warhead verification.
[242] Personal communication between Prof. Steve Fetter from University of Maryland and Peter E. Vanier from BNL.
[243] James R. Lemley, Peter E. Vanier and Leon Forman, "Template Applications for Monitoring Warhead Dismantlement", INMM-42
[244] START III and Mayak Transparency discusses about the application of all six attributes illustrated in table9 (see Thomas R. Rutherford and John H. McNeilly, "Measurements on Material to be Stored at the Mayak Fissile Material Storage Facility"), Plutonium Disposition Agreement allows to inspect the first two attributes (see the Annex on Monitoring and Inspections of Plutonium Disposition Agreement between US and Russia), and Trilateral Initiatives uses the first three attributes plus the attribute of HEU presence (see Nancy Jo Nicholas, et al., "Attributes Verification for Classified Fissile Material").

	4. Provided that there is robust and confident cooperative chain-of-custody over nuclear warhead, attribute measurement can be effective in verifying the existence of nuclear warhead. 5. The well-known physics principle, the insensitive nature of threshold, and the development of information barrier technology make the attribute measurement feasible and acceptable.	spans from the actual value. 5. The calculation or analysis of original data requires very complicated software and algorithm.

4.4 Tag and seal

Tag is the unique identification label or device with intrinsic, unfakeable characteristics such as barcode, random image pattern, and physical surface surveying, that are affixed to controlled individual items to provide the evidence of authorized identity.[245] Seal, which is also called Tamper-indicating Device (TID), have various appearances such as shrinkable foils, films or plastic wraps, pressure-sensitive adhesive tapes, and crimped cables or other (theoretically) irreversible mechanical assemblies, and is used to detect unauthorized access, entry, or tampering of controlled individual items.[246]

Tag and seal are often combined to constitute compliance-confirming devices, which are widely applied in domestic and international safeguards of valuable assets or proliferation-risk materials and confidence-building of arms control treaties. IAEA utilizes various kinds of tag and seals for safeguarding nuclear materials and related facilities such as metal cap seals with tamper indicating features, ultrasonic and electronic seals with fiber optic loops, and tamper indicating paper tape seals for short time applications.[247] IAEA issued more than 22,000 mental cap seals and verified more than 19,000 in 2001.[248] For verifying implementation of START I, tag and seal was defined as the "unique identifier which is a non-repeating alpha-numeric production number, or a copy thereof, that has been applied by the inspected Party, using its own technology, to an ICBM for mobile launchers of ICBMs."[249] Different kinds of technologies such as reflective particle tag[250] and plastic-casting intrinsic-surface unique identifier.[251] were exploited for specific tag and seal utilization scenarios under the requirements of START I. During the performance of CFE, tag and seal were used to identify and track highly mobile TLIs such as tanks and combat aircraft, count the number of TLIs, and provide evidence of violations or compliance.[252] UN

[245] "Investigating the Feasibility of Detecting, Identifying, and Tracking Treaty Limited Items", prepared for DSWA by Futron Corporation on June 15, 1997, pp.75
[246] Roger G. Johnston, Anthony R.E. Garcia and Adam N. Pacheco, "Efficacy of Tamper-Indicating Devices", *Journal of Homeland Security, April 2002*, available at http://www.homelandsecurity.org/journal/Articles/displayarticle.asp?article=50
[247] IAEA Safeguards Glossary (2001 Edition, Web version), *International Nuclear Verification Series No. 3*, pp.55
[248] Additional table IV referred to in the IAEA Annual Report for 2001
[249] "Procedures Relating to Unique Identifiers", Annex 6 to the Inspection Protocol of START I Treaty
[250] OTA-ISC-488, "Verification Technologies: Managing Research and Development for Cooperative Arms Control Monitoring Measures", May 1991, pp.7-8
[251] R. G. Palm and A. De Volpi, "Plastic-Casting Intrinsic-Surface Unique Identifier (Tag)", ANL/ACTV-94/1, April 1995
[252] A. De Volpi, "Tags and seals to strengthen arms control verification", DE94011359; and Richard L. Garwin, "Verification of Limits on Conventional Forces in Europe (CFE)", Talking paper for meeting of CISAC with group from the Royal Society, London, England, March 15, 1990

Special Commission (UNSCOM) and IAEA have tagged and sealed a large number of the materials and facilities both for civilian and military purposes of nuclear, biochemical, and weapon producing activities in Iraq under UN Security Council Resolution 687. For example, the IAEA utilized tag and seals on the specific machine tools at Iraqi nuclear facilities to prevent the manufacturing of enrichment or other prohibited equipment. During the period from December 2002 to February 2003, inspectors at Baghdad Ongoing Monitoring, Verification and Inspection Center (BOMVIC) have been provided with some 35,000 tamper-proof tags and seals for tagging concerned equipment.[253]

Tag and seal is an effective tool for finding evidence of noncompliance activities through the anti-tamper devices directly attached to controlled items. The basic purposes of tag and seal for arms control application are: (1) to distinguish between allowed and banned items, (2) to count the numeric limits of authorized items, (3) to ensure no substitution of controlled objects is taking place when the items are out of inspection view, (4) to keep continuous knowledge of monitored items by polling or sampling check, and (5) to provide compliant or violation evidence.

For arms control application, tag and seal and its utilization should have some basic characteristics:

- They are highly confident in detecting tamper activities and are difficult or costly to defeat. This includes the capability of counterfeit-resistance and well-designed affixation strategy in order to avoid cheating.
- Tag and seal must avoid common-mode failure (particularly for those assets of high military significance. They should be utilized for defense-in-depth, i.e., the employment of different physical, chemical, or intrinsic principles to establish cross-linked chains to increase the probability of discovering the tamper.
- Tag and seal must be fortified against espionage. Tag and seal itself can only accomplish the required verification function without revealing any additional information such as collecting sensitive data covertly or locating controlled items in real-time, thus the principle and implementation of tag and seal should be transparent to both monitoring and monitored parties.
- Tag and seal should be of high robustness and reliability as it would be probably exposed to extreme environments such as low-temperature during winters, vibration during transportation, humidity or salinity near the sea water, and radiation when utilized near or against nuclear materials.

