INSPECTION FOR DISARMAMENT

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Edited by SEYMOUR MELMAN

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FOREWORD

THE "balance of terror," reflecting the deterrent strategies of both the Soviet Union and the United States, is regarded by many people today as the chief sanction and deterrent against the would-be user of thermonuclear weapons. Opinions vary and men differ as to how much and how lasting is the protection which the capability of devastating retaliation now gives. They also differ as to the political desirability of proposals for disarmament or arms control which are designed to give the world a very different kind of protection against the contingency of two-way thermonuclear war. Agreements between governments have so far been hindered by an inability to discover a "disarmament package" which did not seem to the other side to favor the side proposing it. Neither the United States nor the Soviet Union has been prepared to enter into an agreement which might leave it at the mercy of the other if the agreement were violated or if the system broke down.

The "honor system" can be no substitute for effective inspection, whatever the form which an arms limitation agreement takes. Uncertainty about the requirements for an effective international system of inspection can be as great a barrier to agreement as mistrust. New vistas for negotiation and agreement would be opened up by a technically well-founded judgment that it would be possible to install on this planet a disaster-proof alarm system to detect and identify a clandestine violator of a disarmament agreement. To be proof against such a disaster, it would have to give the law-abiding signatories to an arms control agreement warning of a violation in time for effective counter measures.

No militarily decisive amounts of the regulated or forbidden materials of war could remain concealed and undeclared if the system of arms regulation is to work. Nor could the system work unless the detection of illicit production of war materials in significant amounts were quite certain, and the detection of preparation for a major military attack absolutely certain. The system could not work unless it permitted every suspicion of violation to be promptly confirmed or disconfirmed by access to whatever installations and records would have to be opened up to clear away doubts and suspicions. Finally, it could not work for long unless the prohibitions, limitations, and regulations accepted at the outset could be redefined at frequent intervals to take account of scientific and technological developments.

The political obstacles to establishing a reliable system of international inspection may or may not be very great. How great they may be is suggested by the Legislative Drafting Research Fund study by Professor Louis Henkin, which parallels the present study. In this study, *Arms Control and Inspection in American Law,* the impact of a variety of proposals for disarmament and arms control on the most cherished aspects of our American legal system are investigated. Many will think the price of an international inspection system is worth paying only if it can be shown that there are no insurmountable technical obstacles to the establishment of a reliable system of inspection.

Professor Melman's analysis deals with the technical aspects of such a system of inspection in order to see how surmountable these technical difficulties really are. He leaves to others the analysis of the political problem of developing the broad support in public opinion without which democratic governments could not enter into agreements to substitute in any important way a reliance on the disarmament of other states for a reliance on their own arms. He does not deal with the problem of enforcement once a violator has been identified. His research and findings are focused on the feasibility of the system for detecting and identifying violators of agreements, and not on the methods for coping with violators.

National governments do not appear to have had any difficulty within areas under their control in preventing unwanted production or concealment of fissionable materials, of atomic weapons, and of the mechanisms for their delivery. Why, then, is there any difficulty? Does this indicate that disarmament or arms control is primarily a political rather than technical problem? Two answers are suggested.

1. Without government participation, or that of a segment of a government so large as to constitute practically "a government within a government," the successful manufacture, deployment, and use of whole atomic weapons systems are almost inconceivable. An international inspectorate has therefore to reckon with the possibility of government complicity, and the resources of a government for large-scale covert organization of its resources and concealment against a largely foreign inspectorate may be very great.

2. The motivation of private citizens to manufacture and use atomic weapons against their own government would seem to be relatively improbable, while the possibility of a government's being motivated to commit a violation of an international system of arms control has always to be assumed.

Professor Melman's answer to the question of the technical feasibility of effective inspection of future production and of major weapons testing is affirmative and optimistic. He is more cautious in his findings regarding the possibility of guarantees against the existence and control of concealed or undeclared stocks of war materials at the outset of the system.

After more than a decade of fissionable material production in several countries, proposals for all-round disarmament which assume that all the fissionable materials in existence can assuredly be located and brought under control are obsolete. Fortunately, not every design for curbing the atomic arms race requires that all existing atomic arms be surrendered forthwith and *in toto*. A wide range of arms control plans still remains technically feasible if one accepts Professor Melman's main findings. For example, if a plan for international control of the mechanisms for long-range delivery of nuclear weapons can be brought into operation while the technology of guided missiles is still in its infancy—and the missiles already produced are still few, primitive and inaccurate by tomorrow's standards—then the risk of successful concealment would be small. At a later date, effective inspection might be more difficult and perhaps impossible.

This explains the note of urgency that recurs in Professor Melman's report. His sense of urgency is further reflected in his discussion of radiation hazards and in his apprehension that a deviant personality, an errant meteor, or a mistake in judgment may unleash a two-way thermonuclear war which no government had intended to initiate. These latter considerations, however, although they argue for the desirability of international arms control, do not bear directly on the question of technical feasibility.

There is not to my knowledge any comparable study of the feasibility of industrial inspection and of monitoring of bomb and missile tests. To Mr. Earl D. Osborn must go the credit for identifying industrial inspection as a significant area for investigation by private scholars and for being willing to back his judgment. A grant to the Institute of War and Peace Studies of Columbia University was received from the Institute for International Order, of which Mr. Osborn is President.

This study, extending over many areas of knowledge, could not have been completed without the cooperation of the authors of the twenty-one supporting technical papers, and the detailed criticism of a very much larger group of men who read the manuscript in draft form.

The judgments expressed are, of course, those of Dr. Melman and the various authors of the technical papers. At the very least, they will promote discussion in an area of vital public policy. If they stand up under the test of public debate and further private research, they will also point the way toward the greatest practicable disarmament or arms control.

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April 18, 1958

PREFACE

THIS INVESTIGATION has been undertaken on the assumption that a disarmament agreement would help to preserve the human species, and to prevent a world holocaust. The purpose of this study is to define the necessary conditions for a workable inspection system needed to ensure compliance with a disarmament agreement.

It is widely recognized that any proposed steps toward disarmament by international agreement can be meaningful only insofar as they include ways that give mutual assurance of compliance through appropriate systems of inspection.[1]

The analysis of technical feasibility of inspection for disarmament takes on special importance in view of the present or imminent availability of nuclear weapons to many nations. The means for the extermination of the human species thus pass into the hands of many governments, large and small. There is another hazard to mankind that stems from the sheer number of people who handle weapons of great destructiveness.

[1] President Eisenhower, at Geneva on July 21, 1955, expressed the view: "No sound and reliable agreement can be made unless it is completely covered by an inspection and reporting system adequate to support every portion of the agreement. The lessons of history teach us that disarmament agreements without adequate reciprocal inspection increase the dangers of war and do not brighten the prospects of peace . . ."

Marshal Bulganin stated to the Supreme Soviet on August 4, 1955: "The President of the United States justly remarked that each disarmament plan boils down to the question of control and inspection."

U. S. Senate, Committee on Foreign Relations, Subcommittee on Disarmament, Staff Study No. 4, *Control and Reduction of Armaments, Technical Problems,* 84th Congress, 2nd Session (Washington, D.C., U.S. Government Printing Office, October 7, 1956), p. 3.

Undoubtedly, the designers of nuclear weapons have attempted to build into them certain mechanical safeguards against accidental firing — such as the requirement for a deliberate adjustment before such weapons become operative. There are no final safeguards, however, against the probability of human failure. As nuclear weapons are produced by the tens of thousands, and must be used by even more than that many men, the possibilities of world disaster through human failure cannot be ignored. One aberrant, psychotic person, or person gone momentarily out of control, could explode nuclear weapons at a random place, or over any populated area. A space satellite could be mistaken for a ballistic missile.

Since military tactics and technologies have become geared to the idea of rapid retaliation, such accidents would require only one misjudgment in response to set the swift moves and countermoves of catastrophic nuclear war in motion. As nuclear weapons are increasingly available and dispersed in more hands, the probabilities of such an accident must necessarily increase. In the judgement of this writer, such possibilities weaken the assumptions of rationally calculated moves among military powers, which underlie the strategies of peace through mutual armed deterrence.

Lastly, one of the major assumptions of the mutual deterrence strategy will be drastically altered when many countries possess nuclear weapons. If a warhead should be set off in some city, it might be impossible to identify the aggressor, because of the number of countries possessing bombs, and the variety of possible ways for delivering nuclear explosives. Unless the aggressor were known, it would be clearly impossible even to threaten retaliation. Thereby, the strategy of a "balance of terror" fails as a way for deterring nuclear attacks.

This investigation has explored an array of new problems. Clearly, errors in our analyses and points at which improvements may be made may well be discovered as more attention is given to the knowledge that is relevant for inspection for disarmament. I am satisfied, however, that this attempt to define the problem of inspection for disarmament on a scientific, technical basis will accelerate the further development of useful knowledge and workable methods for these goals.

This investigation was initiated through the joint efforts of Mr. Earl D. Osborn, President of the Institute for International Order, and Professor William T. R. Fox, Director of the Institute of War and Peace

Studies of Columbia University. Mr. Osborn was instrumental in providing the funds for executing this project and facilitating rapid publication of the report, and Professor Fox invited me to conduct this investigation, for which privilege I am most grateful.

I am indebted to Professor Fox for his generosity in contributing incisive comment on the drafts of this report.

At the outset, it was clear that the execution of an inquiry of this scope would require the collaboration of many people with specialized technical competence in a wide variety of fields. The collection of technical papers which appears in the second part of this report is evidence of this scope. The writers of these technical papers have contributed unstintingly of their time and earnest effort for this purpose.

A document of unusual interest for the present study was produced by the Institute for International Order in 1956: *Factory Inspection and Armaments Control,* "a report on a pilot study of manufacturer opinion on inspection as a step in disarmament." This is a combined study of attitudes and judgments about disarmament policy and various details of factory inspection techniques.

This report has benefited immeasurably from the critical comments on the manuscript. I wish to extend my warmest thanks to the following persons who have contributed valuable criticism and enabled the rapid and intensive review of this book in manuscript form:

Gerald Albin; Austen Albu, M.P.; Seymour Alpert; Philip Andrews; Antony Antonopoulos; Philip Noel-Baker, M.P.; Professor Max Beloff; Andrew Boyd; Rolf Brodersen; Dr. D. G. Brennan; Elizabeth Brunner; John G. Busharis; Alberto Calderaro; Professor Charles Coryell; Professor Lawrence B. Cohen; Philipp Dilloway; Dr. René Dubos; Professor John T. Edsall; Professor Alexander Erlich; Professor B. T. Feld; Dr. D. Finch; Dr. Hans Frewer; George Feeney; Edward Fletcher; Dr. Erich Fromm; Professor Walter Gellhorn; Professor Leland M. Goodrich; Dr. and Mrs. R. Grinberg; Professor C. Lowell Harris; Dr. T. N. Harris; Jack Hartshorn; Professor Louis Henkin; Dr. Peter Hodgson; Professor Alex Inkeles; Professor Philip C. Jessup; Marvin Kolkstein; Professor Paul Lazarsfeld; Michael Lipman; Duncan Luce; Dr. Myer D. Mendelson; Donald Mitchell; Jack B. McKitterick; Peter Norden; Dr. L. G. Osborne; Tom O'Sullivan; Dr. Gunnar Randers; Professor Yochanan Ratner; Dr. Ruth Sager; Dr. David Schecter; Professor Warner R. Schilling; Dr. Sam Schurr; Campbell Secord; Professor Walter Selove; Professor Ernest

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Dr. George Gallup and Mr. George Gallup, Jr. performed the invaluable service of conducting the poll of public opinion in the United States. They were instrumental in arranging for the speedy and remarkably efficient execution of this work abroad as well. We are most grateful to them and their associates in the United States and abroad, since this international poll enabled us to gauge the extent of public support for inspection for disarmament. In Japan the public opinion poll was conducted by the newspaper *Yomiuri,* and to its editors we extend special thanks.

We are indebted to Mr. Earl D. Osborn and to the Columbia Council for Research in the Social Sciences, who made special grants of funds for carrying out the international poll of public opinion.

The preparation of the manuscript was magnificently supported by the devoted work of Mrs. Ruth W. Edelstein, Mrs. Ruth Hickerson, Mrs. Janet Wehner, Mrs. MaryAnn S. Roston, Mrs. Phyllis Clark, Mr. Richard Kramer, and Mr. Richard E. Barto.

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I wish to extend special thanks to Columbia University Press, and in particular to Mr. Henry Wiggins, for the swift and efficient publication of this book.

The several technical papers appearing in the second part of this report are in each instance the responsibility of their authors. In the first part of this report, the principal findings of these technical papers have been summarized, and inferences have been drawn with respect to recommendations for the characteristics of a workable system of inspection for disarmament. The responsibility for these interpretations and inferences is my own.

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May, 1958

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GENERAL REPORT

THE PROBLEM OF INSPECTION FOR DISARMAMENT

WORKABLE SYSTEMS of inspection can be designed to ensure compliance with international disarmament agreements.[1] That is the principal finding of this investigation of the feasibility of designing an inspection system for disarmament. The range of workable inspection extends from particular objectives, such as halting nuclear-bomb and missiles testing, to the wider objective of halting production and testing of both the weapons of mass destruction and the instruments for their delivery.

The Meaning of Workability

The workability of an inspection system refers to its ability to make an effort at evading disarmament agreements extremely difficult. It is possible to design and operate systems of control which would give substantial assurance that evasions of various types of agreements on disarmament could not be carried out successfully. It is not possible, however, to design and operate a system by which perfect compliance with international disarmament agreements could be guaranteed. Let it be clear at the outset that perfection cannot be guaranteed here, nor in any natural or social phenomenon. Indeed, foolproof and flawless reliability in inspection for disarmament is not only unattainable; it is not necessary for workability.

[1] The term "disarmament" as here used includes partial as well as total elimination of specified weapons systems. It thus includes both "arms limitation," as used by some to imply partial arms reduction and "total disarmament."

Both the capabilities and the limitations of inspection for disarmament are discussed in this report. The strong points of inspection systems are more than sufficient, in the judgment of this writer, to form the basis for an optimistic estimate of workability. Stated in another way: the gains that could be obtained for the security of humankind by the relaxation of the arms race are so substantial as to be well worth the risks of successful evasion that may be involved in concluding disarmament agreements.

Partial and Extensive Disarmament

The workability of inspection for disarmament need not be handled as an all-or-nothing problem. There are many alternative inspection techniques of immediate as well as long-range interest. The results of this study cover a wide range of possibilities—from inspection for nuclear-bomb and missiles tests, to extensive inspection of the production of large-scale missiles.

An inspection system for these purposes must satisfy both technical and allied conditions. The strictly technical features define the kinds of critical points in arms production and testing to which access is essential and which lend themselves to surveillance. The allied aspects refer to the legal status, powers, and administrative requirements of an international inspection agency. An inspection system for disarmament must take account of the technical possibilities for inspection at strategic points in the mining, processing, manufacturing, storing, and deployment of the products to be controlled. It must also take account of the technical possibilities of evasion at each stage. Once the technical possibilities for evasion and for inspection are defined, the legal and administrative prerequisites for a reliable control system can be stated.

The problem of the workability of an inspection system must be subdivided. What things shall be inspected? What conditions, other than strictly technical ones, must be taken into account in the design of the inspection system? Is it possible to give 100 percent guarantees against evasion of an international agreement? If that is not possible, what then is the meaning of workable inspection? Finally, who shall carry out such an inspection system and what are the requirements of its operation? Each of these questions will be dealt with here.

Broadly, this report formulates critical problems as to the feasibility of inspection for disarmament, and gives an estimate of what is possible. This book is not a detailed statement of the procedures to be used by an international inspectorate. Nor have the writers attempted an exhaustive treatment of all weapons possibilities. In order to make this study both possible and useful, the writers have focused upon weapons and problems whose importance is clearly central.

The emphasis on missiles, for example, and the absence of treatment of conventional planes, should not be taken to mean that the latter are judged as unimportant militarily. Indeed, such "conventional" weapons would certainly fall within the scope of an extensive disarmament effort for reduction of all armaments.

The Scope of Inspection

The design of an inspection system is closely affected by the type of disarmament agreement that is to be implemented. In carrying out this study, it has been assumed that an international agreement for extensive disarmament is urgently desired, and that the agreement is politically feasible, if the signatories can satisfy themselves that it is technically feasible to monitor against evasion. An extensive disarmament agreement is taken to mean one that prohibits the production of all major military materiel. Such an extensive objective has been assumed here for two reasons. First, it involves many of the gravest difficulties, and is therefore a way of testing the capabilities and limitations of inspection under severe conditions. Second, within the broad framework there will be found particular aspects which can become the basis for agreements of more limited scope.

For any disarmament agreement there arises the problem: How can the parties to this agreement be assured that evasion of the agreement is not occurring in any of the participating countries? Toward this end it is assumed that some international organization would be charged with administering the inspection for disarmament and that such an agency would be afforded ample means for employing staffs of the quality and size needed for this work.

The Steps in Disarmament

There is, of course, another major aspect of the disarmament problem: What sequence of steps could be taken to attain full disarmament and the inspection system that is appropriate for that purpose? That problem is essentially one of political policy, for which technical feasibility of each step in the sequence must be considered. The selection and the timing of such a sequence of moves involves political problems of tactics and negotiation that are not within the scope of this report.[2]

The formulation of political plans, however, requires an estimate of technical capability. That technical estimate is the center-point of this study.

The United States as the Inspection Area

The United States, which includes a large population and an intricate array of production facilities and transportation and communication networks, has been selected as the model area for inspection purposes. It is assumed here that all countries entering into an international disarmament agreement would be subject to the same degree and conditions of inspection as the United States. There is another reason for the selection of the United States as the model area. It is reasonable to assume that information about the kind of inspection system that would be feasible for the U.S. would provide the best basis for public discussion among the American people as to the kind of inspection system they would consider proposing to the entire world.

[2] On this phase of the disarmament problem, see the following publications which have appeared since the Second World War:

U.S. Department of State, *The International Control of Atomic Energy* (Washington, D.C., U.S. Govt. Print. Off., 1947); U.S. Department of State, *A Report on the International Control of Atomic Energy* (Washington, D.C., U.S. Govt. Print. Off., March 16, 1946); William T. R. Fox, *The Struggle for Atomic Control* (New York, Public Affairs Committee, 1947); William T. R. Fox, "International Control of Atomic Weapons," in Bernard Brodie, ed., *The Absolute Weapon* (New York, Harcourt, 1946); extensive materials on the political and technical aspects of armament (and disarmament) in the *Bulletin of the Atomic Scientists;* U.S. Senate, Committee on Foreign Relations, Subcommittee on Disarmament, *Hearings on Control and Reduction of Armaments,* convening January 25, 1956 (the same Subcommittee was responsible for a series of studies on aspects of disarmament—see especially the volume *Disarmament and Security, a Collection of Documents, 1919-1955;* the Staff Studies of this Committee include unusually interesting materials on the technical inspection and political aspects of disarmament. In Staff Study No. 1 (p. 7) there is a list of Mr. Stassen's task forces to inquire into various aspects of inspection. No reports of these studies have ever been published. Staff Study No. 3 includes a discussion of the evolving policies of the USSR with respect to inspection and control (pp. 20-21). Staff Study No. 8 includes political estimates of Soviet attitudes toward inspection [pp. 7-9]); Jerome H. Spingarn, *Is Disarmament Possible?* (New York, Public Affairs Pamphlet, 1956); Foreign Economic Administration, Enemy Branch, *A Program for German Economic and Industrial Disarmament* (A Study Submitted to the Subcommittee on War Mobilization of the Committee on Military Affairs, U. S. Senate, April 1946, 79th Congress, 2nd Session, 377 pp., Appendix, pp. 379-660); G. Clark and L. B. Sohn, *World Peace Through World Law* (Cambridge, Harvard Univ. Press, 1958); National Planning Association, *1970 Without Arms Control* (Washington, D.C., 1958); Philip Noel-Baker, *The Arms Race* (London, Atlantic, Stevens, 1958).

Many aspects of an inspection process are bound to be similar among countries. However, differences in style of industrial organization and management can require appropriate adjustment of inspection methods. In the Soviet sphere, for example, there are no autonomous organizations of industrial workers, and there has been rather widespread and long-standing indoctrination in keeping information and activities secret. There are no published data for industry in the USSR that compare with the very detailed information available in the United States from such sources as the U.S. Bureau of the Census and from ordinary trade publications and directories. Inspection systems would also take into account international differences in the product and marketing organization of industry.

Weapons for Inspection

What classes of activity should be covered by an inspection system? The relevant weapons and allied devices are those which could be used for massive destruction and domination of large population areas. Accordingly, police weapons and allied small arms are excluded from this study, for these are no longer the decisive means of military combat among large countries. Heavy weapons of a "conventional" type, like tanks, artillery and vehicles of all kinds, are certainly an integral part of any plan for the conquest of a large population area. Even if such weapons were not utilized for striking a paralyzing blow, they would certainly be vital to a conquering power for carrying out extensive policing operations. Nevertheless, such weapons, in order to be strategically useful among large countries, need to be produced in very large quantities, that is, by the thousands. Owing to the sheer mass of metal which must be moved and processed in order to carry out production of tanks, artillery pieces, trucks, etc., inspection of this class of arms does not offer critical difficulties. Even within the extensive industrial complex of the United States, there are a fairly limited number of plants, for example, capable of mass-producing the large engines that are required for heavy military vehicles. The operations of such plants could be readily supervised and the movement of large tonnages of steel and other key raw materials required for these weapons could be readily monitored. Therefore, this class of conventional weapons, though important, is not regarded as central for the purpose of this study.

Next in importance are surface vessels and submarines. These units, while necessary both for purposes of general transportation and as weapons carriers, are produced under very special conditions that would facilitate any inspection operation. Ships and submarines are very large units which must be assembled at or near a seaboard. Because of their sheer size, and the large number of men required to assemble them, the production of ships and submarines is an operation that does not present great difficulties for control by inspection.

Finally, there is the class of weapons which includes airplanes and missiles. For the foreseeable future, missiles represent by far the most potent class of instruments of large-scale destruction. Moreover, airplane design has been evolving so as to approximate the characteristics of missiles. Accordingly, the production of large-scale missiles has been the central area for this investigation. Indeed, the development of missiles technologies since the beginning of this study—January, 1957—has confirmed the reasonableness of this estimate. Therefore, in this investigation we have attempted to define workability of inspection for disarmament in terms of techniques that have both very general applicability as well as particular relevance to the various aspects of the production of large-scale missiles. The possibilities of biological warfare have also been treated, for such weapons have special qualities of destructiveness and cheapness of production.

Inspection Strength Through Multiple Approach

In this investigation an effort has been made to apply several techniques to the question of control of particular armament activities. Thus, the detection of nuclear explosions can be effected by measuring sound waves carried in the air, seismic waves carried in the earth, visible light from the bomb flash, and radioactivity that is released.

Every type of inspection technique has its limitations. Therefore, for this investigation, emphasis is placed on the use of multiple approaches to a given inspection problem. The logic of this method is that the limitation of one technique is not the same as that of another. As a result, multiple approaches reinforce each other. It must be emphasized, however, that the ability of an inspection agency to follow up suspicious evidence is an essential condition for the success of any method of inspection for disarmament.

Publicly Available Knowledge as the Basis for Investigation

This study of inspection for disarmament has utilized publicly available information only. No attempt has been made to obtain access to any secret or otherwise "classified" information. This has naturally limited the kinds of detailed information that were available for this investigation. For example, the second part of this report includes two papers on critical components of the guidance systems needed for large guided missiles. In preparing these technical papers, none of the writers utilized any of the body of "classified" information which might pertain to the analysis. Nevertheless, the broad characteristics of such equipment are well recorded in the published literature, and many critical characteristics of such equipment can be inferred from the purpose which the equipment must serve. Thus, the difficulty of inspecting the production of airborne computers can be inferred from the fact that such computers perform functions comparable to those performed by the electronic computers widely in use in many offices, factories, and laboratories, and that the types of components needed to build both kinds of equipment are readily available in most well-equipped radio components supply stores. Thus, it would be difficult to tell by inventories of these stores which components were to be used for which purpose.

In the case of the precision gyroscopes and accelerometers needed for missiles, it could be inferred from the published literature that this equipment, in order to be useful in long-range missiles, must be able to operate with extremely high accuracy. The exactness to which the mechanical parts must be machined requires metal-working equipment of hitherto unknown precision for quantity production. The special metal-working equipment can be produced in only a limited number of factories and must be utilized under very special conditions. In this case, the writers, through a diagnosis of such conditions, could point to a number of critical, strategic areas for effective inspection, even though they could not themselves examine the equipment in question.

In the opinion of this writer, lack of access to classified information and total reliance on publicly available information has probably given the analysis a conservative bias. In other words, more access and more knowledge might have revealed more strategic control points for inspection. There is also a possibility that access to all existing information might disclose technological alternatives which by-pass points that are now designated as useful for inspection. Since complex weapons systems depend upon an integrated production of many distinctive components, evasion, to be successful, would have to occur at many points simultaneously, while inspection, to be reliable, need operate at few of these points only.

This study defines possibilities and problems of inspection for disarmament. It indicates certain leading characteristics and problems of such a process. The detailed design of an inspection system would probably be consistent with the results indicated here, but would also be based upon more extensive analysis of the relevant technologies than was needed for this study of the feasibility of inspection for disarmament.

Inspecting a Changing Technology

Rapid enlargement of possibilities has become a characteristic feature of all technologies, military technology included. Therefore, an inspection system that is designed with an eye to the weapons of the present will not necessarily be appropriate a few years later. At this writing it is clear, for example, that there are alternative types of missiles, and alternative types of engines and fuels, all of which could be used to propel destructive missiles over long distances and at high velocities. Indeed, the fact that there are alternative available methods for achieving given effects is one of the general features of industrial technologies that are built on extensive scientific bases.

Clearly, then, the evaluation of the feasibility of inspection set forth here is not intended to be serviceable at all times and under all conditions. Rather, the design of an effective inspection system would have to be constantly revised in accordance with the growing body of basic scientific knowledge and its possible application to military technologies.

Objectives of an Inspection System

What is the critical act of evasion which an inspection system at this stage of military technology should be designed to prevent?

It is estimated that between 200 and 400[3] large missiles could be used to devastate effectively any one of the larger land areas of the earth. In this usage, "to devastate" means to destroy some or all major population centers as well as critical industrial facilities. The dimen-

[3] It is assumed here that only about half the missiles launched could actually reach their target areas, owing to missile failure and possible interception.

sions of this objective are indicated by the following data.

The unit production cost for an intercontinental ballistic missile in the United States amounts to about $2,000,000 under conditions of quantity output. This estimate excludes the cost of research and development, capital investment, and the warhead. The smaller, intermediate range missiles are estimated to cost about $1,000,000 each.[4] One may estimate the average cost of a man-hour of labor for this production, including the overhead costs charged to such labor, as amounting to about $5.00 an hour. In these terms an intercontinental missile requires about 400,000 man-hours of labor for its production—directly, and indirectly in the form of labor that is included in the costs of raw materials, components, power, and the like. On this basis we may say that if one man-year includes 2,000 hours, the production of 200 to 400 large missiles would require between 40,000 and 80,000 man-years. Other information indicates that ballistic missiles of the intermediate and intercontinental range include 20,000 to 30,000 parts which are handled in 6,000 to 10,000 subassemblies.[5] Even allowing for considerable error in these estimates, it is evident that the production of these missiles in the indicated quantities is an industrial task of large magnitude.

These estimates indicate the order of magnitude of the effort that would be required to evade an international disarmament agreement which explicitly forbade the further production of large missiles for military purposes.

Under what conditions could such an evasion attempt occur? Let it be assumed that the major governments of the earth join in a disarmament agreement which includes an inspection system. It is assumed, for the purpose of this investigation, that within one country, a group of men, including some highly placed military personnel, develop the opinion that the politicians who concluded such an agreement were in fact leading the country along a dangerous path by opening it to treacherous attack from an enemy. A group so minded, or interested in preparing a deadly blow against another power, decides that, despite the agreement, it must attempt the production and emplacement of the indicated number of missiles. Such a group would then proceed to organize the clandestine production of components of a given missile design, perhaps with the private approval of government officials, and would organize the effort to assemble and emplace such missiles. Another

[4] *American Machinist,* December 30, 1957, p. 59.
[5] *American Machinist,* February 24, 1958, p. 87.

possibility would be a direct effort by a government to evade an inspection system.

Such an effort, in order to be strategically meaningful, would have to be carried out within the space of about two years. The required production effort would probably require not less than two years, and the calculation of danger, which underlies such an effort, would require a minimum of delay in attaining the secret armaments objective. There is also the possibility, of course, that an attempt might be made to accomplish this objective from an already existing stockpile of missiles, part of which could be secured from public view before an international inspection scheme went into effect. This question will be discussed below, in the section on Inventory Validation.

Finally, it should be noted that there are other types of weapons which could have deadly effect over a large area, and which do not require the massive industrial effort that is necessary in the case of the large missile. Special attention must be given, in this connection, to the possibilities of biological warfare methods. Accordingly, critical aspects of these methods are dealt with in one of the technical memoranda included in this report.

An inspection system would have to be able to cope with efforts to produce weapons in clandestine ways, and also with the problem of hidden inventories of arms produced before the inspection system was begun.

The maximum objective of an inspection scheme is to make any secret effort to evade disarmament agreements so extraordinarily difficult as to be virtually impossible.

Method of Investigation

The enormous range of knowledge that must be taken into account in exploring the problem of feasibility of inspection requires the cooperation of specialists in a wide range of fields. Such cooperation was obtained for this investigation and the resulting group of technical papers, dealing with critical aspects of the inspection problem, is presented following this report. The range of subject matter comprehended here, however broad in scope, should not be understood to define the boundaries of knowledge that are, in fact, involved. Rather, the subjects covered by these technical papers are representative. These fields of knowledge are not only critical in themselves, but also an important sample of the knowledge and technique that would have to be reviewed and utilized.

In addition, two memoranda prepared for this report deal with the art of the clandestine organization of production, which includes training personnel for the use of weapons, and the transportation and storage of weapons. This report emphasizes the problems of inspection of missiles and their components. It is likely, however, as pointed out above, that the problems of inspection for production of masses of "conventional" heavy weapons would be less intricate. Therefore, if there is a bias here owing to the emphasis on missiles, it is probably in the direction of the more difficult parts of the total area of arms inspection.

The reader should not infer, however, that the writer is thereby implying that any of these methods is sufficiently effective, separately, for coping with the inspection problem.

Evasion Teams

In order to test the effectiveness (and the weaknesses) of the proposed inspection methods, three Evasion Teams were organized. These teams were charged with devising schemes for evading an inspection system. Their imaginative reports are also given in this book.

GENERAL INSPECTION METHODS

Six general methods of inspection are evaluated in this report. They are general because the techniques are not specific to any particular class of weapon. These methods include aerial inspection, inspection of governmental budgets, detection of bomb testing, detection of missile testing, radiation inspection, and checking on scientific personnel. Another method, inspection by the people, is discussed below.[6]

Aerial Inspection

In his paper on "Capabilities and Limitations of Aerial Inspection," Mr. Walter J. Levison has dealt particularly with the capability

[6] Inspection of military plans, records, and the like is not included in this analysis, which has been focused on problems of controlling production—wherever possible by methods that do not depend on records and statements of groups like the military. It is difficult to conceive of a serious evasion effort which does not involve the collaboration (willing or unwilling) of the professional military men.

of aerial inspection for detecting large military forces, especially those of a conventional character. Thus, he indicates that "ground details as small as one foot in dimension may be analyzed, or huge urban areas, industrial installations, and transportation systems may be encompassed on one photograph." He further indicates that, notwithstanding the limitations of present-day aerial reconnaissance methods, their capabilities for detecting massive industrial installations and large concentrations of troops are substantial.

For the present purpose primary attention must be given, however, to the relation of aerial reconnaissance methods to inspection for preparation of intercontinental ballistic missiles. Mr. Levison's analysis gives particular attention to the very great difficulty of detecting such missiles once they have been produced and placed in position, possibly in camouflaged sites. He indicates that "the task of identifying underground launching sites may be compared to the task of discerning manhole covers from 50,000 feet in the air." And finally, "whereas aerial inspection would serve an important function today, while weapons' delivery systems still consist of conventional aircraft, it will be of almost no value once the intercontinental ballistic missile becomes a part of the military arsenal." Thus, while the capabilities of aerial reconnaissance for locating large military installations, industrial plants, and transportation systems are indeed extensive, the best methods of aerial reconnaissance could hardly cope with camouflaged missile emplacements already in existence. Nor could such methods locate missiles that are in position aboard submarines, merchant vessels, or space satellites. Therefore, it is reasonable to infer that the usefulness of aerial reconnaissance with respect to missiles extends mainly to indicating where they are being produced, but not to detecting their presence once they have been produced and artfully concealed.

Government Budgets

Professor Burkhead's analysis of the feasibility of monitoring budgeting activities and auditing expenditures in government accounts indicates that this mode of inspection possesses major built-in weaknesses. Existing practice permits some types of appropriations to be expended at the discretion of administrators. In other circumstances budgeted funds may be transferred among accounts, and the outlays for certain activities may be concealed by distribution, in whole or in part, of the amounts in budget accounts bearing unrelated titles. In the federal budget of the United States, Professor Burkhead estimates that the particular allocation of amounts up to $100,000,000 is and can be readily concealed from view by such means. Larger amounts could also be concealed, although with increasing difficulty. It is important to note that such possibilities for concealment characterize the relatively open and published budget of the United States government. Such possibilities could very well be multiplied in the case of governmental budgets operating where there are multiple security restrictions over the entire budgeting system.

The estimated direct cost of manufacturing 200 to 400 large ballistic missiles, amounting to $400 to $800 million over a two-year period, is an item which could be feasibly concealed within a governmental budget system comparable to that of the United Nations.

