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A Systems Approach to Chemical Weapons Verification

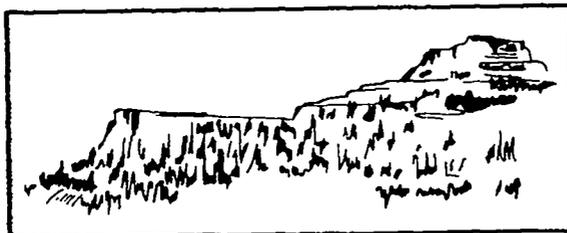
Kenneth E. Apt
Jack T. Markin

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KENNETH E. APT, a Staff Member with the Center for National Security Studies, is investigating arms control verification and other issues involving the interaction of technology with policy. He has a technical background in chemistry and nuclear chemistry.

JACK T. MARKIN is Group Leader of the Safeguards Systems Group of the Nuclear Technology and Engineering Division and has extensive experience in domestic and international nuclear safeguards, with emphasis on mathematical and statistical analyses.

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SUMMARY

The technical credibility of verification regimes for international agreements limiting chemical weapons (CW) is a serious concern for policy decision makers. Whether for a multinational chemical weapons convention or for bilateral U.S.-Soviet agreements aimed at chemical arms reductions, well-designed systems for verification monitoring must be established to ensure that signatories meet treaty obligations.

A systems approach for addressing the monitoring objectives associated with verifying CW arms agreements should include the following elements:

- establishment of verification requirements—typically, elimination of CW agents and production capabilities, nonproduction of proscribed chemicals, nonuse of agents, and compliance with other treaty-specific provisions;
- definition of verification criteria describing significant amounts of materials to be detected, their probability of detection, and the timeliness of detection;
- formulation of verification contexts, i.e., the details of sites and facilities, including material inventories and flows, process equipment, containments, etc.;
- identification of technically credible noncompliance scenarios;
- selection of verification activities (e.g., material measurement, examination of facility records, application of surveillance devices, etc.) at each key inspection point;
- allocation of inspection resources among key points to maximize probability of detecting noncompliance-related anomalies;
- evaluation of performance of the verification system in detecting anomalies; and
- revision of inspection activities, as required, to implement a verification system that meets the verification criteria.

This systems approach is modeled in part on the nuclear safeguards approach commonly used under the Nuclear Nonproliferation Treaty. But, because of the unique aspects of chemical arms and their possible production, the system must be expanded to address the unprecedented requirements associated with verification of CW agreements.

The methodology described here can be used to design and evaluate a verification system that encompasses the diversity of facility types, materials, and activities involved in CW verification. Application of this methodical approach to the definition of a verification system would ensure an efficient allocation of resources among competing verification technologies and activities. It would provide a uniform rationale for selecting system components and could provide a basis for communicating the reasons for technology decisions within the arms control community.

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A Systems Approach to Chemical Weapons Verification*

Kenneth E. Apt and Jack T. Markin

I. THE CONTEXT OF CHEMICAL WEAPONS VERIFICATION

Treaty verification, in its broader definition, involves establishing treaty requirements; monitoring or otherwise confirming those requirements; analyzing information; and finally, assessing compliance. Responding to noncompliance, should the situation arise, is yet a separate action. Although the process of treaty verification is largely political, the technical credibility of treaty monitoring is a critical component. From the beginning of current negotiations on the 1984 draft Chemical Weapons Convention (CWC) being negotiated at the ongoing 40-nation Conference on Disarmament in Geneva, there have been continuing questions regarding the nature—and the adequacy—of chemical weapons (CW) treaty verification measures. The systems approach to verification described here draws upon certain parallels with verification of the Nuclear Non-proliferation Treaty (NPT). It applies to the major requirements of a multinational CW treaty, as well as to those of bilateral CW agreements.

Since 1984, when then Vice President Bush submitted the draft CWC, there has been significant movement toward completion of a multinational treaty banning chemical weapons. Unlike predecessor international agreements on chemical and biological weapons, the

CWC proposes to establish a comprehensive verification regime for monitoring compliance with the tenets of the treaty.

Recent negotiations between the United States and the Soviet Union have resulted in agreements and understandings directed at reducing their stockpiles of chemical weaponry.¹ These bilateral actions are intended to precede and support the multinational CWC. Reductions under bilateral agreements, whether or not they would have been executed unilaterally, could be regarded as significant confidence-building measures, and they could provide the basis for CW reductions under a multinational treaty.

Although much of the text of the CWC is still being negotiated and the appendices are incomplete, the general framework of the treaty has taken shape. Tentative agreement has been reached on major provisions of the CWC.²

Scope. The scope of the Convention prohibits the production, acquisition, possession, and transfer of CW—and any belligerent use of such arms. States parties could not induce any other nation to violate the terms of the Convention, nor could they make preparations for CW use themselves. CW-armed states³ would destroy their CW arsenals and production facilities over a ten-year period after the Convention enters into force.

Definitions. Progress has been made in defining chemical weapons and the toxic materials they employ. Munitions and devices,

*Final report of a study published in draft form January 5, 1990.

together with dedicated support equipment, would be limited if they were "specifically designed to cause death or harm through the toxic properties" of the chemicals they release. With the exception of defoliants and riot-control agents, major agents of the existing CW arsenals would be covered. Chemicals are codified by three levels of toxicity: super-toxic lethal, other lethal, and other harmful chemicals. Chemicals covered by the Convention are sorted into three groups: Schedule 1 includes known CW agents; Schedule 2 covers precursors⁴ of agents, as well as super-toxic lethal chemicals not listed in Schedule 1; and Schedule 3 lists large-volume industrial chemicals with CW potential. CW facilities and equipment are identified in terms of their actual or intended CW operations.

Administration. The Convention proposes that a new international body be formed to achieve treaty objectives. This "Organization for the Prohibition of Chemical Weapons" (OPCW) comprises three organs. The *Conference of States Parties*, made up of representatives from all states parties, is the principal decision-making organ. An *Executive Council*, made up of a smaller number of members, oversees the activities of the *Technical Secretariat*, which is the organ that carries out the actual provisions of the Convention. The Technical Secretariat includes an International Inspectorate, which would be responsible for the daunting task of treaty verification inspection and monitoring. States parties would establish national authorities to serve as interfaces with the Technical Secretariat and to implement their individual treaty obligations.