Tag and seal should be able to decrease the false-alarm rate, which not only reduces unwanted suspicion, but also increases mutual trust and confidence of verification.[254]

There are many different kinds of tag and seal exploiting various principles, which have been developed and proposed for arms control monitoring. According to its appearance, tag and seal

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[253] "Target Iraq: Imminent Threat Analysis", Published by *Priority Peace*, in cooperation with Dr. Alan Gilbert, Denver, Colorado, March 7, 2003; and "The twelfth quarterly report of the Executive Chairman of the United Nations Monitoring, Verification and Inspection Commission (UNMOVIC)", United Nations S/2003/232, 28 February 2003, pp.4-5

[254] Point (3), (4) and (5) are extracted from Steve Fetter and Thomas Garwin, "Tags," in Richard Kokoski and Sergey Koulik, eds., *Verification of Conventional Arms Control in Europe: Technological Constraints and Opportunities* (Boulder, CO: Westview Press, 1990), pp. 140-142

can be divided into two categories: (1) the unique intrinsic signature of controlled items and (2) specificly designed devices affixed to controlled items. Both categories have their advantages and disadvantages (Table 11).

Table 11. The advantages and disadvantages of two categories of tag and seal

	Tag and seal exploiting unique intrinsic signature of controlled items	Specific designed devices affixed to controlled items
Advantages	High reliability and robustness Not easy to be spoofed or defeated Can accompany the controlled item all through its lifecycle Have very high confidence to tamper-indicate both insider's and outside attack Sometimes can be environment-resistant	Very transparent and understandable in principle, easy to implement A large number of Off-The-Shelf commercial systems are available for different applications of various arms control scenarios, and some of them had been experienced with real utilization in arms control activities Easy to utilize multiple systems or devices to accomplish defense-in-depth custody of controlled item Can be designed to target a specific application scenario of various arms control agreements verifications
Disadvantages	Sometimes it is hard to accomplish into engineering and most technologies of this category need to be matured Need to establish the unique signature database for each controlled item, sometimes the data could be very sensitive The identification reader is often complicated	Many can be defeated or spoofed easily. The reliability and robustness need to improve There is a relatively high false-alarm rate
Tag and seal developed or under developed for arms control applications[255]	Ultrasonic intrinsic tags Surface feature tags Acoustic tags Radioactive tag for fissile materials[256]	Reflective particles tag (RPT) Fiber optic seals such as Cobra Seals, Python, VACOSS seal, and Star Seals Electronic identification devices Adhesive seals and Pressure-Sensitive Adhesive Seals such as 3M Tamper Tape seal Shrink-wrap seal E-Type Cup wire loop seal ARC Ultrasonic Underwater Seal E-tag Mechanical Seal Radio Frequency tags VNIIEF Smart Bolt tag and seal VNIITF OPP-1M seal and ZP-1 seal

[255] The reference of tag and seal in this row is from Nikolai Rubanenko, et al., "Tags and Seals in a Transparency Regime", INMM-41, unless it is specified.
[256] G. P. Gilfoyle and J. A. Parmentola, "Using Nuclear Materials To Prevent Nuclear Proliferation", INMM-41

There are various possible ways to attack tag and seals. [257] Most tag and seals are highly vulnerable to attack and tampering activities. From the study of the LANL Vulnerability Assessment Team, given enough time, the appropriate tools, and access permission, nearly all tag and seals can be defeated[258]. The robustness and reliability of tag and seal is also problematic.[259] The problem of how validate tag and seal for various tough application circumstances remains unresolved. Further research and development and innovative strategy for new types of tag and seal are required for future arms control verification scenarios. Many of the enhanced measures can improve effectiveness in order to detect or prevent tamper activities. Measures include the combination of tag and seal and video monitoring[260] or photographic comparison,[261] managed access and dual-key methods applied to the tag and seal, defense-in-depth implementation, choose-and-keep, and careful inspection and scrutiny.

For nuclear warhead reduction verification, tag and seal constitutes one of the most important tools for establishing chain-of-custody of nuclear warheads. The appropriate choice for tagging and sealing nuclear warheads and their components is layered use of multiple specifically-designed devices affixed to the controlled container with reinforced measures (such as coupled with visual surveillance) that can establish the continuous knowledge and prevent illegal diversion.

4.5 Surveillance technologies

Surveillance is another highly important element to constructing chain-of-custody that can effectively prove that no diversion of treaty-limited items occurs and can track those items from their original reduction point to their final disposition. Furthermore, the comprehensive surveillance can enhance the security status of monitored objects. Comprehensive surveillance is of particular importance and is appropriate for nuclear warhead reduction verification for several reasons: (1) It provides high confidence and establishes mutual trust by “looking at” the reduction or elimination process. (2) It is an efficient deterrent to diversion or substitution. (3) It can readily constitute defense-in-depth inspection systems with combining the use of tag and seal. (4) Its techniques and equipments have been developed for many years and have large quantities of experience. Comprehensive surveillance may employ various technologies such as video monitoring, photograph comparing, satellite imaging, various sensor monitoring, and intrusion detection.