However, this is not the only conclusion to be drawn from a study of military budget accounting as a means of inspection. In 1933, the League of Nations published a most elaborate technical report in two volumes on the possibilities for monitoring armaments budgets. This subject was examined intensively by a distinguished international group which drew upon technical talent in many countries. The group reported that, with the use of specified methods, substantial control over military outlays could be established. The recommended methods included: a Model Statement of accounts to standardize accounting in all countries; reconciliation between the Model Statement and prevailing budget categories; necessary methods of supervision and control.[7]

The proposed methods of accounting were tested in terms of the military budgets of various countries. The Commission recommended the system as a workable device for monitoring the actual, in relation to agreed, military budgets.

Bomb Testing

The development of an expanding variety of weapons delivery systems utilizing nuclear explosives has required extensive programs of bomb testing. The problem of Professor Orear's paper is: With the application of present methods for monitoring nuclear explosions. are

[7] League of Nations, Conference for the Reduction and Limitation of Armaments, National Defense Expenditure Commission, *Report of the Technical Committee* (Geneva: League of Nations, Disarmament, 1933. IX. 3, Vols. I, II.)

secret bomb tests possible? The answer to this question is clearly in the negative, provided that monitoring stations are within 300 miles of the blasts, and the bombs appreciably larger than the "blockbusters" of the Second World War. Available techniques for monitoring the atmosphere can account for explosions which discharge large quantities of radioactive waste into the air. Acoustic wave detection is best for atmospheric explosions. Also, the light flash can be seen for several hundred miles. Underwater explosions produce radioactive discharge or seismic disturbances of measurable proportions.

There remains the problem posed by attempts to blanket underground nuclear explosions by setting off test explosions of this kind so that they coincide with natural earthquakes. The state of the art of seismic measurement, however, has become capable of differentiating between natural and man-created phenomena of this type, again assuming a network of 300-mile stations. Therefore, reports Professor Orear, a relatively modest network of monitoring stations could readily carry out continuous and even automatic monitoring for nuclear blasts within the largest land areas of the earth. These stations could be unmanned and automatically operated, if necessary. The maps appended to Professor Orear's paper are suggestive in this respect.

The workability of inspection in this sphere is significant not only in its own right, but also as a possible area of initial agreement for disarmament among the major governments.

Scientific Personnel

The employment of large numbers of engineers and scientists is one of the characteristic features of both the development and production of modern weapons. This fact can be utilized for inspection purposes in several ways. The presence of people in certain occupations can be a signal to check further on a given locality, industrial plant, or laboratory. Registers of technical personnel and alumni lists of technical schools can be sampled in order to discover what are the activities of people in certain crucial occupations.

RADIATION INSPECTION

The various types of industrial plants which can produce fissionable materials for atomic warheads also produce radiation that is dangerous for public health. As a result, there has already been a substantial development of techniques and organizations for monitoring radiation in countries which operate plants or processes that involve atomic fission.

These facts are of special interest here, for detailed inspection for public health purposes of the amount of radiation produced, and of its effect on people in nearby contact, necessarily includes inspection of the major plants that would be inspected for disarmament purposes. That presents an opportunity for implementing inspection for disarmament, in some measure, through the activity of already-operating organizations in various countries.

Professor Penrose has outlined the need for control of sources of radiation as a public health measure. Such steps have already been extensively considered in several countries.[8] Available methods for monitoring the exposure of individuals who are subject to special risk are apparently capable of coping with the problem of measuring exposure in order to limit the hazards of overexposure. An effort to control exposure to radiation would involve registration, together with some sort of periodic inspection, of hospitals, industrial plants, research laboratories, and military establishments where X rays or radioactive materials are regularly used. Professor Penrose points out that the basis for this and similar recommendations is that from a strictly medical point of view any unnecessary exposure to radiation of individuals or of the population as a whole is to be deprecated.

Radiation Inspection and Clandestine Manufacture of Fissionable Materials

The latter part of Professor Penrose's paper calls attention to the possible use of medical knowledge as an aid in the detection of clandestine manufacture of fissionable atomic materials. Two classes of data may be utilized here: the known damaging effects from radiation exposure, and the evidence that protective devices against radiation have been or are being used.

Short-term effects of heavy radiation exposure involve the occurrence of drastic symptoms that are readily recognizable. Hospitals and medical men generally could be on the alert for such symptoms. Long-term physiological effects are less useful here, since they may not be

[8] See the report of the Atomic Energy Commission: *Radiation Safety and Major Activities in the Atomic Energy Programs* (Washington, D.C.: U.S. Govt. Print. Off., January, 1957).

observed until years after exposure. Professor Penrose indicates various marked, short-run symptoms of radiation overdose which may be monitored by hospitals as indicators of radiation exposure.

The development of industrial, military, and medical applications of radioactive materials has led to the extensive development and utilization of techniques for the control of radiation exposure. For the purposes of inspection for disarmament, knowledge of such techniques, and information as to how they have been utilized, serves to indicate the location of such operations. Relevant types of indicators of such activities include: utilization of special clothing and protective devices, the regular wearing and inspection of film badges by the workers, the use of pocket monitoring instruments and, finally, regular blood counts at about quarterly intervals for the working personnel. The usefulness of this mode of inspection is limited, however, by the fact that such devices are also used rather widely in medical, biological, and physical research laboratories. Medical care can be given without public knowledge, especially if an evasion effort is shielded from an inspectorate by wide public support, or is operated by a technically diversified, disciplined organization of a military or quasi-military type, or both. (See the papers by Rivlin and Gumbel.)

The weight of evidence favors the operation of extensive inspection of radiation sources, from a public health standpoint. This consideration is important for implementing possible international agreements on inspection for disarmament. Inspection both for public health purposes and for disarmament would need to include close monitoring of all the facilities that could be sources of explosive fissionable materials.

GUIDED MISSILES

Guided missiles and kindred types of piloted craft have become, and in the foreseeable future will continue to be, a primary form of delivery system for weapons of mass destruction. Accordingly, considerable attention has been given in this study to the various aspects of guided missiles. In each case the question asked is a similar one: What is the feasibility of imposing an inspection system on the production of each of these components? In detail, this question must be translated: What are the possible strategic points, in the form of materials or processes, manpower, or the like, which could be seized upon for inspection control? Primary attention has been given to the larger missiles of the intercontinental ballistic type. The subjects considered here include: production of fissionable materials for warheads, guidance systems, air frames, power plants, and fuels.

Production of Materials for Atomic Warheads

From the vantage point of broad experience in chemical engineering, Professor James H. Boyd has assessed the feasibility of preventing the theft, for clandestine production purposes, of fissionable materials from the relevant processing plants or reactors. The evidence at hand indicates that it is possible to establish tight material controls over the relevant plants and operations.

Professor Boyd also indicates that fissionable materials, usable in atomic warheads, could conceivably be stolen from major processing plants which produce such materials, or from uranium- or thorium-fueled power reactors. Human failure could be the main weakness in the relevant control systems. In the chemical plants which process uranium for explosive use, it is possible to measure process input and output within an error of a few percent.[9] Also, the chemical processing requires large amounts of conventional chemicals. Chemical separation of uranium 235 requires elaborate plants the cost of which is about $1 billion.

The reworking of reactor fuel elements, however, presents a critical inspection point. Periodically, it is necessary to withdraw fuel elements and reprocess the metal in order to eliminate fission products which "poison" the productive fission reactions. Professor Boyd underscores the fact that "the theft of plutonium or uranium 233 after radioactive waste separation appears the most vulnerable point in a nuclear power operation. This is the critical inspection point." It should be noted, however, that limitations on accountability of inputs and outputs in the relevant processing operations do not necessarily mean ease of evasion. Thus, expert opinion indicates that the difficulties in the separation of plutonium from used reactor elements leads to small percentages of

[9] To be sure, the political significance of any given percentage is a function of the state of disarmament within which this occurs. Also, it is entirely conceivable that access to the full technological information on the relevant processes would permit far greater precision of control than is indicated by the data available to the writers of this study.

loss at various points in the processing. These same difficulties, however, also restrict any attempt to salvage such "lost" materials for secret arms use.

The problem of control over warhead materials affords an interesting example of the complications produced by advances in science and technology. Competent opinion holds that the newly developed methods for possible control of fusion processes for power generation would also produce quantities of plutonium, a material which can be used for nuclear explosions. The fusion process may also involve relatively modest capital outlays as compared with the enormous plants constructed in the United States, England, and Russia for plutonium production. As a result, the possibility of producing plutonium could come within the reach of a large number of countries. This is a good example of why any system of inspection for disarmament needs to remain flexible in the choice of critical control points.

Electronic Guidance Systems

A central point of the paper by Professor John Walsh is that electronic elements of missile guidance systems can be produced from components which may be purchased in the well-equipped radio components shops in American cities. This estimate of the matter does not exclude the possibility that certain components of missiles may indeed be of a special type, and therefore useful as inspection control points. If that is the case, however, it is not publicly known. Moreover, the available knowledge does indicate the feasibility of alternative types of guidance systems. That fact multiplies the inspection problem. The difficulties involved here are suggested by the attempt to answer the question: Would it be possible to recognize the manufacture of computers for air-borne use within a plant which manufactures computers for general industrial and scientific purposes? Recent trends in computer design have emphasized extensive utilization of transistors, standardized subassemblies, and compact construction of entire units. The effect of these design features is to render the computers built for non-air-borne purposes more like the air-borne types in these respects than hitherto. These developments, however, do not exclude the possibility that full access to the relevant knowledge would indeed enable an inspection team to differentiate the air-borne type of computer from others at certain critical points in their assembly. Such data, however, are not available to this study. Accordingly, this writer prefers to proceed on the conservative assumption based on available knowledge, which is that the electronic elements of large guided missile systems do not offer readily recognizable critical elements for inspection purposes.

Precision Gyroscopes and Accelerometers

In order to control the flight path of a missile, the guidance system must be given constant information about the position and direction of the missile in relation to the earth. This information is given to the guidance system by precision gyroscopes and accelerometers which inform the guidance computer about "which way is up" and about variation in direction. In order to carry out these functions for a long-range guided missile, the gyroscopes and accelerometers must be built to accuracies hitherto unattainable for quantity-produced machines. Professor Eugene Avallone has examined crucial elements of the production of these instruments. He finds that in order to produce and test these units certain components must be produced to accuracies of millionths of an inch. Such precision requirements have been reported in the literature. They may also be inferred from estimates of the tolerable error in the guidance equipment, in terms of the effect of such error on the accuracy of the missile.

Professor Avallone finds that the production of high-precision gears and bearings, for example, requires metal-working equipment of hitherto unknown precision. Such equipment is found in rather few plants and it must be utilized under very special conditions; for example, critical machines must be placed on seismic mounts so as to isolate them from surrounding vibrations. Moreover, the components produced by such machines must be handled meticulously in dust-free atmospheres, and must be assembled and tested by means of machines that are specially constructed for these purposes.

Altogether, the unusual precision requirements of missile guidance equipment make necessary a series of production elements, including special metal-working equipment, special testing machines, special plant conditions, and specially skilled and trained work forces—all of which are unique to the production of this class of equipment. These characteristics are the more striking since gyroscopes, for instance, are produced for other types of guidance systems as well—for example, in the "automatic pilot" equipment that is widely used in commercial airplanes. A substantial number of plants which can produce this latter class of equipment exists, in contrast to the limited number of facilities capable of producing the unusually precise units needed for missile guidance purposes.

While the production of precision gyroscopes and accelerometers appears to offer several useful strategic points for disarmament inspection, it is possible that these units could in due course become conventional equipment—even for general aircraft use, for example, if much more precise guidance of commercial aircraft were called for.

Air Frames

Large guided missiles, as well as high-performance piloted aircraft, require air frames which have unique characteristics of strength, heat resistance, and ability to withstand vibration. In his paper, Professor Bruno Boley indicates that in order to produce air frames with the requisite characteristics, high-temperature alloys with high strength-to-weight ratio must be utilized. The production of these alloys requires the use of materials, some of which have been in short supply, such as titanium, niobium, vanadium, zirconium, rhenium, beryllium, and tantalum. Furthermore, the production of the requisite shapes for air frames has raised special problems of shaping large sections of alloyed metals to precise dimensions. While the methods employed in this shaping process are frequently special, it is a fact that, hitherto, once such methods have been introduced in the air frame production plants, they are frequently instituted rapidly in a wide range of other industries which can utilize such techniques.

The air frames for long-range ballistic missiles require designs which utilize such techniques.

These air frames require distinctive designs. These include accommodation to structural problems of kinetic heating, of atmospheric exit and re-entry, and of vibration and stability. The designs of ballistic missiles, which are made in an effort to meet these requirements, are themselves thereby earmarked as appropriate elements for inspection purposes. Moreover, structural design for ballistic missiles has typically focused on minimum requirements for satisfying conditions of a single use. Therefore, Professor Boley points out, inspection of the structural analysis pertaining to an airplane or a missile should reveal such design considerations. In his opinion, no single item in air frame production would be sufficient as a single critical element to reveal easily an attempt at illicit manufacture. Nevertheless, in his estimate, attention to the details cited above, in combination, yields useful information for the detection of possible clandestine production.

Propulsion Systems

The availability of alternative propulsion systems is a leading characteristic of the power plants for high-performance aircraft or large missiles. Professor Henry Burlage, Jr., indicates that the development of such power plants would probably afford important strategic areas for inspection purposes. However, if an effort at clandestine production were to involve utilization of an already proved design, this area of inspection could not be relied upon as useful. In the case of the turbojet engine, for example, many of the components are traditionally supplied by subcontractors, while the prime contractors carry out what is mainly an assembly and test function. In the case of the ram-jet propulsion systems, the manufacture of components does not appear to offer clearly defined points for inspection since many of the parts involved are essentially non-precision in character.

Liquid fueled rocket engines offer a number of possibly appropriate inspection points. These include special pumps and turbines for the propulsion system (implying light weight), capable of handling extremely low temperature and/or highly corrosive materials; special valves, able to withstand similar conditions; special heat resistant materials like ceramic oxides, graphite, cermets, processes involving coatings of chromium-nickel, and other combinations of heat-resistant alloy materials; special types of equipment, including light-weight, high-capacity refrigeration units, and the like.

The solid-propellant rocket has been extensively developed for military purposes. Professor Burlage indicates that this engine seems to be a difficult one over which to exercise inspection, owing to the essential simplicity of the unit and the possibility that the components might be manufactured by a considerable number of firms.

Professor Burlage also indicates that certain classes of indirect specialty items and processes involved in the manufacture of propulsion systems might be useful inspection points—the apparatus and methods used to produce extremely small holes of great uniformity. He estimates, however, that such techniques might be utilized in industries far removed from the manufacture of air-borne propulsion systems.

Altogether, in the opinion of Professor Burlage, the true strategic type of inspection point is difficult if not impossible to establish in the propulsion systems industry. Instead, a variety of possible inspection points is suggested, and stress is laid on the importance of each being open to review on the basis of developing technological alternatives.

Fuels

In his paper reviewing long-range missile propellants, Professor Charles J. Marsel explains why, in the main, fuels do not offer likely areas for disarmament inspection. Liquid fuels, as well as many solid fuels for rocket purposes, have been produced primarily from materials that are available in great abundance and are utilized as common articles of commerce—such as combinations of liquid oxygen-gasoline, liquid oxygen-alcohol, and concentrated nitric acid-gasoline. Similar considerations apply to the solid fuels, which can be produced from common chemicals like glycerine and nitro-cellulose. Since such materials and others used in association with them in solid fuel propellants are common chemicals of commerce, it would be extremely difficult, in Professor Marsel's opinion, to detect their diversion into possible clandestine missile applications.

Finally, there is the class of so-called "exotic" ultra high energy-to-weight fuels which require the utilization of chemicals such as dimethyl-hydrazine and the high-energy class of boranes. Such materials have been utilized uniquely as high-energy fuels. Accordingly, this class of materials constitutes possible inspection points for monitoring purposes.

Detection of High-Altitude Missile Tests

At this writing, long-range missiles are being intensively developed in several countries. One of the possible aspects of international disarmament agreements is a prohibition of the development of missiles for military purposes. For this purpose it would be useful to have highly reliable methods for detecting missile tests, which form a critical aspect of their development and production.

The paper by Dr. D. G. Brennan sets forth the basis for a rather reliable system for detecting tests of long-range, high-altitude missiles. Radar instruments of moderate requirements at a network of stations could monitor such launchings on a world-wide basis. Indeed, the spacing requirements between such stations are such that this equipment could probably be combined with the instruments for bomb-test detection that are recommended by Professor Orear. If Orear's stations were used as a base line to be supplemented for the purpose of detecting missile tests, the result would be a radar network more closely spaced than would be necessary according to Dr. Brennan's estimates. By these methods it would be virtually impossible to carry out secret launchings of long-range, rocket-launched missiles, or of space vehicles. The same radar network would supplement the bomb-testing detection methods indicated by Professor Orear, by detecting the vehicles used for mounting bomb tests at high altitudes.

Finally, it is significant that the proposed equipment for detecting missiles could also be made to serve the needs of world-wide monitoring of aircraft for the purpose of air traffic control.

From the viewpoint of capability of inspection, the components of large guided missiles clearly offer a variety of possibilities. The reader's attention will now be turned to another class of weapons—those involved in biological warfare.

BIOLOGICAL WARFARE

While public attention has been focused primarily on the destructive power of long-range guided missiles, sustained research and development has been carried out on another class of weapons whose destructive power may very well be as extensive as that of nuclear explosives. The public record on biological warfare reveals that the major countries of the earth have operated, during the last decades, substantial secret laboratories for the development and testing of biological warfare methods, including the development of chemical, bacterial, and viral agents for attacking human beings directly, or for affecting human life indirectly through attacking plants or animals.

Professor Vincent Groupé points out that the research and development phase of biological warfare involves the utilization of methods, equipment, and personnel altogether similar to those utilized for medical and basic biological researches. Because of this, it is difficult to identify laboratories working on biological warfare methods on the basis of such gross indicators as the main equipment being used.

Other aspects of biological warfare technique offer different possibilities. Thus, the large-scale production of virulent organisms would require equipment and operating techniques whose features could not be inferred from the experience of small-scale laboratory bench experiments. Special equipment, facilities, and techniques are needed for safe handling of masses of virulent material. Further, the handling of virulent material also involves problems of disposal of such material as waste. This would call for special, large-scale, incinerator units and other sterilization equipment whose construction, presence, and operation also constitute a relevant inspection point.

Dr. Groupé also indicates that extensive tests under field conditions are needed to test biological weapons for destructive effect. Large operations are involved and extensive measures would have to be taken to prevent the spread of pathogenic organisms outside of proving grounds. Therefore, it may be inferred that the existence of large, specially guarded areas, and extraordinary precautions for the exclusion of outside persons constitute appropriate inspection points.

Unfortunately, analysis of a sampling of the working materials of a biological laboratory, to detect whether or not it was engaged in biological warfare research, could easily result in a false conclusion. Thus, negative test results would normally be taken to indicate the absence of a given bacterium, virus, or fungus and would "clear" a particular laboratory. But highly virulent pathogens are almost invariably cultivated on culture medium specifically developed for that particular substrain, and the lack of knowledge of that medium would result in failure to detect that pathogen.

The available knowledge certainly does not exclude the possibility that some biological warfare weapons could be developed, even in a small country with relatively limited laboratory and manufacturing facilities, to serve as a "poor man's atom bomb."[10]

The weapons of biological warfare, in the opinion of this writer, should be given continuing and close attention from a disarmament standpoint. The capabilities of biological weapons have been underplayed as against the more spectacular aspects of nuclear weapons and long-range missiles.

[10] Some of the men who have been engaged in biological warfare research have attempted to sound an alarm to the general public concerning the potency of such weapons. Dr. Theodor Rosebury, in his volume *Peace or Pestilence* (New York: McGraw-Hill, 1949), has estimated the destructive potentialities of biological warfare weapons. Rosebury has drawn extensively on the published literature in this field.

METHODS OF CLANDESTINE PRODUCTION

An important aspect of the feasibility of inspection for disarmament is an assessment of the possibility and efficiency of clandestine industrial production methods. Accordingly, an effort was made to discover the characteristics of successful clandestine weapons production. Two papers were prepared to record such experience. One deals with the experience of Germany under the Weimar Republic. The second paper is based primarily on the experience of the Jewish underground army during British rule in Palestine.

The papers prepared by Professor Gumbel and Lieutenant Colonel Rivlin both reflect the critical conditions for the successful operation of clandestine industrial production of weapons. These conditions may be summarized as follows:

A. A group of men exists which is prepared to carry out the clandestine production even at the cost of considerable personal sacrifice and risk. These men have strong allegiance to a guiding ideal.

B. The central working group is backed by a substantial part of a population, including a government or quasi-government, which backs up the operating groups and shields them from the inspecting authorities.

C. The operators of the clandestine production system learn how to simulate appearances that will seem to be ordinary and innocent in the eyes of the inspectors.

In the case of Palestine, a population under alien rule backed a secret army and its armament system. These operated with a high degree of success despite determined efforts, especially after the Second World War, to stop illegal arms production. The Palestine record is made significant for the present study owing to the fact that the inspectorate—in this case the British army, police, and Civil Service—represent a highly experienced, intelligent, resourceful and well-equipped inspecting body. Its members were able to carry out systematic and extensive inspection on roads, at airports, and at seaports. They were also able to carry out house-to-house searches under curfew conditions.

The arms produced included small arms, as well as small automatic weapons, and grenades. The largest weapons produced locally were three-inch mortars, as well as mortar shells. Illegal transportation into the country included heavier weapons.

An intelligent, skilled inspectorate did not discover more than one percent of the illegal arms produced in that small country or imported from abroad. Moreover, this inspectorate, operating in a relatively small land area, was unable to stop shipments of arms, first small- and then large-scale (truckloads), within the country. The inspectorate was unable to stop the operation of a fairly extensive network of workshops, whose staffs ranged from a handful to over a hundred workers, which kept a constant flow of small arms moving to the illegal army.[11]

A network of factories, storage areas, and transport systems, labor supply, internal security, and financial control, as well as modest research efforts for the design of weapons, were all organized on an underground basis. Headquarters were operated in camouflaged premises, whose appearance was that of ordinary business offices.

An on-the-spot check by this writer yielded an abundance of testimony from former operators of the clandestine production system. Over a period of about twenty years an elaborate body of technique was developed to handle problems ranging all the way from organization methods to ways of camouflaging truckload shipments of weapons.

Training in the use of weapons, communications, and transportation among arms plants and military units were all artfully organized. Underlying the success of ingenious devices for simulation, there was the strong popular backing for the clandestine army and its arms production. The strength of public support for the illegal army is contained in the following datum:

While it is not excluded that there were some agents of the inspecting government inside the clandestine organization (Hagana), this writer was advised that no proven case of such an agent was known to the leaders of the underground.

As a result of strong public backing for the clandestine army, the inspectorate was confronted with a virtually impenetrable social solidarity against which devices of technical inspection were of little avail.

In Weimar Germany the operators of the illegal armament system were surrounded by a population that was itself partly hostile to their

[11] It may be noted that the task of the British was somewhat different from the objective of an international inspectorate. The British were trying to locate a production system, whose existence was at least suspected. That knowledge, however, was not necessarily sufficient to prove a case. Presumably, an international inspectorate would have to gather enough information to prove or disprove violation. From an international political viewpoint, of course, suspicion could be important in its own right.

endeavor. In addition, they had to cope with the inspection efforts of varying intensity that were exerted by the commissions of the Allied military powers.

Notwithstanding the substantial differences in locale and surrounding conditions, the data available to this writer indicate that the three major conditions for the successful operation of clandestine industrial production were operative in Weimar Germany. An inner core of men was moved by nationalist fervor to carry out the operation of illegal rearmament. These inner groups were backed by at least a substantial portion of the general population, and any assistance that was given to the inspectorate of the Allied military powers was popularly viewed as an act of betrayal. Finally, apart from the extensive armament production carried out in Russia and elsewhere on Germany's behalf, there were fairly extensive efforts for the production of armaments in Germany by clandestine means. This involved the use of varied devices of concealment, including partly camouflaged "open" factories in which arms production comprised but a part of the work. There were also underground units, physically concealed from the view of possible inspectors. Moreover, ingenious devices were developed for storing arms that were illegally produced. These included underground inventories and storage of arms components in hollow walls of buildings, as well as storage of arms in "floating inventories." A "floating inventory" consisted of a packaged unit of weapons that was kept in motion through the freight system from one shipping point to another. Thereby the freight transportation system became a mobile "warehouse" for clandestine military materials.[12]

Industrial Secrecy and Clandestine Production

There is another mode of clandestine production, so commonplace and ordinary that it is never designated as such. That is the practice of organizing production so that the people working, for example, on parts of a machine or process do not know the nature of the product—the whole machine, or the end-product—of a production process. Such practices are widely known in ordinary industrial and commercial activities.

The prevailing acceptability of such practices could be utilized

[12] It has been suggested that "floating factories" are also conceivable. Commercial-type vessels might carry ordinary cargo, as well as a working industrial plant, or a secret arms inventory.

by the operators of a possible clandestine production organization for armaments. Indeed, the famous Manhattan Project of the Second World War, which secretly organized atom bomb production in the United States, involved extensive application of this technique. Broadly then, the prevalence of security systems in ordinary production (a kind of normal "underground") offers an opportunity for possible application to efforts to evade an inspection system.[13]

The Critical Role of Government

In the case of Weimar Germany and the Jewish community under the British mandate, the illegal arms production was directed and shielded in each case by a governmental body. In the case of Germany, as Professor Gumbel points out, the government of the country organized the clandestine operation under its auspices. In the case of the Jews in Palestine (under the British mandate), the governmental body consisted of the "shadow government" to which the Jewish population gave strong allegiance. This "shadow government," whose legal instrumentality was in the Jewish Agency for Palestine, included the directorate of the illegal Jewish army.

In the judgment of Professor Gumbel, complicity of a government or of part of a government is a necessary condition for the operation of extensive illegal arms production. The facts of the case in Weimar Germany and Palestine bear out his contention.

Certain characteristics of the armed forces of a country are also important factors. Thus, the possibility of evasion is facilitated by a national tradition which makes the military a large, autonomous community of weapons producers or weapons possessors. The existence of such a "state within a state" would be a threat to a system of disarmament at the very outset.

The efficiency of the techniques of clandestine industrial production is critically important for assessing the feasibility of inspection for disarmament. The largest part of the public discussion concerning inspection for disarmament has focused on various aspects of physical inspection, including inspection of transportation facilities, inspection of military installations, and the like. Given the necessary conditions

[13] This indicates the importance of the requirement by the inspection agency that all participating governments submit a list of locations and facilities in which there is activity which, whatever the reason, is regarded as confidential to the government.

cited above, it should be possible to evade, with substantial success, monitoring systems over production whose control points are the products, raw materials, production equipment, work-in-process, and the like—while not relying on securing information from the people doing the work. (Note, however, the important cases of inspection feasibility for nuclear bomb testing and for high-altitude missiles testing.) The implications of this conclusion will be developed in the sections, "Strengths and Weaknesses of Inspection Methods" and " 'Inspection by the People.' "

INVENTORY VALIDATION

Secret stores of arms, set up before extensive inspection is begun, are a possible device for evasion of a disarmament agreement.

An international inspectorate might ask each of the governments which have signed an inspection agreement to declare their holdings and the locations of certain critical military items as of the first day of an inspection scheme. Let it be assumed that such declarations are duly submitted to the inspectorate. One of the most difficult problems confronting an international inspectorate would be that of verifying the correctness of the declared statements. Here the key problem is: Are there additional quantities of the indicated materials available elsewhere? Could these quantities be large enough to make a significant difference with respect to the military prowess of the country in question?

This type of problem might be expressed in terms of certain missile components. Then the question could become: Is the declared inventory of atomic warheads accurate? Is it possible that additional atomic warheads, beyond those formally declared, have been secreted in concealed stockpiles in order to provide destructive power for a potential clandestine missile striking force? Similar questions could be formulated for other missile components.

A brief discussion of various approaches to this type of problem will indicate its characteristics, and the difficulties that are involved.

If the relevant classes of military hardware include costly items, then it may be assumed that, in the normal course of events, detailed records have been kept to account for their production, receipt, and transfer. Moreover, such military material is normally serial-numbered.

An example of the requirements of military routines may be found by examining the relevant regulations of the United States Army covering property accountability.[14] If large military organizations operate rather similarly in these respects, then one would expect to find regularly operated detailed procedures to provide accountability for costly military equipment.

Nevertheless, the existence of such regular procedures does not exclude the possibility of attempts at wholesale double bookkeeping, and forgeries of production records, serial numbers, inventory records, and the like. To be sure, there are various problems involved in carrying out such forgery. Thus, there is a requirement for consistency which may well be difficult under conditions where property undergoes many transfers. Also, there are ways of testing the alteration of records and the age of papers and inks. Still, reliance on methods of records checking does not afford a firm basis for verifying the correctness of a declared inventory.

Estimating Past Output of Industrial Plants

Another approach to the problem of verifying inventory declarations is available through the technique of relating the output of an industrial plant during an observation period to a number of particular physical inputs used in production. An equation may thus be derived which relates inputs to output. Earlier records of some physical inputs —say, water or electric power—could be entered into the equation to estimate earlier levels of production. Such a method involves, among

[14] A reading of AR 735-5 discloses the detailed requirements for record-keeping involved in standard U.S. Army practice. Additional details will be found in the following list of published Army Regulations available from the U.S. Government Printing Office.

No.	*Title*	*Date*
AR 735-2 C 2, 3	Transfer for Property Accountability and Responsibility	9 June 1955
AR 735-3 C 2	Receipt, Shipment and Issue of Property	17 Nov. 1954
AR 735-5 C 1, 2, 3, 4	General Principles and Policies	20 Dec. 1954
AR 735-7-1	Property Procedures	27 May 1953
AR 735-11 C 1	Accounting for Lost, Damaged or Destroyed Property	6 Apr. 1956
AR 735-18	Disposition of Army Property Records	28 Sep. 1956
AR 735-60 C 2	FIA, General Principles and Policies	4 Jan. 1955
AR 735-71	Accounting Policies—Industrial Property	2 Mar. 1956

others, the assumption of similarity in the production system through the period reviewed. The preferred input elements for this purpose should be of a sort that are routinely, perhaps even automatically, recorded during the course of industrial plant operation. Accordingly, the problem was formulated: Is it possible to estimate the past output of an industrial plant on the basis of measured relations between input and output of the particular plant during a limited period of time? If that were possible within the limits of acceptable error, then estimates of past production could be compared with the inventory declarations, made by governments which have signed a disarmament agreement.

An effort was made to carry out an experiment to test the feasibility of measurement and estimation along these lines. The work was done in a midwestern (U.S.) plant manufacturing a precision motor-driven product. The management of the firm gave generous cooperation in this experiment, which is reported in the paper by Professors Derman and Klein.

The report of this effort in estimating past industrial production indicates that the error involved could very well be larger than the tolerable error for checking the accuracy of a declaration of stock-piled weapons.

There are other conceivable pitfalls in such techniques, as indicated by Professors Derman and Klein. Thus, if an unrecorded but steady proportion of finished products were regularly withdrawn from a plant over a long period of time, it would be difficult to detect either that fact, or the magnitude of withdrawal, by the type of statistical technique used. Another source of error in such analyses stems from the instability of production systems. Thus, in the plant that was available to the writers for this experiment in estimation of past output, there has been a sustained growth in labor productivity during the period reviewed. This effect resulted from many detailed changes in the method of production, a feature that is found in virtually every industrial plant of size.

During recent years various writers have called attention to the problem of concealed inventories. Thus, if the production of atomic warheads had long proceeded on a large scale, and if methods of accountability of materials allowed for even a small percentage of error, that percent, applied to a large output, could leave dangerous quantities of fissionable materials unaccounted for. There is thus real danger of a pre-inspection head start in any area of production that is important militarily.

The available knowledge of production systems does not afford a clear basis for a check on past output through the analysis of factory input-output relations. Nor can various routine records be regarded as a firm basis for monitoring—owing to possibilities of unrecorded withdrawals from production or forgery of records.

The Labor Force Factor

All of the critical armaments production has another aspect which contains possibilities for control by inspection. The 20,000 to 30,000 components contained in large missiles must be fabricated, tested, assembled, packed, loaded, transported, unloaded, and stored. All of this activity necessarily requires the participation of many thousands of people, which leads to the problem: How can the manpower factor in arms production be turned to account for discovering current production as well as concealed inventories of weapons? One aspect of this question is the monitoring of scientific personnel. Appropriate sampling methods can be applied here to check on the current use of people with talents that are critical for weapons development and production. Another aspect of the manpower factor in arms production is the problem of how the inspectorate could benefit from the information that is in the hands of the arms producers. This question will be considered in the section, " 'Inspection by the People.' "

STRENGTHS AND WEAKNESSES OF INSPECTION METHODS

The central problem of this section will be to assess the capabilities and limitations of the various inspection methods reviewed thus far. In the light of this assessment an effort will be made to define the requirements for compensating for indicated areas of weakness in various inspection methods.

Area of Inspection Strength

The very size of a clandestine production project involving 200 to 400 large missiles is a strong point, favoring an inspection effort. The estimated number of man-years required to produce these units ranges from forty to eighty thousand. Other elements of the production problem include the variety and the high levels of technical skills necessary to carry out the production task. Clearly, the assembly of these skills at a central point, or their orderly integration at widely dispersed locations, involves a large-scale production effort. Such a production effort is attended by very many problems when carried out normally, openly, and without complications arising from an effort to evade an inspectorate.

Under conditions of clandestine operations, the problems of integrating large work forces, assembling materials, equipment, and the like, would call for extraordinary feats of organized ingenuity and highly disciplined group secrecy.

A related aspect of the production problem is the sheer size of the product itself. The Redstone Guided Missile of the U.S. Army is announced as a unit 63 feet long. The power plant and fuel tanks account for 34 feet, and the control system and warhead for 29 feet. The missile has been reported to be divided into these two units for purposes of over-the-road shipments to launching sites for test areas.[15] Another indication of the size of the production facilities for the manufacture of large-scale missiles is given in a recently published photograph of a new missiles plant on the outskirts of San Diego, California. It is described as a $40 million industrial plant.[16]

Clearly, any clandestine effort to reproduce industrial plants of this size, either in central locations, or in decentralized form, would involve unusual feats of construction and organization. Thus, an effort to assemble critical types of machinery for such production would involve almost insuperable difficulties if certain machine-producing plants were closely monitored by an inspecting group.