Disarmament. Within thirty days from the date the treaty enters into force, states parties will declare not only their CW arsenals, but also their past and present CW production facilities. CW-armed states parties will be responsible for establishing the mode and the schedule for destruction of their CW stocks and capabilities, so long as destruction commences not later than one year, and is completed not later than ten years, after the treaty enters into force.⁵ CW production facilities will be destroyed by the end of the ten-year period, but

they can be converted to temporary CW destruction facilities in the interim.

Allowed Chemical Activities. States parties may engage in numerous activities involving the chemicals listed in Schedules 1, 2, and 3, so long as such activities are conducted for industrial, agricultural, research, medical, or other peaceful purposes. The CWC also allows for domestic law enforcement and protection against CW. This latter provision enables a signatory to have a single, small-scale CW production facility with a strictly limited capacity.

Compliance Clarification and Fact-Finding. One of the most difficult aspects of the CWC deals with the issue of compliance and the ability of a signatory nation to call into question the compliance of another signatory. Currently, provisions of the CWC call for parties to attempt to clarify such problems among themselves or to seek assistance from the Executive Council. For more troublesome situations, provisions are being negotiated for obligatory, on-site inspection "on challenge." At the request of a state party, the Technical Secretariat will conduct these inspections on very short notice. The request for challenge inspections can be at *any time* for locations *anywhere*, with no right of refusal. In addition to allowing fact-finding regarding nonpermitted CW possession or production, the draft CWC will enable the International Inspectorate to investigate alleged use of chemical weapons. Although most of the CWC verification activities would be directed toward confirming treaty compliance, challenge inspections together with investigations of alleged usage will seek to prove or disprove treaty violation.

II. THE METHODOLOGY FOR FORMULATING A CW VERIFICATION SYSTEM

Development of a verification regime for CW agreements poses political, administrative, and technical challenges not encountered in verification of previous international treat-

ties. With the possible exception of conventional armed forces, no other area of arms control (extant or proposed) will have such a deeply intrusive verification framework. Whereas previously negotiated arms control agreements have tended to focus on weapons use and stockpiles, current concepts in CWC verification extend far down into the hierarchy of preparation for use, including stockpiling, CW production, precursor production, related industrial activities, and research.

An effective CWC verification system must encompass the diversity of facility types, chemicals, activities, and military stockpiles covered under the agreement. The International Atomic Energy Agency (IAEA) experience in verifying agreements with parties to the NPT, namely the systematic approach to accounting for nuclear materials in various forms, provides a useful comparison. But the unique aspects of proposed CW agreements (e.g., provisions for challenge inspections and investigations of alleged usage), together with the potential resource intensiveness of a system designed to monitor large numbers of industrial facilities processing a wide variety of chemicals, necessitate a new systems approach to the formulation of a CWC verification regime.

Key elements of a methodology for the design and evaluation of a CW verification system are as follows:

- establishment of verification requirements—typically, elimination of CW agents and production capabilities, nonproduction of proscribed chemicals, nonuse of agents, and compliance with other treaty-specific requirements;
- definition of verification criteria describing significant amounts of materials to be detected, their probability of detection, and the timeliness of detection;
- formulation of verification contexts, i.e., the details of sites and facilities, including material inventories and flows, process equipment, containments, etc.;
- identification of technically credible non-compliance scenarios;
- selection of verification activities (e.g., material measurement, examination of

- facility records, application of surveillance devices, etc.) at each key inspection point;
- allocation of inspection resources among key points to maximize probability of detecting noncompliance-related anomalies;
- evaluation of performance of the verification system in detecting anomalies; and
- revision of inspection activities, as required, to implement a verification system that meets the verification criteria.

The flow diagram in Figure 1 depicts the relationship between these elements.

Several aspects of proposed CW agreements will exert major influence upon the design of a CW verification system. In addition to treaty-specific verification requirements and objectives, several other considerations will be important:

- allowed types of inspections, such as challenge, *ad hoc*, continuous presence, or routine;
- confidentiality and limitations on technology disclosure associated with inspections;
- limitations on disclosure related to national security information; and
- limitations on total inspector-days at a facility.

A. Relevant Aspects of the IAEA Verification Regime

The multinational IAEA is responsible for verifying compliance with certain international agreements, including the NPT, that limit uses of nuclear materials and facilities to peaceful purposes. As part of the IAEA verification process, on-site inspections are performed each year at nearly 500 facilities in some 50 nations.

The successful implementation of these inspections is based on a hierarchical framework for verification including the NPT; agreements between the IAEA and states parties specifying the rights and obligations of each party with respect to inspections; formal procedures for developing safeguards approaches at each facility; and a coherent inspection effort to achieve