Video monitoring has been widely used in domestic security, international safeguards, and verification of arms control treaties. With the development of advanced digital technologies, real-time transfer methods, encryption, adjustable comparative algorithms, and digital video camera techniques, video monitoring plays a more important role in proving treaty compliant activities and preventing illegal activities. Video monitoring is currently becoming one of the

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[257] Roger G. Johnston, “Tamper Detection for Safeguards and Treaty Monitoring: Fantasies, Realities, and Potentials”, *The Nonproliferation Review*, Spring 2001, Volume 8, No.1, pp.103
[258] Roger G. Johnston and Anthony R.E. Garcia, “Vulnerability Assessment of Security Seals”, LA-UR-96-3672
[259] V. A. Lupsha, et al., “Environmental Testing of T-1 Electronic Sensor Platform in Russia”, INMM-43
[260] Eric R. Gerdes, Roger G. Johnston and James D. Doyle, “A Proposed Approach for Monitoring Nuclear Warhead Dismantlement”
[261] William Karl Pitts, et al., “Photographic Comparison for Item Tagging and Tamper Indication”, INMM-43

core IAEA containment and surveillance (C/S) techniques with applications to numerous nuclear facilities, activities, or storage places around the world. IAEA has extensively utilized several generations of video monitoring systems, from the old film and videotape-based surveillance equipment to modern digital image systems such as the All-in-one Portable System (ALIP), Digital Single Camera Optical Surveillance System (DSOS), Server Digital Image Surveillance System (SDIS), and Digital Multi-camera Optical Surveillance System (DMOS).[262] More than 270 single camera surveillance systems were installed for various nuclear facilities in 2001 by the IAEA inspection team.[263] During UN inspections in Iraq, video surveillance systems were deployed by IAEA to monitor concerned facilities or machines, and all of the equipment was operational.[264] US DOE national labs have developed different monitoring prototype systems in which video checking is one of the most important elements for potential nuclear arms reduction or fissile materials surveillance.[265] They have also demonstrated the application of remote video monitoring for container, magazine, and facilities related to nuclear materials or activities cooperatively with their Russian counterparts during 1997-2001.[266] For future nuclear warhead verification application, the capability of video monitoring technology still needs improvement in anti-fakeability,[267] reliability,[268] unattended biasing, cost effectiveness, and high-efficiency algorithm.

The combination of various kinds of sensors is another effective method used to authenticate and track the status of controlled objects. Sensors have configurations such as smartshelf, smart container, electronic sensor platform (ESP), and integrated monitoring systems[269]. The application of sensors can involve diverse technical means including weight, motion/acceleration, radioactive, temperature/humidity, thermal, acoustic, magnetic, vibration, and impact-force-sensitive. These technologies are quite mature and can be readily incorporated into an integrated monitoring system. Both the United States and Russia have developed and tested such systems for potential nuclear warhead reduction and fissile materials safeguards application.[270] The combination of various sensors has its obvious advantages for monitoring nuclear warhead reduction, including that most of the sensors are commercially available, thus it is technically transparent and easy to understand and applicable by all parties; the deliberate designed application strategy of the sensors can be readily integrated into a seamless, layered,

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[262] M. Aparo, G. Hadfi and J. Whichello, “Implementation of Digital Image Surveillance: Problems and Solutions”, INMM-43

[263] “New Safeguards Equipment Systems: Teaming IAEA Inspectors with Technology”, IAEA, available at http://www.iaea.or.at/worldatom/Programmes/Safeguards/Teaming_Inspectors/Teaming%20IAEA%20Inspectors.pdf

[264] “Sixth report of the Director General of the International Atomic Energy Agency on the implementation of the IAEA's plan for future ongoing monitoring and verification of Iraq's compliance with paragraph 12 of resolution 687 (1991)”, S/l 994/1151, October 10, 1994

[265] For example, Integrated Monitoring and Surveillance System designed for ORNL, Integrated Monitoring and Review System, Integrated Facility Monitoring System and Magazine Transparency System developed by LANL, Material Monitoring System and Cargo Monitoring System developed by SNL

[266] Thomas Lockner, et al., “Progress towards Complimentary Cooperative Monitoring Facilities at the Savannah River Site, USA and VNIIEF, RF”; and C. Dennis Croessmann, et al., “SNL/VNIIEF Sotroage Monitoring Collaboration”

[267] The video surveillance can be spoofed by creating a substitute scenario, inserting the cheated artificial image into data transfer line.

[268] James Lemley, et al., “Workshop on Design and Testing for High Reliability: Challenges and Progress”, INMM-43

[269] see Chris A. Pickett, et al., “Automated Systems for Unattended Weight and Item Monitoring at Kurchatov Instutute in Moscow, Russia”; and Massimo Aparo, et al., “Integration Approach for Different Data Generators into Safeguards Unattended and Remote Monitoring Systems”; Robert Kinzel, Brad Mickelsen and Curt A. Nilsen, “Update of Project Straight-Line, a Comprehensive Nuclear Material Monitoring System”; and Eric R. Gerdes, Roger G. Johnston and James E. Doyle, “A Proposed Approach for Monitoring Nuclear Warhead Dismantlement”, *Science and Global Security,* Vol. 9, 2001, pp.113-141

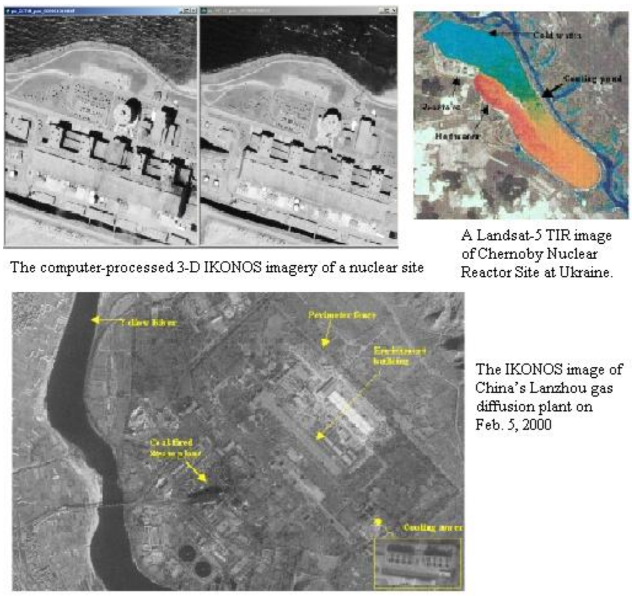
[270] Greg Mann, Andrey Sviridov, and Konstantin Zimovets, “Weapon Storage Technology Demonstration Facility”

and interlocked network to monitor the status of controlled objects; and the employment of combined sensors can adjust to different application scenarios.