Aerial inspection methods have considerable strength for monitoring the kinds of preparations for invasion that require the massing of thousands of men and vehicles.

The clandestine production of atomic warhead materials might be attempted by way of the refueling operations of power reactors. Such units, however, could be subjected to close inspection control.

The mechanical components of large missile guidance systems offer important strategic opportunities for inspection purposes. The same can be said for certain aspects of air frame production. The

[15] *American Machinist,* November 4, 1957, p. 173.
[16] *American Machinist,* January 13, 1958, p. 153.

rocket motors that are used in large missiles suggest certain possible critical points. Finally, successful clandestine testing of major nuclear explosives is probably impossible.

The testing of high-altitude missiles and of nuclear warheads can both be placed under effective control by monitoring the relevant physical phenomena with appropriate measuring instruments. The reliability of the monitoring techniques for these purposes make them appropriate as areas of agreement for the early stages of international disarmament agreements.

The preparation of materials for biological warfare may be monitored, owing to the specialized character of the equipment and staffs that are required for such work. The staffs must include highly trained bacteriologists, virologists, and the like, and they would require an array of special equipment for handling masses of virulent material, even at the experimental level. An intelligent statistical sampling plan could be used to inspect the relevant laboratories and industrial plants.

The Strength of Combination

The total strength of an inspection system would necessarily depend upon a many-sided approach to the inspection objective. Each method of inspection has its limitations. The limitations of each method, however, are not in the same areas, or of the same degree. Therefore, a many-sided approach to the detection of clandestine production has a cumulative strength that is not revealed in any one method viewed in isolation. Thus, aerial inspection could yield certain indicators which need ground follow-up. A report of a suspicious accident would be followed by a demand for access to the premises and the people involved. Characteristics of a budget system, themselves uncertain in meaning, become useful if it is possible to follow them up by appropriate inquiries. The general point involved here is formulated by Professor Boley in his paper: "It is . . . unrealistic to hope to find a single item to be used as a sole criterion of clandestine operations. It is rather necessary to search . . . a number of separate components for possible adverse evidence, final proof of malpractice being provided by the weight of accumulated discoveries."

These elements of strength on the side of an inspection system oriented towards inspecting materiel must be contrasted with the weaknesses that apparently inhere in such an inspection system.

Weakness of Inspection Methods

There is no escaping the fact that several technical papers disclose gaps in inspection feasibility.

Aerial surveillance methods are definitely useful, but not for locating already existing mounted missiles, ready for firing in well-concealed positions. Budget controls for individual countries may not be regarded as reliable devices because of the possibilities for large-scale concealment of end uses of funds. There are alternative kinds of electronic guidance systems. Also, such systems can often be built from readily available components.

Fuels and rocket motors do not appear to offer crucial inspection points owing to the variety of possible fuels and the alternatives available for rocket propulsion in this very fast developing area of technology. This estimate may prove to be overly conservative if, for example, future rockets require special high-energy fuels that utilize materials uniquely appropriate for this purpose.

In the absence of a major development in the relevant techniques, it is necessary to conclude that the problem of validating a declared inventory of past production, on the basis of materials accounting, remains substantially unsolved. Indeed, the prospect that there may be concealed inventories of weapons, while governments are dominated by an "evasion mentality," may lead to international agreements, at least at the earlier stages of disarmament, which control production but permit and register caches of arms.

There are also problems resulting from the methods of clandestine production. The possibilities of this class of techniques must be treated with the greatest respect in assessing the feasibility of an inspection system. The types of techniques which have been reviewed above are reinforced under certain patterns of working. Thus, in many sectors of American industry, it is common for people to work on projects, the end use of which they do not know. Frequently such knowledge is withheld from the people working on a project as a matter of policy by a given management. Nevertheless, where there is a tradition of producing machine elements to be used in equipment of unknown performance, that pattern of working fits in neatly with the requirements of clandestine production activities.

Finally, it is necessary to call attention to the range of powers in the hands of a modern government which can be used to facilitate clandestine industrial production desired by that government. The data reviewed in the cases of Germany and Palestine are illustrative of a situation in which strong ideological commitments of large parts of the population could be drawn upon by the government. It is also necessary to take into account the circumstances where a government uses terrorist methods in relation to its population as a regular policy. Under these circumstances no ideology possesses independent force. Such a government could conceivably compel compliance with or nondisclosure of a clandestine production activity, even in the face of bad feeling and resentment in the population toward such a program.

In this assessment of limitations of inspection, a most conservative view has been taken. The fact is that each of the difficult areas for inspection could nevertheless be subjected to monitoring on a sampling basis. Such methods, if properly designed and executed, could operate as major deterrents of clandestine operations in each of the areas where particular, critical check points of a limited number are difficult to specify. Professor Herbert Solomon's paper on sampling methods for use in inspection for disarmament demonstrates some of the reasonable possibilities of such methods.

"INSPECTION BY THE PEOPLE": MOBILIZATION OF PUBLIC SUPPORT

A method is needed to compensate for weaknesses in inspection techniques which are traceable to capabilities of clandestine production organization and the availability of many technological alternatives for achieving a given result. Limitations of these kinds are inherent in an inspection system which places primary emphasis on the inspection of physical things. The writer suggests the following design for coping with this problem.

There is a common feature of any organized production effort to evade a disarmament inspection system, and that is the participation of a large number of people. This has been characteristic of previously successful clandestine production operations. The participation of many thousands of people in the direct production tasks would certainly be a necessary feature of any attempt to produce a few hundred large ballistic missiles on a clandestine basis, for example. The same condition is necessary in any attempt to produce "conventional" armaments in large numbers. Many people would also be required to emplace secret weapons systems or to create secret inventories of arms during the early stages of international disarmament agreements. Because of the number of people required, defection by even one man from a clandestine effort would reveal its existence and disclose aspects of its character.

Another feature of the manpower requirement for clandestine production would be the diversity of occupations whose participation would be essential. The technical skills needed to produce and to operate large scale missiles cover almost the whole spectrum of skilled industrial, technical, and scientific occupations.[17]

From this viewpoint the problem may be posed: How can the manpower requirements for a major clandestine production effort be used to strengthen the possibilities of inspection for disarmament?

Inspection by the people is a method that would serve this purpose. In addition to the specific monitoring activities of the inspectorate, it would be invaluable to have a randomly distributed network of inspection that is based upon public support for inspection for disarmament. Such public support could reinforce the work of the inspectorate and could help to undercut evasion efforts that require substantial organizations and widespread production systems. The operation of effective world-wide inspection by the people would be facilitated if the disarmament agreements included provisions which made it a duty, an explicit obligation, of the citizens of participating countries to report violations to the international inspectorate.

In order to implement inspection by the people it would be necessary to establish regular channels of communication to and from the population.

Communication to the Population

The channel to the population would extend from the international inspecting organization and could consist of agreements to make available minimum amounts of radio and television time, newspaper space, and the like. Members of the inspectorate could participate in the work of universities and similar institutions of the country where they are stationed.

[17] It should be noted that the armed forces of large countries now include a substantial part of the technical skills of civilian society at large. These men in the military are under a kind of disciplined control that could be used in an attempt to operate a secret production system under an inspection agreement.

The central theme of the inspectorate's communication to the population would be that the international agreement is mankind's shield against mutual extermination and that a violation of this agreement is thereby a crime against humanity. The development of an understanding of this message would secure the commitment of populations to these ideas, and would thereby supplement the formal agreements among governments.

Education along such lines, carried out on a world-wide basis, could very well have the effect of making untenable the position of any government, or group of officials, found guilty of violating the disarmament agreement.

It has been suggested that the degree of success of inspection by the people would probably depend on the success of communication and education in encouraging more openness of personal expression in various countries, so that public opinion would indeed be a factor for governments to reckon with.

An additional feature of such international agreement would be provisions for guaranteeing the security of people who cooperate with the inspectorate. This means, for example, that people who report on clandestine industrial production to the inspectorate must be guaranteed, automatically, the protection of the inspectorate. This could very well include provisions for facilitating the movement of people between countries, as well as provisions for affording temporary local security of persons. Violation of the agreement might very well have to be handled within legal systems set up outside existing national frameworks. The design of the alternatively possible judicial and allied legal aspects of punishment for violation requires detailed analysis by the legal profession.

Apart from clear-cut violations of an agreement, there may be problems of defining enforceable standards of official uncooperativeness. To be sure, the very possibility of such problems may be affected by the changes in political atmosphere that could result from the gradual introduction of steps toward disarmament.

Communication from the Population

Open channels of communication from the population to the inspecting organization are critically important.

The inspectorate would request the population to report to it any evidence of activity in violation of the disarmament agreement. For this purpose it would be necessary to establish and maintain a channel of communication to the inspectorate which would lend itself to constant inspection for reliability. The postal system, for example, might be well suited in this respect. The postal system could be subjected to constant tests by the inspecting organization. It would be possible to mail letters and packages in a constant stream from various parts of the country, addressed to the publicly announced address of the inspectorate in the capital city. Any evidence of tampering with or nondelivery of mail so posted would alert the inspectorate to some form of clandestine activity against the inspecting organization. Use should be made of the chemistry of inks, papers, and adhesives in coping with the problems of devising appropriate envelopes or other containers for the test mail.

In public statements the inspectorate would elaborate on the kinds of things which constitute indicators of clandestine activity. These would include: the production of materiel; the operation of certain processes; the utilization of certain machines; the production of components to particular kinds of dimensional tolerances (as for precision gyroscopes), or for certain strength and temperature requirements (missile air frames). The attention of the population would also be called to such possibilities as the use of workshops in educational institutions for the production of military components, or the camouflaging of research laboratories. Accidents of certain kinds would be evidence of clandestine activity.

The burden of the present argument is that in order to cement an agreement among governments it is invaluable to develop understanding and allegiances that cross national boundaries. Widespread allegiance to ideals of peaceful living and humanitarian methods would undermine the nationalist appeals of any major effort to evade a worldwide disarmament agreement.

Only a few of the numerous parts of an evasion effort would have to be discovered. Therefore, the readiness of rather few people to disclose secret rearmament would be a most powerful adjunct to the work of an international inspectorate which could follow up its findings to check on evasion attempts. Similarly, the knowledge that such disclosure is possible would be a deterrent, in some measure, to clandestine arms production.

Public Opinion on Inspection by the People

Owing to the possible importance of inspection by the people, an extensive effort was carried out on behalf of this study by Professor William Evan of Columbia University, to discover the attitude of the population in several major countries to this question. National surveys of public opinion were made in six major countries, mainly by Dr. George Gallup's American Institute of Public Opinion and its affiliates in other countries.

Three major questions elicited extremely interesting and important responses.

To the question, "Would you favor or oppose setting up a world-wide organization which would make sure, *by regular inspection,* that *no* nation, including Russia and the United States, makes hydrogen bombs, atom bombs, and missiles?" replies of the following percentages of the population were in favor:

United States	70 percent
Great Britain	72 percent
France	85 percent
West Germany	92 percent
India	78 percent
Japan	91 percent

To the question, "If this inspection organization were set up, would you favor or oppose making it each person's *duty* to report any attempt to secretly make atom bombs, hydrogen bombs, and missiles?" replies of the following percentages of the population were in favor:

United States	73 percent
Great Britain	54 percent
France	74 percent
West Germany	86 percent
India	71 percent
Japan	80 percent

To the question, "If you, yourself, knew that someone in (name of country) was secretly attempting to make forbidden weapons, would you report this to the office of the world-wide inspection organization in this country?" replies of the following percentages of the population were in favor:

United States	80 percent
Great Britain	50 percent
France	63 percent
West Germany	73 percent
India	63 percent
Japan	83 percent

The full report of this work, and the names of cooperating organizations in each country, are given by Professor Evan. At this point, it will suffice to examine the main results, showing the proportion of the people in each country who responded favorably to the key questions.

A majority of the people in each of the six countries polled favors inspection for disarmament, and declares itself prepared to cooperate within a setup of inspection by the people. This statistical summary is of greater interest when certain details of Professor Evan's paper are examined, such as samples of the comments which many people added to their replies.

The response of scientists and professional engineers is of special interest because of the critical importance of their work for the design and production of intricate weapons. Taken together, from all six countries, scientists and engineers favored the proposals in the opinion poll more strongly than the population as a whole.

What is the meaning of such opinion data for predicting the possible behavior of people? It is not possible to predict that the same proportions of people would, in the future, actually act in the way that they now say they would. Nevertheless, if the proportion who would act were even half of those who now favor inspection by the people, that would still be a source of massive support against clandestine military activities. Seen in another way, the poll data show that in the six countries there exists the kind of extensive public backing for reporting attempts at evasion of disarmament which could have frustrated the clandestine military activity in Weimar Germany and in Palestine (see the papers by Gumbel and Rivlin).

The Soviet Sphere

No comparable data on public attitudes are available for the USSR and its allied countries. Indeed, it is altogether possible, in the judgment of this writer, that the interpretation of such expressions of opinion, difficult as they are in the West, would be incomparably more difficult within the framework of the Soviet system. The conduct of such polls, and especially the ability to make inferences from them about political behavior, involves certain assumptions about a society. These assumptions include the following: that the people are prepared and able to express their own, individual opinions about public, political matters; that political matters are regarded as an open and appropriate sphere of individual action and initiative; that politics is not a government monopoly; that it is conceivable for people to dissent from and actively criticize their governments; that individuals may dissent from government on public policy matters without fear of serious reprisal.

The available information on the Soviet system indicates that such conditions exist, at best, to only a rather limited degree. If that should continue to be so, then the process of inspection for disarmament in such countries could not rely on important assistance from inspection by the people and would have to be based almost entirely upon monitoring by the inspectorate.

Nevertheless, it may be that the presence of an international inspectorate in such countries might open up possibilities for public support of disarmament. Indeed, the repeated invitation for cooperation by means of inspection by the people could very well be a factor in generating an environment in which such cooperation could become a reality.

In the judgment of this writer, inspection by the people, to the extent that it is workable, could be a bulwark of strength in support of technical inspection, filling its gaps and giving all people mutual assurance against violation of a disarmament agreement. Under such conditions, the limitations of inspection of materiel would no longer restrict the efficiency of inspection for disarmament.

SOME IMPLICATIONS FOR CHARACTERISTICS OF THE INSPECTION ORGANIZATION

The characteristics of an efficient inspection system for disarmament suggest certain of the powers of an inspectorate, as well as the characteristics of the inspection staff—its organization and the development of its function.

Powers of the Inspection Agency

The inspection agency must have unrestricted access to places and to people in order to make determinations of possible violations of disarmament agreements. The need for such powers derives clearly from three conditions: the impossibility of predicting the technological alternatives which may be developed for armaments purposes, the difficulty of anticipating the precise means which might be devised for implementing an effort for clandestine production organization, and the possibility of getting maximal inspection strength only through the use of mutually reinforcing methods.

A good example of the consequences from new technologies may be seen in the problem of missile delivery. It has been suggested that submarines may be efficient vehicles for delivering medium range missiles to within a few miles of their target areas. Moreover, it is suggested that such missiles mounted on submarines could very well be fired under water, thereby rendering the problem of detection extremely difficult.[18] Sustained technological change would be an inevitable condition surrounding the operation of an inspection system. As a result, the inspection methods appropriate to any one technology would have to be revised. Under such conditions the inspectorate must have opportunity for flexibility in determining the kinds of places and persons whose inspection becomes relevant. The papers on techniques of clandestine production suggest that a range of methods can be utilized for these purposes. Moreover, the literature of this field discloses that a virtually unlimited variety of devices can be invented by determined, ingenious people.

The operation of an international inspection agency with unrestricted access would, of course, lead to various legal problems involving governmental, personal, and property rights. These matters have been given extensive treatment in a companion study by Professor Louis Henkin on *Arms Control and Inspection in American Law* (Legislative Drafting Research Fund, Columbia University), in press at this writing.

The code of general law and detailed rules of an inspection organization would have to be well defined. From the vantage point of the

[18] *New York Times,* January 26, 1958, Section I, p. 37. This article, analyzing the possibility of submarine and missile combinations, was written by Sir Philip Joubert, a retired Air Chief Marshal of the Royal Air Force.

present study, it may be said that such a legal code would have to be consistent with the requirements of an effective inspection system. This would include, for example, the right of unrestricted access for inspection.

Beyond that sphere, the designers of such a legal code would have to cope with such problems as: drawing clear dividing lines between what is permitted and what is illicit; who shall make such determinations—the inspectorate, the member states, international courts, etc.; determination of whether responsibility for violation shall be individual or collective (i.e., the problem of individual responsibility of government officials). In order to adapt an inspection system to changing technology, it may be necessary to agree on ways of handling new weapons devices that may be developed. A strong case, for example, may be made for specifying that power to redefine what is illicit activity should reside with the international authority. Otherwise, a given country might attempt to define inspection points in terms of a particular (perhaps soon obsolete) technology. These and allied problems require extensive study and the formulation of alternative solutions that would serve the progressive introduction of disarmament and the allied inspection process.

The Problem of Commercial Secrets

Industrial managements have sometimes called attention to the problem of preserving commercial process secrets under an extensive inspection system. There is evidence, however, that industrial technical eminence is based not on the holding of particular bits of information, but rather on the ability to produce new knowledge. Thus, the operation of substantial research facilities rather than the possession of certain technical "secrets" has become the keystone to the maintenance of industrial technological distinction. Nevertheless, the problem remains: How to adjust the pattern of commercial secrecy to the operation of a disarmament inspectorate.

To be sure, another class of interests is also involved: the protection of commercial information. For this purpose, however, one must rely on the characteristics of the international inspectorate and the checks on inappropriate activity which could be built into an international organization carrying out inspection for disarmament.

Characteristics of Personnel for an Inspection Organization

The staff of an inspection organization must be drawn from many countries. Inspection groups of a multinational character would have the effect not only of giving political reassurance in many cases, but also of supplying a necessary ingredient for making many types of clandestine evasion exceedingly difficult. Thus, the evidence available to this writer indicates that many techniques of clandestine armament production have depended on the ability to adjust behavior so as to suit the expectation of the inspectorate.

In one case a small arms-producing operation was located in the midst of a leather tannery which consistently produced a normal odor so obnoxious to the inspecting officers that they would not think of entering the premises. The same principle has been utilized repeatedly. Broadly, the point is that an appearance of normality, according to the criteria of one culture, will not have the same force when viewed from the standpoint of another pattern of living.

The personnel of the inspectorate must consist of men of substantial technical competence; they must be well paid, given tenure, and accorded prestige for their work.

Part of the inspectorate could be a permanent staff, part of it a rotating staff. Furthermore, the location of inspectors in various countries could be varied on the basis of random selection, within the limits of assuring a certain minimal degree of international representation in each country.

For people who come from various technical occupations, participation in the international inspection organization could be made into a professional opportunity as well, even though their main work would be the operation of a system of technical monitoring. Access to, and participation in, activities of their profession could be arranged in any country in which they were stationed. The inspection organization could arrange for the use of laboratories and other facilities by its scientific personnel in the various countries. The inspectorate could also operate its own research facilities, if deemed necessary, for the sustained training of its own staff, or to carry out special research. Such arrangements would help to secure the services of high-caliber people in the relevant fields of knowledge and technique. This activity would also facilitate the international exchange of scientific personnel and understanding.

Certain areas of technological development would be of special interest to an international inspectorate, including, for example, researches leading to the improved accuracy and reliability of many classes of measuring and controlling instruments, and the development of new methods and techniques for various detection functions.

An international inspectorate for disarmament must be composed of people who would act vigorously, pursuing their work with enthusiasm and imagination. In all the industrialized countries of the world there are substantial numbers of people with special competence for this purpose.

It should be possible to recruit a first-rate staff to carry out the functions of the inspectorate. Various opinions to the contrary were offered to this writer. In order to gauge the condition in this sphere, a questionnaire was sent to all professors and instructors in the Faculties of Pure Science, Engineering, and Political Science of Columbia University. More than half of those solicited replied to the questionnaire. The following were the main responses.

POLL OF COLUMBIA UNIVERSITY FACULTY ON AVAILABILITY FOR INTERNATIONAL INSPECTION FOR DISARMAMENT SERVICE *

	Percent Answering Yes
Would you consider a two-year appointment to an international inspectorate?	68
Do you think your colleagues in other schools would consider a two-year term?	65
Would you be prepared to be a permanent member of such an international inspectorate?	16

* This poll was taken in March, 1958.

The reasonable inference to be made from the Columbia University faculty poll is that highly trained men in many fields of knowledge at American universities would be prepared to consider tours of duty on an international inspectorate for controlling disarmament. In this writer's estimate, men in industrial and government employment would be even more readily available for these functions.

Manpower Requirements for Inspection

To estimate, however conservatively, the number of people needed for various kinds of inspection for disarmament, a set of staff estimates has been prepared for major inspection methods. These estimates are for field technical staff, and are based on the United States as the area for inspection. Administrative staffs are not included.

The inspection areas included here are of two types: those requiring 100 percent inspection (an inspection staff at each plant), like nuclear reactors; and those which could be monitored by means of sampling inspection. The paper by Professor Herbert Soloman indicates a workable method for designing a scheme of sampling for this purpose.

ESTIMATES OF THE NUMBER OF PEOPLE NEEDED FOR POSSIBLE ASPECTS OF INSPECTION FOR DISARMAMENT WITHIN THE UNITED STATES

Type of Inspection	*Field Staff*
Aerial Inspection (Assuming 3 million square mile area. Including air crew, maintenance, and photo-interpreters.)	550-750
Stations for Monitoring Nuclear Bomb Testing (15 stations: field and analytical staff)	50
Stations for Monitoring High-Altitude Missile Tests (15 stations: field and analytical staff)	180
Nuclear Reactors (300, including experimental and planned)	600-1,500
Fissionable Materials-Producing Plants (6 plants)	300-2,400
Uranium (and Vanadium) Mines and mills (637 in 1954)	1,200
Aircraft Assembly Plants (72 in 1954)	700-1,400
Aircraft Engines and Parts Plants (234 in 1954)	2,400-5,000
Aircraft Flight Instruments Plants (129 in 1954)	1,300-2,600
Radio and Radar Plants (225 in 1954)	2,250-4,500
Ordnance and Accessories Plants (493 in 1954)	5,000-10,000
Explosives Plants (74 in 1954)	750-1,500

Note: These estimates were constructed on the following bases: for aerial inspection and bomb and missile testing, the authors estimated the field staffs required for 24-hour functioning; checks on reactors could be maintained by as few as 2 to 5 men per reactor, depending on the need for 24-hour monitoring; in the fissionable materials plants, the range is due to readiness to rely on instrument monitoring vs. major reliance on human controllers; mines and mills could be covered by an average of about 2 men to each mill or mine; the various critical factories for missiles, aircraft, and explosives could be monitored by an average of 10 to 20 men per plant. Such estimates give an order of magnitude. They would be revised in accordance with detailed operating requirements of an international inspectorate.

Sampling inspection could be made in the following areas:

Biological laboratories
Metal-working plants
U.S. government accounting
Scientific manpower

The areas for 100 percent inspection include aerial inspection, and stations for monitoring nuclear bomb tests and high altitude missile tests. It should be noted that these types of inspection, as well as the control of nuclear reactors and plants producing fissionable materials, could be carried out, in the United States, with staffs of modest size.

Organizational Characteristics of an International Inspectorate

Flexibility in methods and the adaptability of organization to the requirement of new technological conditions are key elements of the organizational design of an international inspection agency. Inflexible administrative routines and the conservatism that accompanies a vested occupational interest in particular methods are mortal dangers for the effectiveness of an international inspectorate. Therefore, the organization of such an agency must include built-in features for the review, evaluation, and modification of structure, departmental functions, and preferred techniques.

To be sure, the performance of an intricate function like international inspection for disarmament requires the solution of a host of political, organizational, administrative, and economic problems, apart from those noted above. These involve, for example: the size and composition of the staff, conditions of payment and tenure, problems of securing international representation, and the relationship of such an organization to the United Nations and to international bodies like the Red Cross.

Evolution of an Inspection Function

Once the technical characteristics of various inspection techniques have been indicated, it is necessary to cope with the problem of "phasing-in," or introducing, various inspection techniques. This is preeminently a policy problem requiring the solution of a range of intricate political and economic problems.

The planned evolution of an inspection function to meet public policy requirements might be facilitated by appropriate analyses of the characteristics and effects of various inspection techniques. For example, inspection methods could be analyzed by ranking them according to criteria like the impersonality of the method (inspection of things vs. people) and the costliness of the operation (staff and equipment that would be needed). Similarly, alternative inspection systems could be diagnosed according to classes of effects—for example: impact on the sovereignty of national government,[19] residual capabilities for secret arming under a given inspection system, and the extent of occupational and economic reconversion that would be caused by the given degree of disarmament.[20] These and related aspects of an evolving inspection scheme require thorough analysis.

Undoubtedly one of the difficult political problems of inspection is finding ways to begin. Of the methods that are reviewed in this report, three suggest themselves as especially interesting in this respect: radiation inspection, monitoring nuclear explosions, and monitoring for high-altitude missile tests.

Inspection of plants that produce fissionable materials is a crucial feature of enforcement of a disarmament agreement. It is likely that close inspection of these, for public health purposes, will be progressively intensified. The several networks of radiation inspection established in major countries for public health objectives may lend themselves readily to serve the objectives of inspection for disarmament as well.

The technical workability of inspection for bomb testing and for high-altitude missile testing is especially important for initiating disarmament programs. The monitoring operations for these purposes could be carried out without the more politically sensitive activities that are essential for control over production.

[19] See Henkin, *Arms Control and Inspection in American Law.*

[20] In the United States in 1956, about 15 percent of the labor force was engaged in work on military orders. The national defense budgets financed 30 percent of all scientific research and development in the nation as a whole and 37 percent of all research and development in all industrial firms. In 1953-54 the Defense Department and the Atomic Energy Commission sponsored 40 percent of all research expenditures by American universities. These estimates are based upon statistics in: U. S. Bureau of the Census, *Statistical Abstract of the United States* (78th ed., Washington, D. C., 1957), pp. 197, 238, 367, 495; National Science Foundation, *Science and Engineering in American Industry* (Washington, D. C., 1956), p. 17; and National Science Foundation, *Reviews of Data on Research and Development* (March, 1957), pp. 2, 3.

EVASION TEAMS

Evasion of disarmament means an attempt to violate an international agreement made by a group, inside or outside a government that formally accepts the agreement. Evasion by a government or a part of a government is the more serious possibility, in the judgment of this writer. An evasion effort could be prompted by mistrust and the fearful conviction that a country is unsafe without this—either for international bargaining or for carrying out a surprise military stroke, in an unrelenting drive for power over other countries. Such possibilities must be taken into account here because of two factors: first, the history of mutual distrust among the major governments, and, secondly, the influence of this distrust as a guide for both domestic and foreign policies.

In order to test the efficacy of the inspection systems outlined here for partial and extensive disarmament agreements, three Evasion Teams were organized. Each of these teams was given the same Terms of Reference and charged with formulating a strategic plan for evading the inspection system. Each team was somewhat different from the others in its occupational composition, and each group functioned independently. Moreover, no military men or other governmental officials were included. The Terms of Reference, as well as the reports of the Evasion Teams, are given in this book.

These reports contain material that may very well dismay many people. They are included here as a realistic demonstration of what imaginative, technically trained men can do in this sphere, even in a short span of time. Accordingly, the possibilities of organizing highly destructive, clandestine operations, as shown here, must be regarded as only an approximation of what the full-time military professionals of various countries have probably been able to devise. Finally, the writer wishes to point out that the main technological possibilities outlined by the Evasion Teams have been publicly announced at various times. Thus, on April 12, 1958, *The New York Times* reported (on its first page) the successful firing of missiles by the Navy from under water. The fixed underwater missile system suggested by Evasion Team B is one application of this general technique for launching missiles.

The Possibilities for Evasion

Clandestine production of intricate weapons was regarded as a most difficult task by the Evasion Teams, even when ingenious modes of operation are utilized. This confirmed the prior estimate of this investigation. The concealment of arms during the period of introduction of disarmament was singled out by Evasion Team B as the method most likely to succeed. This writer agrees with that estimate.

Successful evasion for arms production, however, requires more than technical feasibility. It needs an "evasion mentality" among its principal operators. This includes: first, an ideology which requires evasion of disarmament; second, the view that the design, production, and utilization of weapons of great destructiveness is natural, reasonable, thinkable, and even laudable. The latter point is critically important, for it pinpoints, in the judgment of this writer, the area of greatest delicacy for the observance or evasion of disarmament agreements. Able men, moved by an evasion mentality, might attempt such a clandestine armaments effort as is indicated, for example, in the report of the Evasion Teams.

As long as an "evasion mentality" dominates a sufficient part of a population, there is danger of evasion of disarmament through one of the great array of technological possibilities. It is also reasonable to assume that as mass destruction is understood more and more widely as an unthinkable, unnatural act, there is bound to be greater security for mankind.[21]

Dr. Alberta B. Szalita, in her comments on psychological aspects of disarmament, calls attention to the possibilities of strengthening the potentials in human personality which would run counter to an evasion mentality: for self-preservation as against self-destructiveness, for peaceful living as against warlike behavior. In her paper, Dr. Szalita also underscores the crucial role of such attitudes among scientists. Due to the central importance of their work in laying the bases for new technologies, more control by scientists over the use of their work, and the fostering of ideals of peacefulness among scientists, could have special value for mankind.

[21] It has been suggested to the writer that it might be useful for some international agency to monitor ideologies and public political discussion and opinion in a nation as an indicator of efforts to generate an evasion mentality. Such efforts could be an alarm signal to the inspectorate.

It is altogether possible that, as indicated by Evasion Team B, clandestine arms systems can be fully emplaced during a period of phasing-in of disarmament agreements. An international inspectorate could certainly use every reasonable device, including, for example, checks on rockets for scientific use, to prevent someone from slipping in a warhead.

Successful inspection, like successful evasion, requires more than technical feasibility. In the judgment of this writer, the final line of defense against evasion will be a condition of society in which such acts are widely regarded as unnatural and unthinkable. Even if some deadly weapons systems could be operated by as few as six men (see the report of Evasion Team B), those men could not make a military campaign; that would need the collaboration of at least a segment of a population. In this respect, the presence or absence of an "evasion mentality" could play an important part.

Toward the end-in-view of diminishing or discouraging an evasion mentality, the early implementation of even partial steps for disarmament and international inspection is of the greatest importance. For every measure that relieves international tension and limits the fever of an arms race also limits the conditions that produce an evasion mentality. Stated differently: the introduction of particular disarmament measures in regard to highly destructive weapons, with reliable inspection, is bound to have a feed-back effect in reducing the pressures that lead to clandestine armament preparations. Thereby, conditions of mutual international assurance of compliance with disarmament agreements are improved.

SUMMARY: CONDITIONS OF WORKABLE INSPECTION FOR DISARMAMENT

The major objective of this investigation is to estimate the technical feasibility of inspection methods for administering international disarmament agreements. For this reason an attempt was made, for analytic purposes, to gauge the possibilities for enforcing a disarmament agreement of wide scope, including the restriction of arms production.

The main finding of this report is that it is possible to define systems of inspection which would ensure compliance with a wide variety of disarmament agreements. Such monitoring systems can be major deterrents to attempts at clandestine evasion, and are, in that sense, workable systems of inspection. *The range of workability extends from agreements of limited scope to comprehensive disarmament projects which would require rather extensive monitoring.*

The possibility for establishing highly effective physical controls over nuclear bomb testing and high-altitude missiles testing indicates the usefulness of these measures as ways of initiating international agreements on disarmament.

The efficiency of materiel inspection methods for ensuring compliance with a disarmament agreement are limited by three factors: the availability of technological alternatives (like biological warfare in place of atomic bombs) by which given inspection points could be by-passed, methods of clandestine production organization, and the possibility of concealment of weapons during the period of introduction of inspection for disarmament.

The techniques for evasion which can be found in these areas are likely to be applied most extensively when government complicity fosters and is fostered by an "evasion mentality" which gives social sanction to evasion of disarmament agreements. From this standpoint, the greatest safety for mankind is to be obtained from the earliest, even if partial, disarmament agreements—which would serve to reduce international tensions. Such effects would facilitate, in turn, the extension of the scope and the workability of disarmament agreements, and their appropriate inspection methods.

PAPERS

CAPABILITIES AND LIMITATIONS OF AERIAL INSPECTION

by Walter J. Levison

DURING the past few years disarmament negotiations have taken on a new dimension. The London disarmament talks of the summer of 1957 were primarily concerned with the application of inspection to disarmament agreements. The primary question under discussion between the USSR and the Western powers was the form this inspection should take; the fact that inspection was necessary had already been implicitly accepted.

The USSR has long insisted on the use of ground control points as a means of verifying the hostile intent of a possible enemy nation. On the other hand, since the summit meeting at Geneva in 1955, during which President Eisenhower announced his Open Skies proposal, Western powers have proposed aerial inspection as a means of detecting military build-ups for possible surprise attacks.

Prior to either of these proposals, the United States had introduced into the United Nations the idea that inspection was prerequisite to enforcement of a disarmament agreement. The Baruch proposal for international control of atomic energy, introduced by Mr. Baruch into the United Nations on June 14, 1947, was based on the Acheson-Lilienthal report of March 16, 1946. In it, the United States proposed

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. . . the creation of an International Atomic Development Authority, to which would be entrusted all phases of the development and use of atomic energy with managerial control of potentially dangerous atomic energy activities and power to control, inspect, and license all other atomic activities. . . . (Once) an adequate system of control was agreed upon, manufacture of atomic bombs would stop, existing bombs would be disposed of, and the authority would be in possession of full information for the production of atomic energy.[1]

In other words, the proposal implied that in the special area of atomic energy, inspection would be necessary to make sure that violations to the agreement would be detected. The consequences of undetected violations would be sufficiently severe to warrant this revolutionary step in international relations.