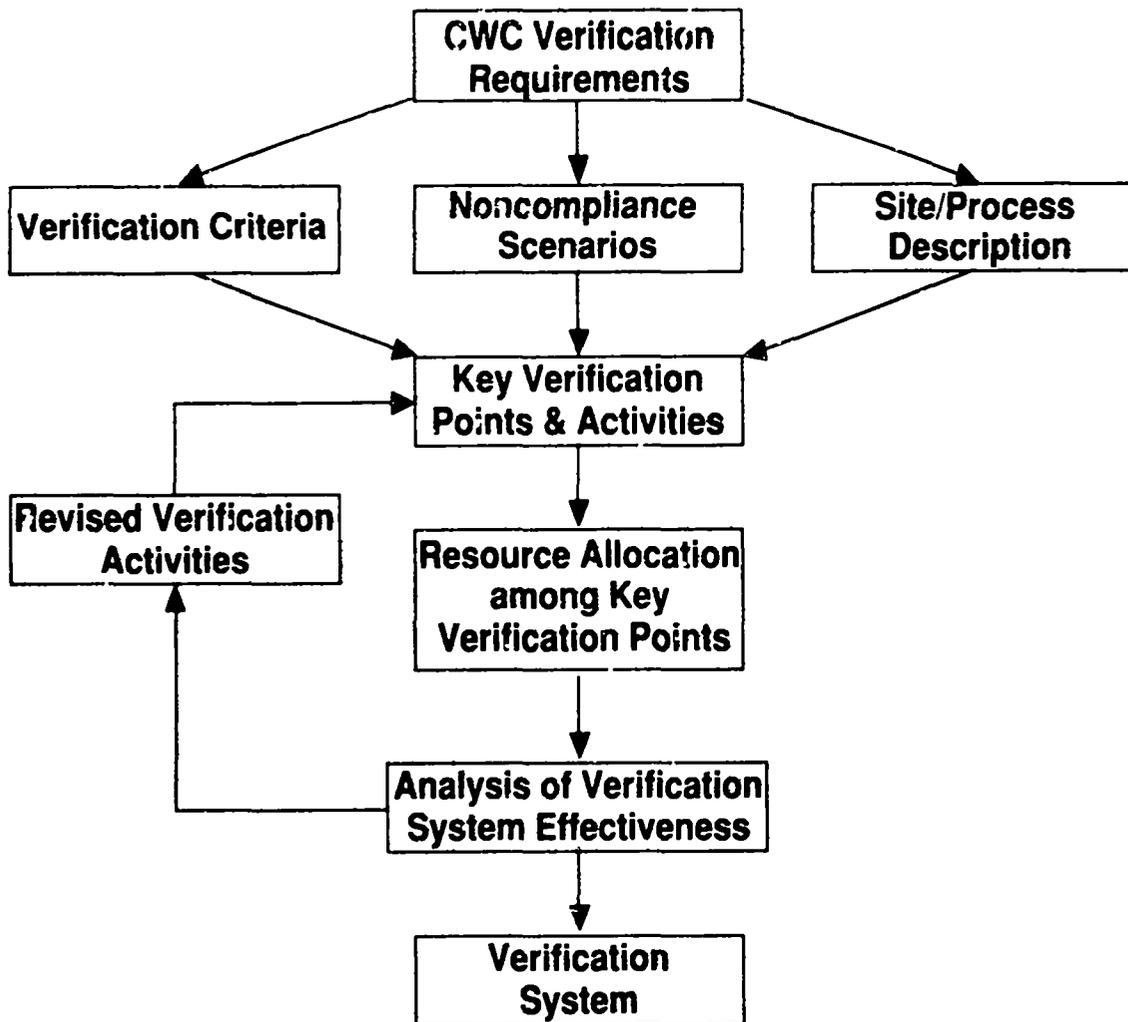


Fig. 1. Elements of the verification system design and evaluation method.

safeguards objectives. Despite significant differences between verification requirements for NPT agreements and those for the proposed CWC or bilateral CW agreements, this IAEA verification framework has general applicability to CWC verification as follows.

Nonproliferation Treaty. The treaty calls for each party to negotiate with the IAEA a safeguards agreement in accordance with the IAEA Statute and the IAEA safeguards system. For purposes of the NPT, the IAEA safeguards system is defined in a model safeguards agreement⁶ that is used as the basis for negotiating detailed safeguards agreements implementing a state's safeguards commitment.

Agreements with States. Among the legal agreements between a state party and the IAEA,

the most relevant to verification of CWC compliance is the facility attachment. A typical document includes

- descriptions of facility design and process operations;
- safeguards inspection activities to be applied by the IAEA;
- records of facility operations to be maintained by the facility operator;
- description of the state's system of accounting; and
- materials accounting reports to be submitted to the IAEA by the state.

Safeguards Approach. At each inspected facility, the IAEA develops a coordinated system of inspection activities. Factors in the system's design are inspection goals, facility

design characteristics, effectiveness of the state's system of accounting, relevant IAEA measurement and surveillance technology, available inspection resources, and technically credible noncompliance scenarios.

Inspection Planning. Limited inspection resources are allocated among the key verification points at an inspected facility to maximize the likelihood of detecting noncompliance. For each material stratum,⁷ effort is assigned to audits of state records and reports, verification of materials through measurement or inspections of seals, and application of containment and surveillance measures.

B. CWC Verification Requirements

The establishment of verification requirements follows directly from the language of a CW agreement or treaty. The objectives of the current CWC draft can be formulated to include the following verification requirements:

- validation of declarations of (a) CW stockpiles and production capabilities and (b) research and industrial facilities that would be subject to inspection;
- confirmation of the destruction of CW stockpiles and CW production facilities;
- monitoring legitimate operations involving treaty-limited chemicals within the chemical industry and at facilities not prohibited by the treaty;
- detection of covert production, diversion, or possession of treaty-limited chemicals; and
- investigation of alleged CW use or other violation of relevant international treaties or law.

The first two requirements would apply not only to the multinational CWC but also to bilateral U.S.-Soviet agreements aimed at reducing stockpiles. These verification requirements are listed in detail as Table I. It should be remembered, however, that these requirements are subject to interpretation and further change resulting from the ongoing negotiations of the Conference on Disarmament.

The backbone of CWC compliance monitoring will be by the International Inspectorate of the OPCW. On-site inspection, comprising continuous or intermittent visits by inspectors, can be augmented by continuous or noncontinuous monitoring with surveillance systems and by inventory control measures. The inspectorate will have the authority to collect samples for on-site analysis with fielded instruments as well as for off-site analysis at a central laboratory of the OPCW. Additionally, CWC verification monitoring will rely heavily on audits of records and reports of the relevant facilities and operations of states parties. Additional methodologies could include (a) medical analysis of victims of alleged CW use and (b) nonintrusive, remote chemical analysis or detection. The possible application of these methodologies to CW verification requirements is shown in Table II.

The initial, one-time verification activities for *validation of CW stockpile declarations* are closely related to activities associated with *confirmation of the destruction of declared CW stocks and production capabilities*. The declared stockpiles to be destroyed must be characterized sufficiently well to confirm that dummy material has not been substituted. Because of the large numbers of accountable items and limited inspection efforts, quantitative or qualitative analysis of each stockpile item generally would not be possible. Rather, a combination of physical attributes measurements and statistical sampling techniques could be used to confirm declared material. A less stringent approach would confirm only that initially declared munitions were CW-capable; actual CW agent contents would then be confirmed at the time of destruction.

