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TAGS AND SEALS TO STRENGTHEN ARMS CONTROL VERIFICATION*

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INTRODUCTION

Tags and seals have long been recognized as important ~~tools in arms control~~. The trend in control of armaments is to limit militarily significant equipment that is capable of being verified through direct and cooperative means, chiefly on-site inspection or monitoring. Although this paper will focus on the CFE treaty, the role of tags and seals for other treaties will also be addressed. Published technology and concepts will be reviewed, based on open sources.

Arms control verification tags are defined as unique identifiers designed to be tamper-revealing; in that respect, seals are similar, being used as indicators of unauthorized access. Tamper-revealing tags are intended as single-point markers, seals for two-point couplings, and nets for volume containment. Seals usually bind two separate components, such as a hatch or flange that provides access to a secure compartment or a valve that controls fluid flow. A tamper-revealing net might be comprised of a coupled fiber-optic bundle wrapped around an object. Sometimes the term "seal" is used to denote the tamper-revealing feature of a tag that is attached to a surface, but in this paper the tamper-indicating connection is considered to be part of the tag concept itself.

The terms "tamper-revealing" and "tamper-indicating" are used interchangeably. The expression "tamper-resistant" is also frequently used without necessarily implying any greater degree of resistance to transfer. "Tamper-proof" would be an overstatement, but "tamper-proofing" might be appropriate to indicate the design intention. Depending on their specific arms control role, tags need to have built-in resistance to counterfeiting and transfer. Seals have the additional requirement of verifying the integrity of a closure.

The functions of an arms control tag can be considered to be two-fold: to provide field verification of the identity of a treaty-limited item (TLI), and to have a means of authentication of the tag and its tamper-revealing features. Authentication could be accomplished in the field or be completed elsewhere.

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TREATY REQUIREMENTS

Neither the INF Treaty^a nor the underground nuclear-weapons testing treaties have had a requirement for tags. As aids to limitations on the number of mobile missiles and to control their modernization and production, tags and seals have been proposed for START.^b If nuclear warheads were to be verifiably removed from service and dismantled, tags and seals might be needed.

For proposed multilateral treaties, tags and seals might have a more widespread role; their value increases with the practical difficulties of accountability when a great many items must be verified. In verification of a CW^c Convention, seals could be important in assuring against prohibited uses of holding tanks, valves, containers, and facilities. The CFE^d treaty has the potential for the largest number of tags -- perhaps hundreds of thousands.

Before the INF Treaty, bilateral negotiations between the United States and the Soviet Union concentrated on the technology of the weapons being limited by the treaty. The text of SALT II,^e for example, contains long sections of technical language defining such properties of missiles as throw-weight. Verification of SALT treaties was to be by national technical means (NTM).

The INF Treaty broke new ground for arms limitation by concentrating on the details of the verification procedures to be used in implementation. Previously only the Non-Proliferation and the Peaceful Nuclear Explosions treaties had placed an equivalent emphasis on verification procedures and technologies. On-site inspection to verify the INF reductions was an important consideration in negotiating the treaty as well as forming a large chunk of its text. The recently ratified Threshold Test Ban Treaty contains a new set of detailed verification protocols.

In the negotiations on reductions of conventional forces (CFE), on-site inspection provisions have again played a major role in the design of the treaty provisions. Advances in tagging technology promise to enhance security under a second-stage CFE Treaty as well as to reduce the cost of verification. NTM can track large concentrations of weapons but cannot verify compliance with ceilings. Tagging and keeping track of each deployed weapon provides automatic control of the total inventory of weapons. Although simple seals and markers have been used from ancient times, more sophisticated devices have been devised to cope with countermeasure technology and with the importance of items to be controlled. For example, the domestic safeguarding of nuclear

^aIntermediate-range Nuclear Forces.

^bStrategic Arms Reduction Treaty.

^cChemical Weapons.

^dConventional Forces in Europe

^eStrategic Arms Limitation Talks

materials and weapons has been facilitated by tamper-revealing seals of many types. These applications have been picked up by the IAEA^a in carrying out its responsibilities on nuclear materials under the Non-Proliferation Treaty (NPT). Commercial applications for secure indicators are on the market.

Verification Requirements

CFE verification entails counting a large number of items; taking account of various sites and zones of deployment, storage, production, withdrawal, and elimination; compliance with limits on holdings and observation of mobilization capability; and recognition of modernization. Other impending treaties have more restricted goals.

From a military viewpoint, the CFE treaty is intended to increase stability and reduce the risk of war by means of force reductions and transparency measures. The reductions in deployed forces will come about in part by withdrawal of forces from the Atlantic-to-the-Urals (ATTU) and by actual elimination (destruction, dismantlement, or conversion) of some equipment. The transparency measures may require verification not only of the objects that are being reduced (troops and equipment) but also of more transient characteristics like mobilization potential and modernization. All of these features must be verified within a multi-dimensional matrix that includes deployment ceilings and subceilings within zones, national and alliance constraints, flexible and declared interzone transit and exercises, storage at designated sites, production at declared facilities, withdrawal through exit points, and elimination at approved sites.

The measures that could be used for verification include on-site inspection (OSI), on-site monitoring (OSM), roving inspectors, aerial surveillance, and -- of course -- NTM. The possible technologies that could aid verification include tags, sensors, cameras, and computers.

Based on the preceding military objectives, certain functional principles can be identified. Of overriding concern is cost-effectiveness.

Strict complete initial item accountability. All agreed treaty-limited items might be subject to strict and complete initial accountability because: (1) any item declared in a treaty becomes as a matter of law subject to verification; (2) overall accountability is facilitated by having accurate verification from the moment the treaty enters into force; and (3) if accountability is not complete from the beginning, the process is not reversible when compliance questions arise. One must keep in mind the possibility of a follow-on CFE-II treaty with further verified reductions.

Timely verification. The time scale for verification is driven by mobilization potential and countermeasure reaction. The degree and rapidity of access, the thoroughness of data collected, and the speed of transmission and assimilation of data are key factors in the utility of verification. The INF short-notice inspection process gives up to eight or nine hours advance notice

^aInternational Atomic Energy Agency.

of OSI at a given site. For CFE it will often be possible to reach many sites in a few hours. In addition, there will probably be a constant presence of attached personnel, roving inspectors, and other informants. Periodic aerial and frequent satellite observation is also likely.

Accurate and efficient accountability. Because of several factors -- the very large number of items that could be subject to declaration (200-300 thousand), the initial surge of withdrawal, and the subsequent stages of reduction -- accurate and efficient means of item counting will be necessary to keep verification costs low and minimize disputes over compliance.

Synergistic support for NTM. The intelligence resources of many treaty parties will continue to provide strategic information on overall conventional-force deployment activities. NTM data interpretation can be expedited and improved by ground verification, and conversely. OSI selection can be guided by data from NTM.

High cost-effectiveness in verification technologies. Technical means of augmenting verification must satisfy stringent tests in cost-effectiveness, especially when one must take into account the large number of objects and factors with military significance.