LIMITATIONS OF AERIAL INSPECTION SYSTEMS

The capability of either a ground or an aerial inspection system is very much dependent on the progress of technological developments in weapons. In this period of rapid technological advances, the ability of an inspection system to keep pace with new weapons must of necessity be open to question. If a nation is to put its trust in a system of inspection, it is essential that the capabilities and limitations of that system be well recognized. The inspection system must therefore be placed in an appropriate context; as a prerequisite to this, the task to be accomplished must be specified.

One of the major concerns of governments is the problem of obtaining adequate warning of attack, not only to minimize the effects of that attack but also to mount a counterattack in sufficient time to prevent a recurrence. Warning of imminence of an attack has a tendency to overshadow almost all other aspects of peacetime intelligence.

Deriving specific knowledge that an attack is to take place is a complex task when conventional weapons of warfare are to be employed. As the technological race continues and the delivery time of weapons becomes shorter, this task becomes more difficult. It is important to note that President Eisenhower, in his presentation of the Open Skies proposal, intended aerial photography as a supplement to the exchange of military blueprints:

[1] U.S. Senate, Committee on Foreign Relations, Subcommittee on Disarmament, Staff Study No. 2, *Disarmament, a Selected Chronology*, April 20, 1956, p. 15.

I propose, therefore, that we take a practical step, that we begin an arrangement, very quickly, as between ourselves—immediately. These steps would include:

To give to each other a complete blueprint of our military establishments, from beginning to end, from one end of our countries to the other; lay out the establishments and provide the blueprints to each other.

Next, to provide within our countries facilities for aerial photography to the other country—we to provide you the facilities within our country, ample facilities for aerial reconnaissance, where you can make all the pictures you choose and take them to your country to study, you to provide exactly the same facilities for us and we to make these examinations, and by this step to convince the world that we are providing as between ourselves against the possibility of great surprise attack, thus lessening the danger and relaxing tension. Likewise we will make more easily attainable a comprehensive and effective system of inspection and disarmament, because what I propose, I assure you, would be but a beginning.[2]

There are a number of limitations on the effectiveness of an aerial inspection system for providing adequate warning of a surprise attack. In the first place, meteorological conditions can obscure large portions of terrain for several months of the year. Furthermore, if the visible portion of the electromagnetic spectrum is utilized, cover of night provides excellent opportunities for the launching of attacks. Incidents from the Second World War, during which military reconnaissance was employed extensively, indicate that the failure of continuity imposed by both meteorological conditions and lack of illumination contributed heavily to the failure of aerial reconnaissance in guiding military decisions. Probably the most famous example of the effect of lack of continuity in aerial reconnaissance occurred in connection with the Battle of the Bulge:

This German counter-offensive was launched after two weeks of extremely low ceilings, low visibilities, and winter fog in the Ardennes, during which aerial reconnaissance was continuously attempted, but for the most part was unsuccessful due to weather. Although previous air reconnaissance and air reconnaissance in areas adjacent to the Ardennes sector, together with results from prisoner of war interrogations, had made possible accurate intelligence of the build-up for this offensive and had enabled the First U.S. Army G-2 to forecast reliably the general nature of the attack, the virtual absence of air reconnaissance in the actual locality of the break-through prohibited the acquisition of timely information which would have given prior indication of the specific region and time of its launching.[3]

[2] Statement by President Dwight D. Eisenhower at Geneva, July 21, 1955.

[3] BUPRL Technical Note No. 44, *Objectives for Research and Development in Military Aerial Reconnaissance*, by Richard S. Leghorn, p. 13.

A second limitation of air reconnaissance is that it is impossible to differentiate between a practice mission and an actual mission. There are no tools available to the reconnaissance aircraft by which it can ascertain whether the bombs in a bomb-bay are atomic or conventional, or are dummies. Consequently, aerial reconnaissance could not unequivocally ascertain the validity of a flight plan describing a practice mission.

A third limitation is the fact that although aerial reconnaissance can be conducted rapidly over extremely large areas, reduction of large quantities of data is both expensive and time-consuming. As a consequence, a time gap exists between the acquisition of the data, the production of intelligence, and the ability to take reasoned action. This problem tends to grow more complex with increasing technological advances in weapons systems. Although an international attack is currently estimated at approximately fourteen hours from time of launching to time of actual attack, advances in the efficiency of intercontinental bombers will decrease this period significantly. Furthermore, use of delivery vehicles such as the intercontinental ballistic missile will reduce this transit time to approximately thirty minutes—an impossibly short time in which to acquire information, process it, and take intelligent action. When such weapons become part of the inventory of an enemy nation, the effectiveness of any inspection system as a means of averting warfare becomes questionable.

CAPABILITIES OF AERIAL INSPECTION SYSTEMS

Given current weapon capabilities, the above limitations are significant primarily in the application of aerial inspection to the problem of warning of a surprise attack. In preparation for such an attack, however, it is at present necessary for a nation to take certain well-defined steps. Sufficient supplies of petroleum, oil, and lubricants must be on hand to make any fighting machine effective. An increase of armed forces above the minimum maintained during the cold war situation must be accomplished by calling up reserves and activating civilian soldiers. Depots must be stocked with adequate supplies of food and material. Military forces and equipment must be concentrated in a relatively few critical areas. Industry must be converted from civilian consumer goods to the manufacture of military supplies.

The population of the nation must be alerted and prepared to wage war. In short, the nation must be converted from a peacetime footing to that of an efficient fighting machine. Such a period of preparation is characterized by intense activity—activity involving both large numbers of people and vast amounts of equipment.

Preparation for attack occurs over relatively long time periods compared to the short time between the launching of an attack and its culmination. Furthermore, the activity of moving men and equipment is susceptible to detection by inspection systems. It is in this context, then, that an aerial inspection system should be judged, rather than as a tool to prevent a surprise attack.

During wartime, aerial inspection—or, in military jargon, aerial reconnaissance—has proved to be an invaluable method for obtaining intelligence to assist the military commander. The principal advantages of aerial reconnaissance are that it can penetrate long distances and cover extensive territories, that it is objective in what it records, and that it is rapid.

AN EVALUATION OF APPLICABLE SENSORS

Almost the entire electromagnetic spectrum has been employed as sensors in military reconnaissance systems, and it is natural to assume that the best of these will be chosen for a peacetime aerial inspection scheme. The portions of the spectrum which have principally been employed are: the visible, from .3 to .7 microns; the infrared, from 1 to 15 microns; and the 1- to 10-centimeter region, much used by airborne radar.

To a very large extent, the amount of information which can be derived is directly dependent on the wave length used; the finest detail is recorded by use of the visible wave length region. The choice cannot be determined entirely by the capability of a system for recording fine detail, however. The utility of the visible and infrared portions of the spectrum is severely curtailed by meteorological conditions. Cloud cover, haze in the atmosphere, and lack of illumination rapidly diminish the returns from instruments employing the visible portion of the spectrum. Infrared instruments are not particularly at a disadvantage during hours of darkness, but are severely hampered by moisture in the atmosphere and cloud cover. High-resolution radar, on the other hand, is an extremely effective all-weather tool. Its primary disadvantage is that it can record relatively poor detail compared either to instruments using the infrared region or to those using the visible region. Since twenty-four-hour surveillance of an entire country would require extremely large numbers of aircraft, it is doubtful that one would sacrifice the detail obtainable by use of the visible region of the spectrum for the advantage of all-weather operation. As a consequence, one must assume that an air inspection system of optimum performance would depend to a large extent on the use of the visible portion of the spectrum and would incorporate instruments designed to use other portions of the spectrum for special purposes.

Of the many reconnaissance instruments employed in the visible region, the eye is the most common. Visual reconnaissance was utilized to a large extent during the First World War, to a lesser extent during the Second World War, and played a relatively minor role during the Korean police action. The major defect of visual reconnaissance is that the eye is a relatively low-resolution instrument, particularly from high altitudes. Images are transitory and consequently subject to misinterpretation, since no permanent record is made for subsequent study and evaluation. As air vehicles become faster, the visual observer is called upon to examine larger areas of territory per unit time; consequently his ability to reliably discern specific objects decreases rapidly. On the other hand, visual reconnaissance does permit the observer to make an immediate evaluation and to take immediate action when necessary.

To meet the requirements imposed by modern aircraft—i.e., high altitude and high speed—optical aids, such as stabilized binoculars, closed-loop television systems, and so on, may be employed. These cannot overcome the inherent limitations of lack of a permanent record, but they do improve the human observer's qualifications for the task to be accomplished.

Electrooptical systems, such as television, combine the advantage of a permanent record with the potential for immediate response. Such systems require complex electronic equipment capable of transmitting the information required on a continuous basis and recording it at a home base for subsequent examination and evaluation. The transmission system must of necessity limit the amount of information which can be gathered by the electrooptical sensor. The advantage of its immediate-reaction capability must therefore be weighed against the amount of information required.

The photographic technique has long been the backbone of military aerial reconnaissance and has been extensively used for commercial purposes as well. Almost all large-scale surveying, for example, is now accomplished by aerial photogrammetry. In addition, many industries use aerial photography as a primary tool in prospecting. This is especially true of the oil industry's prospecting for new locations and of the lumber industry's efforts to discover areas where lumbering operations will be profitable. Civil government employs the technique extensively in urban area planning and in road building.

The major advantage of aerial photography as a reconnaissance technique is that it allows the recording of extremely fine detail in permanent record form. However, it imposes rather severe time delays, since the record cannot be examined until after the aircraft has returned to base and the film has been processed. But in the absence of a requirement for an immediate reaction capability (and the only circumstance under which such a capability would be needed is the specific one of warning of surprise attack) the photographic sensor is the most suitable tool for aerial inspection. It is entirely probable, though, that limited use of both visual and electrooptical reconnaissance as adjuncts to photography will be profitable in the final design of an aerial inspection system.

THE PHOTOGRAPHIC INSPECTION SYSTEM

A photographic inspection system is composed of three major functions:

1. *Data gathering.* The acquisition of raw data by air-borne photographic instruments.
2. *Data reduction.* The processing of the negative, plotting of coverage, and interpretation of the photography.
3. *Intelligence production.* The evaluation and collation of information and subsequent preparation of an intelligence report.

Data Gathering

Although the types of information needed for an effective inspection system have been discussed generally above, a more precise analysis may be made. The ensuing discussion is based on the conditions presented by a major land mass of about 10 million square miles. The estimated inspection method would be useful both for inter- or intracontinental surveillance.

Table I summarizes a proposed photographic data-gathering system, giving scale, frequency of mission, and other requirements of the three main types of mission which comprise such a system.

The search mission. The first task of an aerial inspection force would be to conduct a search mission to verify the accuracy of previously submitted military and industrial blueprints. This could be accomplished by photography of relatively small scale on the order of 1:100,000, because objects of gross proportions would be involved. The total area to be covered would be approximately 9,000,000 square miles. Since major changes occur over long time periods, it is doubtful that total area search would need to be carried out more frequently than twice a year, a frequency appropriate to times involved in major construction projects.

The limited area search mission. This second type of data-gathering mission is primarily concerned with major routes of communication. Navigable rivers, railroad lines, and main arterial highways would be patrolled, since appreciable changes in density of traffic along these transportation routes are excellent indicators of military activity. An appropriate scale for limited area search would be on the order of 1:20,000. The frequency of coverage would have to be increased to approximately once per week, in view of the transitory nature of the traffic.

It would be extremely difficult to maintain surveillance of each mile of a complex transportation network. Selection of critical area could be accomplished by using the results of the search mission and by keying the transportation arteries inspected to the specific objectives discussed below.

The specific objectives surveillance mission. There are three categories of specific objectives to be monitored in this third type of data-gathering mission: military installations, transportation centers, and selected industries. Military installations include air bases, proving grounds, training grounds, supply depots, army bases, naval bases, and conventional and unconventional weapons stores. Transportation centers include commercial shipping facilities and docks, rail centers, air

TABLE 1

A Proposed Photographic Data-Gathering System

Mission	*Targets*	*Dimensions*	*Scale*	*Equivalent Number 9 x 9 Photos*	*Frequency*
SEARCH	Total Area	9 x 10^6 sq. mi.	1:100,000	225,000 [d]	Every 6 months
LIMITED AREA SEARCH	Rail Lines Navigable Rivers & Canals Roads 1st Class, all weather	180,000 lin. mi.	1:20,000	66,500 [e]	Every week
SPECIFIC OBJECTIVES					
Transport Centers [a]	Shipping Rail Air Road Hubs	5,500 sq. mi.		13,000 [d]	Every week
Selected Industry [b]	Aircraft Shipyards Steel Military Vehicles Atomic Energy Electronics Chemical Petroleum Refining Power (major hydro. plants)	3,000 sq. mi.	1:10,000	7,500 [d]	Every week
Military Installations [b]	Air Bases [c] Army Bases Naval Bases Proving Grounds Training Grounds Supply Depots Conventional Weapon Stores Unconventional Weapon Stores	3,700 sq. mi.		9,000 [d]	Every week

[a] Estimated at 25 sq. miles/target.
[b] Estimated at 15 sq. miles/target.
[c] Reliability of estimated numbers questionable.
[d] Computed on the basis of 50% side lap and 60% overlap.
[e] Computed on the basis of 10% overlap.

transportation centers, and truck depots. Finally, selected industries include aircraft factories, atomic energy plants, shipyards, the steel industry, power facilities, military vehicle factories, electronics factories, and petroleum refining chemical plants.

The purpose of surveillance of these specific objectives is to detect changes, such as a shift of personnel from one military center to another, an increase in training activities, or an increase in output by manufacturing concerns. All these can be conveniently detected at scales of approximately 1:10,000. Once again, a frequency of once per week would probably suffice to record the changes that a specific site was undergoing.

These targets do not comprise an exhaustive list. They are intended only to provide a crude estimate of the magnitude of effort required in a data-gathering system.

Table I also contains an estimate of the number of 9 x 9 prints per year that would be obtained by this proposed data-gathering system, based on some assumptions as to numbers of installations, transportation centers, and selected industries to be surveyed. This in turn forms the basis for estimating the number of personnel required in order to process this information and to formulate intelligence estimates as a result; this estimate is discussed below in connection with data reduction and intelligence production.

The unit of 9 x 9 prints has been selected only because experience gained in the Second World War can be directly expressed in these terms. Improvements in the quality yielded by aerial photographic systems have been made and as a result more detail per square inch of film can be obtained. For computational purposes, these can be transformed into 9 x 9 prints of quality equal to that of prints made during the Second World War.

The author has discussed more comprehensively the relationship between observable detail size and ground coverage for various specific optical systems, in hearings held before the Subcommittee on Disarmament of the Senate Committee on Foreign Relations.

> The flexibility of air reconnaissance is such that ground detail as small as one foot in dimension may be analyzed, or huge urban areas, industrial installations and transportation systems may be encompassed on one photograph. These two capabilities do not exist concurrently. Detection and analysis of small detail implies limited area coverage and the expenditure of time, both in flight and in the analysis of collected data. For example, we conceive

of a search system composed of a single 6″ vertical camera at an altitude of 50,000 feet. A reasonable estimate of the detail size detectable would be on the order of 20 feet on the ground. Such a photograph encompasses a total ground area of approximately 225 square miles. These are all quite conservative estimates. On the other hand, to detect objects of a one foot dimension would require an optical system of such a magnitude that ground coverage is reduced to a little over one half of a square mile. To detect objects which are of a two foot dimension, the optical system required would produce a ground coverage of approximately 2¼ square miles. It is evident that the detail size required is all important in determining the feasibility of the reconnaissance system since the number of photographs required increases at an astounding rate with a decrease in detail size.

A system of inspection in support of a disarmament program today may be faced, for example, with the necessity of surveying a huge land mass of approximately 9 million square miles. If we are concerned with the detection of the initiation of an air attack with current weapon systems, the size of significant targets makes the task formidable but well within the scope of existing search systems. This, I believe, is equally true for the case of an intercontinental attack against this nation or a relatively short-range air attack against member nations of NATO. Preparations for ground attack in Europe or peripheral areas which require the massing of men and machines is equally susceptible to detection by means of this existing search system.[4]

Implementation of Data-Gathering

In order to implement a mutual inspection system, it would be necessary to provide safeguards to ensure against evasion or misuse. Accordingly, a hypothetical operational plan has been outlined by the White House Disarmament Staff, incorporating control procedures which could be employed in regulating air inspection missions.

a. *Inspecting aircraft's port of entry.* Specifically designated peripheral air bases just within the boundaries of participant nations could be used as clearance points. In the case of USSR inspection of the United States, it is possible the Soviet air inspection command may be stationed permanently within U.S. territory. Whatever bases this command might use could probably also serve as the Soviet origin and clearance point in this country. Air bases other than designated peripheral bases would be used by USSR inspection aircraft only in an emergency.

b. *Inspection of aircraft by host government.* Preparatory to every aerial inspection mission, inspection aircraft could be closely examined by representatives of the host country either visually and/or by radiation detection devices. The planes themselves might be painted special colors, and

[4] Hearing before a Subcommittee of the Committee on Foreign Relations, United States Senate, Part 5, April 9, 1956, pp. 205, 206.

would likely bear the insignia of either the United Nations or the international disarmament control organization. While it seems highly doubtful that any nation would attempt so flagrant a violation as the concealment of bombs or other weapons, such attempts would be immediately detectable in a pre-flight examination of the craft. Host country officials would be under obligation to avoid any undue delay to the flight in conducting this check.

c. *Observer on inspecting aircraft.* With an inspecting plane ready to leave on its mission, a representative of either the host country or of the international disarmament control organization could come aboard to observe the operation throughout the flight. If deemed necessary, the observer could maintain radio communication with monitoring agencies of the host country. Reports filed by these observers would assure full compliance with whatever laws might govern the program.

d. *Filing of flight plans.* Air inspection teams would in no way be restricted as to what and where they might photograph, as long as the object or territory fell within bounds of the agreement. However, air traffic safety factors would demand certain precautions, and one of the most important of these would be the filing of detailed flight plans with the host country prior to each air photo mission. In this regard, aircraft could be required, regardless of flight conditions (Instrument Flight Rules or Visual Flight Rules), to maintain the exact altitude and follow the exact route designated in the flight plan. Prior to implementation of an inspection system it is probable that inspecting nations will make known their projected plans for initial, overall coverage.

e. *Restrictions on inspecting aircraft.* The planes must be entirely unarmed. Their crews will have to adhere closely to regulations governing air traffic safety in the country under inspection. As long as this latter requirement was honored, the aircraft would probably be granted complete freedom of access to ensure the success of their photographic missions.

f. *Monitoring of flights within host country.* Throughout their inspection flights, aircraft would be kept under constant surveillance by the host country. This could be accomplished electronically, or through actual visual observation by a host country companion plane, armed and flying alongside the inspection craft. Continuous charting of the progress of the air photo plane would be maintained at air control centers. Should the inspection aircraft deviate from the stated flight plan, or indicate any suspicious intentions, the host country companion plane could force it to land at the nearest suitable air base, or return to its base of departure. In addition, alerted by a flight monitoring center, fighter aircraft could intercept the inspection air craft in a matter of minutes and force it to land.

g. *Monitoring of aircraft to and from host country.* Basically, the same techniques suggested in paragraph (f) could be employed to track approaching and departing inspection aircraft, which could be required to follow designated air corridors. The host country would probably require radio contact and clearance, well in advance, as foreign inspection craft approached its borders. Electronic surveillance of the nature and position of the approaching planes could be maintained. Simultaneously, a squadron of planes could be dispatched to meet and escort the inspection craft into a port of entry. Normal radar facilities would detect any unannounced arrival.

h. *Bases for U.S. and Soviet inspection planes.* The United States currently has available air bases in many parts of the world, and from economic and other standpoints, it would probably prefer to use these as headquarters for planes inspecting Soviet Russia. Permission would be sought from countries within which the bases are located. Since air bases available to the Soviet Union are far from the United States, our nation might offer the use of two or three locations for the stationing of planes and the billeting of some personnel. Some thought might therefore be given to Soviet use of bases in the Pacific Northwest and Northeastern areas of this country.

i. *Actions of departing inspecting aircraft.* The inspection aircraft would probably land again at what had been their original entry point, and the flight observer would deplane. Certain routine actions—refueling for the return flight, perhaps—would undoubtedly take place, but the host country would have no access to whatever reconnaissance material had been gathered. Unless an agreement provided for filing of this information with the international disarmament control organization, it would remain the sole property of the nation which had conducted the inspection mission.[5]

Photographic Equipment for a Data-Gathering System

Photographic aircraft sufficiently equipped to accomplish the tasks listed in Table I under the conditions specified are presently available in the United States Air Force. A suitable choice of vehicle would be the RB-47 (medium reconnaissance aircraft).

The RB-47 contains seven precision cameras, each with a specific job to do. The seven cameras are arranged in four installations: the trimetragon, the true-vertical, the split-vertical, and the forward oblique.

The trimetragon installation, which consists of one vertical camera with two oblique cameras arrayed at right angles to the line of flight, covers the area on the ground from horizon to horizon. This type of installation is principally used for charting, but because a relatively short focal length lens (6″) is employed, it is excellent for large area search. Sufficient detail for discovery of targets is obtained out to about 60° from the vertical.

The true-vertical installation, consisting of one 9 x 18 format

[5] Disarmament Background Series, No. M-9, *Fact Sheet on Aerial Inspection*, prepared by White House Disarmament Staff, September 28, 1957, pp. 4-6.

camera, covers a considerably smaller area on a much larger scale. This camera would be used for specific objective surveillance.

The split-vertical installation consists of a pair of cameras, each mounted slightly off true-vertical, to provide more coverage than a single vertical photograph and is capable of acquiring more detail than the trimetragon arrangement. Such an installation would be of use for either limited area search or specific objective surveillance.

The forward oblique installation consists of a 9 x 18 format camera pointed directly ahead of the plane at an angle between vertical and horizontal, to obtain oblique views of ground tragets. In specific cases an oblique view is of great assistance in interpretation.

An excellent description of the RB-47 aircraft and its photographic installations is presented in a publication by the United States Information Service entitled *Mutual Inspection for Peace*. This booklet introduces the reader to the general principles of aerial photography, including the use of camouflage detection film, and offers a good example of an interpretation report on an urban area.

Data Reduction and Intelligence Production

The total number of photographs produced by the proposed inspection system is comparable to that obtained in the course of significant military actions during a major war. Data reduction thus constitutes a problem of major proportions, particularly if it is to be accomplished in a reasonable length of time.

The task could be reduced considerably by a judicious combination of ground point control and aerial inspection. Such a combination would, of course, overcome some of the basic limitations of aerial reconnaissance, such as its inability to differentiate between a practice mission and an actual attack, and the lack of continuity imposed by meteorological conditions, while permitting the employment of aerial photography in the manner best suited to its capabilities.

The task of examining the 225,000 photographs yielded by the total area search mission in a period of thirty days, for example, is not unreasonable for a group of fifty skilled photointerpreters. With some augmentation, such a group could cope with the returns from the specific objective mission as well. However, in order to make the most of the group's efforts, techniques for gaining rapid access to previous coverage will have to be developed and equipment designed for rapid indexing, storage and retrieval. These must of necessity play a dominant role in the success or failure of such an inspection system.

The task of maintaining surveillance over major transportation routes, however, imposes an overwhelming work load on the data reduction system. It will be necessary either to use a very sophisticated method of sampling, so as to drastically reduce the number of photographs obtained, or to depend on ground inspection at key centers to obtain traffic information.

The problem of intelligence production is made more complex by the necessity of combining previous data and data from other sources with the information collected. Existing intelligence systems lack sufficient automatic equipment to meet the time limitations that a functioning inspection system would impose.

CONCLUSION

It is apparent that aerial reconnaissance makes its greatest contribution to the inspection problem in the function of checking on the accuracy of a previously submitted "blue print" and detecting major trends in the state of preparedness for waging war. To be valuable as a means of supplying warning of an imminent attack, it would require in addition a well coordinated plan of ground point control.

At this writing, it is assumed that major countries do not as yet have an intercontinental ballistic missile in their inventory. Public announcements have been made of the successful test firing of such a missile, and in recent weeks the first earth satellite has been observed describing its orbit around the world. The technical achievement of placing the satellite on the difficult orbit chosen by the Soviets indicates that they have in all probability solved the propulsion problem associated with the ICBM, and to some extent have solved the navigation problems as well. Nevertheless, it will take time for them to manufacture an operational quantity of intercontinental ballistic missiles and to construct and secrete suitable launching bases. The aerial reconnaissance system discussed above is perfectly adequate for conventional aircraft. When the intercontinental ballistic missile becomes a part of the Soviet inventory, however, it will pose a threat which cannot be detected by such an aerial inspection system. Well-camouflaged installations, conceivably for the most part under ground, when completed will present the problem of detection of extremely small object sizes. The task of identifying underground launching sites may be compared to the task of discerning manhole covers from 50,000 feet in the air. Ground inspection would be of even less value in this situation; to have ground parties conduct an inch-by-inch search of large land areas like the entire Soviet Union or the whole United States would be an inconceivably difficult project.

Mr. A. H. Katz of the Rand Corporation has recently expressed the concept that the area of the earth to be inspected in a mutual inspection system is rapidly increasing. At the present time, a relatively small portion of the earth's surface is involved, possibly 15,000,000 square miles. If the possibility of missiles being launched from submarines is taken into account, then a good deal of the earth's surface which is covered by water will have to be considered, and this increases the area to be inspected to 200,000,000 square miles. This requirement is, of course, far more formidable than the requirements that an inspection system would have to meet today. Furthermore, it is not inconceivable that there will some day be space platforms from which missiles could be launched.[6] When this happens, the yardstick of millions of square miles will become meaningless; the area to be inspected will defy human capabilities.

The important point to be drawn from the foregoing discussion is that whereas aerial inspection would serve an important function today, while weapons delivery systems still consist of conventional aircraft, it will be of almost no value once the intercontinental ballistic missile becomes part of the military arsenal.

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[6] *Life*, October 24, 1957, pp. 19 *ff*.

THE CONTROL OF DISARMAMENT BY FISCAL INSPECTION

by Jesse Burkhead

THE GROWTH of government has been accompanied by the invention, establishment, and improvement of techniques intended to assure increased responsibility and accountability in fiscal affairs. Every modern government has a budget system, with an established procedure for proposing, reviewing, and approving government revenue and expenditure. Every modern government has an accounting system with both internal and external controls over funds. Moneys may not be committed nor expenditures made to liquidate obligations until prescribed legal safeguards have been observed. The books of account are audited periodically by the staff of an agency other than the spending agency. Customarily, this audit is under the jurisdiction of an independent tribunal or the legislature.

The federal government in the United States has a system of fiscal administration whose contemporary characteristics date from the Budget and Accounting Act of 1921. The system will be outlined, as background for a specific examination of the feasibility of controlling disarmament by fiscal inspection.

I

The legislation of 1921 established the Bureau of the Budget and the General Accounting Office. The former agency is charged with

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assisting the President in preparing, for each fiscal year, a statement of proposed appropriations and expenditures to be transmitted to Congress. The General Accounting Office is responsible for auditing the books of account of the administrative agencies and departments. The GAO is headed by the Comptroller General, and reports to Congress.

Budget and accounting procedure in the U.S. government is, in general, as follows:

The fiscal year begins on July 1st and terminates on the following June 30th. In the spring of each year, about fifteen months before the beginning of the fiscal year to which the estimates are to apply, each department and agency in the federal establishment initiates the preparation phase of the budget cycle. This consists of securing budget proposals and statements of requirements from the various bureaus and field agencies of a department or agency and, as a second step, consolidating these requests into the departmental budget. Somewhat later, in June or July of each year, the Director of the Bureau of the Budget issues a formal call for estimates, asking each agency to submit its request for funds, and suggesting the underlying assumptions with respect to policy on which budget requests are to be based. Agencies submit these estimates to the Bureau of the Budget in the fall of each year. The estimates are then subjected to detailed scrutiny by the staff; closed hearings are held for purposes of questioning and challenging the estimates as presented.

It is the responsibility of the Budget Director, working with and in behalf of the President, to review and balance all agency requests for funds. New programs or expanded programs may be presumed to be subject to particularly sharp examination. Such programs are usually initiated by the agencies but may emerge from the Executive Office or from *ad hoc* presidential committees. The budget as it emerges is the President's budget and is an expression of Presidential responsibility for the fiscal management of the Executive Branch.

In Congress proposed budget expenditures are examined by subcommittees of the House and Senate Appropriations Committees. This examination, particularly in the House, is very often searching and revealing. Experienced members of the subcommittees are able to probe the "soft" spots in the budget to disclose areas where reduction may be made. Each agency or department defends its own budget before the subcommittees; the Bureau of the Budget does not intervene at this stage. However, the staffs of the appropriations committees are small and Congressional examination of the details of the budget does not match in thoroughness and depth the examination by the staff of the Bureau of the Budget.

The important budget-making work of the Congress is carried on by the subcommittees of the appropriations committees. This work is reflected in a series of appropriation bills—from 12 to 15 each year. These are customarily acted upon by both the House and the Senate with very little floor debate, and are then reconciled in conference committee and sent to the President for signature.

With the exception of funds appropriated to the President, appropriations are generally made to agencies and departments. However, before obligations may be incurred by the agencies, the Bureau of the Budget must apportion the obligational authority which is available. This means that each agency or department must propose a fiscal plan for the forthcoming year to show the rate at which funds will be committed. Beyond this, each agency controls the use of funds within the agency. The budget office of the agency allots funds to units or divisions of the department, usually on a monthly or quarterly basis.

These controls over the execution of the budget are paralleled by a pattern of financial control administered by the Treasury Department to assure that expenditures are made in accordance with the constitutional prescription that "No money shall be drawn from the Treasury, but in consequence of appropriations made by law . . ." (Article I, Section 9). After appropriation bills have been signed by the President, the Secretary of the Treasury directs the Treasurer of the United States to open accounts to the credit of disbursing officers of departments and agencies. These accounts are maintained in Federal Reserve Banks. Responsible designated officials in the departments now enter into contracts for the purchase of goods and services. As public creditors present bills for payment, other officials certify the account and direct the disbursing officers to issue checks to liquidate the obligations.

Sometime after the close of the fiscal year the General Accounting Office audits the books maintained by certifying officers and disbursing officers. The audit extends to examination of the legality of transactions to ascertain that moneys were spent in accordance with purposes designated by Congress. The Comptroller General reports to Congress the results of all audits, including cases where established procedures have been violated or where fraud has occurred. Since 1948 the General Accounting Office has encouraged the decentralization of accounting within the federal establishment. Agencies and departments have been given greater control over the installation and maintenance of their accounting systems. Correspondingly, the GAO audits have sought to verify the accuracy and reliability of the agency's system as a whole rather than the accuracy of individual transactions.

II

Most students of public finance would agree that the pattern of budgetary and accounting controls in the U.S. government maintains reasonable standards of accountability. This system of fiscal administration was established to assure that agencies would spend in accordance with the specific purposes set forth by Congress, and to assure that agencies would not spend more than their appropriation and thus require a deficiency appropriation. The system also makes it possible to detect fraud and embezzlement.

The question to be asked is this: Could this pattern of budgetary and accounting controls be used to enforce a disarmament agreement to which the U.S. government was a party? To answer this question it must be assumed that fiscal inspectors would have access to all of the financial records of an agency—budget presentation, books of account, and internal audits—and the records of the Bureau of the Budget, the Treasury, and the General Accounting Office.

Two cases may be distinguished. The first is a disarmament agreement which has been operative for a number of years and which has been effective in achieving substantial reductions in U.S. government outlays for national defense. It might be assumed that this would bring net budget expenditures down to about $50 billion, of which $20 billion might be for national defense. At this budgetary level fiscal controls might be effective in enforcement. That is, if an attempt were to be made within the U.S. government to violate the agreement by the expenditure of a relatively large amount—say $1 billion—for "illegal" weapons, such expenditure would be most difficult to disguise.

The second case, which will be examined here in detail, assumes that disarmament starts from existing budgetary levels and seeks to prevent the accumulation of specific weapons whose annual costs would approximate $100 million. In this case the budget and accounting system could not be expected to be effective in controlling disarmament. Fiscal inspection could make no contribution to the support of a general inspection plan for the control of specific weapons.

In the first case an unexplained and large change in budgetary expenditures could be detected by a careful observer of the published financial statements. But in the second case such detection could not be made. The U.S. fiscal control system is not designed to thwart complicity. If there were an agreement among a dozen key officials strategically placed in such agencies as the Department of Defense, the Bureau of the Budget, the Treasury, the subcommittees of the appropriations committees, and the General Accounting Office—an agreement that it was desirable and in the national interest to spend annually the sum of $100 million on armaments—the budget and accounting system would not in itself disclose that this was being done. For amounts of expenditure greater than $100 million increasing difficulties would be encountered. At some point—perhaps at an annual expenditure of $1.0 billion—detection would be most difficult to escape.

There are two known experiences which support the conclusion that at least $100 million of expenditure could be undertaken without public knowledge. The first is the Manhattan Project. After atomic bombs were exploded over Japan in the summer of 1945, it was disclosed that the expenditures to date on the Manhattan Project had amounted to about $2 billion. For the fiscal years 1944 and 1945, the amounts expended must have totaled at least $400 to $500 million annually. An indication of the size of the atomic energy program during the war years is revealed by the expenditures recorded in the 1948 budget for the Atomic Energy Commission. The AEC, organized under the Atomic Energy Act of 1946, assumed control over the projects which had formerly been administered by the War Department. It may be assumed that expenditures in the first year of AEC's operation were of about the same magnitude as those of the Manhattan Project in immediately preceding years. These are shown as $418 million for fiscal 1946.[1] Comparable amounts were buried in the budget during the war years, undoubtedly within the general heading of "War Activities."

The second experience is with the Central Intelligence Agency. Although Congress has legislated with respect to CIA, the *Budget of the*

[1] *Budget of the United States Government for the Fiscal Year Ending June 30, 1948*, p. 83.