Although standard analytical methods for characterizing the agents of CW munitions and stocks are readily available, the use of non-destructive and noninvasive physical measurement techniques and procedures would eliminate the need to draw samples from munitions.

The treaty requirement of validating declarations also includes inspection of declared research and industrial chemical facilities to confirm production capacities and plant lay-

Table I. Verification Regime Requirements Inferred from the Text of the Multinational Chemical Weapons Convention (CD/961).

1. Initial One-Time Requirements for Validating Declarations
 - A. Validating declarations of CW and stocks.
 - B. Validating declarations of CW production facilities.
 - C. Validating declarations of single, small-scale Schedule 1 production facilities and confirming that production capacity does not exceed allowed limits.
 - D. Validating declarations of facilities (other than the single, small-scale production facility) producing less than 10 kg of Schedule 1 chemicals per year.
 - E. Validating declared purposes and capacities of Schedule 2 (and possibly Schedule 3) industrial facilities.

 2. Destruction of Chemical Weapons and Production Facilities
 - A. Monitoring declared CW storage facilities for illicit or unauthorized movement of CW or stocks.
 - B. Monitoring the movement of weapons and stocks for purposes of destruction.
 - C. Confirming that declared CW and stocks are destroyed.
 - D. Confirming that declared CW production facilities are disabled and that production is not resumed and declared items are not removed.
 - E. Confirming the destruction of declared CW production facilities or their temporary conversion for CW demilitarization purposes.

 3. Monitoring Permitted Operations Involving Treaty-Limited Chemicals
 - A. Monitoring the production of Schedule 1 chemicals at single, small-scale production facilities declared for permitted purposes to verify that production is correctly reported.
 - B. Monitoring Schedule 2 facilities to confirm the types and quantities of Schedule 2 chemicals produced, transferred, processed, and consumed.
 - C. Monitoring Schedule 3 facilities to confirm the types and quantities of Schedule 3 chemicals produced, transferred, processed, and consumed.
 - D. Monitoring facilities producing less than 10 kg per year of Schedule 1 chemicals to ensure that production limits are not exceeded.

 4. Detection of Nonpermitted Production, Possession, or Diversion of Treaty-Limited Chemicals
 - A. Monitoring the production of Schedule 1 chemicals at single, small-scale production facilities declared for permitted purposes to verify that production limits are not exceeded and that Schedule 1 chemicals are not diverted for prohibited purposes.
 - B. Monitoring Schedule 2 facilities to ensure that Schedule 1 chemicals are not produced or otherwise handled.
 - C. Monitoring Schedule 3 facilities to ensure that neither Schedule 1 nor Schedule 2 chemicals are produced or otherwise handled and that Schedule 3 chemicals are not diverted.

 5. Characterization of Allegations or Suspicions of Nonpermitted CW Activities.
 - A. Responding to requests for on-site challenge inspections at either declared or undeclared sites suspected of producing or storing CW or of possessing proscribed material or equipment.
 - B. Responding to requests for on-site or challenge inspections to verify alleged use of CW.
-

Table II. Candidate Methodologies for Verification Requirements of the Multinational Chemical Weapons Convention (Those Inferred from Text CD/961 Underlined).

Requirement	Candidate Methodologies*
1A. Validating Declarations of CW Stocks	<u>OSI</u> , <u>IC</u> , SC, OSA
1B. Validating Declaration of CW Production Facilities	<u>OSI</u> , <u>IC</u>
1C. Validating Declarations of Single Small-Scale Schedule 1 Facilities	<u>OSI</u> , <u>DR</u> , SC, OSA
1D. Validating Declarations of Other Schedule 1 Production Facilities	<u>OSI</u> , <u>DR</u>
1E. Validating Declarations of Schedule 2 and (Schedule 3?) Facilities	<u>OSI</u> , SC, OSA
2A. Monitoring CW Storage Facilities	<u>OSI</u> , <u>CM</u> , <u>CP</u> , <u>SC</u> , <u>OSA</u> , <u>IC</u>
2B. Monitoring Movement of CW Stocks	<u>OSI</u> , <u>IC</u> , CM
2C. Confirming Destruction of CW Stocks	<u>OSI</u> , <u>CP</u> , <u>CM</u> , <u>SC</u> , <u>OSA</u>
2D. Confirming Closure of CW Production Facilities	<u>OSI</u> , <u>CP</u> , <u>CM</u> , <u>IC</u> , SC, OSA
2E. Confirming Destruction of CW Production Facilities	<u>OSI</u> , <u>CP</u> , <u>CM</u> , SC, OSA
3A. Confirming Production at Small-Scale Schedule 1 Production Facilities	<u>OSI</u> , <u>OSM</u> , <u>DR</u> , <u>OSA</u> , SC
3B. Confirming Schedule 2 Facilities for Schedule 2 Operations	<u>OSI</u> , <u>OSM</u> , <u>SC</u> , <u>OSA</u> , <u>DR</u> , CP, CM, RA, IC
3C. Confirming Schedule 3 Facility Operations	<u>DR</u>
3D. Monitoring Other Schedule 1 Production Facilities	<u>OSI</u> , <u>OSM</u> , <u>DR</u> , <u>OSA</u> , SC
4A. Monitoring Production at Small-Scale Schedule 1 Production Facilities	<u>OSI</u> , <u>OSM</u> , <u>DR</u> , <u>OSA</u> , SC
4B. Monitoring Schedule 2 Facilities for Schedule 1 Production	<u>OSI</u> , <u>OSM</u> , <u>SC</u> , <u>OSA</u> , <u>DR</u> , CP, CM, RA, IC
4C. Monitoring Schedule 3 Facilities for Schedule 1 and 2 Production and Schedule 3 Diversion	<u>DR</u> , OSI, OSM, SC, OSA
5A. Challenge Inspections for Nonpermitted Activities	<u>OSI</u> , <u>IC</u> , <u>SC</u> , <u>OSA</u> , RA
5B. Investigating Alleged CW Use	<u>OSI</u> , <u>IC</u> , <u>SC</u> , <u>OSA</u> , RA, MA

* Systematic International On-Site Verification comprises Continuous Presence (CP) or periodic On-Site Inspection (OSI) by the international inspectorate; Continuous Monitoring (CM) or noncontinuous, On-Site Monitoring (OSM) with surveillance instruments; Sample Collection (SC) for on-site or off-site analysis; On-Site Analysis (OSA) with portable or transportable instruments; Inventory Control (IC), including seals, markers, and monitoring devices; and Data Reporting (DR), which is also used in non on-site verification. Additional methodologies could include Medical Analysis (MA) of victims of alleged CW use and nonintrusive, Remote chemical Analysis (RA) or detection.

outs. Determination of inspection points and sampling plans might also be conducted during initial inspection.