Limited redundancy through different approaches. It is an accepted principle in many fields to allow redundancy by similar or different means when the objectives are sufficiently important. There might be some situations in CFE verification where overlap in types of verification should be accepted. For example, is the cup half-full or half-empty? If 5000 out of 10,000 TLIs are eliminated, what is more important: verifying the elimination or verifying the residual? Verifying just one of these two aspects might be sufficient, but verifying both would give added confidence.

Strong reliance on human observation. The human being is a highly capable and discriminating sensor and integrator of various indicators (but with limited and short-term memory). Perhaps the most important aspect of inspection will be the observations and inferences drawn by qualified military personnel, particularly in terms of the less quantitative aspects of on-site inspection. In fact, one goal of technology will be to relieve the inspectors of certain routine steps in verification so that they can concentrate on qualitative aspects such as war-fighting capability and treaty circumvention.

Burdensharing. Costs of verification will have to be borne by the parties to the treaty in some agreed manner. There have been 16 members of NATO^a and 7 members of the Warsaw Pact. With a drawdown in troops occurring, no doubt considerable weight will be given to uniformed inspectors as a key means of apportioning cost with minimal impact on national budgets.

Shareability. Because of the large number of nations involved--with diversity in language, culture, and outlook--the shareability of equipment, data, organization, and inspections, along with commonality and transparency, will be extremely important in CFE (and CWC).

^aNorth Atlantic Treaty Organization.

Because the military value of individual items of account in CFE is much less than (for example) nuclear weapons, the threshold for military significance of discrepancies in verified account can be placed at levels corresponding to numbers like 10 or 20% of the limited items. However, detailed accountability is needed in order to reach such conclusions, and there are several reasons why small-scale discrepancies should be detected:

- 1) Even if the violations are not militarily significant, but they are deliberate, the earliest possible tip-off is needed in order to recognize the symptoms and to institute the earliest possible remedies.
- 2) Detection of small-scale violations will discourage cheating that is disguised as minor anomalies. What better way is there to increment deployed forces than to put up and maintain a smokescreen of small discrepancies, with each detected discrepancy being able to mask several more real illegal increases?
- 3) Political confidence, in this and in other pending negotiations is enhanced by day-to-day and long-term demonstration of strict compliance. The design of verification regimes that convey this approach is likely to encourage signing and ratification of such treaties.
- 4) It is axiomatically better to resolve discrepancies as they occur rather than to wait until they become militarily significant.

The Potential Role of Tagging

Although tagging for START at one time was considered for a comprehensive role, it has ebbed to keeping track of mobile missiles.

Discussions held regarding CFE have recognized the need for stabilization of troops and armament at lower levels. This improved stabilization could take qualitative and/or quantitative forms, in terms of offensive/defensive postures or in terms of specific items of account -- such as troops and major armament platforms.

Because major armaments are to be reduced in number and controlled in deployment, tamper-revealing tags could play a significant role. The key functions for such tags would be to assist in inventory and location of items of account during baseline and drawdown phases. Some straightforward, concurrent means of keeping track of objects eliminated or retained would increase confidence in compliance.

On the other hand, tags have several potential drawbacks that need to be addressed: overhead costs could be high for tagging tens or hundreds of thousands items of account, and tag survivability is important under a wide range of field conditions.

The foundation of a cost-effective framework for CFE could be self-applied tagging of all TLIs to gain rapid and accurate accountability. Rapid accountability expedites the inspection process and allows more items to be checked in a given inspection period; accurate accountability supports

effective verification and avoids unwarranted compliance disputes. The results are reduced cost of verification, improved accuracy in item counting, and enhanced security.

A constraint on tagging is the notion of "parsimony". The most demanding extension of this notion is the requirement of developing a tag that can be applied during the baseline period by the party to be inspected without witness by other treaty parties. A statement of this requirement has been given by two former officials of the Western European Union as follows:

As far as we are aware, no "ideal" tag has yet been developed for verifying conventional armament levels. Of course, a tag must be nonreplicable by an adversary which has all necessary resources available. It must also be nonremovable from one TLI to another without a clear indication to the inspector that it was moved.

It is probably not too difficult to develop a rugged tag with these characteristics and which is easy to validate or interrogate utilizing existing technologies provided that the inspecting side is able to affix and remove the tags. To be able to do that, the inspectors have to see all TLIs within a short time span after the entry into force of the agreement, which defeats the main purpose of the tags i.e., to avoid unnecessary intrusiveness. It would be much better if the inspected side could affix the tags to its own TLIs. The resulting problem is to develop a tag which is still foolproof in that case. A solution would be that the inspected state has to send to the inspectorate unique information on the tag which can only be acquired after the tag has been affixed to the TLI. Examples might be the unique pattern of an optical fiber seal which is formed when sealing the tag to the TLI, or a tag consisting of a "fingerprint" of part of the TLI itself [MAX-89].

The baseline period after a treaty goes into force could be more effectively utilized by each side in inventorying its own equipment and in applying the tags. During this period each side will probably uncover anomalies in its inventory that are better straightened out through this registration process that would result in a revised declaration.

Some generalities about verification quality for unique identifiers can be stated. First, verification quality -- in terms of non-counterfeitability and non-transferability -- depends on the needs of the specific treaty; the degree of stringency for START, CWC, CFE, and NPT will vary. Second, verification standards also depend on the military significance of the TLIs; e.g., nuclear weapons vs. armored personnel carriers. Third, it will depend on the rigorousness of verification, as reflected in part by national legal requirements. Fourth, there is some linkage of verification quality with other tag/seal attributes, such as durability and readability, inasmuch as tradeoffs in design must often be made.

Tagging for conventional weapons differs in two principle ways from tagging for strategic arms limitation. First the number of conventional weapons that might be tagged is an order of magnitude larger than the number of strategic weapons systems that must be counted. Under President Bush's proposal of May 29, 1989, each side would be limited to 20,000 tanks, 28,000

armored troop carriers and 16,500 to 24,000 artillery pieces in addition to ceilings on troops and land-based combat aircraft and helicopters. Thus CFE monitoring is likely to track of many tens-of-thousands of individual TLIs on each side. In comparison, the U.S. and the Soviet Union each deploy fewer than 40 submarines armed with SLBMs.^a The strategic bomber fleets are smaller than 500 planes, and each side deploys fewer than 1300 ICBMs.^b Although the United States plans to deploy 4000 sea-launched cruise missiles, fewer than 800 of them will carry nuclear warheads and they all will be deployed on 200 vessels [TH-89]. Under the INF Treaty the Soviet Union agreed to destroy 1836 missiles and the U.S. to dispose of 859.

Clearly the number of tags for CFE monitoring could be significantly larger than the number of tags that could be used for monitoring strategic arms limitation. Moreover, CFE will limit the numbers of weapons deployed in specific geographic zones. Data management for CFE verification will also be significantly more of a problem than for strategic arms because ceiling, subceiling, zone, subzone, national, and foreign limitations need to be verified. The multinational, multilingual aspects of CFE place a premium on a unified numerical designation.