Photograph-comparing is a method to detect tamper activities by carefully examining the recorded images of controlled objects. It can be enhanced through a process implementation strategy such as drawing random pattern images or marks near the item, and photography from all angles to form a comprehensive image. As it requires specific interpretation (artificial or algorithmic) and can easily raise disputes, photograph comparing is often co-utilized or embedded into tamper-indicating monitoring methods such as RPT photographing, fiber optic seal picture, and shrink-wrap seal picturing. Because the picture taking process can be affected by many environmental elements, photograph comparing can only be a complimentary means for arms control verification.

Satellite imaging is a very powerful tool to detect the faceted change of large facilities or objects. It is one of the most important NTM elements and requires advanced space and electronic sensor technologies. Satellite imaging can integrate visual, thermal/infrared, multi-spectra, synthesized aperture radar (SAR), and other photographic technologies into a comprehensive system that can provide a meaningful picture of the concerned area or objects. Figure 8 shows the pictures taken by visual and thermal/infrared sensors and their associated computer processed, 3-D, colored images. For nuclear warhead reduction verification regime, the satellite imaging technologies can be an effective deterrence to mass or certain-scale covert nuclear activities.

Figure 8. Several visual, multi-spectra and computer-processing satellite images



Sources: "Potential Applications of Commercial Observation Satellite Imagery for the Verification of Declared and Undeclared Nuclear Production Facilities", Hui Zhang, INMM-41; and "3-D Map Generation of Nuclear Sites from IKONOS Imagery", Q.S. Bob Truong and C. Vincent Tao, INMM-43

Intrusion detection is a very common utilization of security for high-value assets often used in arms control applications for PPCM and guarding treaty-limited-items. It includes varieties of mature and available technical solutions such as microwave, infrared beam, weight detection, capacity-sensitive, and motion/acceleration sensors. All of these individual technical means can be composed into an efficient system to detect unauthorized access. The reliability and efficiency of intrusion detection methods and technologies are still in continuous development and improvement to better fit specific arms control applications such as indoor radiation field and outdoor tough climatic environment.[271]

The surveillance technologies can be employed individually and comprehensively to configure specific-targeted, defense-in-depth, and interlocked systems that can apply to different verification scenarios for nuclear warhead reduction. They are of great importance and can be achieved to establish a limited or seamless surveillance system for nuclear warhead reduction verification.

4.6 Inability, dismantling, and disposition technologies or methods

Irreversible management of nuclear warheads is an essential feature of a warhead-centered arms control regime[272] and should take the solid steps towards irreversibility of having warheads military disabled, dismantled, and disposed. The irreversible disposal of nuclear warheads has very important significance for future nuclear arms control. Irreversible disposal shows the decisive process towards nuclear reduction and thus can greatly enhance the confidence, credit, and trust not only between treaty parties but also to the non-nuclear weapon states. It can greatly reduce the concern and risk for breakout scenarios through rapid uploading on existing missiles. Irreversible disposal is the compelling force that can shrink the military function of nuclear weapons with fewer available or intact nuclear warheads. It is a positive action for promoting and consolidating nonproliferation regime, and a substantial process complying with Article IV of the NPT Treaty. The next steps of nuclear arms reduction should strongly focus on the irreversible disposal of nuclear warheads.

For military inability of nuclear warheads, particularly to nuclear components of primary, some arms control experts had proposed feasible solutions such as pit-stuffing, pit crashing, and pit mixing. Pit-stuffing is a technical method that disables nuclear warheads permanently and verifiably through inserting steel wire, aluminum powder, or epoxy into the center hollow core of boosted primary,[273] thus disabling the performance process of a nuclear weapon. This method can be easily verified at low cost and limited intrusiveness by taking a partial gamma ray photograph, post-dismantled stuffing inspection, and unique radioactive fluorescent tag[274]. Pit-stuffing is a very promising technical option to irreversibly *destroy the military utility of vast numbers of nuclear weapons that are agreed to be in excess*.[275] However, pit-stuffing is only appropriate for modern boosted primary with a hollow core. Pit crashing is another feasible way to quickly

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[271] Mel Maki, Roger Nieh and Michael Dickie, “Outdoor Intrusion Detection Sensor Field Testing Experience”, INMM-43
[272] Harold A. Feiveson, ed., The Nuclear Turning Point: A Blueprint for Deep Cuts and De-alerting of Nuclear Weapons, (Brookings Institution Press: Washington, D.C., 1999), pp.175
[273] Matthew Bunn, "Pit-Stuffing": How To Disable Thousands of Warheads and Easily Verify Their Dismantlement
[274] Ibid
[275] Richard L. Garwin, “Comment on Matt Bunn's "Pit-Stuffing" Proposal”

convert the pit (nearly all forms of nuclear warhead primaries) into military non-usable status. It deforms the pit by crushing slightly on one-side of pit to make the nuclear weapon unable to perform a desirable compression process unless it is recast. Although it can be universally adopted to different pit configurations, the verification and safety problems still need to be resolved. Pit mixing adheres or tags some highly radioactive waste (choosing the strong neutron emitter) to the surface of the pit. The strong neutron emitter can not only trigger an early chain reaction of primary to decrease the performance of nuclear explosion but can also erode the surface of the pit gradually. Therefore, it can effectively make the pit unusable for military purposes. The verification and safety concerns (particularly the safety problems including health, environmental and critical safety), still remain open for consideration and research.