Monitoring the permitted operations of the industrial chemical sector may constitute the greatest effort on the part of the OPCW. Monitoring will necessarily involve an array of on-site inspection, sampling, analysis, and auditing activities. Analytical techniques are generally available to monitor the legitimate production, processing, transfer, and consumption of treaty-limited chemicals, but additional constraints on the analytical methodologies and procedures may be required in order to prevent compromise of proprietary information or to minimize physical intrusiveness in process operations.

Closely related to monitoring permitted operations is the requirement of *verifying that CW agents are not produced and that precursors of CW agents are not diverted for clandestine purposes*. Verification associated with clandestine production, diversion, or storage of CW agents or precursors by the industrial sector presents one of the most difficult and technologically challenging aspects of CW verification. The difficulty of providing adequate analytical methods for the identification of trace amounts of CW agents or their by-products is complicated by questions that would inevitably arise concerning the forensic quality of the measurements.

In addition to analytical, sampling, and noninvasive techniques associated with the above verification activities, real-time sensors capable of continually monitoring process and effluent streams could be used to minimize inspection efforts. Real-time sensors for this monitoring are available from related industrial applications and could be adapted to meet CW verification needs. It may be necessary, however, to develop real-time diagnostic and data management systems tailored to special CWC verification requirements.

Successful *on-site inspections on challenge* depend fundamentally on *in situ* analytical methods as well as on more definitive off-site analysis of collected samples.

In addition to the array of on-site and off-site analytical methods, detailed sampling and trans-

portation protocols must be established within the framework of the multinational agreement to ensure sample safety, security, and authenticity. These protocols must cover all sample-collection activities.

Alleged use verification activities require special analytical methods because of the potential risks and political sensitivities involved. For example, unacceptable battlefield hazards may limit sample collection and make remote analysis necessary. Nevertheless, such a verification scenario could use many of the same high-sensitivity analytical methods needed in verification of nonproduction of CW. The analysis methods, however, should be sensitive to new toxic agents, including materials not currently recognized as agents.

Many of the CWC verification requirements can be supported by containment and surveillance measures. Monitoring systems such as surveillance cameras and closed-circuit television would be particularly useful in extending the "presence" of the inspectorate. Containment systems, including tamper-resistant seals, tags, and other item-identification systems, could assist in the difficult task of monitoring inventories. The broad capabilities in containment and surveillance that have been developed for support of the NPT and the Intermediate-Range Nuclear Forces (INF) Treaty, for example, apply to chemical verification, although attention would have to be given to the different operating environment of chemical facilities.

C. Verification Criteria

A verification system must be evaluated on a technical basis in terms of verification criteria that quantitatively state the performance requirements of the system. The criteria are, in effect, a means of measuring the system's effectiveness in meeting its objectives.

The objectives of any arms control verification system are to provide assurance that all parties are complying with the terms of the agreement and to deter noncompliance. These general objectives are supported by the more specific objective of timely detection of a sig-

nificant quantity of treaty-limited material. Verification criteria, then, give quantitative meaning to the general terms *timely*, *detection*, and *significant*.

The definition of verification criteria may vary depending upon the particular aspect of an agreement that is to be verified. For a CW agreement, whether bilateral or multinational, factors affecting the criteria include the type of site or facility where verification is applied; the applicable measurement, containment, surveillance, and other verification technologies; the amounts and types of chemicals or CW; and the available inspection resources.

The IAEA applies a gradation of verification criteria in which nuclear materials directly usable in a weapons system are subject to more stringent criteria than are materials requiring processing before use in a weapon. The characterization of a militarily significant amount of CW agent, however, is not nearly so clear-cut as the characterization of fissile critical masses of nuclear material. The CWC Schedule 1, 2, and 3 designations for chemicals described earlier constitute a possible basis for establishing graded verification criteria. These criteria are roughly related to the progression from smaller amounts of material directly usable in weapons to larger amounts of chemicals that are either indirectly or not as effectively usable in weapons. Such a graded-criteria structure, however, must consider such factors as obsolete delivery systems (which might mean that certain materials reasonably could have less-stringent verification criteria) and the military employment of chemical weapons.

Developing criteria for evaluating the effectiveness of a CWC verification system will require the specification of the amounts of CW agent or other treaty-limited chemicals that constitute a significant detection goal. The associated likelihood (stated as a probability where possible) of detecting the existence of that goal amount at an inspected site or facility will have to be specified, as will the timeliness of detecting that amount. Criteria of this kind are essential for establishing the acceptable performance of a verification system and for

comparing the effectiveness of competing verification technologies.

D. Verification Context

A description of the CW verification context, in terms of facility layout, types and amounts of chemicals, etc., is necessary in determining where verification information can be acquired. The general verification contexts of relevance to CW agreements, together with descriptive information necessary for determining key points where monitoring methods and technology can be applied, are as follows.

Storage Sites for CW. Such sites could contain weaponized and non-weaponized agents and could be associated with CW destruction facilities. Information includes numbers and types of weapons, storage configuration, chemical composition, bulk inventories, containments (fences, walls, and barriers), and vehicle and personnel portals.

Declared Production Facilities. These include small-scale production facilities where limited amounts of chemical agents are produced, as allowed by the CWC; industrial facilities where Schedule 2 and 3 chemicals are produced; and former CW production facilities. Necessary information includes physical layout, process description, process equipment, and inventories and flows of chemicals (amounts, chemical composition, item or bulk, etc.).