Another important difference between the treaties arises from the fact that strategic weapons are produced, deployed and maintained at a limited number of facilities that are subject to intense security precautions. Land-mobile missiles and submarines can, of course, range over large areas of land and ocean respectively, but to date they must return to a limited number of bases or ports for servicing and can be monitored when they are there. In contrast, conventional weapons require less specialized facilities for servicing. They are deployed at a larger number of bases. All TLIs that have been mentioned in CFE negotiations are highly mobile and could generally be easily concealed in cities or the countryside. Our experience during World War II demonstrated that civilian industrial plants can be quickly converted to the production of these weapons. Monitoring schemes for conventional weapons must be prepared to cover far more facilities and a considerably greater land area than is required for monitoring strategic arms.

CFE drawdown will require a phased implementation. First each side must prepare a baseline inventory of all TLIs during which all equipment could be declared. Once the baseline inventory has been established to the mutual satisfaction of the parties to the treaty, destruction or withdrawal of appropriate weapons must be checked. The destroyed weapons must be subtracted from the baseline inventory. Finally inspectors must check at least a sample of equipment to ascertain that no new TLIs have been deployed and that existing weapons systems have not been illegally upgraded. If new models of weapons limited by the treaty are produced, the production must be monitored so that the weapons can be accounted for as they leave the factory.

^aSubmarine-Launched Ballistic Missiles.

^bIntercontinental Ballistic Missiles.

Requirements for tags are stringent since a large number of tag failures would undermine confidence in treaty compliance. Each tag must uniquely identify one weapon. Tags must be resistant to counterfeiting and be tamper proof and very difficult to remove from a weapon once they are attached. But because of the distribution and numbers of TLIs to be tagged, the tags must be easy for inspectors to read under field conditions. Exposure of the tags to operational and environmental stress is likely to be much more severe than that for strategic weapons.

Conventional weapons deployed in Europe are subjected to a variety of weather conditions. Tanks are routinely driven through water, mud, sand, forests, gravel, and even salty water from winter roads or the ocean. Troops are not noted for always handling weapons with special care. Thus tags must be rugged enough so that they will not fail under extremes of vibration, abrasion, temperature, or humidity. Because so many TLIs will be tagged, tags will need to last for at least a decade, and they should be as inexpensive as possible if the costs of monitoring the treaty are to be manageable. Tags for strategic weapons are likely to be in a protected environment.

In assembling a list of specific requirements at this stage in time, it is difficult to make note of all specific needs to be met by tags and even more difficult to assess their relative priority. Although setting requirements is primarily a function of the user-community, the following qualities would appear to have some bearing on the selection of a tagging approach.

1. Identifiability. Inherent capability to identify either individual items or a class of TLIs as required.
2. Counterfeit resistance. Resistant to efforts of tag replication, that is, resistant enough to make the counterfeiting costly, risky, and lengthy.
3. Transfer resistance. Tag cannot be readily (without detection) transferred by cutout or removal of the substrate, particularly in timeframes associated with short-notice inspections.
4. Operational ruggedness. Withstand an operational environment that places all exposed surfaces at risk to damage in the field.
5. Environmental survivability. Able to cope with realistic deployment conditions from the Atlantic to the Urals, north and south.
6. Human tolerance. Resistant to human misuse, abuse, or error.
7. Field verifiability and rapidity. Easy and rapid verification in the field.
8. Application by inspected party. Inspected party can apply tags without inspectors as witnesses.
9. Economical in outlay. Low-cost tags because of the many potential items of account.
10. Economical in overhead. Low personnel overhead costs for application, maintenance, and verification of tags.

11. Inventory assistance. Capable of assisting the computerized functions of baseline and drawdown inventories in both speed and accuracy.
12. Serviceability. Subject to minimal requirements in frequency and skill of field servicing of tags and their reading equipment.
13. Field testability. Can be tested in realistic field trials with high confidence in extrapolating to actual use on a large scale.
14. Long-term durability. Able to stand one or more decades of use in the field.
15. Availability. Available for negotiation and application on a timely basis.
16. Operational impact. Little impact on normal overhaul, cleaning, and painting operations.
17. Replaceability. Can be replaced in the field if necessary.
18. Amenable to remote verification. Compatibility with remote field verification to expedite and to reduce intrusiveness of verification.
19. Technology transferability. Technology not embargoed.
20. Locatability. Can be located on identical, conspicuous, and secure components of a treaty-limited item.
21. Technology transparency. Not limited by concerns over technology transfer or component transparency.
22. Intelligence susceptibility. Misuse of tags for purposes outside scope of a treaty.
23. Field authentication. Can be authenticated on a selected basis in the field with minimum difficulty and time.

No doubt other government requirements will be added, and the ones listed above can be refined.

To summarize the role of tagging, especially for CFE, the following features are highlighted:

Bar code registration. In order to provide accuracy, rapidity, simplicity, universality, and reliability to a standard accounting process, a recommended machine-readable method is the use of bar codes for registering and tracking TLIs. For in-field confirmation, a human-readable numeric should also accompany each bar code. Bar codes can be applied as permanent or attached markers. There are some acceptable variants of bar codes such as the block-form varicode.

Survivable tags. For any type of tag, locations must be chosen where operational and environmental damage risk is minimized and protection of the tag must be provided. Threaded bolts or riveted plates could be used where field

damage is possible. A mechanically attached bar code plate can act as a protective cover for an intrinsic tag.

Selective authentication. The tamper-revealing aspects of tags could be authenticated during short-notice inspection by a process of selective sampling derived from statistical considerations. High confidence can be achieved by authenticating only a small fraction of the total number of tags (while reading all the bar codes). The authentication process is more time consuming than the bar code reading.

Unwitnessed application. Application of tags without an inspector being present is a tag concept feature that would allow significant reductions in cost for CFE. Some tags can be installed by and at the military unit level without inspectors present at the time. Authentication data would be sent to the central CFE organization where they would be kept on file and compared eventually with short-notice inspection results. For the CW Convention, it would be helpful to have either unwitnessed applications or removal of seals [-90]. For nuclear weapons and delivery systems, all tagging operations are likely to be closely watched.

Universal tagging. A tag concept that is durable and inexpensive enough to allow all TLIs to be uniquely identified is most desirable.

Inasmuch as cost is a high priority in CFE, tags and seals should help reduce the overall cost of the verification system. Moreover, inspectors will have limited time available at a site and a limited quota of inspections; so tags could:

- 1) help expedite inspection and reduce costly and misleading human error in the collected data;
- 2) let inspectors make better use of human faculties to observe qualitative features, such as equipment modernization, maintenance practices, and state of repair;
- 3) reduce the cost of the most expensive form of on-site verification, which would be continuous monitoring at storage, demilitarization, or production facilities -- by supplementing or obviating the need for sensors or humans on full-time duty.

GENERAL FEATURES OF TAGS

Proposed tags can be considered to be of two types: attached tags and intrinsic tags (see Table). Attached tags are devices which are manufactured elsewhere and attached to the equipment in the field. Intrinsic tags use some feature of the TLI itself as the unique marker. Attached tags range from very sophisticated electronic devices to simple epoxy paint with mica flakes suspended in it.