United States Government contained no mention of the agency until fiscal 1957. This budget recorded a $5.5 million supplemental appropriation which had been made by the Congress for fiscal 1956 for planning the construction of a CIA headquarters installation. The budget also proposed a $49 million appropriation for construction.[2] However, neither this budget nor previous budgets have presented information on the operating expenses of CIA. There are no data on the amounts of annual expenditure or on the number of employees.

On the basis of the information on CIA's headquarters construction, speculations may be made about the possible minimum size of the agency's budget for headquarters operating purposes. It has been reported that the Atomic Energy Commission expects to house its 1,600 headquarters employees in a new building costing about $10 million.[3] For fiscal 1958 AEC expects to pay its headquarters staff about $11,-244,000.[4] If it may be surmised that the cost of space per employee is about the same in AEC as in CIA, and if it may be conjectured that salary levels and skills are comparable in the two agencies, it would follow that the CIA headquarters staff is about five times as large and spends about five times as much for headquarters staff salaries as AEC. This would mean that the Central Intelligence Agency might employ about 7,800 persons in its new building and pay this group salaries of about $56 million.

This estimate would not, of course, cover the whole of CIA's annual appropriation. The agency might occupy other structures in Washington; it might conduct some operations in the field outside of Washington. Its total appropriation may be guessed to be at least $56 million; it may be several times this amount. The exact amount is irrelevant here. The fact is that large sums of money are hidden in the budget each year for the support of this agency.

III

There are a number of conditions which characterize the operation of the national government and which would contribute to the ineffective-

[2] *Budget of the United States Government for the Fiscal Year Ending June 30, 1957*, pp. 123, 255. There was a brief discussion on the floor of the Senate of the cost of CIA's proposed structure at the time of the supplemental appropriation. See *Congressional Record,* June 25, 1956, p. 10970.

[3] *U.S. News & World Report,* March 22, 1957, pp. 62-5.

[4] *Appendix to the Budget for the Fiscal Year Ending June 30, 1958,* p. 25.

ness of fiscal control of disarmament. The first of these is the sheer size of the federal government, and particularly of the military. Net budget expenditures for fiscal 1958 are estimated at $72.8 billion. Of this, national security outlays will amount to $44.7 billion. It may be noted that the gross national product for the economy as a whole will probably be in the neighborhood of $430 billion for fiscal 1958. Therefore, federal expenditures are about one sixth as large as the total of the nation's economic activity. This means simply that departments and agencies, the Bureau of the Budget, and Congressional committees deal with very large magnitudes and are not able to follow with exactitude the programing and expenditure of each and every million dollars. Experienced members of the Appropriations Committee of the House have, on occasion, found errors in the budget presentations of the armed services that amount to tens of millions of dollars.

A second factor which would contribute to the ineffectiveness of fiscal controls over disarmament is the character of the expenditure programs of the Department of Defense. A substantial portion of military expenditures consists of the procurement and production of major equipment. For fiscal 1958 this is estimated at $13.6 billion of the $44.7 billion total for the fiscal year. This is in addition to the construction of $1.9 billion of military public works.

These very large outlays on equipment require that the armed services have an extremely complex procurement pattern, with several thousands of contracts with several thousands of firms. The procurement officers in the Army, Navy, and Air Force must themselves be depended upon to assure performance under these contracts. The complexity and size of the operations are beyond the competence of the Bureau of the Budget, the General Accounting Office, or the staffs of Congressional committees to review adequately. Moreover, military technology has reached the point where projects are broken down into sub-projects and sub-sub-projects with a corresponding complexity in procurement. This might make it possible to outwit the fiscal reviewers by the purchase of legal components and sub-components for assembly into an "illegal" combination. That is, items which were permitted under an international agreement might be obtained quite legally and put together at an installation that was outside government control.

A third factor is that budget programs in the armed services change substantially from one year to the next. Changes are dictated not only by strategic considerations, but also by changing military technologies, changing command structures, and changes in budget classification within the Department of Defense. Fluctuations in the size and nature of budget programs would contribute to the possibility of disguising specific expenditures.

A fourth factor which would contribute to the ineffectiveness of fiscal controls is the trend toward decentralization of accounting responsibility. In recent years, as noted above, the General Accounting Office has revised its system of auditing. Agencies and departments now have responsibility for their own accounting systems. Individual transactions are audited on a sample basis. This system has made a substantial contribution to the improvement of accounting efficiency in the federal government. Nevertheless, if there were an organized effort for the "illegal" expenditure of funds, the absence of a detailed central audit of every transaction of an agency would make this expenditure easier to carry through successfully.

If there were an intent to engage in the expenditure of—say—$100 million of federal funds in violation of an international disarmament agreement, by what technique could this be accomplished? There would appear to be a number of possibilities, and the following are certainly not exhaustive.

It may be conjectured that such an effort would seek to divert the $100 million out of the federal government, that is, it would be arranged that a private firm or a private group would engage in the surreptitious production of armaments. It would be necessary to pay this group with federal funds. These payments might be arranged within the budgetary totals, as recorded in the accounts of the federal government. There is also a possibility of diverting revenues before they are recorded as budgetary receipts.

To keep such transactions within the budgetary totals would mean that the Treasurer of the United States would be making payments within an aggregate which had been authorized by Congress. The expenditure would thus need to be disguised within an existing appropriation. There are several possible ways of effecting this subterfuge.

One of the most likely ways for disguising an appropriation would be in armed forces procurement contracts. For example, appropriations might be padded for the alleged purpose of creating a contingency reserve as a protection against rising costs. The accumulations in such a reserve might then be diverted for the procurement of "illegal" armaments, perhaps from the same companies that are providing other items of military hardware for the same armed services. The atmosphere of secrecy which surrounds much of military research and military procurement would contribute to the success of such a venture.

A second possibility, also within the military, would involve the use of the revolving and management funds that have been established in recent years for the operation and financing of enterprise-type activities within the Department of Defense. The Army Stock Fund, for example, will incur obligations of $2.4 billion for fiscal 1959; the Navy Industrial Fund will obligate $1.4 billion in fiscal 1959.[5] These sums are not appropriated directly to the management funds but are transferred from other branches of the Army or Navy, as the case may be, in payment for goods and services. Since no direct appropriations are involved, the financial operations of the management funds are not always subject to the same degree of examination by the Bureau of the Budget and Congressional committees as is the case with appropriated funds. In these circumstances it might be possible to divert substantial moneys to the production of "illegal" armaments.

A third possibility is the utilization of military assistance and defense support funds which are appropriated to the President. These are a part of the Mutual Security Program and permit obligations of $1.9 billion in fiscal 1958. In these programs the President, working with the Secretaries of State and Defense, has wide latitude in the procurement, at home and abroad, and in the distribution of military equipment to strengthen the defense of nations friendly to the United States. The diversion of a part of these funds for the support of a prohibited armaments effort might be possible.

If expenditures were to be made without a prior appropriation, it would be necessary to divert budget revenues into a special deposit account. Non-tax revenues would be easier to divert than tax revenues. Therefore, such items as income from the sale of agricultural surpluses, income from the sale of war surplus material, or revenue destined for the National Service Life Insurance or Old Age and Survivors' Insurance trust funds might qualify for diversion. This kind of diversion would probably be more difficult to effect without detection than that

[5] *Budget of the United States Government for the Fiscal Year Ending June 30, 1959*, pp. 464, 491.

which disguised an "illegal" expenditure within an appropriation. Nevertheless, it should not be ruled out as impossible.

Finally, it might be possible to arrange for the production of $100 million of armaments entirely outside the pattern of budget revenue and expenditure. This might be arranged by "trading" a tax concession to firms that would produce armaments in exchange. A favorable audit for tax purposes, or a tax amortization certificate which entitled the holder to accelerated depreciation for a period of years, might be traded under these circumstances.

The foregoing possibilities are illustrative of ways by which it would be possible to arrange for the financing of "illegal" expenditure for armaments in violation of an international agreement. The conclusion is this: Fiscal inspection would not be effective in the control of expenditures of $100 million in a budget of $70 billion. However, if the national budget were substantially reduced, and if national defense expenditures were at a much lower level than at present, then fiscal control would be useful in contributing to the detection of outlays of the magnitude of $1 billion in a budget of $40 billion.

THE DETECTION OF NUCLEAR WEAPONS TESTING

by Jay Orear

INTRODUCTION

THIS PAPER will discuss the problem of detecting possible violations of an agreement banning nuclear weapons testing. Such an agreement could either be a part of a general disarmament agreement, or it could be a separate "first stage" agreement.

It is well known that many unannounced nuclear weapons tests have been detected at large distances by various monitoring techniques. This paper is mainly devoted to the technical question: Under what conditions are these techniques sufficient to detect violations of a test ban agreement? In particular it is of importance to know whether such a monitoring system is so simple and workable that it would not encroach upon a nation's internal security. Because monitoring stations present almost no interference with internal security, a test ban has often been proposed as a possible "first step" to disarmament. It would not in itself be disarmament, but it could be a test of good faith which could lead to further agreements. In fact the establishment of monitoring stations by an international inspectorate throughout the entire Soviet Union and United States would in itself be more progress toward disarmament than has been made in the last twelve years. Most other types of disarmament agreements would require a degree of inspection and free access which a limited access nation like Russia would be reluctant to accept.

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It will be shown in this paper that an adequate inspection system for a test ban would require the establishment of monitoring stations at various locations deep inside large geographical testing areas. About twenty-five such stations uniformly distributed throughout the Soviet Union and seven such stations within the United States should be sufficient for these two testing areas. If the presently existing seismic stations were required to mail copies of their records to the international inspectorate, this number of stations could be vastly reduced. For example, the existence of four or five international seismic stations in the Soviet Union would make alteration of the records of the other seventy-five existing stations an impossibility. There is hope that such an inspection system would be acceptable to Russia, since it was Soviet delegate Valerian Zorin who proposed in the June 14, 1957, meeting of the UN Disarmament Subcommittee that the test ban agreement "be implemented by scientific control posts to be set up in the United States, Union of Soviet Socialist Republics, United Kingdom, and Pacific Ocean areas."

The main techniques for detection of nuclear weapons testing are: (a) detection of acoustic waves, (b) detection of seismic waves, (c) detection of electromagnetic radiation, and (d) detection of radioactivity. These techniques will now be discussed in more detail.

METHODS OF DETECTION

Detection of Acoustic Waves

Much of the radiation released in a nuclear explosion is degraded by atomic processes to kinetic energy of the air molecules. Except in the immediate region of blast effects, this disturbance travels with the speed of sound and can be detected by sensitive microbarometers (1-5). This technique accurately gives the location and time of the test, and also gives a measure of the size of the explosion (yield in kilotons of TNT). The general feeling is that except for deep underground explosions, and except for those of sub-nominal yield,[1] nuclear tests can be detected at very large distances by this technique. Thus low yield tests of just a few kilotons TNT equivalent would probably require monitoring stations within large testing areas. Low yield tests could probably be detected at distances up to a few hundred miles. Dr. S.

[1] Nominal yield is defined as that of a Hiroshima-type bomb.

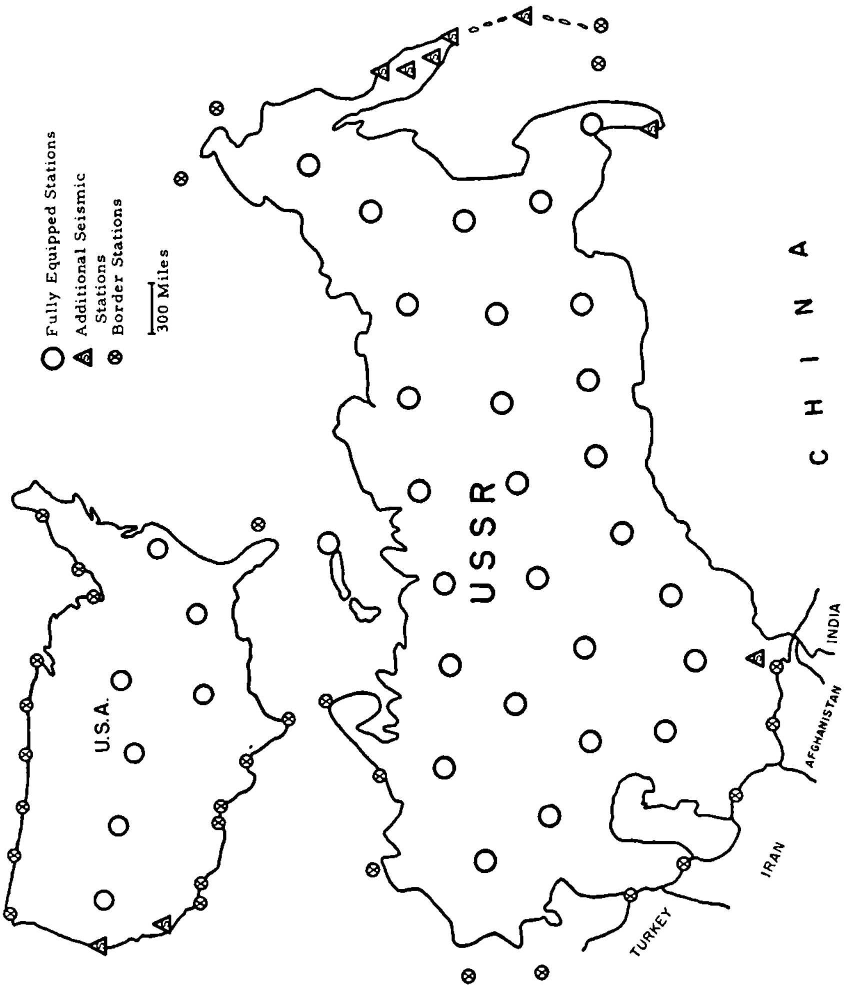

FIGURE 1

Minimum Number of Stations to Meet 300-Mile Requirement in the United States and the Soviet Union

Kawabata, chief of Observation Division, Japan Meteorological Agency, says: "Assume an observatory every 300 miles is placed in Soviet territory and these observatories are equipped with very sensitive seismographs, microbarographs, and instruments to detect radioactivity. In this case, we think we can detect all of the explosions" (6).[2] If we require that every point be within 300 miles of a monitoring station, about twenty-five stations would be needed within the borders of the Soviet Union and seven inside the United States. (See Figure 1.) A similar density of stations would be needed in other possible testing areas. In general, the microbarographic technique of detection is the most sensitive and would usually be the most relied upon. The special problem of very low yield tests will be discussed later. The problem of deep underground tests is treated in the following discussion on seismic waves. The problem of very high altitude tests is discussed in the section on electromagnetic radiation. In this case there will still be an acoustic wave, but its magnitude may be reduced.

Detection of Seismic Waves

In air, underwater, and surface explosions, a significant fraction of the energy is transferred to the ground as seismic waves. Thus, all tests, whether underground or not, give rise to seismic waves which can be detected within certain distances. Air bursts in the megaton range have been detected all over the earth (7). The 1946 Bikini Baker test was detected by seismograph in the U.S. (8). This was a shallow, underwater test of nominal yield. Recent Nevada low yield air bursts have been detected by seismological stations hundreds of miles away (9). The September 19, 1957, deep underground test (Rainier) of 1.7 kiloton yield was detected as far as College, Alaska (10). Seismic records can tell the location and time of the explosion with great precision. The monitor network proposed in this paper using recent unpublished information on travel times of bomb tests can probably locate a test site within one mile (assuming local "calibration" explosions are made). Seismic techniques can give some measure of the size of an explosion for deep underground tests.

As with the acoustic wave, the seismic wave cannot be detected at very large distances for sub-nominal tests. For example, the Japanese have not detected our Nevada tests by seismograph. However,

[2] See note 3, page 97.

small explosions can be detected by stations within several hundred miles. An extreme example of detection sensitivity is a recent experiment in the Soviet Union where chemical bombs of 0.0001 kilotons (100 kg. of TNT) were detected beyond 200 miles by special techniques. One would expect that low yield underground tests down to 1 kiloton should give good seismic signals up to 300 miles.

However, several dozen natural earthquakes of comparable magnitude can occur per year in the Soviet Union or United States. For detection of deep underground tests to be practical, one needs a technique of analysis which can distinguish most of the earthquakes from man-made explosions. One would expect such a technique to be possible because of the striking differences between the mechanism which produces earthquakes and an explosion. An earthquake is produced by slipping of ground along a fault plane. It is usually a broader and deeper source, of longer time duration than an explosion. This large difference in the initial earth motion excites waves which are different in polarization, rise time, harmonic analysis, radiation pattern, frequency, duration, relative amplitudes, etc. The initial longitudinal wave pattern from an earthquake tends to be a cloverleaf, with the leaves alternating in polarity (direction of first motion). For an explosion the initial longitudinal wave pattern tends to be uniform and is always a compression rather than a rarefaction. Transverse waves can be generated by reflection and refraction of the longitudinal wave. But this mechanism initially produces transverse waves of vertical polarization, while the initial transverse earthquake waves can have large horizontal polarization.

In the proposed network of 300-mile monitoring stations, the worst possible case would be a test which is at the maximum distance of 300 miles. But in this case there would also be about three other stations in the other three directions at 300 miles. The test would be ringed by about 12 stations within 600 miles. Suppose an earthquake occurred at such a location. Then, about half the stations would be located where the longitudinal initial polarity is R-type. The existence of just one such record would definitely establish the disturbance as an earthquake and not a bomb. By this technique alone, probably the vast majority of earthquakes in the magnitude range $M > 4.5$ can be eliminated, assuming the 300-mile stations. For example, the initial polarity of the Rainier test ($M = 4.6$) was definitely established as

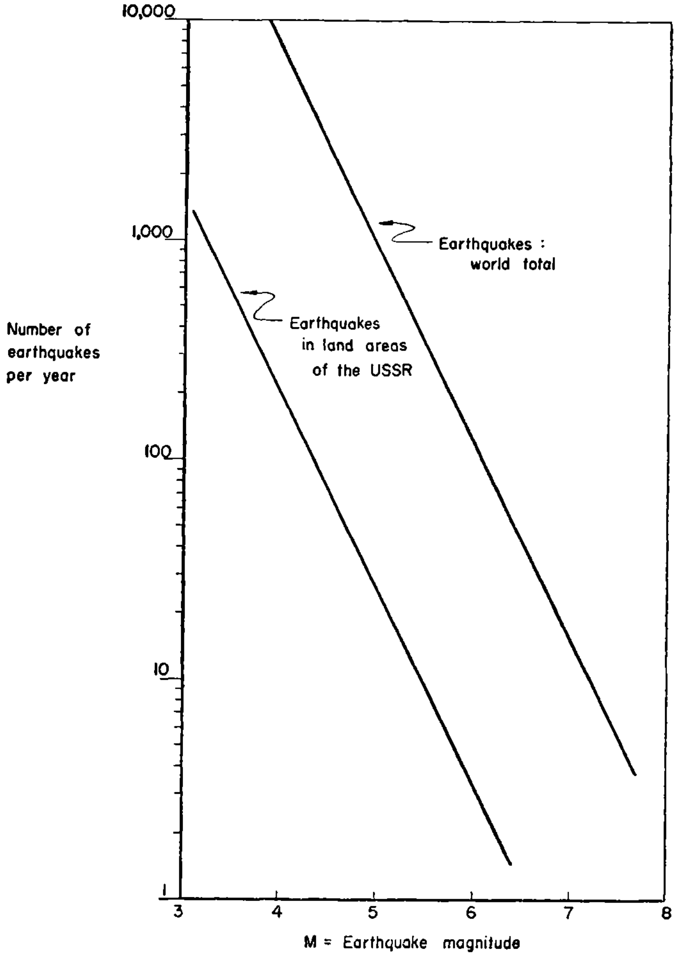

FIGURE 2
The Number of Earthquakes Per Year above Magnitude M

The curve for the USSR is based on the assumption that three percent of the world's total occurs in the *land* area of the USSR. These estimates are based upon the data in the volume by B. Gutenberg and C. F. Richter, *Seismicity of the Earth and Associated Phenomena* (Princeton University Press, 2nd ed., 1954). The above curves show that there should be about 120 earthquakes per year in the USSR greater than magnitude 4.25.

far as Pinedale, Wyoming, 520 miles away. Now that more is being learned about the seismic records of large bombs, new techniques and methods of analysis should improve the situation.

The feasibility of monitoring deep underground tests also depends upon the abundance of natural earthquakes. In this discussion we will use the land area within the borders of the Soviet Union as an example. In the USSR the average rate of earthquakes greater than magnitude 6 ($M > 6$) in the period 1920 to 1942 was about three per year (12). The world totals are estimated to be 124 per year for $M > 6$, 920 per year for $M > 5$, and 7,100 per year for $M > 4$ (11). According to this, there should be about twenty-four Soviet earthquakes per year with $M > 5$ and about sixty per year with $M > 4.5$. This may be an underestimate, because since 1952 the earthquake rate in the Kamchatka peninsula has increased.

We will now show that deep underground tests of bombs of several kilotons should be in the region of $M > 5$ and that very low yield tests of about one kiloton should be in the region $M > 4.5$. The most recent relation between energy release (E in ergs) and magnitude is (12):

$$\log E = 9.4 + 2.14M - 0.054M^2$$

According to this relation the most catastrophic natural earthquake ever recorded ($M = 8.6$) has the same energy release as a 15 megaton bomb. Thus man has exceeded the "forces of nature." The energy release of 1 kiloton of TNT would be $M = 5.5$. However, a nuclear bomb air burst has only 50 percent of its energy as blast energy. The rest is electromagnetic radiation and radioactivity. Also, underground blast energy can be used in rock deformation in addition to seismic wave energy. According to the information available to this author prior to March, 1958, a safe assumption was that at least 10 percent of the energy of a deep underground nuclear bomb would go into seismic waves. The recent estimate of K. E. Bullen (14) was consistent with this. Bullen estimated that an explosion of 30 kilotons of TNT would give $M = 6$. The seismic energy in $M = 6$ is 4.8 kilotons, so Bullen was using a loss factor of 6. Bullen reported the 20 kiloton Bikini Baker test as $M = 5.5$ (13). This would be a loss factor of 20 or a 5 percent energy transfer. However, this was a shallow underwater test, where a large amount of energy was used in shooting up a large column of water and steam. So according to the Baker test, 5 percent would be a lower limit on the amount of energy which would go into seismic waves in a deep underwater test. Using the 5 percent figure, a 1 kiloton bomb would be $M = 4.7$. However, according to an AEC report released in March, 1958, the Rainier test was $M = 4.6$ and 1.7 kiloton yield (14). Assuming the AEC yield figure is correct, this is a loss factor of 50 rather than 10, and a 1 kiloton nuclear explosion could be as low as $M = 4.5$. The only apparent explanation for this extra factor of 5 in the loss factor is that the Rainier test was conducted in a volcanic tuff which is easy to shatter and that an abnormal amount of energy was absorbed in shattering and deformation. Rainier was preceded by test explosions in the same rock, so the answers to these questions are known to the AEC.

Using present techniques, it may occasionally be difficult to positively identify a shock of M less than 4.5 as an earthquake by stations at 300 miles. This difficulty can be largely overcome by installing a higher density of seismic stations in the seismic belts. In the case of the Soviet Union, about six additional stations in the Kurile Islands and the Kamchatka peninsula would give 100 mile coverage.

A problem which should be considered here is the possibility of rigging up a bomb to go off "simultaneously" with an earthquake of larger magnitude. Because of the scarcity of earthquakes greater than magnitude 6 (about three per year in the USSR), this method of deception would not be very practical for bombs giving $M > 6$. It may be difficult to separate signals of tests giving $M = 5$ from nearby earthquakes giving $M > 5.5$ (about nine per year in the USSR). If the bomb signal is triggered by a distant earthquake, the bomb signal will arrive several minutes behind the initial earthquake signal at some stations.

In conclusion, the practical lower limit of detection and identification of deep underground tests is probably about 1 kiloton with the 300-mile network. The 100-mile network in the seismic belt should push this limit down to less than 1 kiloton. Tests somewhat above these limits might go undetected if conducted within a few seconds and within a few miles of a major earthquake ($M > 6$). A provision which would push these limits down further and would make seismic detection more certain would be the right for an inspection team to investigate the origin of a suspicious disturbance. Such a provision would be a great deterrent to clandestine underground testing. Serious risk of possible detection would always accompany any attempt to evade.

If the parties to the test ban agreement have reservations about the uncertainties involved in underground detection and the possibility that a very low yield test (less than 1 kiloton) may escape positive identification, the first stage agreement could ban only those tests which are detectable. Another possibility would be to ban all but the deep underground tests. In either case, the progress made toward the improvement of East-West relations and the establishment of a working international inspectorate would be almost as great as that made by an agreement which included all tests. There is no reason why the test agreement should ban peaceful uses of nuclear explosions. However, such peaceful experiments should be under international supervision and be open to the inspectorate.

Complete seismological instrumentation of a monitoring station would cost three to five thousand dollars, using commercially available items. If necessary, it should be possible to obtain seismological instruments for a few dozen stations within six months. Special equipment designed to distinguish earthquakes from explosions would be more expensive. A quicker and simpler solution to seismological monitoring would be to make use of existing research stations. For example, the Soviet Union has a network of about seventy-five high-quality stations. As a part of the agreement, these stations could send copies of all their seismograms to the international inspectorate. At present Soviet and U.S. seismologists freely exchange records upon request. There would be no risk of falsification as long as the inspectorate had a few stations of its own.

Underwater tests can be detected both by the seismic waves in the earth (Bikini Baker test was $M = 5.5$) and by the seismic waves in the water using hydrophone detectors. This latter method is very sensitive, because the underwater waves concentrate in the sofar layer. Thus the intensity drops off only as $1/R$ rather than as $1/R^2$. Underwater explosions can also be detected by the radioactivity contained in the water which rises to the surface and by the tidal waves.

Detection of Electromagnetic Radiation

The high frequency end of the electromagnetic spectrum (X rays, ultraviolet) is quickly absorbed in the atmosphere and converted to lower frequency electromagnetic energy and molecular energy. Thus, an appreciable part of the bomb energy travels in the regions of the electromagnetic spectrum where there is little atmospheric absorption: namely, as visible light and radio noise.

Detection of the visible light at distances up to about 300 miles is quite simple. One merely points a photocell at the sky. It doesn't matter whether it is day or night, clear or cloudy. As long as the test is not deep underground, a very distinctively shaped light pulse will be observed (15). The same mechanism which gives twilight after the sun has set will give a glow in the sky due to the nuclear explosion. The twilight of the sun is observable until the sun reaches 18° below the horizon. This is a distance of 1,200 miles beyond the horizon and represents an upper limit on the range. Because of the large number of photons involved, the intensity of sky glow from the bomb could be a million times smaller than the brightness of the daytime sky and still be detected. Spurious signals such as lightning would have the wrong pulse shape and also would not appear at the other stations. Directional information could be obtained by using several photocells at each station. If the stations were fed common timing signals, the bomb site could be located very accurately by using the photocell signals.

In the case of a nuclear explosion well above the atmosphere, the shape of the pulse will be different, but there will still be plenty of visible light generated when the X rays (thermal radiation corresponding to millions of degrees) emitted from the high-temperature explosion hit the upper atmosphere. This same mechanism will also produce an acoustic wave. One should be able to calculate the magnitude of such an acoustic wave as compared to that of a low altitude test. If the loss in magnitude is too great, the very high altitude tests can still easily be detected at 300 miles by light and radio noise.

Detection of Radioactivity

According to estimates of United States officials, one should expect that some of the future tests will have no fission content and that some current tests have had the fission content down to about 4 percent. One should keep in mind that "a 100 percent clean bomb" is a practical impossibility, due to neutron-induced activity in the bomb components and atmosphere. This activity should be equivalent to about 1 percent fission content, so that if we already have bombs with only about 4 percent fission content, there is not much room for improvement.

Because of the neutron-induced activity, all except the deep underground tests will produce radioactivity which may be detected. For example, the Japanese have detected low yield Nevada tests by collecting dust from air at sea level (16).

Because of the rapid decay, one would expect to obtain maximum sensitivity by collecting dust downstream from the test at high altitudes. The closer to the test, the greater the sensitivity. Collection at high altitudes and within about 1,000 miles of the test area would require monitor aircraft flying within foreign territory. To agree to this form of monitoring requires more of a sacrifice of internal security than the establishment of fixed ground monitoring stations. Since the fixed monitoring stations at distances of about 300 miles give adequate detection using acoustic, seismic and electromagnetic instruments, one need not rely on detection of radioactivity. On the other hand, in the absence of the internal monitoring stations, an adequate job of detection of conventional tests can be done by aircraft outside the territorial limits.

VERY LOW YIELD TESTS

The AEC has announced that the Nevada test of September 19, 1957, was 1.7 kiloton of yield. Such a yield is smaller than the largest chemical explosion of 4 kilotons of real TNT at Heligoland on April 18, 1947. Because of the fact that many of the Nevada tests had such a low yield, it was concluded that low yield tests are useful to modern weapons development. Since one of the purposes of a test ban agreement is to impede weapons development, it would be desirable that such an agreement also cover low yield tests. If the agreement covers very low yield tests, the detection of violations becomes more difficult. A major detection problem would be how to distinguish the monitor signals of a 3 kiloton nuclear bomb from those of a 3 kiloton chemical bomb. The easiest solution to this problem is to write into the test ban agreement a provision that if large chemical explosions are set off, international observers must be present. Very low yield tests can be detected at distances of about 300 miles. Also whenever the stations have the indication of a test, the inspectors should have access to the indicated test site. Of course, ultra-low yield "tests" of yields comparable to the blockbusters of the Second World War could escape detection by the monitoring stations proposed here.

UNCONVENTIONAL TESTS

We will now discuss the possibilities of evasion by using unconventional testing techniques. Two such possibilities have already been covered. These are the ultra-low yield explosion and low yield deep underground tests which are simultaneous with earthquakes. There are two more possibilities of evasion worthy of discussion. These are testing in a giant box, and testing in foamy water.

It should be possible to construct a giant box resting on pillars so that essentially no shock wave is transmitted to the ground or air. The simplest form of such a box would be a steel sphere strong enough to hold all the energy released by the bomb. Essentially all the energy of the bomb will be quickly converted to molecular kinetic energy and the gas inside the sphere will reach an equilibrium pressure P. Then $PV = .4E$ where V is the volume of the sphere and E is the yield of the bomb. For example, if E is 1 kiloton and the sphere is 500 feet in diameter, then $P = 8$ atmospheres. This is very close to the measured peak overpressure as given in Reference 15. However, the peak overpressure on reflection would be more than twice as great. In order not to burst, such a sphere would require walls over 8 inches thick and would weigh over 100,000 tons. The weight would be almost independent of the diameter and it would be proportional to the bomb yield. Such a method of deception is not practical except for low yield tests, and even then the construction time would probably exceed the duration of the first stage agreement.

It is well known that foamy water absorbs underwater shocks. Thus, if a bomb is exploded in the center of a large volume of gas-containing water, the seismic energy can be absorbed. Lakes of depth greater than three hundred feet would be required. Water from such lakes could be periodically monitored for radioactivity by the inspectorate. A variation on this technique would be to build a new artificial lake 300 feet deep by damming up a deep canyon. All this would be a major engineering project which would be expensive, would take several years, and would be limited to low yield tests.

SUMMARY

We see that it is possible to detect nominal yield tests outside the boundaries of the nation conducting the test. However, sub-nominal tests of low fission yield could possibly escape detection from outside monitoring. Such clean small bombs have not yet been developed. Actually, a test ban agreement which could be checked only by outside monitoring would still fulfill many of the purposes of such an agreement. To restrict tests to the point where they must be undetectable by outside observers certainly does impede weapons development. The view of M. Taketani, professor of physics in Tokyo and a leader in the Japanese test ban movement, is: "Underground explosions are morally preferable to explosions in the atmosphere, because the former has no fallout. In the present situation, I would like to propose, pragmatically, the cessation of all of the tests of A- and H-bombs whose explosions are detectable."

The main conclusion of this paper is that even these tests which could escape outside detection could be effectively detected if about twenty-five ground monitoring stations could be uniformly distributed over the Soviet Union and about seven over the United States.[3] Several stations might also be required for Pacific Ocean areas, Australia, China, and for the nations bordering the USSR and the USA. Then any test would be within 300 miles of at least one station and would usually be within 600 miles of twelve stations. The 300-mile requirement proposed here may be too conservative. If so, perhaps only a few stations would be needed. For example, a 500-mile requirement in the Soviet Union can be met with eight stations. On the other hand, it might be desirable to have a few additional seismic stations in the seismic belts. Confusion with large chemical explosions could be eliminated by a simple provision in the test ban agreement that members of the international inspectorate must be invited to all large chemical explosions. Also, it is clear that if the monitoring stations had evidence of a bomb test, the inspectorate would have to be given access to the location in question. The number of stations could be vastly reduced by the simple requirement that existing seismic stations send copies of their records to the international inspectorate.

In the case of a general disarmament agreement, the type of large scale inspection system necessary to prevent secret military build-up would certainly be adequate to prevent nuclear weapons testing. Such a

[3] This conclusion is strengthened by the testimony of Dr. W. F. Libby, acting chairman of the U.S. Atomic Energy Commission. In testimony before a Congressional committee on March 6, 1958, Dr. Libby said: "On the technical matter of whether you could develop a system to enforce a test ban, I think you can do this. It is a much more difficult job than some people have indicated, but you can do it to the point where it will be good enough so that the chances of being caught are big enough so that it probably would be adequate."

large scale inspection would involve inspection of areas which are now highly classified. The monitoring stations proposed here need not be set up in classified areas.

In the absence of a large scale general inspection system or unlimited access, it would still be impossible to carry on an effective nuclear weapons testing program, provided the minimum monitoring conditions proposed here were established. The objection that these minimum conditions would interfere with a nation's internal security is not valid, provided the inspection personnel were confined to the monitoring station and that the monitoring station were located in normal civilian territory. Thus, the beauty of a test ban agreement as a "first step" trial agreement is that adequate inspection can be provided without running into the usual objections that the inspection system would interfere with a nation's internal security. Apparently Russia recognizes this feature of a test ban agreement, since it was Soviet delegate Valerian Zorin who proposed the establishment of scientific control posts. Whether this means that twenty-five stations in the USSR would be acceptable is unknown.