Nuclear warhead dismantling[276] not only involves a complicated and intrusive monitoring and authentication process and associated technologies described in the previous chapters, but also needs to develop a safe, secure, and specific dismantling process and associated technologies. Both the United States and Russia dismantled thousands of retired nuclear warheads in the past[277] and have gained valuable experience and practice. Nuclear warhead dismantling process and associated technologies include the physical separation of nuclear components (pit, canned subassembly (CSA), and D-T gas) and non-nuclear components (neutron generator, AF&F system, and structural materials) from a nuclear warhead, which requires special-designed facilities, technical equipments, and mechanical tools; strictly controlled safety regulations or rules; and various specific procedures. Past dismantling activities have proven that US-developed special facilities, equipment, and process for dismantling nuclear warheads were safe, effective, and reliable (although some accidents occurred during the dismantling process, most of the dismantlement were safe and reliable, and a strict controlled process was developed to ensure the safe and reliable dismantlement by drawing the success and failure experience from the past activities[278]). In addition, it was thought that USSR/Russia had developed its own appropriate facilities, tools, and process for disassembling nuclear warheads.[279] Because of the extreme sensitivity of nuclear warhead configuration and the dismantling process that can reveal the detailed information of this configuration, the appropriate technologies, procedures, and method for cooperative nuclear warhead dismantling is still in development with the help of computer simulation.[280]

The disposition of nuclear warheads means to destroy the non-nuclear components and convert

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[276] For detailed discussion of status, procedures, technologies, and control for nuclear warhead dismantlement, see "*Dismantling the Bomb and Managing the Nuclear Materials", OTA-O-572* (Washington, DC: US Government Printing Office, September 1993), US Congress, Office of Technology Assessment.

[277] See US DOD and DOE, "Summary of Declassified Nuclear stockpile Information: Declassified Stockpile Data 1945 to 1994", available at http://www.osti.gov/html/ositi/opennet/document/press/ pc26tab1.html; and "US Nuclear Warheads, 1945-2002" and "USSR/Russian Nuclear Warheads, 1949-2002" in "Archive of Nuclear Data" from NRDC's Nuclear Program, available at http://www.nrdc.org/nuclear/nudb/datainx.asp

[278] George Lobsenz, "Pantex's Cracked Plutonium Pit Remains A Mystery", *The Energy Daily,* April 12, 1993; Don Moniak "Part III: Plutonium In Pits", in *Plutonium: The Last five Years,* available at http://www.bredl.org/sapc/Last_Five_Years.htm; and "More Attention to Health and Safety Needed at Pantex", GAO/RCED-91-103, April 1991

[279] See Alan Sussex, "Pantex: Dismantling the Bomb", *Outlook,* August, 1996; "Mission Statement" of Pantex Plant, DOE, available at http://www.pantex.com/ds/pxgend1.htm; and Oleg Bukharin, "Downsizing Russia's Nuclear Warhead Production Infrastructure", *The Nonproliferation Review,* Spring 2001, Volume 8, Number 1, pp.116-130

[280] Joseph W. Jackson, "3-D Simulation for Assessment of Transparent Weapon Disassembly Operations"

nuclear components (pit and CSA) into military non-usable form. Due to the ease of reproducing the corresponding non-nuclear components, the irreversible nuclear warhead reduction should focus on the conversion of pit and CSA. For WgU from nuclear weapons, there exist feasible and workable means to blend down and convert nuclear components into LEU fuel for commercial applications. The successful implementation of US-Russia HEU Purchase Agreement proved that it is possible to irreversibly convert HEU from dismantled nuclear weapons for peaceful purpose and that it can be no longer returned to military circles.[281] There are mainly two methods to convert plutonium pit into military non-usable form:[282] (1) Blend WgPu down and then change it into MOX fuel for commercial or fast reactor. (2) Mix the military usable plutonium from nuclear weapons with highly radioactive waste, and then immobilize it for underground burying. Both methods are still in assessment, and more R&D needs to be done in order for it to become feasible and acceptable in cost, technology, safety, security, and decreased proliferation risk.

The existence of large amounts of excess fissile materials for national defense and intact nuclear warheads (plus strategic pit reservation) not only bring the potential of proliferation risk, and problems to the environment and valuable resources, but also raises political concerns of mistrust and suspicion between NWS-NWS and NWS-NNWS. Thus, the future nuclear warhead reduction should irreversibly eliminate the most important component of nuclear weapons – pit and CSA and resulted fissile materials.

4.7 Confidence, intrusiveness and information security

The two main concerns of past nuclear arms control practices are the confidence of compliance by treaty parties and the intrusiveness of verification designed to ensure the treaty implementations. Confidence of compliance and intrusiveness of verification are generally contradictory for treaty execution, stated, "Despite its deterrent role, it is accepted that no verification regime could possibly be devised to provide 100% confidence in its effectiveness; some residual risk must remain. The higher the required confidence, the more expensive and invasive the regime, and, crucially, the higher the degree of cooperation or transparency,"[283] and vice versa (Figure 9). [284] Therefore, the technologies or equipments used for treaty verification often require a long time to be well researched and carefully negotiated in order to gain the appropriate balance for achieving a defined level of confidence. The degree or level of intrusiveness of a proposed verification method is dependent on the sensitivity of information, the treaty parties' acceptance, the political environment, and status of technology development. For example, before INF, the on-site inspection and associated intrusive equipments targeted at nuclear arms control, were firmly rejected by USSR (also partly by the United States itself)

[281] Nuclear Nonproliferation: Implications of the US Purchase of Russian Highly Enriched Uranium (Letter Report, 12/15/2000, GAO/GAO-01-148)

[282] There are large number of publications introducing the disposition of plutonium, for detailed discussion on management of plutonium from nuclear weapons, see "*Management and Disposition of Excess Weapons Plutonium"*, Committee on International Security and Arms Control, National Academy of Sciences, (Washington, DC: National Academy Press, 1994); "*Dismantling the Bomb and Managing the Nuclear Materials", OTA-O-572* (Washington, DC: US Government Printing Office, September 1993), US Congress, Office of Technology Assessment.