Although tags are installed to allow treaty inspectors to periodically inventory TLIs, they must be designed so that they cannot be used for intelligence collection. Both sides must be satisfied that they cannot be activated for targetting purposes in the event of a war [FE-89]. Any

monitoring scheme must prevent the inspecting side from gaining sufficient information on the deployment of conventional weapons to deduce the other side's detailed order of battle or the precise location of mobile strategic missiles to defeat their intended invulnerability.

Intrinsic tags make use of unique features that belong to a TLI. Tagging a component that is part of or is the TLI is inherently advantageous in terms of making it difficult to circumvent the tamper-revealing aspects of unique indicators.

Attached tags require some means of bonding a tag onto the surface of a TLI. Both the bond and the attached tag must each provide tamper-revealing features. Thus, attached tags require an added level of tamper-resistance that intrinsic tags do not need to provide. The authenticity of an attached tag is no better than the tamper-revealing capability of its bond to the surface.

Two types of features can be considered intrinsic: those that are as-manufactured and those that are introduced into the surface. The as-manufactured features include metallic grains, precipitates, inclusions, oxides, voids, fibers, machining marks, and abrasions. Features deliberately added for enhancement of tagging include mechanical and etched markings, as well as particles and ions implanted within the surface.

An intrinsic tag may make use of surface roughness or subsurface features for its uniqueness. One of the advantages in principle of subsurface features is that they are protected by the outer surface from the external operational environment.

No matter what type of tag is used, there are four common practical installation imperatives: location, preparation, stabilization, and protection. The designated location for application -- exposed or sheltered from operational and environmental conditions -- will depend on the type of TLI, the sensitivity of its design, and the availability of suitable surfaces.

Location. It is first necessary to designate and find the location on the TLI where the tag is to be installed. The designation might be embodied in a treaty MOU,^a based on the particular type and version of the TLI. One or more major components of the TLI might be subject to tagging, such as the turret, the tub, or the main gun of a tank. Depending on these choices, the locations might be in exposed or sheltered locations. Once designated, the particular coordinates of the location must be found repeatedly by those who are to install and read the tag.

Preparation. The surface at the location to be tagged will undoubtedly need some preparation, regardless of whether it is an attached or intrinsic tag. Intrinsic tags need reproducible surface conditions, and attached tags need surfaces to which they can adhere for many years. Moisture, grease, paint, and rust will have to be removed to reach bare metal (or other surface that

^aMemorandum of Understanding.

does not deteriorate). Most likely a portable electric sanding drill will be needed, along with a wirebrush, sandpaper, and cleaning solvent.

Stabilization. Once a surface has been cleaned, it will be necessary to ensure that it does not revert to an unstable base: Attached tags would lose their adherence, and intrinsic tags would lose some of their signature capability. Stability can probably be obtained by preventing air and moisture from reaching the surface. Attached tags could do this with their adhesive, and intrinsic tags by covering the surface with a protective coating or cover.

Protection. At almost any location, whether exposed or sheltered, tags will require protection against operational conditions and abuse. At exposed locations, they will also need protection against the environment. If an attached tag is sufficiently self-protected against damage, it might not need additional protection; however, a tag that protrudes excessively from the surface is vulnerable to detachment by shear forces. An intrinsic tag will require some protective cover, which could be a thin polyvinyl or metal barcode adhesively and/or mechanically attached. Bare metal surrounding the tag in excess of the tag area would probably be primed and painted again to the edges of the tag.

Non-transferability

Substrate transfer is a problem common to all tags. Cutting out or undercutting the tag substrate provides a potential means of treaty circumvention. Ultrasonic probing of microcracks is very likely to detect such substrate transfer. Even if the transferred substrate were outside the field of visual inspection or masked by the highest quality repair, the residual evidence of changes in the substrate should be detectable by ultrasonic surface and body waves. All known tag concepts are vulnerable to substrate transfer or cutout. Consequently, development of a means of secondary verification (as by ultrasonics) would benefit all the concepts.

However, it does not follow that substrate transfer or cutout is a serious concern in every treaty. For SNDVs^a the marginal value of a nuclear weapon might be sufficient to induce a high expenditure to illegally remove a tag. However, for CFE it is much less likely, and it might also be impractical to cutout or undercut a tag without an inspector noticing the effect. Also, if there is a short period of time between the act of tagging and inspecting (as in a possible nuclear-warhead-dismantlement treaty), it might be very difficult for a cheating party to have confidence in a tampered tag.

PHYSICAL PRINCIPLES PROPOSED FOR TAGGING

As indicated in the tables, many physical principles have been mentioned in European and American literature [BA-89] [KN-90] as applicable to tagging. Even "radioactive" tags have been suggested [KN-89].

^aStrategic Nuclear Delivery Vehicles.

Reflective-Particle Tag

The most developed of the attached tagging technologies is the glitter-paint (reflective-particle) tag [BA-89]. In this scheme, a number painted on the weapon is covered with a transparent paint which contains suspended mica flakes. The flakes form a unique pattern over the numbers which would be extremely difficult to duplicate. The pattern is photographed from several angles using a still video camera with sequenced lights attached to it. Data will be recorded on a floppy disk, and the information will be filed to identify the TLI in question. To protect the tags in a CFE environment it would be necessary to apply an overcoat or metal plate over the tag. To verify in the field, a portable computerized image data base must be carried.

Electronic Tags

Electronic tags could be made from integrated circuits that are attached to the weapon in such a way that removal would be sensed [GA-88]. Mechanisms that are suggested to make them tamper-proof include making them position sensitive or encasing the chip in a fibre optic net. The device can be activated by electronic signals or keys. Probably each side would hold one of two keys necessary to activate the tags. The electronic circuit could then broadcast a signal identifying itself or permit interrogation by an inspector. Inspections could be conducted by detectors mounted on vehicles or in airplanes, helicopters or even satellites. Inspectors would not have to get close to the weapons they are monitoring [CH-89]. The agreement signed in 1986 by the Stockholm Conference on Confidence- and Security-Building Measures and Disarmament in Europe provides for airborne inspection of military maneuvers in Europe. This agreement has been implemented without problem, so there is precedent for aerial inspection which has the advantage of being less intrusive and faster than inspections conducted by ground observers.

Dosimetric Tag

A dosimetric tag might be useful to indicate whether a nuclear weapon has been present in a warhead compartment. For a dual-purpose weapon system, such as the U.S. Tomahawk cruise missile, this could be important. The Tomahawk can have either a conventional high-explosive or a nuclear warhead. A strategic arms control agreement might limit the number of nuclear-armed missiles, but not restrict the conventional armament. A dosimetric tag attached at both ends of the missile canister (or missile, if accessible) would indicate whether a radiation-emitting device had been present.

Intrinsic Surface-Roughness Tags for CFE

The intrinsic-surface tag has been evaluated for two types of application that involve the direct and indirect use of the scanning electron microscope (SEM) [DE-90]. The direct approach involves bringing to the TLI a portable SEM, using it to make measurements of topology and morphology of the surface. Combining three-dimensional topographical with x-ray analysis of the surface composition provides highly detailed and unique characterization.

The indirect approach makes use only of the three-dimensional topography by examining a plastic-casting fingerprint taken of the surface. In this case the SEM could be a fieldable system brought to a site where all fingerprints

are examined during the course of an on-site inspection, or it could be kept at the laboratories of each verification organization where the fingerprints are compared upon return of the inspection teams.