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RADIATION, PUBLIC HEALTH, AND INSPECTION FOR DISARMAMENT

by L. S. Penrose

IN VIEW OF the dangers to health of artificial radiation of all kinds it is generally recognized that medical protection services are expedient to ensure that individual exposures do not exceed certain agreed permissible levels.

The possibility of making use of an established protection service of this kind in an inspection scheme concerned with preventing unauthorized manufacture of nuclear explosives comes into consideration. There seem to be two ways in which this link might function. First, the medical organization set up in a given area could keep record of all protective measures used or required and of the total quantity of individual exposure. Second, if exposure measurements and other precautions were not taken, casualties might ensue and these might reveal previously unsuspected sources of artificial radiation.

The basic facts concerning radiation hazards, which would have to be taken into account in developing any such scheme, are briefly outlined in the memorandum which follows.

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SURVEY OF PRESENT KNOWLEDGE OF BIOLOGICAL EFFECTS OF RADIATION, INDIVIDUAL (SOMATIC) AND GENETICAL

Some of the deleterious effects of ionizing radiation became known within a few months after the discovery of X rays by Roentgen in 1895. The first injuries noticed were burns, irritation of the eyes, and loss of hair. By 1911 it was recognized that, less than ten years after exposure to X rays, malignant changes could occur in the injured tissues. Animal experiments showed that two other important hazards were sterility and anemia. Parallel injuries were demonstrated in people who worked with radium. They developed burns and, ultimately, leukemia. Although, from the very beginning, the therapeutic possibilities of the new discovery were widely exploited, not without some success in the treatment of malignant disease, the full nature of the dangers, both to patients and to operators of X-ray apparatus, were only slowly appreciated. This was largely because of the long latent period before the appearance of many of the effects. By 1922, one hundred radiologists had died from malignant disease caused by radiation.

A very important step forward in knowledge of the biological significance of radiation was taken in 1927, when Muller and Settles published their demonstration that it could cause permanent changes in the hereditary substance carried in cell nuclei.

A new factor was introduced into the radiological world in 1945, when the first atomic explosions were produced. The problem of whole-body irradiation had now to be fully considered. The effects of exposure in large populations, from the point of view of future generations, also became a matter of moment.

The damage to living cells is directly caused by electrically charged atoms and molecules, called ions, that are left in the tracks of radiation. The amount of ionization produced in any tissue depends upon the quantity of radiation received and this, in turn, depends upon the type of particle involved and its penetrating power.

Alpha particles have high energy and are biologically very destructive, but they have very small power of penetration. Beta particles can vary in energy and penetrating power; in general they are more penetrating than Alpha rays and, when substances which emit them are ingested, damage can occur within the body. Gamma rays are electromagnetic radiations of high energy emitted by atomic nuclei. They are very penetrating and equivalent to X rays produced at extremely high voltages. X rays have a biological effect similar to that of beta particles because they liberate high energy electrons in the cells they traverse. Fast neutrons can be produced by atomic nuclear disintegration, and they resemble alpha particles in their biological actions.

The measurement of radiation is expressed in terms of "roentgen" or "r," which is standardized in terms of quantity of ionization brought about in air. It has been calculated that, in our natural surroundings, the total amount of external and internal radiation to which we are exposed, is about 0.1 r per year. Its sources are cosmic rays, radioactive soils and rocks, and radioactive potassium and carbon in the body. In the course of a generation of 30 years, each person receives about 3 r in this way.

By the end of 1955 it was estimated that fall-out from atomic test explosions might have increased this amount by not more than 1 percent. Occupational exposures may amount to a quantity of nearly 2 percent of the natural background, if averaged over the whole community. Comparable quantitative estimates have been made for other radiation sources. Television and luminous clocks and watches are thought to supply an extra 1 percent. A large quantity of artificial radiation is absorbed by individuals in the community on account of diagnostic X ray procedures. This adds up to some 25 percent of the natural background in England and perhaps 100 percent in the United States. In countries where such procedures are not used on a large scale, the total dose from this source, averaged over the population, will be very much less than these estimates. Similarly, people, living in countries where atomic power is being developed, at the present moment will expect to experience a rise in background level of the order of 2 percent on that account. Internal body radiation can be increased by the incorporation of radioactive materials from the environment, such as strontium 90 or cesium 137, mainly through food if the ground or water supply becomes contaminated. This can happen when rainfall brings down radioactive fall-out from bomb explosions or if effluent from atomic plants is not fully safeguarded.

An important point in assessing the risks of radiation damage is the relation of dose to effect. Small doses, insufficient to produce any symptoms or leading at once to recoverable changes of the mildest type, have usually been considered harmless. Thus, in general, short-term damage does not seem to be proportional to the amount of exposure because ten times a harmless dose may produce much more than ten times its effects. On the other hand, genetical changes of the "point mutation" type, which can produce hereditary defects, have been experimentally shown to be precisely related in linear fashion to the quantity of radiation administered when large doses are used (above 100 r). It is therefore argued that no extra dose, however small, is harmless or ineffective in the long run from the genetical point of view. Put in another way, increase in mutation rate is proportional to increase in gonadal radiation exposure. It is important to state the matter thus, because there are many other causes of mutation besides radiation, for example, chemical mutagens and spontaneous errors in gene copying at cell division. Evidence is being accumulated on the question as to whether or not the tumor formation, induced by radiation, is governed by the law of linearity. At present it seems that it might be so in some cases.

SOME RELEVANT RESEARCHES NOW IN PROGRESS

At the present time intensive researches are being carried on all over the world on the question of radiation protection. Among these are many studies of the effects of radiation on lower organisms to supplement the knowledge rapidly accumulating about the effects on man. Some examples of this kind of work are given here.

Typical of new investigations on lower animals are those being carried out by Russell at Oak Ridge in the United States and by Carter at Harwell in England. Attempts are made to establish the effects on mutation rate of very low doses of X rays, because most of the previous critical work on insects had been carried out with doses large enough to be lethal to man. The individual effects of large doses of X rays on animals is also much studied, and demonstration, by Loutit and his colleagues at Harwell, of methods by which the resulting anemia can be corrected in mice is encouraging. Russell and his co-workers have continued to examine the individual effects of X rays upon foetal mice, showing how different malformations are produced according to the time at which the pregnant mother is exposed. It is uncertain yet what is the minimal dose of X rays which can damage the foetus either in experimental animals or in man. Probably it is less than 25 r.

Further direct observations on man have included many searches for pathological changes in individuals and their offspring after exposures of various kinds. The immense amount of work carried out by the Atomic Bomb Casualty Commission and their helpers confirmed the known individual effects but failed to establish any firm evidence of genetical effects. The conclusion was drawn that the human germ cells cannot be especially sensitive to ionizing radiation, or at least that they are no more sensitive than had been supposed on the basis of other work. Indeed, the survey demonstrated that genetical damage is very difficult indeed to detect in one generation. On the other hand the induction of leukemia by radiation seems to have been demonstrated more firmly than ever, and quantitative results obtained by Court, Brown, and Doll indicate that a dose of even a few times the normal background level in a lifetime may raise the leukemia level quite significantly.

Attempts to follow up children of therapeutically irradiated subjects, or of occupationally exposed people, have been made on several occasions with varying results, but Lejeune reported that evidence of mutation was shown by sex ratio changes. Examinations of human diseases which have apparently arisen spontaneously by fresh mutation are continuing in many countries, including those places where natural radiation is known to be high. The spontaneous mutation rate of a considerable number of genes in man has been measured, and this is a necessary preliminary to evaluating data on induced mutations. A promising new development is the comparison of human cells with other animal cells, in their reaction to radiation, using tissue cultures as experimental populations.

It will be noticed that a thread running through most of these investigations is the idea of finding out just how sensitive human cells are to radiation damage and, in particular, what their reaction may be to small doses or to the accumulation of minimal quantities over a long period of time. The indications are at the present time that a general increase, covering the whole population, amounting to an extra quantity equal to the natural background, that is, 3 r per person, might introduce some important hazards, but that the bad effects, though present, would be very difficult to demonstrate precisely in any given population. However, an increase amounting to ten times the natural background, that is 30 r per person, would be very serious. It is believed that it would lead eventually to a doubling of the incidence of all hereditary disease. A noticeable increase in several types of hereditary illnesses would be found even in the first generation after the new radiation level had been reached. The incidence of leukemia would also be quickly doubled.

NEED FOR CONTROL OF SOURCES OF RADIATION AS A PUBLIC HEALTH MEASURE

In view of the gradually increasing uses of ionizing radiation in medicine and industry and, recently, in military affairs, from time to time recommendations have been made on a wide scale, first national and then international, to reduce hazards. A British X ray and radium protection committee was formed in 1921. An international congress in Stockholm in 1928 issued general recommendations, and these are continually being brought up to date. One of the main problems has been to establish a permissible dose for workers in close contact with radiation, since it is not yet clear how far very small doses above the natural level are to be feared. Proposals to make it compulsory for everyone in the whole community to record individual exposure have been made but they are considered impracticable. It would seem preferable to keep accurate records of sample populations and specially exposed groups.

From the genetical point of view, the total amount of irradiation reaching the gonads, in the part of the population young enough to be likely to reproduce, is the significant figure. Since the genetical effects of increased radiation are likely to be for the most part hidden and very difficult to measure, especially within the space of one generation, the only index of damage will be the calculated dose of radiation actually received by the population. From the public health point of view, ascertainment of radiation levels, by monitoring systems of all kinds, is necessary, whether we are concerned with individual or genetical effects. If it is desired to prevent short-term dangers only, individual monitoring of subjects at risk may give sufficient protection. Where long-term hazards are concerned, the correct method would seem to be combination of monitoring by physicists of local and general quantities of radiation with measurements made upon selected individuals to see how much has been absorbed.

From the strictly medical point of view, any unnecessary extra radiation to individuals or to the population as a whole is to be deprecated. In order to control exposure, the output of radiation from all sources would have to be accurately checked. This would involve registration, followed when desirable by some kind of official inspection, of all hospitals, industrial plants, research laboratories, and military establishments where X rays or radioactive materials were regularly used. Only by such a system could the total amount of exposure of the population be kept down to a tolerable level. It seems likely that any organized procedure of this kind, to be effective, would have to be standardized by international agreement after pooling the available physical and medical data. Any country not agreeing to limit its own sources of radiation in this way would, from the public health point of view, be at a disadvantage as compared with the others who accepted the standardized methods.

MEDICAL ASPECTS OF RADIATION AND THEIR POSSIBLE RELATION TO THE PROBLEM OF INSPECTION

If it were desired to use medical knowledge as a possible aid to the detection of clandestine manufacture of fissionable atomic materials, the following procedure would have to be used:

1. The known damaging effects of radiation exposure on man could be looked for in workers or in people who came to hospitals in a suspected district.

2. On the assumption that the factory would use protection schemes against radiation hazards, evidence of such methods would be sought.

The present memorandum briefly sets out the facts under (1) and (2) and attempts to make an assessment (3) of them from the point of view of inspection.

1. In any plant or organization, whether industrial, military, medical, or academic, where radiation is used, damage to workers will occur if they are inadequately protected.

a. *Short-term individual effects, that is, those occurring within a few weeks of exposure:* After a heavy accidental dose to the whole body, nausea, vomiting, and diarrhea occur early and can be followed by exhaustion, fever, and delirium. People who survive more than a week show progressive anemia, loss of hair, ulceration of the mouth and digestive tract, loss of weight, and delayed healing of wounds. Besides depending upon the strength of the dose, the effects vary with the type of radiation and the part of the body exposed. For example, burns are produced by beta radiation on the skin where it is not protected by clothing.

b. *Long-term individual effects:* These are observed sometimes years after exposure. The main conditions are leukemia and cancers of many different sites. Milder effects are cataract and skin pigmentation. The type of lesion depends upon the type of exposure and the site exposed. Ingestion of radium or strontium which is stored in bones can lead to tumors of bone or of overlying skin.

c. *Genetical effects:* Various types of change can occur in the germ cells in consequence of ionizing radiation. Sterility can be produced by large doses but, in the male, this is usually temporary. Genetical effects can be caused by mutation, and this can be either in the nature of structural alteration in chromosomes or single gene change. Structural changes are not usually transmitted, because they cause germ cell death. Single gene mutations can produce effects noticeable in the children of the exposed person, but more often the effect is concealed and is spread very thinly over many generations. The types of anomaly caused by induced mutation are not likely to differ from known anomalies due to spontaneous mutation which occurs naturally.

2. Protection against radiation hazards in medical or industrial units has undergone many changes and is very variable. Standard practices are the use of film badges carried by workers, pocket monitors, blood counts at regular intervals, say, quarterly, and special clothing.

Methods either recommended or in use are described in the U.S. Bureau of Standards *Handbook on Radiation,* the "Recommendations of the International Commission on Radiological Protection" (*Brit. J. Radiol.,* 1955, Supplement No. 6) and the *Code of Practice for the Protection of Persons Exposed to Ionizing Radiation* (H.M.S.O., London).

3. It is obvious that an organization intending to conceal its activities would keep its protection measures as inconspicuous as possible. In doing so, however, it might reduce efficiency of protection and therefore allow suspicion to arise on account of injuries to workers. Here only the short-term effects are likely to be of significance. Radiation sickness, if it occurred, would be recognized in patients seeking hospital treatment. Superficial burns, if frequently observed, would arouse suspicion.

There would be little likelihood that a knowledge of long-term effects, such as leukemia or cancers, could be used for this purpose, and nothing of value could be obtained from search for genetical effects. These observations would be much too small in numbers and too unreliable in their interpretation to use as pointers.

The information that badges were being carried by workers and that such special garments as lead aprons were being used at a given site would indicate at once that hazards of radiation were being taken seriously. It would, however, appear that such protective measures taken for medical reasons would be nonspecific, and not in themselves indicative of military, as opposed to industrial or even therapeutic, uses.

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CAN THE THEFT OF FISSIONABLE MATERIALS AND THEIR USE IN WEAPONS BE PREVENTED UNDER A DISARMAMENT PROGRAM?

by James H. Boyd

SUMMARY

IT IS UNLIKELY that the theft of concentrated forms of the fissionable elements of their metals can absolutely be prevented, but it is likely that any systematic thieving of the metals or purified concentrates of the fissionable elements can be detected. Our discussion here is directed primarily toward uranium 235, uranium 238, plutonium, and, to a lesser degree, toward thorium and uranium 233. These elements are all heavy metals of relatively low radioactivity, and are all toxic, plutonium being a particularly dangerous poison. Of these, the fissionable elements usable in warheads when in rather high purity are uranium 235, plutonium, and uranium 233. The latter two would be purified and separated in high concentration in the uranium-fueled and thorium-fueled reactor power cycles, respectively. Here is the critical point to be watched, since fissionable material might be stolen which needs only relatively simple means for conversion to warheads. Because of their low radioactivity, it is easily possible to shield small amounts of any of these metals so that they may be carried safely in lead capsules on the person of a thief. While such capsules could be detected by X-ray photography, this method would prove impractical for routine daily inspection of personnel because of the health hazard.

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The greatest hope of detection of the systematic theft of fissionable materials for use in weapons lies in the close, continuing inspection of authorized operations making or employing fissionable materials and in close scrutiny both of the production of chemicals used in processing fissionable materials and of the auxiliary uncommon materials vital to nuclear operations. A list of these is given in Table 1.

TABLE 1

Materials Important in Nuclear Operations

Material	*Source*
Source Elements	
Uranium	Natural Ores
Thorium	Natural Ores
Fissionable Elements	
Uranium 235	By separation from U 238
Plutonium 239	By neutron irradiation of U 238
Uranium 233	By neutron irradiation of Thorium
Fusion Elements	
Lithium 6	Lithium manufacture
Deuterium	Heavy water
Tritium	
Key Materials in Irradiation Units	
Beryllium	
Zirconium	
Heavy Water	Water
Purified Graphite	
Stainless Steel	
Aluminum	
Processing Chemicals	
Hydrofluoric Acid (HF)	Fluorspar
Fluorine (F)	
Sulfuric Acid	
Nitric Acid	

The most important factors in any inspection system are the ability and continued alertness of the inspectors themselves. Boredom will constantly threaten the stultification of the perception and imagination of the individual inspectors. The quality of personnel required to do an effective job must be high, but personnel of the mental caliber necessary to do a good job will find it most difficult to sustain interest in a highly repetitive, nonproductive task. Human fallibility is potentially the weakest point in any inspection plan.

These general conclusions were arrived at after visiting the Argonne Laboratories and their experimental boiling water reactor, and the Brookhaven Laboratory, holding discussions with informed people, and reading some of the already voluminous nuclidic literature. A list of helpful references appears at the end of this paper.

FISSIONABLE MATERIALS

General

Nuclear devices, the fission and fusion bombs, are the most devastating explosive weapons known. Since the technology of their production is but partially disclosed, a portion of this discussion is speculation, but is probably not far from the truth. Only unclassified information has been used in this report.

The basic elements of fissionable nuclear devices are uranium and thorium. Uranium is the one which has been used so far, and therefore is emphasized here.

Uranium Sources

Known deposits of uranium bearing ores are widely distributed, as shown in the following table.

TABLE 2

Uranium Bearing Minerals. Mineral	*Typical Weight Content of U_3O_8*	*Source*
Pitchblende	1.0-50%	Belgian Congo
		Canada
		Czechoslovakia
		Saxony
Sandstone Deposits	0.2-0.4%	Colorado Plateau
Phosphate Deposits	0.01-0.03%	Russia
		North Africa
		United States
Black Shales and Lignite	0.06-0.6%	Sweden
		Russia
		Alaska
		United States
Gold Ore	0.01%	South Africa

Pitchblende

This is the most sought after ore because of its high uranium content. The largest reported deposits are in the Belgian Congo, the next largest deposits in Canada. The great bulk of uranium ore processed in the United States is found in sandstone deposits in the Colorado Plateau and typically contains from 0.2 to 0.4 of U_3O_8. Uranium concentrates are also recovered from the Florida phosphate deposits, from Swedish black shales, and from South African gold ore tailings.

Rich pitchblende ores may be concentrated by gravity separation in water of the ground ore, since the desired U_3O_8 has a much higher specific gravity than the gangue from which it is desired to separate it. However, in the United States the uranium bearing compounds are usually acid- or alkali-leached from ores which have been ground to at least 14 mesh. The prime purpose of leaching is to concentrate the uranium values by separation from the inert siliceous or carbonate gangue. Simultaneously some of the objectionable chemical elements are eliminated, so that substantial purification results. The leach liquor is processed to concentrate the uranium values and reject objectionable elements such as radium, lead, cadmium, silver, aluminum, iron, and vanadium. Depending on the characteristics of the ore processed, ion exchange resins may be employed to segregate uranium selectively. The ultimate purpose of these techniques is to recover a relatively pure uranium compound $Na_2U_2O_7$, which is "the yellow cake" sent to the refinery for purification. This cake contains about 55 to 56 percent uranium.

Uranium Purification

The yellow cake is shipped from the concentrating mill to a plant for purification. There it is converted to UF_6 for subsequent processing in a diffusion plant for the separation of the fluorides of the uranium isotopes, U 235 and U 238, or for conversion to uranium metal either to be used in fuel elements or irradiated for plutonium manufacture. At the purification plant the cake usually is dissolved in nitric acid to give a nitrate solution, which is extracted with an alkyl phosphate in kerosene. This dissolves the uranium values but not the contaminating metals from the original ore, which are still associated with the uranium. The uranium may be recovered from the pregnant organic solution by aqueous nitric acid extraction with subsequent evaporation of the resulting uranyl nitrate solution and heating of the residue to give uranium trioxide, UO_3. This is reduced with gaseous hydrogen to give the dioxide UO_2, which is then treated with hydrofluoric acid, HF, to give the tetrafluoride. The tetrafluoride, UF_4, is then treated with elemental fluorine to give the volatile hexafluoride, UF_6. This UF_6 is physically processed in a gaseous diffusion plant to separate the hexafluorides of U 235 and U 238. Uranium 235 is the only naturally occurring fissionable material and is indispensable for any fission atomic energy development.

Uranium metal is made by reduction of the fluorides with metallic magnesium, Mg. This natural uranium metal is irradiated with neutrons for the production of plutonium. Alternately it may have its natural U 235 content of 0.7 percent enriched by the addition of U 235 metal made from the enriched fluorides from the diffusion plant.

Plutonium

Uranium 235 (or plutonium) is necessary as a source of neutrons for the irradiation of U 238 to form plutonium. Pure uranium 235 liberates more than one neutron per atomic fission, so that when fission is carried out in an environment where the neutron loss or leakage to the surroundings is sufficiently low, then the fission reaction is self-sustaining. A self-sustaining fission reaction is called a chain reaction. By selection of suitable conditions, the neutron loss can be minimized and the chain reaction vastly accelerated, so that it will occur with explosive violence and the liberation of great energy. This is the basis of the atomic bomb. Plutonium is likewise capable of sustaining a chain reaction and producing violent explosions. In a power reactor the fission is controlled by hindering the neutron flow or flux from the neutron source to the basic fuel uranium 238, which forms plutonium, which then splits to give the heat-producing fission with liberation of additional neutrons. Either uranium 235 or plutonium may be the neutron source. The heat released by the fission is removed from the reactor by circulation of a fluid which in turn is used to heat water to generate steam, which is then used to drive a conventional turbo-electric generator. Neither uranium 235, uranium 238, nor plutonium metals are strongly radioactive when charged. However, as fission proceeds, the fissionable products are violently radioactive and are also neutron absorbers without yielding productive fission. Thus they tend to poison or kill the productive fission reactions and, the higher their concentration in the fuel elements, the greater is this effect. It is thus necessary periodically to withdraw a fuel element and reprocess the metal in order to eliminate the fission products.

At this point in a uranium-fueled power reactor cycle, plutonium is separated in purified form. Here is the point in the power reactor process at which theft of fissionable material is most possible.

The radioactive fission products which exist in the irradiated fuel elements in concentrations of the order of parts per million and less are reduced to levels of one in 10,000,000 of the parts originally present. This must be done with practically complete recovery of the fissionable fuel. The separation of the radioactive fission products is a most difficult process, because of the need for protection of personnel from the dangerous radiation and of the need of critical mass restrictions limiting the mass of fissionable material which may be present within a certain shape and dimension, because of the danger of the occurrence of an uncontrolled fission reaction. The need for these precautions, coupled with the demand for extremely high precision in these quantitative chemical separations of uranium, plutonium, and waste products, requires a most elaborate chemical plant.

The disposal of the highly radioactive fission products is a major operating problem. At Hanford, Washington, the waste solutions are stored in large underground tanks provided with agitation and cooling. Here the decay of the highly radioactive fission products occurs. Basically this is not a solution of the problem, but rather an isolation of the hazard. The recovered uranium isotopes and plutonium are reconverted to metal and returned as fuel elements to the power reactor. Conceivably a plutonium concentrate in solution might be pilfered from this operation with but slight radioactive hazard.

Process Input versus Output

The foregoing processes for fissionable materials are basically elaborations of conventional chemical process art developed for these purposes. The errors inherent to checking input versus output are those arising in weight or volume measurement, in the securing of samples representative of the average material being processed or produced, and in the analytical methods employed.

In the ore concentration, the securing of a laboratory sample of the natural ore truly representative of that processed during an hour, a shift, or a day is practically impossible. As the ore varies, so will the yellow cake obtained from it. On the basis of general experience, agreement within 2 percent for the analyzed uranium content input and output would be excellent and possibly fortuitous.

At the purification plant, uncertainty in sampling and uranium analysis of the yellow cake might well approximate at least 1 percent. The measurement and analysis of the volatile uranium fluorides for uranium should give a combined accuracy of about 0.1 percent. For the metal, the weighing and purity could be most precisely determined. The major uncertainty here resides in the input determination.

Little detail is publicly known about the reworking of reactor fuel but this is probably done after about 1 percent is consumed. If we assume that uranium recovery is 99.9 percent of that in the used fuel element, and that the fuel is used and reused until fully consumed, then in this multiple refining of the fuel 10 percent of the original charge will have disappeared in processing, despite fantastically high uranium recovery in each step. This loss will be unrecoverable unless unforeseen process developments in the art occur. Hence the absolute check of input versus output of these processes appears impractical in the present state of the art. Chemical analytical methods must be relied on for quantitative measure of the uranium isotopes, plutonium and thorium, since these elements are themselves of low radioactivity.

Theft

Considering only a uranium-fueled power generation cycle, it is difficult to visualize how any concealed attempt to create fission weapons based solely on thefts from an inspected series of operations has much chance of success until we reach the plutonium separation just outlined. For fission warheads, highly concentrated uranium 235 or plutonium is required. The chemical processing of the yellow cake concentrate or of U_3O_8, if a freak and extremely rich pitchblende were available, is chemically complicated in the purification sequence necessary to free the natural uranium from neutron absorbers. Further, the separation of U 235 and U 238 employing their hexafluorides would require extensive installations, whether done by gaseous diffusion, as in the United States, or by centrifugation in high speed centrifuges whose manufacture could be monitored. Each of the three diffusion plants in the United States cost over $1,000,000,000. It is extremely unlikely that important uranium isotope separation could be accomplished undetected with even a physically small yield of high purity U 235, unless some wholly new method for accomplishing this were discovered. However, policing of the manufacture of HF and fluorine compounds offers an important and valuable check on uranium isotope separation activity.

Some Critical Materials

Assuming that somehow an enriched uranium can be made secretly, it will be necessary to have a reactor in which the irradiation to form plutonium can be performed. Critical materials for reactors are beryllium, zirconium, aluminum, deuterium oxide, stainless steels, and high purity graphite. Of these, the manufacture of beryllium, zirconium, deuterium oxide, and high purity graphite is susceptible to monitoring. The inspection of the manufacture of these materials, coupled with the conventional techniques of coinage mints in the control of precious metals, appears the most practical method of control. It would also be desirable to follow the manufacture of aluminum and of the key stainless steel components, chromium and nickel.

NUCLEAR WARHEADS

Fission

No detailed information on this subject has been released. What follows is speculation. The production of major nuclear explosions requires nearly pure fissionable material, U 235 or Pu 239. The critical mass required is about 90 pounds of the metal. The theft of metal from operations innocently employing fissionable elements cannot occur until the desired metals have been separated. This is unlikely to be U 235, since for fuel operations pure U 235 is not needed and the uranium metal used in making reactor fuel elements will probably contain not more than about 3 percent of the U 235 at the most, since the separation of the natural uranium isotopes is difficult and costly and their separation will be carried no further than needful for power reactor use. Of course uranium is valuable (about $40 per pound) and should be handled with the techniques employed in the great coinage mints to prevent pilferage of precious metals.

The greatest hazard may lie in the availability of plutonium concentrates or the metal itself from the uranium-plutonium-fission products separations. Here plutonium concentrates or metal are made free from fissionable products and are of low radioactivity, and so might be stolen with negligible radioactive hazard to the taker. However, plutonium is exceptionally toxic and hence cannot be handled with impunity. In itself, this property will tend to hinder theft.

This section of the operations offers the greatest possibility of illicit diversion of fissionable material, since these plutonium concentrates would yield purified metal. Thus the theft of plutonium concentrates or the metal itself would yield an essential ingredient of a nuclear fission warhead.

Fusion

The most devastating warheads are those employing fusion reactions of the light elements, as the energy release is much greater in a practical device than is the case in a fission bomb. The fusion reactions demand the creation of solar temperatures of the magnitude of 2,000,000 to 5,000,000 degrees centigrade for a short time. As temperatures of this magnitude are attained briefly in fission reactions, it is believed that a fission device is used to trigger a fusion reaction. The raw materials for the explosive fusion reaction are believed to be lithium and deuterium. Tritium would give a very high energy yield, but is possibly too scarce and difficult to obtain to merit consideration as a practicality in the secret manufacture of fusion warheads. Deuterium is a naturally occurring isotope of hydrogen. Deuterium oxide or heavy water can be concentrated from water by intensive distillation. It also is concentrated in the electrolysis of water, as it has a higher disassociation potential than does water. Some Norwegian electrolysis operations are sources of heavy water. In the United States the Savannah River plant is believed to be a producer of heavy water. The winning of deuterium oxide from water requires intensive processing and massive plant facilities so that it could be produced only in a large plant built for this purpose or as a by-product of electrolytic operations like those in Norway for the production of hydrogen for ammonia manufacture. The other likely component of a fusion warhead is lithium. It has only a limited number of commercial uses as in greases, welding fluxes, and bleaches. Thus the unaccounted-for production of lithium or heavy water would be a clue to possible illegal production of hydrogen bombs.

Fall Out

The cobalt bomb is an elaboration of the hydrogen bomb, which incorporates cobalt parts for the express purpose of creating a highly potent radioactive fall out down wind from the bomb explosion. This would yield a radioactive contamination deadly to life. Thus the unaccounted-for production of cobalt could furnish another indication of nuclear weapons fabrication.

Thorium

A chief source of thorium is in the monazite sands of India, Australia, and Brazil. The irradiation of thorium with slow neutrons yields the fissionable uranium 233, which physically may be a substitute for plutonium in either bombs or fuel. Probably the vulnerable point in a thorium-based nuclear power operation is after the thorium-uranium 233-fission wastes separation. This is comparable to the plutonium situation.

Processing Chemicals

Many conventional chemicals are used in processing ores, and in refining and purifying the heavy fissionable metals and many of the key critical materials. An example is the chemical requirements for the processing of South African ore tailings for uranium values. These quantities are:

Sulfuric acid	39,000 tons a month
Lime	13,500 tons a month
Manganese dioxide	7,200 tons a month

This chemical consumption is so large that it indicates a major recovery operation and could not escape notice under an inspection system. Such clues can lead to significant discoveries if the operation is not satisfactorily explained.

Particular attention should be paid to sources of fluorine chemicals, namely, the mining of fluorspar and by-product fluosilicates from phosphate rock operations. Fluorspar is used in steel making. It is also the primary raw material for the manufacture of hydrogen fluoride (HF) used in making uranium fluoride, and is the source of fluorine (F) used in making the volatile uranium hexafluoride in the separation of uranium 235. As HF has limited industrial use, the monitoring of its manufacture and distribution and of the fluorspar from which it is made will provide an important check on uranium processing.

CONCLUSIONS

Any inspection instituted in a disarmament program must be applicable within each subscribing nation, since it appears certain that each would insist on a common inspection system. While obvious plant safeguards and inspection practices will be employed, it is likely that they can be circumvented by ingenuity. Human failure of the inspectors because of boredom may pose the gravest problem. *The greatest possibility of theft of plutonium or uranium 233 occurs after radioactive waste separation. This is the critical inspection point.* The scrutiny of the production and use of key materials offers a valuable secondary means of detecting the secret misuse of nuclear materials.

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TECHNICAL CONSIDERATIONS RELATING TO THE COVERT PRODUCTION AND EMPLOYMENT OF ELECTRONIC MISSILE GUIDANCE SYSTEMS UNDER A MASSIVE DISARMAMENT INSPECTION

by John B. Walsh

INTRODUCTION

A MAJOR AIM of massive disarmament inspection is to prevent a sneak attack by guided missiles armed with nuclear war heads. One effective means of implementing this aim is to control the manufacture, distribution, and use of missile components which are difficult to manufacture covertly. Suitable components would be those, for example, which require large special machines of high precision for their manufacture. These will be referred to as "critical" components.

In this report, missile guidance systems are investigated to determine whether they contain any essential component which is critical, as defined above. In addition, the possibility of using alternative guidance schemes to circumvent the necessity of using such critical components is considered.

This discussion is solely from the viewpoint of the technical feasibility of producing guidance systems, and is not directly addressed to the problems associated with their clandestine development and testing. Nor does it consider the problem of keeping under cover the actual organization of an offensive strike, which is discussed elsewhere.

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CONTROL AND GUIDANCE SYSTEMS

What is often loosely called missile guidance generally refers to two separate functions: flight control and guidance proper, although the line of demarcation is often ill-drawn.

Flight control systems are those which operate controls to vary the attitude of the missile in response to instructions from the guidance system. Generally, pitch, roll, and yaw are controlled. A typical single axis (here, yaw) control system is shown in Figure 1. The heading made good θ, and the heading error ϵ_θ, are determined by the guidance system. Thus, the control system merely provides control surface deflection (engine gimbal rotation, thrust, deflection, etc.) until the heading error is reduced to zero. Signal input to the control servo is electrical, and signal gain is provided by electronic amplifiers. Power to actually operate the control surfaces is generally applied by electrically controlled pneumatic or hydraulic actuators. The rate gyro is required for angular velocity feedback in order to improve the response of the system.

The electronic amplifiers used are of conventional design, but use high quality components designed to withstand extreme environmental conditions. While such components might appear to be critical, recent developments in the field of reliability of electronic equipment show that high quality components improve the reliability even of equipment which is not exposed to environmental extremes. Thus, the types of electronic components necessary for missile guidance systems may be found in any electronic shop where quality commercial equipment is constructed. Furthermore, the finished guidance elements, amplifiers, simple computers, and the like, have the physical appearance of amplifiers and com-

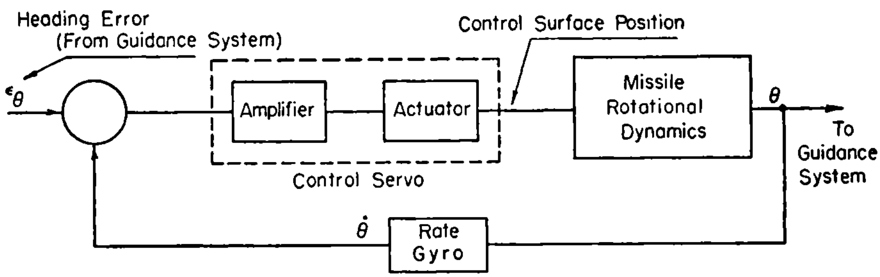

FIGURE 1

Single Axis Flight Control System

puters which might be part of many commercial items. Thus, the electronic equipment itself neither contains nor forms critical components, in the sense of this report. The rate gyros must be rugged, but need not be particularly accurate, and so are not critical. The control surface actuators are more an air frame than a control problem, and have not been considered.