Facilities for Weapons Destruction. Necessary information for these facilities includes numbers, types, and chemical compositions of weapons (or agents) to be processed, weapons stored at destruction site, physical layout, process description, and process equipment.

Clandestine Sites. These include both facilities for clandestine production and sites for possession of proscribed materials. Necessary information includes locations for surveillance (in-country, remote land-based, aerial, space-based), assumed characteristics of facilities, and effluent signatures.

Locations of Alleged CW Use. These geographical locations require information on

assumed use scenarios, assumed weapons types, morbidity and moribundity analyses, local terrain descriptions, and meteorological conditions.

E. Key Measurement and Surveillance Points

Implementation of a CWC verification system for the relevant verification contexts can be based on the concept of key measurement and surveillance points, which are locations where monitoring technologies or procedures are applied. Within the framework of the verification and evaluation methodology, selection of key points is determined by the context description (above) and the necessity to gather sufficient information to detect possible non-compliance with the CW agreement. Examples of the types of key measurement and surveillance points and associated inspection activities that could be considered for each verification context are given below. These activities are intended to be illustrative and may not be identical with those finally agreed upon in multinational or bilateral agreements.

1. Storage Sites for CW

- **Weapons inventories:** for each weapons stratum, random selection of weapons for verification, *in situ* measurement of chemical agent(s), nondestructive evaluation of weapons characteristics, examination of records, surveillance of stratum to detect noncompliant activities, tagging of munitions or agent containers, and audit of records.
- **Weapons movements:** checking weapons tags, sealing weapons into transportation containers, and visual inspection of preparations for transportation.
- **Perimeter of site:** application of containment systems, surveillance of containment integrity, and surveillance of area to detect noncompliant activities.
- **Portals:** surveillance at portal to detect and identify entry or egress by personnel or

vehicles, and control of access to deny unauthorized movement of weapons.

2. Declared Production Facilities

- **Material inventories and flows:** for each material stratum, *in situ* monitoring or measurement, sampling of material for off-site or on-site analysis, sealing of items, review of records and reports, and surveillance of materials.
- **Physical boundaries:** use of containment to limit personnel or vehicle movement, and surveillance of containment integrity.
- **Portals:** surveillance of personnel or vehicle portals to detect and identify movement, or application of barriers to prevent unauthorized movement.
- **Area surveillance:** surveillance of internal or external areas to detect presence of personnel or movement of items.

3. Facilities for Weapons Destruction

- **Weapons inventories:** as described above for CW storage sites.
- **Weapons movements:** for received weapons, verifying integrity of sealed container and checking weapons tags.
- **Weapons destruction:** verifying weapons tags, monitoring the destruction process using containment and surveillance or materials balance, and monitoring process lines.
- **Chemical flows:** monitoring all chemical flows across site boundary through *in situ* measurement or sampling for off-site or on-site analysis.

4. Locations of Alleged CW Use

- **Chemical agent contamination:** selecting locations for *in situ* measurement or sampling for on-site or off-site analysis, and medical analysis of alleged victims.

Key measurement and surveillance points for clandestine sites would be derived from those given above, depending upon the type or location of facility being investigated.

F. Resource Allocation

Attainment of the verification criteria for each inspected site or facility will require judicious allocation of limited inspection and technology resources. The inspection effort and monitoring technologies assigned to a site or facility will depend upon the stringency of the verification criteria as well as the verification context in terms of quantities, types, and accessibility of treaty-limited materials. Clearly, verification criteria based on small significant quantities, high detection probabilities, and short detection times would be more demanding technically than those based on more relaxed standards. Furthermore, inspecting a site or facility with a large and dynamic inventory using less-stringent criteria might still require extensive inspection resources if a substantial portion of the inventory is to be adequately measured. In general, the stringency of verification criteria and the size and nature of the inspected inventory will influence the level of inspection effort and technology for each site or facility. Thus, although criteria associated with Schedule 1 chemicals are likely to be stringent, verifying the limited number of small-scale, Schedule 1 facilities and the small amounts of material involved should not be resource intensive. The same criteria as applied to Schedule 2 facilities, however, could demand inordinate monitoring resources for attainment of the criteria.

Application of such technologies as noninvasive diagnostics, in-line measurement, and surveillance devices may reduce the inspection effort by reducing the time spent on a monitoring task or by reducing the frequency of inspector visits to a facility. Tradeoffs between inspection activities at a key point should emphasize the use of technologies to conserve inspection resources that could then be applied to the verification effort at other key points.

Statistical sampling of chemical strata combined with *in situ* measurement of selected items can reduce the inspection effort while maintaining a quantifiable confidence of detecting noncompliance. Random sampling at several levels might include selection of items or locations for measurement within a stratum, random selection of strata for verification within a facility, or random selection of facilities to be monitored within a class of facilities. However, implementation of random sampling requires that the inspected facility provide all relevant inventory information and that the random inspection schedule and plan be kept confidential.

Because stringent verification criteria are likely to strain verification resources where large numbers of facilities or large quantities of material are involved, resource requirements will probably influence the establishment of actual verification criteria under the CWC. The IAEA precedent for establishing graded criteria that consider the difficulty of verifying certain materials may be a useful concept for the CWC verification regime. Graded criteria could also reflect the ease with which material could be converted to a militarily significant threat.

G. Noncompliance Scenarios

The design and evaluation of a verification system must consider possible scenarios for treaty noncompliance in order to ensure adequate coverage by the selected inspection technologies and procedures. Indeed, a measure of the performance of a verification system is its ability to detect anomalies associated with these scenarios. Thus, development of scenarios in which an adversary seeks to acquire or use a CW capability is an integral part of CW verification system development.

For CW arms agreements, relevant noncompliance scenarios include

- nondeclaration of CW agents or munitions in existing stockpiles or nondeclaration of

CW production capability during the initial declaration process;

- diversion or substitution of CW agents or munitions during the storage and destruction process;
- production of CW agents, or diversion of treaty-limited chemicals to that purpose, at declared facilities;
- production or storage of CW agents at clandestine facilities; and
- belligerent use of CW agents.

By falsifying initial declarations of CW stockpile or production capacity, a state could, in principle, retain a significant clandestine CW capability. Detection of such noncompliance, as well as detection of undeclared production or storage at a clandestine site, would rely on challenge inspection concepts.