Whatever the role of tagging -- total inventory control, distinguishing legal from illegal, special-status equipment, or selected armaments -- the intrinsic-surface tag is applicable. For START the direct SEM approach would appear to offer the highest counterfeit resistance of any type of tag. For CFE the indirect SEM approach provides high cost-effectiveness. In both approaches, bar codes are an integral feature of the intrinsic-surface tag concept in order to maintain accurate and rapid inventory.

A typical intrinsic tag would use a portion of the surface to uniquely identify a particular TLI. Surface-roughness tags use an as-manufactured or altered portion of the surface -- or the bottom of a hole drilled into the TLI. With modern casting techniques, it might be possible to counterfeit a weld or a machined surface sufficiently to fool the unaided eye. Therefore the tags should be authenticated by a high-resolution device such as an electron microscope. Researchers are faced with either making a scanning electron microscope portable and usable under field conditions or with developing a method for carrying surface details back to the laboratory for examination.

A concept that appears attractive for CFE involves just two steps: "registration" and "fingerprinting". Treaty-limited equipment would be "registered" with treaty authorities by identifying such equipment with a standard registration mark or sticker. Next, a "fingerprint" of the surface roughness in the vicinity of the registration mark would be made and sent to the treaty authorities. Both of these steps could be accomplished by the custodians of the equipment without necessarily being witnessed by other treaty parties.

Mapping surface features with plastic castings would be particularly well-suited for a CFE treaty. The magnification and depth-of-field of the SEM is so powerful that a very small area of the plastic-casting fingerprint is needed for authentication. At the bottom of a deep surface marking, the area to be checked could be much less than 1 sq mm. A 0.01 x 0.01 mm area would have from 10^3 to 10^5 unique resolvable topographical features; an entire 1 sq cm could provide up to 100 gigabytes of data if needed.

The castings of machined surfaces and welds can be prepared easily by cleaning the surface and applying a quick-drying cellulose-acetate casting tape to a preselected area. Casts that are sufficiently accurate to uniquely identify the surface can be made by personnel with minimum training and then examined under the scanning electron microscope by technicians in the laboratory. One way to tag a TLI would be to mark it with an incised number, a bar code, and a rectangle designating the surface to be used as the intrinsic tag (Fig. 1). A casting would copy the number and the bar code as well as the characteristics of the surface tag. If the intrinsic surface can be secured with a protective plate that contains a visible barcode, then the surface needs to be marked only by hand to produce some recognizable fiducials; a crude 1-cm² rectangle or three stamped marks will do quite well.

Alignment of the casting in the field during subsequent inspections would not be necessary because the casting would record the rectangle designating the tag. Alignment of images would then be performed in the lab. Several casts could be prepared during an inspection to guard against a poor replication. Each casting tape used in the tagging process would be identified by a unique bar code provided by the inspector to keep track of them and to avoid "slight of hand" substitution of a fake casting. Between inspections, the tag surface should be protected, although only a small portion of the tag surface needs to remain unaltered. In fact, less than 1% of the fingerprinted surface is needed for a positive identification of the TLI.

The casts are easy enough to make so that baseline inventory could be carried out by troops stationed in the field. Each side would label its own TLIs and prepare castings of the tag surfaces. The casts would be shipped to a central location. Inspectors from each side would verify the declared baseline inventory by making castings of the surface on a random sample of TLIs during short-notice inspections. These castings would be compared in detail with those on file from the baseline. Other castings would be filed without examination. Because inspectors need only carry the simple equipment needed for making the casts, sensitive equipment like scanning electron microscopes and computers necessary for storing the large volume of information required to identify tags would be kept in laboratory conditions.

The combination of fingerprinting by the side being inspected and the registration of all TLIs during baseline could be implemented in phases while a CFE came into force. In the first phase, a defined location on each TLI would be prepared as a tagging surface by such steps as removing rust and paint. This surface would be covered by a bar code label, and its identify entered along with the bar code number in the baseline inventory. Fingerprints could be taken either at baseline or during subsequent inspections. As the castings are recorded, the simple adhesive sticker would be replaced with a more permanent bar code label and additional durable protection added for the fingerprinted surface.

The concept of using surface-roughness features as a tag has been strongly urged in Europe. Based on extensive experience in on-site inspection and analysis of ways of improving OSI value to treaty verification, the Western European Union Agency for Control of Armaments has concluded that intrinsic surface features (roughness and grain structure) may be particularly useful for tagging CFE TLIs. They consider intrinsic surfaces to be "practically invulnerable to evasion measures" and suggested urgent attention to such "viable" tagging.

In a WEU paper [JA-90] delivered in January 1990 detailing their extensive OSI experience, Col. Klaus Jacob concludes that "Tamper-proof tags fixed to TLIs... could considerably ease effective verification."

Intrinsic surface tags have inherent advantages in application to CFE. No tag must be attached to the surface: Intrinsic tags make use of features that belong to the TLI or marks that are introduced into the surface. In fact, for this application shallow- or deep-surface incised tags are useful because of the added natural protection that is provided by the surface (see Fig. 1). Intrinsic-surface tags have inherent protection against environmental and operational conditions. Shallow surface (0.1 mm) marks are less

self-protected than deep (mm), narrow (mm) cuts. Whenever a tag is an intrinsic feature of the TLI, it is also inherently resistant to tampering and transfer.

TLIs that do not have suitable accessible markings can be easily marked by handtools or by mechanical or electronic tools. These markings can be applied by the inspected party without witness. The markings can be of a type that will make inspections rapid and accurate. If factory markings are inconveniently located or absent, inventory marks can be simply added to the surface with a carbide scribe or with various mechanical or electronic tools. For example, a laser or chemically etched marking will have sufficient irregularities when examined in large magnification that it could serve as both inventory aid and unique identifier.

In addition to expediting and improving the accuracy of inventory, the bar-code labels serve to indicate the location at which the fingerprint is to be made. This makes it easier to return to that location on the TLI for fingerprints to be made during subsequent short-notice inspections. An adhesive bar-code label could be accidentally removed or damaged, but the MOU will indicate where on the TLI the unique fingerprint can be obtained. More durable markings can be made in the future using a portable programmed commercial laser-marking unit.

The most economical approach to authentication is to store the baseline "fingerprint" on file at one or more central repositories (as the FBI does); then when there is need to make a comparison with a post-baseline fingerprint, the corresponding baseline copy is removed from storage and matched at the computerized central scanning-electron microscope (SEM). It would be possible to digitize all fingerprint data upon receipt and store on laser disk. The central repository/laboratory approach has significant cost and procedural advantages (compliance decisions are deferred until internal review of all relevant information). In fact, in a CFE treaty where the threshold of military significance could be in the thousands, there is little point in overreacting to singular unresolvable discrepancies in the field.

Field analysis of plating casting can be conducted, if desired. One approach is to have a portable SEM which is brought to an inspection site to preview all fingerprints that are collected during the inspection period. Another approach is to use an optical microscope to screen the castings at the site. Although the resolution and depth of field of the optical microscope is much inferior to the SEM, it should be sufficient as a quality-control step. Improved technology for digital data transmission could, if needed, allow a more thorough field comparison of the baseline data with the new casting.