Thus, there are no suitable critical components in the flight control system.

The guidance system is that which actually measures the position, velocity, and attitude of the missile, and issues commands to the flight control system in order that the missile assume the proper values of these quantities. Guidance systems for long range missiles are based on inertial guidance, radar, radio, celestial guidance, and on combinations of these.

Before discussing the guidance systems, however, the two major types of long-range missiles will be described, in order that the accuracy requirements on guidance may be established.

LONG-RANGE MISSILES

Ballistic Missiles

Ballistic missiles are those the major portion of whose flight is unpowered, unguided, free flight. That is, after an initial period of powered flight, during which the missile is set up on a proper course with a proper velocity, the missile "coasts" to its target. Its behavior is like that of a self-powered rifle bullet. The powered portion of flight corresponds to time in the rifle barrel.

The free-flight path of a ballistic missile is an ellipse with one focus at the center of the earth. In order to establish the order of accuracy required for a control system, an error analysis was made of a single trajectory. This was for a 4,000-mile missile on a minimum energy trajectory. It can be shown that the range error $\triangle R$ and the lateral error $\triangle L$ are related to the error in velocity $\triangle V$, the elevation angle error $\triangle \Phi$, and the heading error $\triangle \Theta$, by

$$\triangle R = 12300 \triangle V - 700 \triangle \Phi \text{ miles}$$
$$\triangle L = 3750 \triangle \Theta \text{ miles}$$

where $\triangle V$ is expressed as a fraction of the required velocity, and $\triangle \Phi$ and $\triangle \Theta$ are measured in radians.

Thus, a 1-mile impact error requires that the missile velocity be measured to within 0.0082 percent and that its direction of flight be known to within 0.014°. (It should be recognized that this is a very crude analysis, and that a proper error analysis must be statistical in nature. However, orders of magnitude are all that are required for this report.)

Air-Breathing Missiles

A class of missiles which is often underestimated because of the publicity given to the "ultimate weapon" ballistic missile is the air-breathing missile, such as the supersonic Snark or hypersonic Navaho. These missiles are essentially unmanned aircraft, but they are much less expensive than ballistic missiles and, in the opinion of the author, much better suited to covert employment.

The flight plan of air-breathing missiles does not admit of as simple an error analysis as that of ballistic missiles. Thus, such analysis will be deferred until the actual guidance systems are discussed.

GUIDANCE SYSTEMS

Inertial Guidance Systems

Inertial guidance systems are based on the measurement of missile accelerations. Integration of the accelerations with respect to time yields velocity components, and integration of velocity gives position. Inertial guidance systems have the advantages that they are self-contained, do not radiate signals, and cannot be jammed. On the other hand, extremely accurate components are required.

Each accelerometer used in an inertial guidance system measures only the component of acceleration along a single axis. In order that the output of an accelerometer be meaningful, it is necessary that this axis always be aligned with one of the axes of a suitable coordinate system. This requires that the accelerometer be mounted on a platform which does not rotate with respect to the coordinate system—the so-called "stable platform." The orientation of this platform is held fixed by servo systems in conjunction with gyroscopes, which provide the stable references, since a spinning gyro maintains its orientation in space. One typical implementation of an inertial guidance reference is shown in Figure 2. Three one-degree-of-freedom (or two two-degree-of-freedom) gyros are used for a spatial reference. In the particular configuration shown here a "g-computer" is required to balance out the effect of gravitational accelerations, although it can be eliminated in cases where altitude information can be obtained, for example, barometrically. The attitude of the missile is measured with respect to the stable platform.

Missile position, velocity, and attitude are fed from the inertial system into a guidance computer which determines corrections in attitude in order that the missile reach its target.

The accuracy of an inertial guidance system is limited by the accuracy of the accelerometers, and the drift rate of the gyros. In a ballistic missile guidance system ("ballistic missile initiator") the more severe requirement is on the accelerometers, as the time of guided flight is so short that little gyro drift can accumulate. For the 4,000-mile case previously considered, the accelerometer accuracy must equal the velocity accuracy, better than 0.01 percent, but for a powered flight of 6 min., a gyro drift rate of 0.1°/hr is acceptable. To indicate the required accuracy as a function of range, Figures 3 and 4 show required accelerometer accuracy and gyro drift rates as functions of range. For simplicity, these figures were calculated for a plane earth, but the results are comparable to those calculated exactly. It may be noted that there are available commercially 0.01°/hr gyros.

In the inertial guidance system ("position monitor") used for air-breathing missiles, it is the stable platform which produces the most significant errors. An accelerometer having an accuracy of 0.01 percent is satisfactory for one mile accuracy on a 10,000 mile flight. On the other hand, in Figure 5 are plotted required gyro drift rates for a one mile

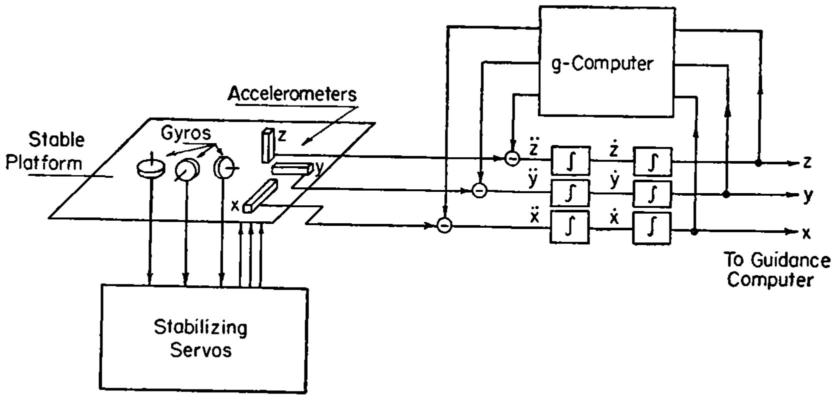

FIGURE 2
Inertial Position Monitor

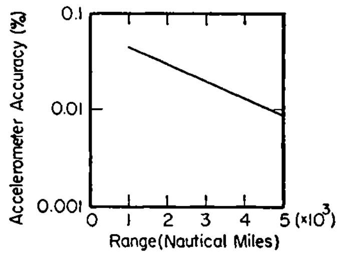

FIGURE 3
Required Accelerometer Accuracy for Ballistic Missile Initiator: One Mile Error (Plane Earth)

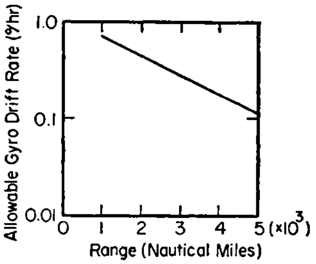

FIGURE 4
Allowable Gyro Drift Rate for Ballistic Missile Initiator: One Mile Error (Plane Earth)

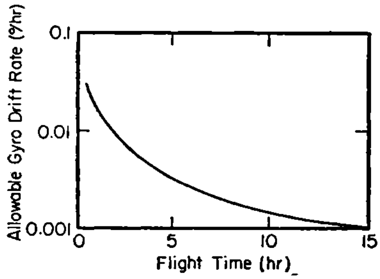

FIGURE 5
Allowable Gyro Drift Rate for Position Monitor System: One Mile Error

error as a function of duration of flight. Excellent gyros are required for all but the shortest flights.

Radar Guidance Systems

There are several ways in which radar is used in missile guidance systems. Ground stations measuring Doppler frequencies may be used to measure ballistic missile velocity at burnout. Self-contained Doppler systems may be carried by air-breathing missiles to measure their velocity and, hence, their position. Finally, automatic radar presentation following may be employed.

As a result of the Doppler effect, the radar return from a moving target is shifted in frequency by a fraction 2v/c relative to the transmitted frequency, where v is the radial component of target velocity, and c the speed of light. By measuring the difference between the transmitted and received frequencies, one may determine a velocity component. Three spaced Doppler stations suffice to give total target velocity. In the case of the 4,000-mile ballistic missile discussed previously, velocity has to be known to within 0.0002 miles/second for one mile accuracy. For a Doppler system using a carrier frequency of 1,000 megacycles, this implies that the frequency difference must be known to within two cycles per second. This kind of measurement is within the state of the art today, using commercial components, and can probably be improved by at least one order of magnitude. (Two cycles out of 1,000 megacycles may appear to be an extremely difficult measurement, but it is only the difference frequency which need be measured, and this amounts to one part in 10,000.)

In self-contained Doppler navigators, the (air-breathing) missile transmits two radar beams, and measures the frequency shift of the returned signals in order to obtain two components of translational velocity. These, integrated, give plan position. The accuracy of this system depends not only upon the accuracy with which frequency can be measured, but also upon the smoothness of the terrain over which the flight takes place. Also, on over-water flights, since velocity is measured with respect to the (moving) water surface, additional errors are introduced.

Self-contained Doppler navigators are commercially available (e.g., General Precision Laboratory's "Radan") with an advertised accuracy of 1 percent of distance travelled. This is probably unsatisfactory for missile guidance, but may be sufficient for initial positioning for the Atran system.

Atran is a system which compares the radar image of the terrain over which the missile flies with radar photographs of the same area which are stored in the missile. All the details of the system are classified, but it may be presumed to be better than the self-contained Doppler navigator, and perhaps as good as manned radar navigation, which is good to a fraction of a mile.

Radio Guidance System

It is a simple matter to make a guidance system which can "home" on the enemy's civil navigation aids, or which can utilize these aids to navigate to desired targets. Although such a system anticipates a degree of cooperation unlikely from a potential enemy, it is attractive for an initial sneak strike by air-breathing missiles.

Radio guidance systems which operate at long ranges utilizing facilities in friendly territory are not nearly accurate enough for missile guidance.

Celestial Guidance

Some missile systems utilize celestial guidance, with automatic star-tracking telescopes. No unclassified information is available on the performance of such systems, nor on the existence of any critical components in these systems.

CRITICAL COMPONENTS

Critical Components in Inertial Systems

It is clear that the critical components in inertial guidance systems are the gyros and the accelerometers. However, the whole stabilized platform, and in particular the gimbals, must be made to extremely high tolerances.

To obtain the required tolerances, it is often necessary to rebuild new machine tools, such as precision boring machines, and to build special machines for balancing gyros. In addition, the assembly of gyros and accelerometers must be performed in almost sterile rooms, with filtered pressurized air. These components are hermetically sealed, however, and some of the stringent requirements on cleanliness can be relaxed on the final assembly of the stable platforms. It is interesting to note, though, that one of the current production gyros reputedly must be kept at a constant temperature, even when this instrument is being transported.

A typical inertial guidance system, exclusive of electronic equipment, may weigh from 500 to 1,000 lbs. It consists of a three-gimbal platform on which are mounted three gyros and three accelerometers. The electronics equipment may weigh upwards of 100 pounds. However, that equipment does not contain any critical components for the reasons discussed previously.

Although the details of manufacture of such systems are, naturally, classified, it is probable that precision borers, grinders, and lathes figure significantly. The precision gyro balancing machines are probably the most significant single item.

Critical Components in Radar and Radio Guidance Systems

There is no suitable critical component in radio or radar guidance systems. Equipment developed nominally for, say, ionospheric measurements could well be employed in guidance. Digital techniques are coming into use even in air-borne computers, and an appropriate digital computer can readily be modified to solve guidance problems. That is, an air-borne general purpose computer is a probable development as a commercial navigation aid. This can be made into a guidance computer merely by changing its program. This change can be executed with the aid of, say, a punched paper tape, in as little as five minutes. Only a few more minutes would be required to remove the computer from an aircraft and place it in a missile.

Critical Components in Celestial Navigation Systems

Insufficient unclassified material has been released to permit one to determine if automatic celestial navigation systems contain critical components. The most likely such items are the automatic star trackers, but it is quite conceivable that they are not extremely critical.

CONCLUSIONS

Although the intercontinental ballistic missile is more nearly an "ultimate weapon" than is an air-breathing missile, it also presents more formidable problems in its production, particularly its clandestine production. It is difficult to disguise its guidance system as anything but what it is: a guidance system for a missile.

The heart of the system is the stable platform, which looks like a stable platform, and cannot be explained away as anything but a stable platform for a ballistic missile guidance system. Should such a missile be produced covertly, it is necessary to avoid the use of critical components. It appears that this can be done, but only as an operation with marginal chance of success.

The most critical components are accelerometers and gyros, and the more critical of these is the accelerometer. The need for accelerometers might be eliminated by use of the radio Doppler scheme of measuring velocity, discussed earlier. Precision gyros could be manufactured prior to disarmament and stored, as they are relatively small (about one fourth of a cubic foot). Or, they might be manufactured regularly, but be labeled, and even used, as low-accuracy gyros. This implies that the inspection may have to be concerned with the gimbal system (stable platform) itself.

Intercontinental air-breathing missiles on the other hand, have guidance systems which are very well suited to covert development and use. Indeed, since the air-breathing missile is but a high-performance aircraft, a navigation system ostensibly developed for a manned aircraft, or even installed in a manned aircraft, could quickly be transferred to a missile. Another advantage of air-breathing missiles is the fact that their logistic and ground handling requirements are less severe, so that they can be launched from almost any strip of cleared ground, the deck of a merchant ship, or the like.

In conclusion, then, it appears difficult, if not impossible, to manufacture ballistic missile guidance systems; it may not be at all hard to conceal the fact that position indicators are being manufactured for air-breathing missiles.

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INSPECTION FOR DISARMAMENT: HIGH PRECISION GYROSCOPES AND ACCELEROMETERS

by Eugene A. Avallone

INTRODUCTION

Objective of Inspection as Applied to High-Precision Gyroscopes and Accelerometers

THE FRAMEWORK of the inspection system being postulated assumes, among other things, the following:

1. The country open to inspection is about the size of the United States and, presumably, highly industrialized.
2. Inspection shall be administered by an international agency.
3. The inspection agency has unrestricted access to persons and places.
4. The inspection agency has ample funds and, presumably, will be staffed with sufficient competent personnel to carry out the inspection functions.

In this space age, many of the inspection points will be concerned with manned and unmanned aircraft, guided missiles, and the other weapons capable of rapid and massive destruction of the important in-

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dustrial centers in the extensive network of manufacturing enterprises in a highly industrialized country. An attack on such targets would be most effective if carried out with the element of surprise. It is further assumed that the massive destruction would be wrought by some type of nuclear warhead (A-bomb, H-bomb, and so forth).

High-precision gyroscopes and accelerometers as applied to the missile and aircraft fields afford a good example of a critical armament component. If the clandestine manufacture of such equipment can be effectively prevented through an inspection system as postulated above, then the ability to mount an all-out surprise attack will be denied a would-be aggressor. In the case presently to be discussed, the question of inspection resolves itself into determining whether the manufacture of high-precision gyroscopes is amenable to effective inspection.

TYPES OF EQUIPMENT

Use of High-Precision Gyroscopes and Accelerometers in Inertial Guidance Systems

The modern, miniaturized, high-precision gyroscope can best be appreciated in its application to inertial guidance systems, and for the purpose of this brief discussion, the gyroscopes considered are intended for use in such applications.

The heart of an inertial guidance system is the stable platform provided by gyroscopes, the platform serving as a fixed space reference. In missiles (or in space rocketry in general), the inertial guidance system operates by dead reckoning from one of two known points to the other. Once placed in operation, the system functions independently of outside information. A set of three single-axis gyroscopes, for example, once set spinning with axes in prescribed directions, will maintain those directions. The orientation of a space reference provided by gyroscopes will remain fixed as long as the spin axes uniquely maintain their original position.

Accelerometers sense speed changes as the vehicle travels along its flight path. The speed changes are interpreted as changes in vehicle motion referred to a coordinate reference system. Coupled with a suitable computer, the net result will be to maintain motion along a prescribed trajectory.

Bearings and Gears

Bearings and gears are cited as typical examples of extremely accurate components of the gyroscope and accelerometer assemblies. The difficult and complex problems met in the manufacture of bearings and gears for these high-precision components are representative of problems met in the manufacture of many parts of the gyroscope system. In the "forest" of high-precision gyroscope and accelerometer parts, bearings and gears are two "trees" which can serve as a convenient index to employ in appraising the fabrication problems of the components as a whole.

It is interesting to note at this point that the modern, high-precision, miniaturized gyroscope is similar in its essentials to Foucault's original gyroscope. The mechanics and behavior of the gyroscope have not changed since Foucault. The problems which arise today in engineering, design, and manufacture of the modern gyroscope result from the stringent specifications set upon it by its required performance.

In a word, the modern gyroscope, as well as the accelerometer, must be *extremely* small, *extremely* precise, *extremely* light, and *extremely* reliable. And all this is required of a unit in which the gyroscope itself, for example, at times may be only slightly larger than a ping-pong ball!

High-Precision Bearings

Most low friction bearing requirements in high-precision gyroscopes and accelerometers are presently satisfied with the most accurate miniature precision ball bearings obtainable, manufactured to ABEC-7[1] tolerances (+0.00000", −0.00015" on bore diameter; maximum eccentricity TIR[2]=0.0001"), or better.

Manufacture of high-precision ball bearing elements is carried out in air-conditioned spaces, with dust-free filtered air closely controlled as to temperature and humidity. Tolerances on sphericity and size variation as low as 0.000005 inches and very fine surface finish (down to 0.5 microinch rms[3]) are the quantities the bearing manufacturer must cope with. Thus, process control of a higher order than usual must be exer-

[1] Annular Bearing Engineer's Committee.
[2] Total Indicator Reading.
[3] Root mean square.

cised in all phases of manufacture, from inspection of incoming raw material through rough machining, heat treating, grinding, honing, cleaning, inspection, assembly, and packaging. Component parts as well as completed assemblies are always handled with utmost care in order to avoid contamination and/or physical damage.

By way of example, bearing components and assemblies are truly "untouched by human hands." Lint-free garments and gloves, tweezers, and so forth are standard equipment in the inspection and assembly areas. Bearings are individually packaged in sealed containers opened only when ready for final installation of bearings in the equipment.

Finishing operations in particular must be accomplished with special machine tools mounted on isolated bases, in areas of light traffic, to prevent transmission of external vibrations and disturbances through the machine tool to the workpiece.

Inspection equipment is of special design and construction to handle the minute tolerances, and inspection personnel must be above average in skill, for this phase of the work is slow and very exacting.

Sleeve bearings lubricated with a film of liquid or gaseous lubricant show desirable low friction characteristics too, but require pressurized gases for the bearing, extremely close fit between journal and bearing, and consequently small component tolerances of 0.0001 inch or less, and may be subject to operative instability such as whirl if not properly designed. While inherently simpler than ball bearings, the sleeve bearing's requirements of a pressurized lubricant supply system and small component tolerances contribute to its complexity.

High-Precision Gears

Spur gears are generally employed in servomechanisms associated with the use of high-precision gyroscopes and accelerometers, in the stable platform reference system and elsewhere. With constant speed input, mating involute gears operate with a constant velocity ratio and transmit torque with neither acceleration nor deceleration. They are likewise suited for transmission of precise, positive motion from one to the other. Tooth size and proportions, size of gears, and involute profile accuracy generally represent the major problems in manufacturing high-precision gears for these systems.

Accuracy obtained at the present time in cutting these gears in some plants amounts to two seconds of arc on any part of the profile on nonadjacent teeth; concentricity on representative sizes of cut gears runs in the order of 0.00001 inch. Such requirements, extending to millionths of an inch, place the manufacture of these gears among the most difficult precision-machine operations ever attempted (and accomplished).

Generally, a precision machine tool is built with accuracy ten times better than the required product precision. This is not possible in equipment whose product tolerances are of the order of 0.00001 inch. Machine tools for such precision work are built to feasible precision (0.0001″) and the products selectively inspected and assembled, with a large portion (falling outside required precisions limits of, say, 0.00001″) declared as scrap.

The special ultra-precision hobbing machine producing gears of the above accuracy was several years in the design and development stage before it was successful. Rigidity and stability of construction, in addition to tolerances in the machine itself of the order of 0.0001 inch or less, required heretofore unheard-of care and precision in the manufacture of a machine of the size constructed. The hobber was assembled and is operated on an isolated base in a dust-free, air-conditioned space with controlled temperature and humidity. Of more than 100 sources, only one manufacturer (Barber-Colman Co.) actually built the hobber for and in collaboration with the Sperry Gyroscope Co.

Special hobs, inspection equipment and tools, and specially trained skilled personnel are required in manufacturing these gears. Furthermore, in order to minimize variation in parts during a production run, long tool life between grinds is essential.

Certainly the manufacture of this class of accurate gears cannot be accomplished by the methods and machines found even in a well-equipped gear-cutting plant manufacturing "conventional" precision instrument gears.

PRODUCTION OF EQUIPMENT

Missile Requirements for a Surprise Attack

Assume an aggressor contemplates mounting a surprise attack on 200 prime targets, utilizing missiles with nuclear warheads. Assuming a delivery efficiency of as high as 50 percent, the aggressor would require the minimum production of about 400 missiles, each requiring at least six high-precision units (gyroscopes and accelerometers).

The manufacturing time needed for the number of gyroscopes required will be phased in with the production of other missile components. The clandestine nature of the attack and preparations therefore is such that all parts should come together for assembly in accordance with a master plan of operation. Furthermore, it would be dangerous to extend the preparatory phases of manufacture and assembly of equipment over too long a period of time. For this crash program, then, assume the gyroscopes and accelerometers must be produced within a one-year period.

Considering the high-precision gyroscopes employed to establish the stable reference platform and related accelerometers, and assuming each missile has three single-axis gyroscopes and three accelerometers, at least 2,400 units would be required. Accounting for spare units (20 percent) and an expected high total rejection rate resulting from inspection and testing (50 percent or more), the manufacturing facility must be capable of a production rate of approximately 4,500 gyroscopes and accelerometers per year.

Plant and Manufacturing Facilities Required for Production

In attempting to establish the plant and personnel requirements for the production of this number of high-precision units, one must remember that in the complete assemblies, a high percentage of parts is comparable in quality to the gears and bearings.

There exist in the United States today about half a dozen plants capable of accommodating the above production quota. Each is a special purpose complex; to do the same job, any other plant would have to be built or revamped along essentially identical lines. The existing plants are not completely integrated; that is, not every item which goes into a complete gyroscope and accelerometer assembly is manufactured in the plant proper. Items such as ball bearings, electric wire, and so forth are purchased from outside suppliers who, in turn, manufacture them according to the purchaser's specifications. Likewise, existing manufacturers engaged in this high-precision production do not make their own machine tools; generally, except for some small, special equipment used in the production, inspection, or testing areas, most equipment is procured from external sources.

This estimate of requirements for an integral manufacturing facility gives the order of magnitude of such production. In an attempt to evade inspection, the work might be dispersed among existing plants in order to "cover" it.

Machine tools alone required for the plant—from jeweler's lathes and Swiss automatic screw machines to jig borers and ultra-precision hobbers, grinding, lapping, and honing machines, toolroom equipment, and so forth—are estimated at about 900. To this figure must be added thousands of hand tools and items of inspection equipment—from precision gage blocks and optical comparators to pneumatic and electric gages, microscopes, measuring and recording apparatus for electrical and mechanical testing of subassemblies and completed gyroscopes, heat treating facilities, degreasing and cleaning equipment, environmental test chambers, and so forth.

A few items of necessary manufacturing, inspection, and testing equipment are found in our present high-precision gage and instrument industry. Much of the equipment required, however, is unique to the intended application because of either design or limits of manufacturing accuracy, or both.

Thus, building and equipping an integral facility under normal circumstances is difficult; under conditions as adverse as these, the task becomes formidable indeed.

Personnel Required for Production

Operating on a single-shift basis, the personnel required to operate the plant and meet the production schedule would amount to approximately 1,200 to 1,600. This figure includes all categories of personnel—managerial, supervisory, production, inspection, testing, toolmaking, maintenance and janitorial services, and so on.

All personnel included above are presumed competent, trained, and ready to start work immediately. Lost time for training and extensive on-the-job orientation cannot be tolerated inasmuch as (a) the very nature of the crash program will not allow it, and (b) the gyroscope and accelerometer production rate must dovetail with production schedules of other missile components.

INSPECTION

Possible Avenues for Accomplishing Inspection

A manufacturing plant of the type described, housed at one location or split up in several locations, cannot remain under cover for any length of time, let alone be constructed without notice, be it a surface or an underground installation.

Likewise, a large employee population is difficult to ignore, be it in a metropolitan area or in a more remote outlying part of the country.

Equipment for the plant must come from many outside sources, especially precision and ultra-precision machine tools (large and small), inspection equipment, and so forth. Existing suppliers of specialty items, or those capable of producing specialty items, are relatively few. The case of the hobber, cited above, serves to illustrate this point. Considering jig borers as a further example, domestic production of this type of machine tool is in the hands of three to four manufacturers at most.

Electric power requirements would be large for an integral manufacturing plant. Public utility power can be accounted for without undue difficulty. If power is generated at the plant site, large quantities of fuel and cooling water, as well as large prime movers and generating equipment will be required.

Feasibility of Accomplishing Inspection

It is the writer's opinion that effective inspection of high-precision gyroscope and accelerometer production is feasible. The avenues above can be used singly or in combination as a point of departure for establishment of an inspection system falling within the framework postulated at the outset of this discussion.

First, regarding the plant itself. Either a special purpose plant can be built or an existing suitable structure can be revamped. A comprehensive inventory of plant facilities, kept up-to-date by frequent inspections, will rule out the possibility of such a facility going into operation undetected.

The size of the employee population will require locating a plant near a suitable source of labor. This restriction considerably narrows the field of possible plant locations, with its attendant benefits in easing the inspectorial task.

The equipment of the plant, notably the special, ultra-precision machine tools, offers one of the best ways of implementing an effective inspection. These critical machine tools can be produced by relatively few manufacturers.

Factors that could limit inspection capability include wide use of ultra-high-precision components in ordinary industrial and scientific equipment, and attempts to select acceptable components for high-precision instruments from a large output of low-tolerance units by careful gauging and selection methods. (See "Report of Evasion Team A.")

Inspection in Countries Engaged in Research Involving Rocketry

A country subject to inspection and which happens to be engaged in space and rocket research will, of necessity, require high-precision gyroscopes and accelerometers for its peaceful pursuits. This implies the existence of manufacturing facilities capable of producing the required high-precision units.

Under these circumstances, the previous methods of effecting inspection can still apply to prevent any clandestine production of such units. Those plants known to be producing high-precision gyroscopes, accelerometers, and the like for scientific or other nonmilitary uses can be effectively inspected by a team of resident plant inspectors. Not many such plants will exist, hence the number of inspectors so engaged need not be large.

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CRITICAL ASPECTS OF AIR FRAME DESIGN AND PRODUCTION

by Bruno A. Boley

INTRODUCTION

ANY ARMAMENT INSPECTION procedure must without doubt include an examination of the air frame, since this is certainly the most obvious physical component of all flying craft. The discussion presented below has the principal aim of estimating the feasibility of air frame inspection, and of determining what aspects of such an inspection might be more likely to prove fruitful and practical. The basic hypotheses underlying this entire discussion are outlined first, so as to bring air frame inspection into focus as part of an over-all program. Some general considerations are then examined which, though valid in principle for the inspection of other aircraft components as well, will be found to yield useful conclusions when viewed from the standpoint of the air frame. The detailed study of the air frame is then divided into two parts, respectively concerned with the inspection of the physical components themselves, and of their engineering design and analysis. Some final conclusions are then summarized.

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BASIC ASSUMPTIONS

It will be assumed in what follows that discovery of manufacturing or design operations has already been made; the problem is then to search for any aspects of this operation which may be regarded as suspect. It is, however, unrealistic to hope to find a single item that can be used as a sole criterion of clandestine operations. It is rather necessary to search separately a number of separate components for possible adverse evidence, final proof of malpractice being provided by the weight of accumulated discoveries. Thus, air frame inspection represents only one phase of the over-all problem, one capable of furnishing at most prima facie evidence; this must then be sifted in the light of the entire body of information gathered from other viewpoints and different sources. In this manner one may avoid errors which may enter in any extrapolation from the characteristics of a single component, to the size, mission, and capabilities of the entire craft.

GENERAL CONSIDERATIONS

Listed below are a number of basic questions which, though general in nature, have a direct bearing on a program of air frame inspection, and will in fact determine to a large extent its reliability and effectiveness.

1. *Prediction of future developments.* A meaningful inspection program cannot account specifically only for current methods of manufacture and design which may be superseded; it must be sufficiently flexible to detect future technological advances. The difficulties of forecasting the growth of the aircraft field have frequently been pointed out (1), and unfortunately have tended more often than not to be on the unsafe side, or, in other words, to underestimate the pace of development (2). As concerns the air frame in particular, it is safe to predict that great improvements will take place in the use of metals and plastics with good high-temperature properties, and in the corresponding machining and fastening procedures (3). The impact of such developments on the inspection problem will be discussed later; the next item indicates, however, some of the difficulties which are encountered.

2. *Convertibility of civil craft to military use.* Advances in military aircraft are likely to be paralleled to some extent by corresponding

improvements in general aviation; thus, not only can such advances not be used in the detection of military construction; they also facilitate the possible conversion of a civil craft to war operations. This is an obstacle particularly to the discovery of bomber construction since, from the standpoint of the air frame, little essential difference exists between the construction of a bomber and a large civilian transport. It appears in other words feasible (account being taken of item (3) below) to build transports with high performance characteristics, provisions being made in advance to make possible detail changes for the accommodation of military equipment. It is more difficult to do so in the case of fighters and missiles; the performance requirements of this type of craft have no direct counterpart in civil aviation, while large scale production of acrobatic aircraft and of equipment for scientific work may be a priori excluded. The possible exploitation of this fact in devising an air frame inspection procedure is analyzed further below.

4. *Importance of economic factors.* Economy of construction and operation plays a major role in the development of civil aviation, but must in many instances be subordinated to military necessity in the case of craft intended primarily for wartime operations. This difference between civil and military aircraft is, however, minimized by the fact that economic factors may vary a great deal from country to country. Thus one may speak, for example, of a practical limit to the performance of commercial transports in the United States (4), while at the same time the Russian TU-104, which is uneconomical by American standards (5), is being produced.

5. *Concealment of operations.* The expectation that an effort will be made to conceal the planning and the production of military craft is, of course, the prime reason motivating an inspection program in the first place, and the difficulties it introduces are thus basic to the entire problem and not restricted to the present problem. In the case of the air frame, however, some special circumstances must be considered. The structural frame of even the smaller fighters or missiles is always comparatively large, so that concealment would seem to imply one of two alternatives; either a craft is being produced which can be easily converted to military use, or the construction is divided between a number of subcontractors in such a manner that the completed product can be rapidly assembled in case of need. The first of these alternatives has already been pointed out in item (2) above; the second is capable of

detection through a comparison between the total number of completed aircraft and the number of parts being produced, due allowance being made for a reasonable number of spare parts. This problem appears to be to a large extent one of bookkeeping, in that it requires the identification of the final disposition of a number of separate components; it is therefore not, strictly speaking, one which can be handled solely by inspection of the actual frame or its component members.

INSPECTION OF PHYSICAL COMPONENTS

On the basis of the underlying hypotheses and of the general considerations of the previous sections, it is now possible to proceed to a more specific examination of the aspects of the air frame that may form part of an over-all inspection program. The inspection of components themselves and their manufacture is discussed here, that of design and engineering procedures in the next section.

The factors which, in the light of the previous discussion, appear to offer some possibility of use in the present problem are examined below so as to determine their drawbacks and advantages. It might be well to recall that, as has been pointed out earlier, it is in any case not possible to obtain conclusive evidence of clandestine production from an examination of any one of these factors alone.

1. *Use of scarce materials.* Use of scarce materials with good high-temperature properties is not in itself evidence of military production, since high speeds (as cause of high temperature) may be found in civil aircraft as well. Their scarcity and their high cost makes it likely, however, that these materials will be allocated primarily to military use. The principal metallic materials which fall in this category, to be used either as alloys or in comparatively purer form, are titanium, niobium, vanadium, zirconium, rhenium, beryllium, and tantalum (3); a few of these are discussed below.

Titanium is the most frequently employed of these metals; it finds its principal outlet in aircraft work (6), though it finds increased use in various phases of chemical engineering. Because of its high melting point (about 1660°C) it was hoped that alloys might be quickly forthcoming which retained a great deal of their strength at high temperatures. Although this may not have been yet fully realized, a great deal has already been accomplished as concerns production techniques (7, 16) and cost (6). As a measure of the improvement, it may be mentioned that the price of titanium has about halved in the last three years. Titanium is at present most useful for operations in the high subsonic and transonic ranges, while stainless steels are usually required for the primary structure of higher speeds (8).

Increased use of the other metals, as well as titanium, is indicated for the future. The scarcity of zirconium stems principally from difficulties of extraction; its exploitation in an air frame inspection program is, however, somewhat limited by its use elsewhere, notably in the atomic energy field (8). Vanadium and niobium seem to provide better criteria in this respect, particularly the former, which is at present already in use in the manufacture of sheet alloys with good properties up to about 1200°F (9).

2. *Difficulties of production.* The production of air frames for high-speed craft often involves difficult problems of machining and fabrication, due in large part to the smaller allowed tolerances. Thus difficulties were encountered (10) in fabrication of sandwich panels for the XB-58, in welding in the ICBM, in machining in the F-102 and F-106, for example. Such problems are of course not restricted to the military field, but have been found to become more and more serious with increasing speeds; the term "producibility barrier" has, in fact, been introduced to indicate a lack of definite means for making a certain aircraft part (10). Various techniques have been proposed to overcome such problems, as for example chemical milling; however, from the standpoint of effectiveness of an inspection program, their value is limited by the fact that the same techniques are likely to find their way rapidly in civil production as well.