Within declared locations, a noncompliant party can falsify the accounting data, perhaps by overstating the amount of material in a declared inventory, thereby creating a reserve of material for diversion. In some bulk facilities the total measurement uncertainty for verifying a materials balance may be large, and diverted amounts of material might go undetected, provided they are small compared to the measurement or process uncertainties. Additionally, diverted chemicals replaced with other materials possessing similar attributes may allow undetected diversion if the inspectorate's measurement technology cannot discriminate between actual and dummy materials.

In those instances where the inspectorate employs seals, surveillance devices, *in situ* analytical instruments, or other means for monitoring materials or facility activities in an unattended mode, an adversary may attempt to tamper with these devices to remove evidence of noncompliance actions. Candidate measurement and surveillance systems must therefore be assessed against a range of technically credible noncompliance activities to ensure that anomalies are detected.

H. Effectiveness Evaluation

An evaluation of the effectiveness of a CW verification system provides a basis for com-

paring candidate systems and for selecting the combination of technologies and activities that most efficiently achieves the verification objectives. Because the selected system must accommodate a variety of verification requirements, contexts, and noncompliance scenarios, its evaluation must be sufficiently comprehensive to ensure that the selected system is effective for all verification possibilities. Further, the desired system performance should be attainable at an acceptable cost, a fact suggesting that resource requirements are an adjunct measure of effectiveness.

Effectiveness of a verification system may be characterized by associating a collection of *attributes*. For a CW verification regime, such attributes include

- likelihood of detecting a significant non-compliance action;
- timeliness of detecting a significant non-compliance action;
- likelihood of falsely indicating a non-compliance action;
- intrusiveness into operations of the inspected facility;
- risk of disclosure of proprietary or other confidential information; and
- risk of disclosure of national security information.

For each attribute, a quantitative or qualitative measure of the attribute (e.g., probability, time, lost productivity, or classification level of disclosed information) and set *performance criteria* can be established. These criteria can be considered singly, or related criteria can be aggregated into composite performance criteria. For example, a specified probability of detecting a significant quantity of a proscribed chemical agent within a given time after its production represents a composite performance criterion. In this example, the performance criterion overlaps the verification criteria discussed previously in Section C. Indeed, verification criteria may constitute the principal measure of system performance, whereas other single or composite criteria may serve as ancillary constraints on system performance. Where resource or other limitations require compromise in attaining performance criteria,

verification criteria preferentially would be retained while selected ancillary performance criteria might be relaxed.

A measure of effectiveness based on performance criteria that are either attained or not attained is more appropriate to a CWC verification system than is a continuous measure of effectiveness. Indeed, the political need to have clearly defined levels of treaty violation, the resource intensiveness of open-ended requirements to detect successively smaller violations, and the daunting task of verifying large numbers of sites and materials argue for bounded measures of effectiveness. Further, the IAEA experience in basing performance criteria on achievable verification goals supports the utility of this approach for evaluating system effectiveness.

Resources required for development and implementation must also be considered in the selection of the candidate verification system. For each candidate system, the resource costs comprise research and development funds to obtain needed technologies or procedures and resources to implement and maintain the verification system. The latter costs include support for the following:

- **administrative support** such as inspector training, inspection coordination and scheduling, and reporting inspection results;
- **technical support** such as equipment maintenance, data analysis, laboratory chemical analysis, and review of surveillance records; and
- **inspection implementation** including inspector travel, inspector-days on site, and shipment of equipment and samples.

In summary, an evaluation of the effectiveness a CWC verification system consists of the following steps:

- definition of system attributes;
- development of quantitative or qualitative measures for each attribute;
- evaluation of verification criteria and other attribute performance criteria for each candidate system;
- assignment of resource costs to each candidate system; and

- selection of the system that attains the criteria at minimal cost.

I. Verification System Design

Definition of a verification system is an iterative design and evaluation process consisting of the following steps: (1) statement of the constraints imposed on the system design by the CW agreement, verification criteria, and the specific details of sites or facilities where the system is to be employed; (2) specification of noncompliance scenarios detailing each component action of the scenario; (3) for each key verification point, identification of the candidate monitoring activities and the non-compliance actions that they can detect; and (4) selection of monitoring activities through an iterative qualitative or quantitative effectiveness analysis.

For each CW verification requirement and site or facility description, noncompliance scenarios for accomplishing a material breach of the agreement must be devised. These scenarios are defined by listing the sequence of specific adversary actions for accomplishing the noncompliance objectives. Actions are of two types: (1) the essential actions for illegally acquiring treaty-limited chemicals or chemical weapons, or for employing such weapons, and (2) the essential actions for deceiving the verification system to avoid detection. An example of adversary actions in the noncompliance scenario of CW agent production at a declared industrial facility is described in Table III.

The following steps can identify candidate monitoring activities for inclusion in the verification system:

- identify each key location at the site or facility where measurements, containment, and surveillance, or other inspection activities may be applied;
- considering the noncompliance scenarios, identify the inspection activities that can be applied at each key location to detect noncompliance; and

Table III. Postulated Noncompliance Scenario: Production of CW Agent at a Declared Industrial Facility.

- Transfer Schedule 2-precursor chemical(s) into facility through routine shipment or produce precursor(s) within plant.
- Store precursor chemical(s) with other allowed chemicals.
- Reconfigure process line.
- Tamper with in-line process monitors.
- Falsify accounting records.
- Remove precursor chemicals from storage.
- Produce proscribed chemical agent.
- Flush process lines.
- Remove CW agent with routine shipment of allowed or treaty-nonlimited chemicals.

- for each relevant inspection activity, identify the component actions of the noncompliance scenarios that the activity can detect.

For the postulated noncompliance scenario described in Table III, Table IV presents an analysis in which numerous monitoring activities address specific noncompliance actions.

Table IV. Detection of Possible Noncompliance Actions by Verification Activities at a Declared Industrial Facility.