Alternative Intrinsic Tags

Other logical means of intrinsic-surface fingerprinting have been considered worldwide. Some also make use of the intrinsic surface by extracting unique features other than surface roughness or by using other means for recording the surface information. These do not have the spatial resolution capabilities of the electron microscope. There is also an intrinsic concept that derives unique features from below the surface.

Weld photography. One alternative intrinsic tag is to take photographs of unique markings, such as welds or as-cast surfaces. Two types of problems arise in this concept: (1) difficulties in data processing and data management in order to assure accuracy and retrievability at low cost, and (2) limited authentication capability of macrophotography.

Recent efforts to counterfeit a weld tag have proven to be unsuccessful when examined by an SEM at magnifications greater than 40x; however, for practical purposes, it appears at lower magnifications that counterfeiting was successful from the viewpoint of macrophotography. It would be very difficult for counterfeits to also pass a "wirebrush" test, that is, resist damage when being scrapped and hammered.

Ultrasonic subsurface signature. One of the potential weaknesses of the surface fingerprint is its possible susceptibility to operational damage and weathering. Although these issues are addressed by protecting the fingerprint, there is appropriate interest in subsurface signatures. One way of obtaining a subsurface signature would be by ultrasonic means, in which the underlying region is mapped. Ultrasonic techniques are in common use for flaw detection. A non-uniform medium will propagate and reflect ultrasonic waves in a manner that is dependent on the non-uniformities, thereby providing the essence of a subsurface "signature".

Several important research and development issues remain to be examined. First, at any given defined tag location, there might be no uniqueness in the subsurface acoustic pattern; a cast and rolled metal might have no detectable local defects or inclusions unless very high ultrasonic frequencies are usable. This is not a problem for fiber-reinforced rocket-motor casings, but it might for armor plate. Second, due to the complexity of the signature and the non-reproducibility of the transducer in contact with a surface, it must be established that a reproducible pattern can be obtained after many years. Much would have to be learned about the effect of surface damage and weathering on the ultrasonic image, which is collected by transducer contact with the surface.

Third, a substantial data base would be required for ultrasonic verification. If verification were to be confirmed in the field, the inspector would have to carry the detailed data for essentially every TLI for each inspection. If, on the other hand, the ultrasonic image were to be returned to the central laboratory for comparison, this method would lose its potential advantages when compared to the surface-roughness fingerprint.

For verification of mobile strategic missiles, the ultrasonic tag would encounter conditions best suited to its application.

PROTECTIVE COVERINGS FOR TAGS

All tags will either have to be self-protected or be covered with a protective layer. The removal and reattachment of protective coverings will take additional time during field verification; the required time cannot be considered without taking into account the degree of protection needed. For this purpose, a minimum protection standard must be established, at which point each tag concept could be graded. For example, if no protective covering were

required, then none of the tag concepts would be at a disadvantage. If, however, a metal plate were necessary to protect a tag from potential operational damage in the field, then only a few tags are compatible with such covers (Electronic devices could not be interrogated remotely if covered with a metal shield). The table below indicates those tags that appear compatible with various protective coverings.

PHYSICAL PRINCIPLE	APPLICABLE PROTECTIVE COVERINGS					
	(INTRINSIC)	NONE	VINYL TAPE	PLASTIC COATING	METAL PLATE	THREADED BOLT
Weld	X					
Deep etching	X					
Ultrasonic	X		X	X	X	X
Surf. roughness	X		X	X	X	X
(ATTACHED)						
Optical				X		
Electronic				X		
Laminated tape			X			
Serial numbers	X					

Intrinsic tags (especially those using deep incisions) have some inherent resistance to abrasion, and can therefore be used without any protective cover, as indicated in the column marked "None". Attached tags have a built-in level of self-protection, usually a plastic coating or a fabricated plastic case. The levels of increasing resistance to damage go from left to right in the table. Painted serial numbers are classified as "attached" for the purposes of this table. The attached "optical" tags, such as reflective-particles in a transparent matrix, are those that are read out by laser scanning or cameras.

Any level of protective technology is compatible with both surface-roughness and subsurface-ultrasonic signatures, while additional protection would tend to defeat the design goals of other tags. For tagging main battle tanks at an exposed location, a highly durable, low-profile protective cover would be necessary, such as a mechanically affixed metallic plate mounted over the tagged intrinsic area.

SEAL TECHNOLOGY

Seals for arms control verification are likely to be based primarily on the experience derived from domestic and international safeguards. However, weapon treaties might need seals to be developed to meet more stringent goals.

A CW Convention might require considerably more seals than utilized for the NPT; thus, it would difficult in the field to have lengthy verification procedures or to carry an overly large data base. Some compromise in the steps that constitute field verification of integrity and identity might be required, with additional authentication to be carried out at headquarters.

A bolt-seal has been thoroughly proven after joint multi-national development centered at the Ispra Euratom Laboratory. It is used to seal nuclear-reactor fuel bundles. The unique part of the seal consists of a metal stub that retains its integrity unless broken and that provides an ultrasonic signature of defects randomly introduced.

For high-value weapons of mass destruction, the highest degree of seal authentication would be needed. Seals might be placed on nuclear weapons prior to being shipped for verified dismantlement. Considerable time might lapse between the placement of the seal on a shipping container and its witnessed opening at a dismantlement facility after transport. Such arms control seals are likely to be attached in addition to owner custody requirements.

A nuclear-weapons seal should be designed to assure the verifying party that during transit to the portal the container could not be opened without revealing that the seal had been decoupled. Such a seal might have a standard of verification quality that exceeds that which is normally associated with domestic or international safeguards (e.g., Type E seals [DOE-89]) for two reasons. First, the resources for defeating the seal available to a national party generally exceed those that are available to adversaries usually considered in design of a domestic safeguards seal. Second, weapons of mass destruction require a much higher level of assurance than normally associated with international safeguards on fissile materials.

Seals that might be improved to meet the more stringent arms-control verification standards include two particular types: fiber-optic seals (VACOSS and COBRA) [DR-90] that have light-transmitting cables which can be wrapped around a container, and brittle-ceramic seals that have ultrasound-conducting cables which can be interrogated by acoustic methods. The fiber-optic seals have been developed by Sandia National Laboratory and the Euratom Joint Research Center; the ceramic ultrasonic seal is under development at Argonne National Laboratory. The ceramic seal would be particularly useful in highly toxic and high-temperature chemical environments. When two separable parts can be spot-welded or fused together, the plastic-casting fingerprint method would be a highly tamper-resistant means of seal authentication.

Reading requirements for tags can be an important factor in suitability for field application. The size, portability, power, durability, capacity, versatility, and sufficiency of such readers are significant. A tag or seal that collects and stores image data for the unique identification usually requires more field storage than devices that condense the identification by some other means. In CFE, the mobility and number of armaments would make it difficult to carry along with every inspection team all image data for all TLIs; yet that might be necessary because total limits rather than specific locational restrictions apply. In a CW Convention many sealed items are likely to stay at specific locations, so the data required for field authentication might be manageable in the field.