[283] "Confidence, Security & Verification: the Challenge of Global Nuclear Weapons Arms Control", Atomic Weapons Establishment, Aldermaston, 2000, pp.9

[284] The increase of verification confidence requires more rapid rising in expense of intrusive utilization of data transparency, multiple advanced equipments, on-site inspection, elaborate verification strategy.

because of the fears of exposing national security-related information, the political hostility between the West and the East, and technical limits.[285] INF created unprecedented opportunities for detailed data exchange, intrusive on-site inspection, and use of some advanced technologies. Many confidence and verification concepts such as "enough," "adequate," or "effective" were proposed for pushing the establishment of nuclear arms control, verification, and confidence.

Unlike missile technologies whose principle, configuration, structure, and material were already nearly fully grasped by the major powers (all five declared NWS have developed ICBM capabilities for delivering nuclear explosives), nuclear warhead technology is regarded as top secret and as the most concerning proliferation factor by the nuclear states. Its configuration and structure are also very restricted even among the nuclear states, although its fissile materials production and simple principle (mainly for a rough nuclear atomic bomb) are well known. Furthermore, the data about excess, reserve, or covert nuclear warhead stockpiles have special military significance under scenarios such as large numbers of existing missiles, capable of uploading more warheads than are currently being carried, and the entry stage of deep reduction in which strategic stability is more critical than numbers of nuclear warheads. So, it is of particular importance and difficulty to settle the balance of confidence and intrusiveness for nuclear warhead reduction verification regime.

[285] Timothy J. Pounds, "Proposals for On-Site Inspection over the Years: From the Baruch Plan to the Reagan Initiatives", and William C. Potter, et al., "The Evolution of Soviet Attitude toward On-Site Inspection", in Lewis A. Dunn and Amy E. Gordon eds., *Arms Control Verification and New Role of On-Site Inspection*, (Lexington Books: 1989), pp. 69-91 and pp.185-206

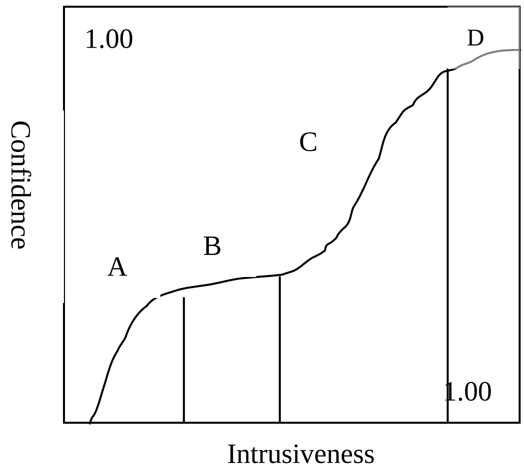

Figure 9. The relationship between verification confidence and intrusiveness

Note: the A and C areas represent that with the increase of intrusiveness of verification, the confidence rises dramatically; B area shows the relative flat line in which though employing higher intrusive verification regime, the confidence remains nearly unchanged; D tells that (1) even with "any time, any where" intrusive verification, it is impossible to gain 100% confidence as the monitored always can find some ways to conceal the non-compliant activities in a certain period, and (2) it is very costly to achieve a little increase in confidence with the intrusiveness approaching 100% level.

If possible, it is always required for treaty parties to first apply simple technology such as those radiation measurements used in INF and START. NTM also provides a good method for off-site purpose. But, obviousl,y the simple technology and sophisticated NTM are limited in their ability to verify the small treaty-limited-items, particularly for the nuclear warhead, with high confidence.

During past arms control experiences, there has always been a contradiction between the monitoring and monitored parties. For the monitoring party, the more precise the measurement or the more the information procured, the higher the confidence the monitored party will comply with the obligation. For the monitored party, the less the information or process involved, the higher the security. One of the key elements for nuclear arms control is information management between the monitoring and the monitored. The information involved in past nuclear arms reduction can be divided into several categories:

- Mutual exchanged data: the conception, definition, description, and accounting rules in terms of types, numbers, locations, capabilities, technical specifications, or other distinguished information for TLIs or prohibited activities
- Identification or signature information for verification: the technical discriminated characteristics of TLIs or banned activities; inspection of associated sites including deployed, stored, or produced; and on-site measurement data
- Surveillance information for compliance monitoring: the information acquired unilaterally or cooperatively by NTM and other monitoring methods
- Deduced information: to generate an integrated image of the treaty implementation through analyzing data sets from various channels.

All of the above information can be of concern for both monitoring and monitored parties. Concerns include how to obtain enough data to confirm the compliance by each party and reveal the prohibited TLIs or activities without compromising national security or non-proliferation regime. These remain the central focus of past arms control campaigns but also should be researched and developed for future nuclear arms control regime.

Several kinds of information must be carefully dealt with in order to verify nuclear warhead reduction:

- Directly related national security or strategic stability influenced data including the exact locations, types, numbers in aggregation and types, status, and historical archives of nuclear warheads. The technologies connected with this information include tag and seal, surveillance such as NTM, remote sensing and human intelligence, OSI, and chain-of-custody.
- Proliferation information (vertical and horizontal) including the design, configuration and composition of nuclear warheads should also be carefully dealt with. The technologies linked with this information are mainly measurement data (nuclear and non-nuclear) and surveillance of dismantling procedure.
- Accompanying information of nuclear warheads including detailed historical data about fissile materials; the production, maintenance, refurbishment and dismantling facilities and deployed sites of nuclear warheads; and rapid recovery capabilities of nuclear warheads is also important.

The information threat for nuclear warheads can come from the monitoring side, the monitored side, or the third side (i.e. those outside the treaty). Each side has different purposes and methods for managing or acquiring the information generated during the data exchange and verification or inspection procedures for nuclear warheads. To prevent information disclosure, many techniques and measures have been proposed and developed in the past, particularly during the verification implementation process of INF, START-I, and HEU Agreement, and technical discussion, preparation, and cooperation for verifying CTBT, START-II and -III, Plutonium Disposition Agreement, Trilateral Initiatives, Mayak Transparency, and assumptive nuclear warhead reduction (Table 12).