Key Point	Verification Activities	Noncompliance Action Detected
Receiving area	Review shipping documents	Falsified documents
	Sampling of material for measurement	Possession of nondeclared chemicals
Storage area	Surveillance of storage area	Anomalous activity in storage area
	Sampling of material for measurement	Possession of nondeclared chemicals
Process area	In-line monitors for agents	Production of proscribed chemicals
	Tamper protection of monitors	Tampering with monitors
Waste area	Sampling and measurement of waste tanks	Production of proscribed chemicals
Shipping area	Sampling of material for measurement	Possession of proscribed chemicals

Selection of the optimal CW verification system is based on a cost-effectiveness evaluation that determines the combination of verification technologies and procedures that attains the performance criteria with the least resource expenditure. Analysis of the effectiveness of the verification system is diagrammed in Figure 2. The site or facility is broken down into key inspection points and associated verification activities; noncompliance scenarios relevant to the verification requirements are developed into their component noncompliance actions; and the verification activities are mapped onto the component noncompliance actions that each activity can detect. Total system performance is measured by the attainment of the verification criteria for detection of noncompliance scenarios and the criteria for the other system attributes discussed above.

Those verification systems attaining all criteria are feasible candidates; the selection of the optimal system is based on the most efficient use of inspection resources.

III. CONCLUSIONS

The design and evaluation of a verification regime for a CW arms agreement require the allocation of limited resources among candidate technologies and activities to maximize the confidence that they will detect noncompliant actions. The system design and evaluation method described here is a top-down, hierarchical approach beginning with the general verification requirements and refining these into facility- or site-specific descriptions, verification criteria, noncompliance scenarios, and relevant monitoring activities and technologies.

This systems approach is sufficiently general to encompass the unique and diverse aspects of an anticipated CWC verification process that covers large numbers of facilities; large quantities of mutable materials; dual-use facilities; routine, challenge, and *ad hoc* inspections; CW stockpile destruction; and declared and nondeclared CW-related activities. The methodol-

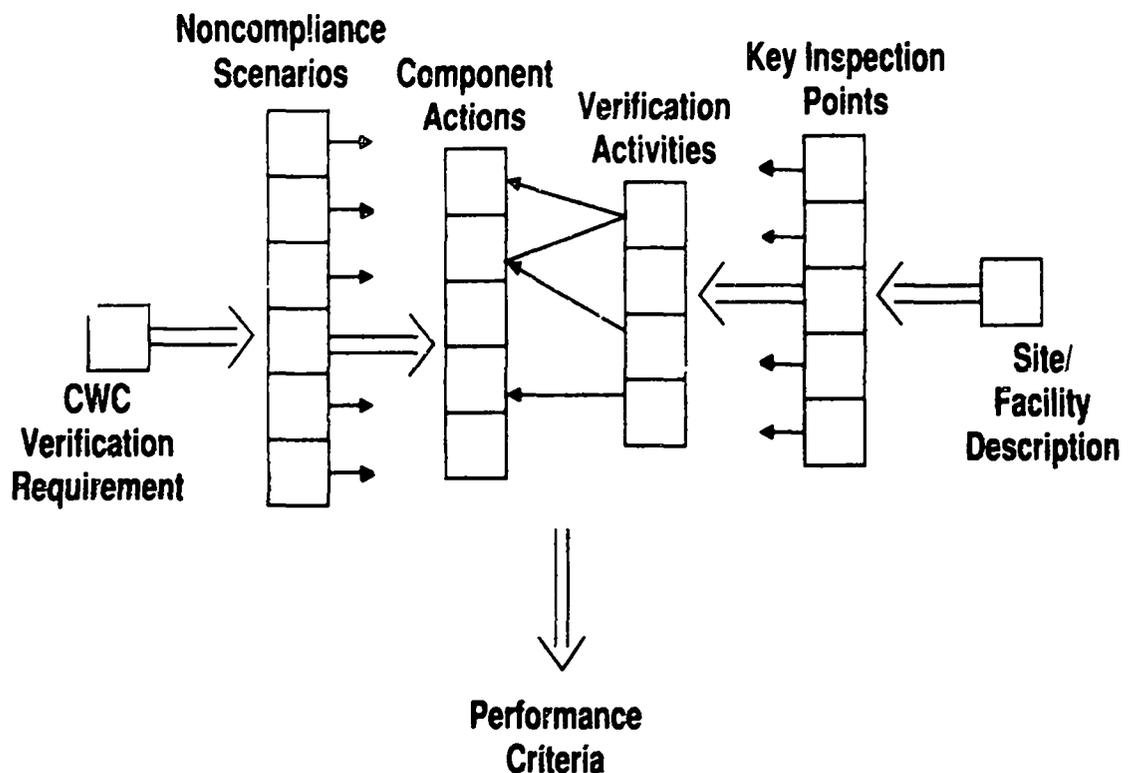


Fig. 2. Effectiveness analysis of verification system.

ogy, however, is best applied to declared sites, facilities, and activities.

This methodology applies to several phases in the evolution of a CWC verification regime: during the negotiating phase, when technical feasibility and confidence in noncompliance detection are addressed; during the planning phase, when the most effective expenditure of research and development funds is determined; during the implementation phase, when more detailed system design tradeoffs, cost-effectiveness analyses, and resource allocations are required; and during system upgrade, when the effectiveness of the verification regime is evaluated and improved.

NOTES AND REFERENCES

1. For instance, the Memorandum of Understanding signed in September 1989 by the United States and the Soviet Union provides for declaration and inspection of each other's CW stocks and production facilities *before* completion of the multinational CWC.
2. "Report of the *Ad Hoc* Committee on Chemical Weapons," (CD/961), Conference on Disarmament, Geneva, February 1, 1990.
3. Only the United States, the Soviet Union, and Iraq (informally) so far have declared possession of CW, although more than twenty additional nations are thought to have CW capabilities.
4. There is some uncertainty in the rolling text as to the inclusion of certain key precursors (including key components of binary weapons) in Schedule 1.
5. The Soviet Union and the United States are proceeding with arrangements to reduce their respective CW arsenals under a bilateral agreement.
6. "The Structure and Contents of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," IAEA document INFCIRC/153 (corrected) (June 1972).
7. Material strata are safeguarded inventories compiled according to chemical composition, physical form, item or bulk, batch or flow, amount, location, etc.