VERIFICATION PROTOCOLS

Four relevant phases of treaty implementation are (1) pre-MOU, (2) baseline inspection, (3) short-notice inspection, and (4) elimination. The TLIs could be marked during the pre-MOU phase, as part of an inventory submitted in the treaty MOU. Because of the large numbers of candidate TLIs and their widespread geographical deployment, it will be extremely difficult to track TLIs in a CFE treaty. During the baseline phase, some or all of the MOU should be verified, including the tags. But the large number of objects, the short time available (say half a year), the mobility of the TLIs, and the similarity of weapons within a TLI class dictate exploitation of modern technology to provide timely and accurate verification.

Subsequent verification in short-notice inspection or elimination could consist of two steps. The first step is field verification of inventory which would consist of automated reading of the inventory markers coupled with trained inspector observation of the TLI characteristics. This primary verification step will include inspector corroboration of the TLI and non-transfer of the tag. The numeration of all inspected TLIs is an essential step in the process of building and maintaining a verification database.

The second verification step is tag authentication, which could be conducted selectively during baseline, short-notice, and routine inspections. In the pre-MOU stage, each side would have inventoried its holdings and each TLI could have been marked, tagged, or sealed.

The markings that might be applied can have any coding, shape, or color. A bar code or varicode would be well-suited for this purpose because of compatibility with accurate and rapid portable readers. Large barcodes or checkered varicodes could be read from distant ground or air vehicles.

ECONOMIES

A knowledgeable artillery or tank officer is likely to be an essential member of any inspection team, regardless of tag concept. In fact, a very important aspect of verification will be the judgement of experienced military service personnel: They will have to ensure that the TLI appears to be of the type declared in the MOU and that no tampering or component transfer appears to have taken place. This is an extremely important human sensory integration stage. Since OSI has to take place anyway, the verification regime should be designed to take advantage of this observational capability.

For the registered-fingerprint approach, which results in a storable form of the fingerprint and the registration number, no immense image data base need be retained at central headquarters or brought to the field during OSI. Tags that rely on in-field verification of compared images require tens or hundreds of thousands of images to be brought along during each inspection by every inspection team. Although the self-application potential of the fingerprinted-registration tag provides the option of bypassing baseline inspections, such inspections could be carried out if required by policy considerations, thereby providing an added degree of surety.

All treaty-limited items can be accurately, quickly, and inexpensively counted if they are "registered" along with their unique fingerprints. The use of bar codes read by portable lasers will provide an efficient low-cost computer-based accounting system for keeping track of the large number of TLIs to be monitored.

The fingerprinted-registration tag does not require that the inspecting side make a complete baseline inspection. The accuracy of the inventory submitted by the side being inspected could be checked by subsequent inspection of a relatively small random sample of the tens of thousands of TLIs. Although this would eliminate the necessity for a time-consuming and expensive baseline inventory before the treaty could be implemented, the baseline inspection could still be conducted with more attention to other interests. Items immediately removed from inventories could be destroyed, and their destruction verified by subsequent short notice inspections. Items declared to be withdrawn from a zone or the ATTU should not reappear on inventory.

The best concepts for CFE verification should be simple, inexpensive, reliable, and ready for implementation, as recapitulated below:

Simple. Standard existing factory markings can form the basis of TLI accountability. As a better option, bar-code labeling could be applied to improve the accuracy and rapidity of the inventory process. Authentication could be based on a "fingerprint" of the intrinsic surface adjacent to the factory marking or bar code.

Inexpensive. The initial inventory made during the baseline under an abbreviated schedule could use either existing factory markings or adhesive bar-code labels that would be affixed during the MOU preparation phase at designated locations on each TLI by the party to be inspected. Plastic-casting "fingerprints" could also be made during the baseline phase by the inspected party with or without witnesses. As a result, the cost of tagging operations would be apportioned to those parties that have the most declared TLIs. However, because military personnel are already assigned to maintain equipment, no additional labor costs would be incurred.

Reliable. Because the surface of a TLI is manufactured to withstand operational and environmental rigors, its fingerprint is a highly reliable indicator (just as human fingerprints are unique and durable). Minimal protection over the fingerprinted surface is easy to be added where needed. Attached tags will need to have either an unexposed location or be highly durable.

Ready. The only materials needed for authentication of the factory-marking or intrinsic surface option are cellulose acetate strips marked with a bar code and a small quantity of acetone. If the bar-code option were adopted, commercially available adhesive labels could be used. All of these materials can be supplied and used by the respective parties of the treaty. The bar-code labels need not be applied in the initial phases of the treaty; they could be added later -- provided plastic castings were obtained initially. Fieldable (commercially available) bar-code readers and laboratory facilities for SEM evaluation of the castings would be needed for post-baseline inspection support.

DATA HANDLING

Data taken in the field for tags or seals will have to be shared between inspectees and inspectors and usually jointly certified. Data might be agreed to be taken from the site, provided each side has copies. If "fingerprint" castings are made, each side could retain castings.

If authentication is completed away from the inspection site, it would probably be at central facilities set up for each major party and for the coordinating verification organization. For example, for CFE both NATO and Warsaw Pact could each have such a facility, along with a central coordinating verification organization to adjudicate differences. For a CW Convention the central organization might undertake all of the authentication.

Where image comparison is required, the data should be processed to yield a normalized correlation coefficient to compare the baseline with the inspection images. Minimal human judgement should be involved.

Results from all tag/seal verification would normally be reported by each party and by the central organization. Compliance decisions would be a broader process involving other information gathered by treaty parties.

ON-GOING PROGRAMS

Programs for development of tag/seal technology are largely focussed at national laboratories in the United States and at the Joint Research Center at Ispra. The U.S. Department of Energy has funded most of the tag/seal development reported in this paper, much of the original work being conducted by Sandia National Laboratory under nuclear safeguards programs. The Defense Nuclear Agency is tasked to test and evaluate developed devices on behalf of the Department of Defense.

Under joint programs with Euratom and with other national organizations, the Ispra center has developed several seal concepts. The Western European Union has suggested the development of a surface roughness tag for CFE [JA-88].

Dornier Aerospace in Germany has carried out an extensive analysis of tag applications and has applied for a patent on an electronic tag [KN-90].

BENEFITS OF TAGGING AND SEALING

The benefits of tags and seals depend on the particular treaty. Seals are very important to the NPT, and will probably be equally important in a CW Convention and in a warhead-dismantlement treaty. Seals might also have some limited use in START and CFE.

Tags are seriously considered for mobile missiles in START and have high potential for a warhead-dismantlement treaty. Particular benefits of tags to CFE are listed below:

All treaty-limited items can be accurately and inexpensively counted

Accurate counting of all TLIs is important for compliance confidence and for avoiding uncertainties in the otherwise complex treaty bookkeeping. Because of the low cost of bar-code scanning systems, the overall cost of verification will be reduced when compared to other means of accounting. Security is enhanced by ensuring that large deployments or activities could not be masked by the "noise" level of less accurate means of accounting. Some tags are so inexpensive that they do not serve as a fiscal barrier to effective verification.