Table 12. The primary data generated during nuclear warhead reduction verification and associated protection methods

The primary data generated for verifying nuclear warhead reduction	Verification techniques	Channels or methods to manage information[286]	Information protection measures
Data initiated for exchange such as quantities, types, locations, and ID serial	OSI, NTM, PPCM, Chain-of-Custody, and Cooperative monitoring	Cheating Espionage Decryption of concerned data	Encryption to the exchanged data list Managed Access to the items or facilities Administrative control Controlled intrusive verification

[286] Cheating here means that the monitored party tries to fool the monitoring party with false information either during data exchange period or in measurement for verification. The most effective method to defeat cheating is to utilize more intrusive verification techniques or equipments for both deterrence and evidence-proof. Leakage refers to the possible emanation mode such as electromagnetic or radioactive radiation, heat flow.

Measurement data or result (nuclear and non-nuclear) for verifying individual nuclear warhead	OSI, PPCM, Chain-of-custody	Cheating Leakage Reverse-engineering and analysis Espionage Data intercepting	Utilization of information barrier Managed Access to the items or facilities Information blurring Administrative control Controlled intrusive verification
Information produced during treaty execution activities such as transportation and monitoring	OSI, NTM, PPCM, Chain-of-Custody, and Cooperative monitoring	Cheating Leakage Decryption Espionage Data intercepting Reverse-engineering	Encryption to the sensitive data Utilization of information barrier Managed Access to the items or facilities Information blurring Administrative control Controlled intrusive verification

The common characteristics of information or data are reproduction, promulgation, massiveness, and diversity. The sensitive data produced during the verification of nuclear warheads have the same intrinsic nature, requiring the protection of different layered methods. For reproductive and promulgated characteristics, unbreakable encryption and data self-destruction techniques can be applied to the sensitive information. For massive and diverse nature, there is the technique of blurring some key data sets.[287]

There are two notable developments in protecting nuclear warhead information during the negotiation and preparation for reducing nuclear warheads and disposition of fissile materials. The first is the employment of a hash function to encrypt any data either for exchange or produced by verifying measurement. The second is the introduction of information barriers to prevent the divulgence or reverse-engineering of the sensitive data. For example, the high-resolution full energy gamma spectrum of a nuclear warhead can reveal nearly everything in its design, composition, and configuration.[288] Thus, US DOE national labs conceived, prototyped, and demonstrated both hash function and information barrier application for "transparent" nuclear warhead authentication[289]. In principle, there is opportunity to apply some very intrusive techniques or equipments for nuclear warhead verification that incorporate newly developed hash functions and information barriers.

More research and development efforts toward protecting sensitive data by employing intrusive technologies and assuring confidence in reduction verification, particularly in the area of cooperative work, must occur to ensure mutual technical understanding for future nuclear warhead verification negotiation.

5. Conclusion

The history of alleged and mutual condemned violation and non-compliance in past arms control

[287] One high confident techniques for nuclear warhead verification is to measure the full energy gamma spectrum which contains large quantities of sensitive data. Because of the massive data produced and physical complication, it is impossible to deduce meaningful result some with key data sets blurred or missed.
[288] Personal communication with Prof. Steve Fetter, University of Maryland.
[289] Kevin D. Seager, et al., "Trusted Radiation Identification System", INMM-42; and the Joint US DOE-DOD Information Barrier Working Group, "The Functional Requirements and Design Basis for Information Barrier".

treaties such as those performed under SALT I and ABM[290] teaches a very important lesson. Without comprehensive, sophisticated, and intrusive verification techniques or technologies, there is always the high probability for activities of deception, concealment, and cheating, particularly in a deteriorated political atmosphere. There is always low confidence of verifying the obligation of treaties in a timely manner. The late successful implementation of INF and START-I can be attributed to unprecedented, detailed data exchange and intrusive verification regime such as different kinds of OSI and PPCM. There are also other successful intrusive verification examples for arms control such as UNSCOM and IAEA inspection activities in Iraq, specific designed monitoring procedure and equipments for uranium downblending of HEU Agreement, and the very strict inspection process of the CFE Treaty.

Past nuclear arms control focused on decreasing the numbers of nuclear capable delivery vehicles, reducing the threat of nuclear war, and blocking nuclear weapon research and development capabilities. There were no actions taken toward the reduction or disposal of nuclear warheads. The newly signed Moscow treaty took a step toward limiting the total deployed strategic nuclear warheads without mentioning how to manage the reduced nuclear warheads and corresponding verification arrangements. After the end of the Cold War, it was widely recognized that it was imperative to establish a regime for controlling and reducing nuclear warheads and associated fissile materials. Both the United States and Russia signed several agreements for disposing weapon-usable fissile materials. Both countries developed concepts and techniques for transparent nuclear warhead reduction verification. At the same time, the United States alone publicized its plutonium stockpile inventories. Although there were no real activities for nuclear warhead reduction in place, many technical research preparations were under development, and various proposals for different scenarios and phases were suggested.

Since nuclear warhead reduction involves (1) sensitive information exchange, (2) intrusive verification regime, (3) situations of military significance (serious national security concern), and (4) complicated and vast technical problems, it is better for the United States and Russia to start the formal or prototyped practice as early as possible. This will have the very positive impact of pushing multilateral nuclear reduction forward.