No portal-perimeter monitoring is required

Portal-perimeter monitoring could be used for storage and production facilities in CFE, but with universal tagging of treaty-limited equipment, it would not be necessary. It would be incumbent on equipment custodians to attach tags on appropriate items of equipment before distribution from a production facility and to ensure that tags remain on equipment that is in storage. Short-notice inspections of deployed and stored items would be sufficient to check on inventory restrictions.

No inspection of production facilities would be needed. Tagging could reduce intrusiveness and save substantial costs because of the high cost of equipment and personnel for portal and perimeter monitoring. Although storage sites might be monitored, perhaps only minimal alarm systems need be installed. It is much less expensive to have an occasional inspection team drop by than to maintain a continuous presence. NTM can also keep a continuous eye on declared storage sites.

Zonal limitations can be easily and concurrently enforced

Computer-based data systems will be able to track deployment restrictions much more accurately and promptly when the entire population of TLI are subject to systematic statistical sampling. An inspector in the field only surveys a small portion of holdings at any one time; NTM sees a broad picture, but with difficulty in ascribing specific items to particular locations. A computer-based registration system, which can have either real-time or post-inspection data processing, can check findings against the treaty numerical, locational and holding restrictions for the entire distribution of forces--if given sufficient accurate and periodic samples.

Movement of items can be inferred

If all TLIs are tagged, movements of TLI can be tracked to reveal possible strategic shifts, irrespective of treaty limitations. Certain movements are legitimate within zones; other movements might be related to declared exercises; all of these activities are relevant to intelligence assessments.

Modernization can be noted

In concert with visual inspection, the pace of replacement or modernization can be followed if all items are required to have registrations once released from the production site. With 100% registration, some ambiguities regarding qualitative features can be avoided. In fact, increased combat value can be

more explicitly tracked if certain specific items are also tagged, such as tank turrets and gun breeches.

Operational aircraft can be counted

All aircraft (fixed wing or rotary) must return to base at some time where they could be checked for proper tags just like all other TLIs. Although this does not deal with the high instant mobility of airframes, their tag information coupled with registration of other forces will indicate patterns. It would be possible for short-notice inspections to occur in Europe within a few hours of declared intent, in fact in even less time by attached or roving inspectors.

No continuous presence at elimination facilities required

With universal tagging, it is not necessary to continuously witness the destruction of weapons. When TLIs are destroyed, the treaty verification organization will be informed. Tags found during on-site inspection verification corresponding to items declared destroyed would constitute a discrepancy. Whether presence at elimination facilities will be required to verify actual destruction (in contrast to withdrawal from the ATTU) is a decision based on the actual treaty adopted. Short-notice inspections can be utilized to inspect marshalling yards at elimination facilities. In contrast to INF, the detailed observation of CFE destruction is likely to be an extended, uninformative, and boring process.

THE UTILITY OF TAGGING

The preceeding considerations indicate that the cost of tagging in arms control should not be considered in isolation -- but in conjunction with the utility tagging provides to the total verification system, thereby strengthening the effectiveness and reducing the cost of overall verification. Partial verification (not tagging some TLIs) in order to save costs is a policy based on mistaken impressions. Cost savings incurred by tagging a smaller fraction of armaments are trivial compared to the broader consideration of verification confidence for a given cost increment. On the contrary, the more comprehensive the tagging (at least for self-applied intrinsic tags), the higher the cost-effectiveness of tagging and the lower the overall cost of verification.

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PHYSICAL PRINCIPLES FOR INTRINSIC TAGGING (I)⁺

<u>PHYSICAL PRINCIPLE</u>	<u>VERIFICATION CHARACTERISTICS</u>				<u>AUTHENTICATION</u>		
	<u>OPERATING MODE</u>		<u>APPLICATION SCOPE</u>		<u>LOCATION</u>		
	<u>ACTIVE</u>	<u>PASSIVE</u>	<u>UNIQUE</u>	<u>NON-UNIQUE</u>	<u>CONTACT</u>	<u>STANDOFF</u>	<u>DISTANT</u>
ELECTRON MICROSCOPY		X		X		X	
PLASTIC CASTINGS		X		X			X
HOLOGRAPHY		X		X			X
OPTICAL MICROSCOPY		X		X			X
ACOUSTIC*		X		X		X	
RADIOLOGICAL**		X		X			X

+ BASED ON A. KNOTH, DORNIER

* SUBSURFACE SIGNATURE

** ADDED SUBSURFACE FEATURE

PHYSICAL PRINCIPLES FOR ELECTRONIC TAGGING (II)⁺

<u>PHYSICAL PRINCIPLE</u>	<u>VERIFICATION CHARACTERISTICS</u>				<u>AUTHENTICATION</u>		
	<u>OPERATING MODE</u>		<u>APPLICATION SCOPE</u>		<u>LOCATION</u>		
	<u>ACTIVE</u>	<u>PASSIVE</u>	<u>UNIQUE</u>	<u>NON-UNIQUE</u>	<u>CONTACT</u>	<u>STANDOFF</u>	<u>DISTANT</u>
ACTIVE	X		X	X	X	X	X
STANDBY	X		X	X	X	X	
LASER		X	X			X	
INTERFEROMETRY							
MICROWAVE		X	X			X	
RADIO FREQUENCY		X	X			X	X

+ BASED ON A. KNOTH, DORNIER

PHYSICAL PRINCIPLES FOR TAGGING WITH ATTACHED COATINGS (III)⁺

<u>PHYSICAL PRINCIPLE</u>	<u>VERIFICATION CHARACTERISTICS</u>					<u>AUTHENTICATION</u>		
	<u>OPERATING MODE</u>		<u>APPLICATION SCOPE</u>			<u>LOCATION</u>		
	<u>ACTIVE</u>	<u>PASSIVE</u>	<u>UNIQUE</u>	<u>NON-UNIQUE</u>		<u>CONTACT</u>	<u>STANDOFF</u>	<u>DISTANT</u>
REFLECTIVE		X		X			X	
GEOLOGIC		X		X			X	
FLUORESCENT		X			X		X	X
BIOLOGIC		X		X			X	X
LAMINATED TAPE*		X		X	X		X	X
METAL PLATE**		X		X	X			X

+ BASED ON A. KNOTH, DORNIER

* COULD HAVE MORE THAN ONE AUTHENTICATION FEATURE

** UNDERSIDE AUTHENTICATED BY ELECTRON MICROSCOPE

AUTHENTICABLE INTRINSIC TAG INSCRIBED INTO TLI SURFACE AND INVENTORIED BY A BAR CODE

TLI IDENTIFICATION
BAR CODE & ALPHANUMERICS
ADHESIVE LABEL OPTION

TLI IDENTIFICATION
BAR CODE & ALPHANUMERICS
LASER INSCRIBED OPTION

TLI AUTHENTICATION
AREA (~1cm²)

MICRO-WAND BAR CODE
READER/COMPUTER

CASTING IDENTIFICATION
BAR CODE & ALPHANUMERICS

PLASTIC CASTING

SCANNING ELECTRON
MICROSCOPE PHOTO OF
0.051mm² CASTING REGION

DATE

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END