5.1 Several nuclear warhead reduction options

There are several options to reduce nuclear warheads in terms of comprehensiveness and intrusiveness:

Option I (minimum). The five NWS and *de facto* nuclear weapon states (Pakistan, India, North Korea and Israel) can make unilateral, bilateral, or multilateral assurance with (1) limited transparency (including selective stockpile data declaration and limited data exchange) of which different degrees and phased procedures to be adopted for three state levels,[291] (2) utilization of

[290] See Michael Krepon, "Arms control verification and compliance", (New York, N.Y.: Foreign Policy Association, 1984); and Gloria Duffy, Compliance and the Future of Arms Control, (Cambridge, Mass.: Ballinger), 1988
[291] The three state levels are divided mainly according to the nuclear weapon capabilities and status such as numbers of nuclear warheads, quantities of fissile materials, and deployed nuclear forces. They are (1) US and Russia, (2) France, U.K. and China, (3) de facto nuclear weapon states (Pakistan, India and Israel). In every following option, various degrees or extents can be applied to three state levels, for example, to limited data exchange, US and Russia can have more information about their nuclear

NTM and remote sensing to provide limited evidence of obligation, and (3) cooperative research and development of associated techniques and technologies for nuclear warhead reduction verification and monitoring.

Option II. The five NWS and *de facto* nuclear weapon states (Pakistan, India, and Israel) can take mutual or multilateral transparency initiatives and issue memorandums about their nuclear stockpiles and capabilities with (1) selective stockpile data declaration and limited data exchange, (2) utilization of NTM and remote sensing to provide limited evidence of obligation, (3) adoption of limited cooperative monitoring measures to increase the authenticity of transparency, (4) cooperation in prototyping associated techniques and technologies for nuclear warhead reduction verification and monitoring, and (5) the promotion of societal verification.

Option III (maximum I). The five NWS and *de facto* nuclear weapon states (Pakistan, India, and Israel) reach a formal agreement to reduce and dispose their nuclear warheads with (1) associated detailed data exchange, (2) limited OSIs to confirm and verify the exchanged data, (3) application of limited chain-of-custody to assure the implementation of reduction, (4) adoption of comprehensive cooperative monitoring measures to increase the reduction transparency, (5) complementary NTM and remote sensing without interference to deter the covert nuclear activities, (6) fully cooperative utilization of associated techniques and technologies for nuclear warhead reduction verification and monitoring, and (7) the promotion of societal verification.

Option IV (maximum II). The five NWS and *de facto* nuclear weapon states (Pakistan, India, and Israel) manage a formal agreement for achieving NTP Article IV with (1) detailed exchange on all nuclear weapon related data including deployed forces, capabilities, facilities, and activities, (2) various intrusive and comprehensive OSIs to confirm and verify the exchanged data, (3) application of full-scope chain-of-custody to ensure the implementation of reduction, (4) adoption of comprehensive cooperative monitoring measures to increase reduction transparency, (5) complementary NTM and remote sensing without interference to deter the covert nuclear activities, (6) fully cooperative utilization of associated techniques and technologies for nuclear warhead reduction verification and monitoring, and (7) the legal status of societal verification.

Since nuclear warhead reduction is very sensitive, militarily and politically significant, and highly technical, it requires significant technology preparations, mutual understanding, and a benign international atmosphere. Reduction is also a phased procedure with the above options. A practical phased procedure for nuclear warhead reduction would follow these stages: (1) Both the United States and Russia reinforce the Moscow Treaty with the verification regime on nuclear warhead reduction with continuous dismantling and eliminating of the large number of retired or reserved nuclear warhead stockpiles. It must also promote the transparency of total nuclear warhead and fissile materials inventories. (2) Both the United States and Russia reduce the deployed nuclear warheads to 1000 and total nuclear warhead stockpile to 2000, with comprehensive, cooperative, verified, and irreversible reduction on nuclear warheads. The other three NWS freeze the agreed upper limit of total nuclear warheads, provide limited transparency of the nuclear warhead inventories, and cooperatively developing the warhead reduction

capabilities transparent than those of the other two levels' states.

verification and elimination technologies. The *de facto* nuclear weapon states should join NPT and freeze the nuclear weapon development activities. (3) The five NWS reduce the total nuclear warheads to an agreed or proportioned number by transparent, comprehensive, cooperative, verified, and irreversible means. The *de facto* nuclear weapon states should be transparent on their nuclear stockpiles and freeze the number of total nuclear warheads with preparation for verified nuclear reduction. (4) All nuclear capable states should eliminate nuclear weapons with full-scope, range and transparent verification, monitoring and inspection regime. Table 13 shows the phased nuclear warhead reduction procedure with various options.

Table 13. The various options applied in the phased nuclear warhead reduction

	The United States and Russia	France, U.K. and China	*De facto* nuclear states
Stage 1	Option I and partial Option II		
Stage 2	Option II and partial Option III	Option I and partial Option II	Partial Option I
Stage 3	Option III	Option II and Option III	Option II
Stage 4	Option IV		

5.2 The way ahead

The successful completion of the START Treaty's phase in December 2001 indicates the end of a meaningful treaty that reduced strategic nuclear capable delivery vehicles. Since then, the United States and Russia each maintain fewer than the Treaty's mandated limits of 1,600 deployed strategic delivery vehicles and 6,000 accountable warheads. The START Treaty reductions, inspection regime, notifications, and telemetry exchanges have produced stabilizing changes that have contributed to international security and strategic stability.[292]

On May 24th, 2003, the United States and Russia signed SORT opening another era for limiting total deployed strategic nuclear warheads. But due to the lack of enforcement provisions, the treaty is more of a political sign than a real step toward nuclear warhead reduction. With the improvement of US-Russia relations and the international atmosphere, it is illogical for both the United States and Russia to maintain the huge nuclear warhead stockpiles inherited from the Cold War. With the technical preparation and mutual understanding established during negotiation of START II and III, it is possible to continue the interrupted work for transparent elimination of nuclear warheads and reduction of total nuclear stockpile under the framework of The Moscow Treaty.

Nuclear warhead reduction is very significant for future nuclear arms control and the international security environment. The promotion of future nuclear warhead reduction and associated verification regime is informed in large part by past nuclear arms control verification activities. Irreversible nuclear warhead reduction is a giant step not only for the United States and Russia, but also for the security and peace of the entire world.

[292] Fact Sheet: START Treaty Final Reductions, (State Department says reductions promote stability) (710) available at http://www.fas.org/nuke/control/start1/news/startfinalnum.htm