3. *Use of test facilities.* The production of missiles must be accompanied by an extended test program, particularly in the field, and in fact its success is largely dependent on such a program (15, 17). The need for experimental verification is much more critical in the case of missiles than in that of conventional aircraft (12); it is in fact possible, in the latter, under conditions of a low calculated risk, to release production changes on the premise that they will be subjected to flight test on the first unit. Experience has shown, however, that a missile does not possess as large a capacity to absorb modifications on this basis; therefore, a missile program must be supported by adequate laboratory and, particularly, field development and testing facilities, competently

staffed; this circumstance would seem to point to a fruitful area of inspection.

4. *Inspection of components.* It was mentioned earlier that, particularly with fighters and missiles, inspection would have to be performed on individual components rather than on the assembled product. This is due mainly to the presumed desire for secrecy of production, though it has been stated (10) that the trend toward over-all weapons system development makes it mandatory for prime contractors to place greater reliance on specialized subcontractors. The validity of this opinion has, however, been challenged by the view that the widespread use of subcontracting in this country's program has been principally due to government policy rather than to technical necessity (11).

INSPECTION OF ENGINEERING AND DESIGN OPERATIONS

In addition to the inspection of the actual air frame components, a possible controllable area is provided by the operations connected with the design and engineering analysis of aircraft and missiles. Some of the principal facets of this type of inspection are outlined below.

1. *Design conditions.* The design of long-range ballistic missiles presents some very difficult structural problems, much more so in fact, than the design of the short-range guided weapons (13). For the latter, as for defensive or tactical weapons, the structural problems are related to ease of assembly and access, and to installation and storage, as much as to strength. With the long-range ballistic types however, structural problems of kinetic heating, of atmospheric exit and re-entry, of vibrations, and of stability are greatly accentuated and form actually one of the most difficult areas of their design. An inspection program could thus be devised which would include an examination of the structural and aerodynamic analyses; such a study would disclose information as to speed, temperature level, altitude desired, and so forth, from which the mission of the particular craft could be deduced.

2. *Factors of safety.* Military air operation places great emphasis on maneuverability and, in comparison with civil aviation, less on safety. As a consequence, factors of safety are apt to be lower in military design, and actual structural failure is in fact often used as a design criterion. This is particularly true of missiles whose life expectancy is a single

mission. A great deal of attention is thus being currently given to the so-called "fail-safe" philosophy of design (14). An inspection of the structural analysis pertaining to an airplane or a missile would be capable of detecting such a design, which would then be considered an indication of clandestine operations.

CONCLUSIONS

While no single item can be used as a sole criterion of illicit manufacture, certain aspects of air frame production lend themselves to use as part of an over-all inspection program. Particular attention should be given to the following items: (a) numerical discrepancies between component production and available finished products; (b) use of scarce metals with good high-temperature properties; (c) examination of test facilities, particularly in the field; (d) reviews of the design philosophy and design conditions used in the engineering analyses.

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AMENABILITY OF THE AIR-BORNE PROPULSION SYSTEMS INDUSTRY TO PRODUCTION INSPECTION

by Henry Burlage, Jr.

THE PRESENT CONCEPTS of global war involve the high speed delivery of devices capable of mass destruction through, and possibly above, the earth's atmosphere. This mission demands vehicles of impressive capabilities. An ideal inspection method, to implement any attempt to limit construction and possession of such "weapon systems," would suppose completely free access to persons and places. Even if agreement for open inspection did exist, there would always be the possibility of subterfuge and deception. Therefore, the considerations for any inspection system should include, in all phases, the mechanisms whereby these possibilities would be taken into account. As a consequence of this argument, the concept of indirect inspection, whereby parts and subparts are monitored, becomes important. Following this thesis, the first task is to dissect the "weapon system."

A major part of the modern air-borne "weapon system" is the propulsive mechanism. To accomplish the Herculean transport task that is involved requires a propulsion system which is, in itself, a massive

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scientific, technological, and organizational accomplishment. Of course the vehicle, its armament, guidance system, instrumentation, service and supply complex, operational training requirements, and host of associated functions are also subjects for analysis. The following discussion will, however, be concerned primarily with the propulsion system for manned or unmanned vehicles capable of the relatively long-range transport of a payload of catastrophic destructive capabilities.

It is known that conventional aircraft, using reciprocating engines and propellers, can deliver mass destruction weapons. However, this method is rapidly becoming outdated, and apparently no new vehicles and propulsion systems of this type are being developed. Existing equipment is, according to public announcements, rapidly being replaced with high-speed manned jet aircraft. It should be noted, however, that the major intercontinental retaliatory power of most nations at this time still rests mainly with conventional aircraft. This means that inspection now would involve probing the make-up of existing forces which are, of course, highly classified. Inspection at any manufacturing level concerned with the reciprocating engine would be almost useless. Actually, the remaining production facilities for such engines are relatively small, although there are a number of plants that could be quickly converted for quantity production of existing designs. Based upon the above considerations it seems fruitless to discuss in detail any possible inspection of the propeller-reciprocating engine propulsion system, or any of its variations. Attention will be given only to the "modern" propulsion systems.

Because of the number of propulsion systems that are now available, or may be available within a relatively short time, it is important to determine which ones could satisfy the mission requirements. Also, in order to separate the peculiar features of each suitable propulsion system which might serve as part of an inspection that would not require direct examination of the engines themselves, it is desirable to classify the propulsion systems according to some common characteristics. This also brings with it the general implication of possible physical similarities in each group that might be investigated for use as crucial inspection criteria. Thus it should be possible to determine the development and production facilities, as well as various peripheral activities that form part of the complex required for construction and utilization of such engines, that might in some way be common to two or more types.

A Classification of Propulsion Systems

I. Propulsion systems using air for energy liberation and thrust production:
   A. Turbo-propeller
   B. Turbojet
   C. Ram-jet
   D. Dual-cycle engine (turbo-ram)
   E. Pulse jet and "wave" engines

II. Propulsion systems that do not require air for either energy liberation or thrust production:
   A. Liquid propellant rocket
   B. Solid propellant rocket
   C. Nuclear rocket
   D. Solar rocket
   E. Ion rocket
   F. Photon rocket
   G. Plasma jets

III. Propulsion systems using air for thrust production and independent of air for energy liberation:
   A. Nuclear turbojet
   B. Nuclear ram-jet
   C. Ram-rocket

This list presents a rather imposing challenge for analysis, particularly when the wide divergence of hardware is considered. The work can be simplified, however, by making certain assumptions. Considering the present technology, and the factors that involve the practical selection of a propulsion system for various missions, it is possible to discount certain of the systems listed. The turbo-propeller system, at the present time, is best suited for relatively low-altitude (40,000 feet) low-speed (500-600 MPH) operation. This is apparently somewhat inconsistent with the defined mission, since no major effort seems to exist in this country to utilize such a propulsion system for this purpose. (It should be noted that certain foreign powers have made more use of this mode of propulsion and seem to have a considerable number of aircraft so equipped.) The pulse-jet, as it presently exists, is inefficient and suitable only for low-speed flight, while "wave" engines are apparently not sufficiently well developed for practical use. Nuclear engines, using air for thrust production, are under investigation, but practical application still appears to be some years in the future. Finally, some of the technology required to construct a nuclear rocket, solar, ion, photon, or plasma engine, with any degree of sophistication, does not yet exist. Furthermore, many of this latter group of engines, for various reasons, would probably not fulfill the requirements of the mission.

Thus, at the present time, it appears to be necessary to consider only the turbojet, ram-jet, and liquid and solid propellant rocket engines and their various combinations. To establish the areas in which inspection might be accomplished, the major elements of the propulsion systems industry, as it exists in the United States today, that would be directly concerned with the types of engines under consideration, should be identified. They are:

1. Research and development facilities.
2. Research and development facility equipment manufacturers.
3. Engine manufacturers.
4. Engine components manufacturers.
5. Materials manufacturers.
6. Specialty tool manufacturers.
7. Manufacturers of equipment for engine operation and servicing.
8. Fuels and propellants manufacturers.
9. Engine shipping and storage container manufacturers.

A summary of some general characteristics of propulsion system development will be helpful before the discussion of the detailed features that may be amenable to inspection. It is clear that a development program for a propulsion system, for the defined mission, must involve a large technical effort to evolve the required knowledge and to design and develop all of the components that are needed. Hardware must be built and tested, to confirm the workings of the system, before the development effort can be satisfactorily completed. What is not always obvious is the extent to which the whole development program hinges on a variety of practical factors. It must be based upon the close integration of military requirements, technical knowledge, the state of the art as it concerns the manufacture of the components and their assembly and, finally, the satisfactory coordination of all the parts of the larger program—the entire "weapon system."

To quickly attain a useful item that is complex in concept and being, it is necessary to utilize teams of experts who must be brought together to exert continued and objective influence on the effort. The selection of the people, and organizations, that will participate in various phases of the program is usually based upon their experience as well as their technical, physical, and organizational resources, information that is generally widely available. This suggests an inspection point, involving people, that could be used to detect activity. Since the number of people possessing the ability to participate in such efforts is relatively few, even in a nation the size of the United States, and since the peculiar technical capabilities of the individuals are easy to identify, the build-up of such a group would be easy to detect if "open" inspection existed. The character of the group could lead to some conclusions relating to the problem they were considering. Deception could of course be effected by having extraneous participators but, for the long term, this would be untenable because of the shortage of quality personnel. The results of this "inspection" would be a forewarning and guide to possible new inspection points that might be needed to prevent circumvention of existing controls or to forecast possible new critical areas. This would give the tremendous advantage of active inspection before concealed security screens could be set up to guard the critical area from detection.

There is probably no characteristic of major propulsion system development that has been a greater determining factor in the speed and efficiency of engine development than the development test facilities. This, then, is the key to the achievement of efficient operation of a propulsion system, of whatever kind it may be, and to the attainment of reliability. Facilities capable of handling complete propulsion systems of the size needed for the defined mission are very few indeed. Furthermore, the nature and location of most of them are a matter of public record. For inspection, recognition of the size and scope of these facilities is of vital importance. Major facilities involve such a complicated maze of arrangements and acquisitions that, if any freedom of inspection can be achieved, it would be impossible to keep them undetected. Such facilities also require special equipment and instrumentation, most of which is made by only relatively few manufacturers. From an inspection of the equipment, which by itself is usually not classified, it should be readily possible to approximate the size and capabilities of the facility. This knowledge would provide the basis for estimating the kind and size of hardware that is being tested. Some knowledge regarding the kind of production facilities and materials that would be required could then also be inferred. This might lead to inspection points in time to prevent surreptitious production of hardware.

Research and development facilities for any existing propulsion system, using air for both energy liberation and thrust production, involve some equipment common for research in all types of engines in the category. Therefore it is conceivable that such a facility could serve a dual purpose or be converted, without too much effort, from one area of specialization to another. Liquid propellant rocket research facilities involve entirely different requirements and are therefore physically different. Finally, although solid propellant rocket research could conceivably be carried out in facilities designed for liquid rockets, the inverse would represent a much more complex transformation.

The possibilities of significant points of inspection, to monitor research facilities, appear to be limited and also rather delicate because no large-scale production items are involved. The main areas of sensitivity would seem to be the instrumentation and equipment supply. The specialized instrumentation (e.g., flow meters, force measuring systems, various optical devices, high frequency response recording systems, data encoding and evaluation systems, etc.) that is required is available from very few manufacturers, and in some instances from only one. The same is true for some of the special pumps, valves, dynamometers, and control apparatus required. This suggests that, in an open inspection system, checks in a few selected plants, that would not normally be considered militarily critical, could detect replacement or modification of existing research and development facilities as well as possible new construction. A good deal of the nature and capabilities of a propulsion system under development could be inferred from rather limited information about the instruments that would be involved.

The number of organizations that presently have, or had in the past, responsibility for the development and manufacture of a complete propulsion system are also few in number. In addition to these, there have been some companies, particularly in the automotive field, that were able to set up and operate production facilities for complete engines. It is probable that these latter organizations could also quickly acquire the personnel and experience to undertake the design and development of complete engines. Finally, there are also a few companies and organizations that have staffs, and the technological background, to be able to develop and design propulsion systems, given the proper facilities. Notable among these are a few of the Engineering Schools and Universities. These facts suggest that inspection at the design level would be difficult unless personnel were moved and regrouped, in which case detection would easily be possible.

Assuming the retention of the present organizational scheme, propulsion system manufacturers are so few, and new facilities so difficult to acquire without detection, that they represent the most critical inspection points possible. To use them, however, implies direct inspection of the complete product. The dispersion of existing facilities, or the conversion of nearly analogous facilities, particularly for the manufacture of components, is a factor that must be considered. However, the problem of transferring equipment without detection, in a free inspection situation, would be monumental.

It is essentially true, particularly in times of high production, that the propulsion system manufacturer serves to a large extent to develop, assemble, and test the product. A very large percentage of all components are supplied by other manufacturers. In fact, some components are totally supplied by outside concerns. This is particularly true of accessories (e.g., control valves, ignition parts, fuel metering systems, fuel nozzles, pumps, instrumentation, etc.). Until quite recently a handful of companies produced all of the fuel and ignition accessories for all aircraft propulsion engines, regardless of engine manufacturer. Such a situation would be ideal for inspection but the newer propulsion systems have introduced problems that have been met by new or different companies. In the case of the turbojet engine, turbine and compressor blades and even complete turbine and compressor assemblies, as well as bearings and structural parts, are supplied by outside vendors. Special coatings for the blades lie in another area where outside groups have been active. In the recent past the technology and equipment for fabricating the high temperature alloys to the precision shapes required for gas turbine blades were possessed by relatively few organizations. A similar situation existed relative to the manufacture of the complex fuel nozzles that are in use. Although the proven suppliers of fuel system components for the propulsion systems under consideration are few, a considerable production potential exists because of the number of companies that are engaged in the manufacture of diesel engine injectors and oil burner fuel nozzles. The number of manufacturers of the control systems that are used to govern the operation of the engine and its accessory devices is also limited. Although the types of controls that are used with various engines differ, thereby eliminating a possible common "bottleneck," each of the manufacturers who are in the field is, in general, constructing a variety of units of differing designs.

These facts suggest good inspection points, particularly in conjunction with inspection of the relatively few suppliers of the special materials that are required. However, the demands of the present, and prospects for the future, are causing more companies to participate in components manufacture. Furthermore, the rapidly growing technology is allowing more companies to come into the sphere because the methods and tooling required are becoming more diverse.

The problem of ram-jet propulsion system production is less clearly defined than the turbojet. This is due mainly to the fact that, apparently, no large-scale production of any particular model has yet been set up. At present the major inspection points would seem to be the engine manufacturers, because there are only three who, to public knowledge, have been active in this area. However, because of the nature of the engine itself (exclusive of accessories), a large portion of the parts that are involved are essentially non-precision and, therefore, it would be a simple matter to have a large number of concerns, now manufacturing apparently unrelated products, convert to the manufacture of such engines. The main remaining areas of inspection would again be the fuel system and controls apparatus. In general, the same companies designing and manufacturing these components for the turbojet industry also participate in the ram-jet engine development programs.

Considering the present trends in long-range flight missile programs, it is a certainty that liquid rocket engines will play a most important part. Here again, although the number of prime manufacturers is few, the manufacturing problem is not clear because of the considerable security surrounding the design characteristics and capabilities of the present engines.

But, because of the newness and apparent potentialities of the field, numerous companies, large and small, are participating in the many peripheral activities associated with liquid rocket propulsion. Which companies will retain important positions in the industry is still a moot point.

Although much of the work is highly classified, the areas that should be investigated for possible inspection points include the following:

1. Liquid rocket engine manufacturers.
2. Special pumps and turbines, for the propulsion system (which implies light weight), capable of handling extremely low-temperature or highly corrosive materials.
3. Special valves, for the propulsion system, for extremely low temperature of highly corrosive materials.
4. Control systems.
5. Rocket engine igniters.
6. Special materials (ceramic oxides, graphite, reduced ceramics, ceramets, fluorocarbons, molybdenum, processes involving coatings of chromium-nickel, cobalt-nickel, cobalt-tungsten, and nickel-tungsten alloys or refractories).
7. Injector heads.
8. Cryogenic equipment.
9. Chemical propellants.

The final engine to be considered is the solid propellant rocket. The use of this propulsion system has largely been restricted to auxiliary boost units to aid the other propulsion systems during "take-off," relatively short-range ballistic vehicles, air-air and air-ground offensive weapons, and ground-to-air defense weapons. Although these applications are not completely within the defined mission, there are strong possibilities of extended applications in the future. The solid propellant engine is, from the point of view of hardware, a simple device. It consists mainly of an engine case, a nozzle, the propellant, and an igniter. Of the components, only the propellant manufacture (which is now generally classified) could serve as an inspection point. The reason for this is that the other components could be manufactured by a great number of companies, whereas a somewhat specialized, although not too complex, plant is required for propellant manufacture. All in all this engine, except for the development facilities required, seems to be a difficult one over which to exercise inspection with any degree of ease.

In addition to the main propulsion system, the vehicles capable of the defined mission usually require a source of power to operate functions such as the guidance, instrumentation, and the vehicle flight controls (whatever their nature). These APUs (auxiliary power units).

which are generally totally independent of the main propulsion system, are essentially small engines. Since this field is also a relatively new one, a number of companies are endeavoring to establish themselves therein. The problems associated with these devices (they are heavily classified) appear to be those associated with high energy propellants, reaction chambers (where hot gases are generated), turbo-machinery (shaft power is obtained through the use of high speed miniature turbines), and the associated controls. Thus, the devices cut across the problems encountered in turbojet and liquid rocket systems. The points of inspection would therefore seem to be analogous to ones already discussed. Further, it is reasonable to suppose that the accessory manufacturers supplying the turbojet and liquid rocket industry will also be the prime manufacturers and suppliers in the APU industry. Evidence to support this contention is already in the public print.

In closing the discussion of possible inspection points covering the entire propulsion systems industry, it is well to consider indirect specialty items and processes. For example, the apparatus and methods to produce extremely small holes of great uniformity are of vital importance in certain applications. In general, however, it would be expected that if such areas of extreme sensitivity exist, they would be closely guarded secrets. The process or device might also be equally important to totally unrelated industries. Thus it would seem difficult, and possibly fruitless, to define inspection points in areas that are so indirectly related to the main items.

A last, and extremely important, consideration of any inspection program should be the provision for possible and probable future developments. It is obvious that existing critical points, useful for inspection, would be easy to find if no security measures existed. If such critical points do exist, it is certainly true that the manufacturers and government agencies concerned are also aware of them. Thus it is likely that a blanket of security and deceptive camouflage surrounds the sensitive factor. A way must be found to deal with this situation, if inspection is to succeed. Probably the greatest single advantage to the inspector in this matter is the fact that propulsion systems today are undergoing rapid development and change. Since the next development is somewhat of an unknown to both parties, it presents the inspector with the opportunity to anticipate new critical areas and provide for some control before they can be surrounded by secrecy. The importance of the development facilities in this matter cannot be overemphasized.

Further, a propulsion system cannot, for the purposes being considered here, be developed as an independent item. Instead, it is related to some over-all objective, and thus to some comprehensive program. Any program that requires a vast number of interrelated steps cannot be precisely determined in advance. Therefore, the progress usually depends upon data obtained in each phase. This means that the inspector also has the advantage of time, which allows backtracking and refinement of data. Each of the other elements in the program, as well as the servicing and supply that will ultimately be needed, involves complexities of the same order as the propulsion system. Although this discussion does not include the factors that are involved with the associated efforts in the over-all program it is clear that a similar inspection approach could be used to detect and evaluate elements pertaining thereto. Now, since the pieces must come together, two important opportunities are presented. The first is that a cross-check of information can be carried out, thereby reducing the possibility of successful evasions. Secondly, because a complex web of communication is needed to enable direction and coordination of the "team" members, so large a communication problem suggests the possibility of using the communication as the "bottleneck." Careful analysis of the kind of information that would have to be transmitted, and the means of transmission, might lead to a very significant inspection point.

In conclusion, it becomes clear that a practical "open" inspection system involves the establishment of many indirect information points. Careful analysis of a wealth of data should establish the required information with acceptable accuracy. The true "bottleneck" inspection plan seems to be essentially impossible to establish in the air-borne propulsion industry.

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TECHNICAL MEMORANDUM ON THE FEASIBILITY OF INSPECTION OF CERTAIN ASPECTS OF LONG-RANGE MISSILE PROPELLANTS

by Charles J. Marsel

INTRODUCTION

The following are some of the assumptions being made as a framework within which the design of an inspection system is being postulated: inspection of a country of the size of the United States; inspection to be administered by an international agency; the inspecting agency to have unrestricted access to persons and to places and a source of ample funds for its work. The main aim of this particular study is an examination of the feasibility of designating various inspection points which could enable the control, within acceptable error, of the use of propellants for long-range missiles.

The importance of the consideration of this problem was sharply pointed up by the announcement from Moscow that the super-long-distance intercontinental rocket had been successfully fired. The results showed, Moscow contended, that it is possible to direct rockets into any part of the world and that the giant missile has replaced strategic

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air forces and piloted planes, which are vulnerable to defensive weapons. The claim that strategic air forces are obsolete is premature; in fact, the missile may never entirely replace the piloted plane or the gun for all missions.

There is no doubt, however, that for many roles, such as short-range air interception, point defense of ground targets, area bombardment over great distances, or more precise bombardment of targets over much shorter distances, the guided missile is becoming the primary means of delivery at the expense of the antiaircraft gun, the fighter-interceptor plane, the long-range bomber, the lighter bomber, and field artillery.

The missile has far greater speed than any piloted planes now in service or in immediate prospect, and far greater range than any gun. Coupled with a nuclear warhead, it possesses virtually unlimited destructive capability; it has, in other words, added new power to both offense and defense.

In considering long-range missiles, one must differentiate between a ballistic missile and a guided missile. A ballistic missile is a missile that for most of its flight travels through space like an artillery shell in a fixed arc influenced only by gravity, rotation of the earth, atmospheric density, etc. It is powered by rocket motors during the first stage of its flight and during this period it can be guided, but after the engines burn out the guidance ends. The engines fall away and the missile is then on its ballistic trajectory. A guided missile, on the other hand, maintains power in its engine throughout its entire flight and therefore can be guided all the way to target. The guidance may be radar beam, radio instructions from the surface or aircraft, a homing device, or self-contained celestial navigation. At present, all long-range guided missiles of this type use air-breathing power plants and, therefore, must travel relatively low and more slowly than the ballistic missile.

The long-range ballistic missile promises to have greater military and political-psychological effect upon warfare and global relationships than any of the rest of the missile family. This is because the giant rocket, capable of spanning oceans and continents at maximum speeds of 12,000 to 20,000 miles per hour, is the least stoppable weapon now known to man. At the moment it is not an accurate weapon, but its thermonuclear warhead presages such a wide area of destruction that precise accuracy against an area target is not necessary.

In the long-range bombardment ballistic missile field the United States has three 1,500-mile missiles (so-called IRBMs) under development, and two 5,500-mile ICBMs. The intermediate missiles are the Navy's ship-launched Polaris, a solid propellant rocket, the first of which may be tested next year; the Army's liquid-propelled Jupiter, which is in an advanced state of development; and the Air Force's liquid-propelled Thor. In the intercontinental missile area the Convair Atlas and the Martin Titan are the United States entries in this field. In the field of long-range guided missiles, the Air Force-sponsored Northrop Snark has been in operation and use for some time. This is an air-breathing engine. Therefore, it can be seen that both solid and liquid rocket propellants must be considered, as well as fuels for air-breathing engines. However, in this study primary consideration will be given to the solid and liquid rocket fuels, since these probably represent the ultimate in weapon design.

LIQUID PROPELLANTS FOR ROCKET-POWERED MISSILES

There are many severe requirements which must be met before a material can be selected for operational use as a propellant; therefore, at the present time relatively few chemicals are in actual use. The first requirement is that the combination of liquid fuel and liquid oxidizer must give a high performance as measured in terms of so-called "specific impulse" of the combination, which is a term analogous to horsepower and is expressed as pounds of impulse per pound of propellant consumed per second. In order to have such a high performance, the combination must have a high content of chemical energy per unit of propellant mixture and a low molecular weight of the product gasses of the propellant combination. Desirable physical properties of the propellant combinations include a low freezing point to permit operation of the rocket in cold weather; a high specific gravity in order to accommodate a large weight of propellant in a given missile space; a minimum amount of deterioration of the materials on storage; a minimum chemical reaction with the piping of tank walls, valve seats, and gasket materials, even at relatively high ambient temperatures; a low vapor pressure to permit easy handling and storage of propellants; and a good stability upon exposure to heat. Table 1 lists performance characteristic as measured by specific impulse values of a number of practical combinations of liquid rocket fuel and liquid rocket oxidizer. Of the various combinations listed, the three marked with an asterisk indicate liquid propellant systems actually reduced to standard rocket practice in the United States: these are liquid oxygen and a hydrocarbon fraction such as gasoline or kerosene; liquid oxygen and ethyl alcohol; concentrated nitric acid and gasoline or kerosene. The table indicates the ultimate which might be expected in rocket propellant combinations usable in the foreseeable future, namely, liquid fluorine and liquid hydrogen with a specific impulse of 373 compared to 264 for oxygen and gasoline.

TABLE 1
Performance Values for Liquid Propellant Combinations for Rockets (1)

Rocket Oxidizer	*Rocket Fuel*	*Specific Impulse (Isp) at 500 lbs./sq. in. Chamber Pressure*
Hydrogen Peroxide	Gasoline	248
Hydrogen Peroxide	Hydrazine	262
*Nitric Acid	Gasoline	240
Nitric Acid	Aniline	235
Nitric Acid	Ammonia	237
*Oxygen	Ethyl Alcohol	259
*Oxygen	Gasoline	264
Oxygen	Hydrazine	280
Oxygen	Hydrogen	364
Fluorine	Ammonia	306
Fluorine	Hydrazine	316
Fluorine	Hydrogen	373

Liquid Fuels

Primary consideration will be given to the fuel materials pointed out as already being operational, namely hydrocarbon fractions such as gasoline or kerosene, and ethyl alcohol.

Petroleum hydrocarbons represent an extremely important source of fuel components, because of the outstanding facilities of the petroleum industry in this country, the tremendous supply of petroleum products available, and the cheap cost and easy handling properties of the petroleum fuels. For this reason, a very careful analysis of the petroleum fuel picture is necessary in a study of this nature. The question of petroleum hydrocarbon fractions as used for turbine and rocket fuel was recently reviewed by D. N. Harris and W. S. Little, of the Shell Oil Company (2).

It is appropriate at this point to discuss briefly the use of hydrocarbon fuels in jet engines before proceeding to their use in rockets.

The first turbine fuel specification in the United States was JP-1, now MIL-F-5616. This was a high flash point, narrow boiling range material having a freeze point of −76°F. Of high quality, the product was used quite successfully during the Second World War in the limited jet operations of the United States Armed Forces. However, the availability of this type of fuel running between 1 and 2 percent of the barrel of crude oil was far too limited to enable successful coping with any future national emergency, and steps were taken to broaden the specification to include a number of gasoline fractions, thereby increasing availability to over 50 percent of the crude. This fuel, JP-3, was a wide boiling range material having a 5 to 7 pound vapor pressure with no limit on flash point and a very low freezing point. However, as the versatility and performance of jet aircraft increased, JP-3 became undesirable from an operational standpoint, because of the large fuel losses encountered during rapid climb to altitude. Hence, while JP-3 met the availability criterion, its operational deficiencies required a modification of the specification. It is still covered by military specification MIL-F-5624, but only while those few obsolete engines designed for its use are still in operation.

The next step was the drafting of JP-4, the backbone of our military turbine fuel requirements to date. JP-4 is composed of approximately 65 percent gasoline fractions and 35 percent kerosene fractions, with a vapor pressure of 2 to 3 pounds. JP-4 can be made virtually in all refineries with a maximum yield of approximately 35 percent of the barrel of crude. It also has a very low freezing point (−76°F) and no flash point limit, and it represents an ideal compromise between fuel availability and performance for aircraft as we have known them for the past decade. However, it has become marginal for use in high-speed weapon systems.

Several years ago JP-5 was drafted by the Navy because of their need for a high flash point kerosene fuel to be carried aboard aircraft carriers. At first this fuel was blended with aviation gasoline on the carrier to approximate the distillation characteristics of JP-4. However, the advent of supersonic aircraft with their even greater rates of climb led the Navy to the use of straight JP-5 for all shipboard operations this year. It is similar to the fuels now being considered for ram-jet and rocket engines. Its availability is quite limited in the United States, but an analysis of forward requirements of the military manned aircraft operations and refining capacities indicates that adequate quantities of this material can be made available in the event of a national emergency.

The Air Force, at the same time, with supersonic aircraft becoming broadly operational, has prepared specification MIL-F-25656, JP-6, also a kerosene type fuel but having a somewhat more restrictive freezing point than found in JP-5, that is, −65°F versus the −40°F of JP-5. This material represents the compromise between the broad characteristics of JP-4 and the more restrictive JP-5, and is an effort to meet increased high temperature stability of turbine fuels and to meet the needs of high-altitude, high-speed flight.

It should be emphasized that individual weapon requirements may dictate the use of a certain type or fraction of hydrocarbon fuel. The requirements must be evaluated in each case for the specific needs involved. However, the several fuels named below may be considered indicative of those which will be used for future requirements. In the case of the Vanguard project, the launching of an earth satellite, the fuel used for the first stage (which is a hydrocarbon-liquid oxygen propellant combination) is RP-1 (specification MIL-F-25576). These specifications reflect a burnability requirement by controlling aromatic content to a maximum of 5 percent, smoke point to a minimum of 25 mm., and gravity to a narrow range, and by providing a controlled distillation range. In the case of the Vanguard, the fuel was to be furnished by the Shell Oil Company and is material designated as Shell UMF grade B. According to the Shell Company, it is also being used in other selected missile applications and shows tremendous promise in that field.

The Navaho missile presented the same problems with distinctly different aspects. Here the fuel was subjected to high temperatures in the fuel tanks for an extended period. These temperatures were high enough to require a significantly higher boiling range material, and consistency of properties was paramount. The RJ-1 specification (MIL-F-25558) was the first effort to describe a fuel meeting these requirements. It would appear from experience to date that the specification is satisfactory, although an improved test method is needed for defining thermal stability requirements of this weapon. RJ-1 is a light gas oil fraction which has been extracted to improve burnability and thermostability characteristics without seriously affecting yield.

Table 2 lists the physical specification of the fuels described above.

TABLE 2
Hydrocarbon Fuel Specifications (2)

	Mil-F-	*Mil-F-*	*Mil-F-*	*Mil-F-*
Designation	5624C	25656	25558	25576
Grade	JP-6	JP-6	RJ-1	RP-1
Effective Date	3/8/56	9/10/56	5/28/56	5/8/56
Gravity, API	36-48	37-50	32.5-36.5	42-45
Specific Gravity	.788-.845	.780-.840	.842-.863	.801-.815
Freezing Point, °F, Max.	–40°F	–65°F	–40°F	–40°F
Aromatics, Vol.%, Max.	25	25	5	5
Olefins, Vol.%, Max.	5	5	1	1
Heat of Combustion, BTU/lb., Min.	18,300	18,400	18,500	18,500
Flash Point, °F, Min.	140	—	190	110
Distillation, °F				
Initial Boiling Point	—	250° min.	—	—
10% Distilled	400° max.	350° max.	440°-480°	365°-410°
50% Distilled	—	425° max.	510°-550°	—
90% Distilled	—	500° max.	—	—

It can readily be concluded from the foregoing discussion that it would be very difficult indeed to monitor in an effective way the production by a refinery of any of the petroleum fractions described. Any modern refinery produces such a variable series of products that it would be very difficult to check on their production or utilization. This is particularly true when it is seen that the turbojet fuels used for military aircraft, which will presumably also be used for future civilian jet aircraft, are very similar in composition to the fuels in use today for rockets and ram jets.

In addition, the quantities of fuel envisaged for use in missiles would be much smaller than even that used for turbojets, because the number of missiles flown would be fewer, and they would be held in a state of readiness and not be used for constant practice flights.

This is pointed up by Table 3, showing estimated usage of RJ-1 and RP-1, compared to other jet fuels, for the next few years.

TABLE 3
Air Force Fuel Estimates
(millions of gallons per fiscal year)

	1957	1958	1959	1960
Av gas	1,350	1,400	1,400	1,350
JP-4	3,000	3,800	4,500	5,000
JP-6	0.5	3	4	5
RJ-1	0.5	3	5	6
RP-1	1	5	10	11

Source: AIA

The other fuel material mentioned earlier, ethyl alcohol, while not as plentiful or cheap as hydrocarbon fractions is nevertheless one of the common chemicals of industry. It can be produced readily either from the fermentation of blackstrap molasses, a by-product of the sugar refining industry, or from corn or corn products. In the United States, industrial ethyl alcohol is prepared today largely from ethylene gas, which is readily available from cracking operations in any modern refinery. Ethyl alcohol has many uses in the chemical industry as a solvent and as an intermediate for further synthesis. In 1955, approximately 1.5 billion pounds of ethyl alcohol were produced in the United States.

Another material which has been suggested as a liquid rocket fuel is hydrazine. For some time it has been known that hydrazine has excellent rocket propellant characteristics. However, some of its physical properties were not as good as could be desired. These included high freezing point and a tendency toward decomposition under certain circumstances. In the early 1950s, the U.S. Government sponsored an investigation of derivatives of hydrazine and other compounds which might possess the desired propellant characteristics of hydrazine without some of the undesirable physical properties. From this research unsymmetrical dimethyl hydrazine was chosen. Some of its characteristics are low freezing point, excellent stability, good propellant characteristics and ready synthesis from abundant raw materials (3). This material is readily available from the large chemical companies.

Like many other newly developed commercial chemicals, UDMH (as the compound is called in the trade) has been known for some time. The earliest preparation reported is from the reduction of N-nitrosodimethylamine, which can be prepared from dimethylamine and nitrous acid. Dimethylamine, the starting material, is readily available by manufacture from methanol and ammonia, both widely used chemicals. Another easy method of preparation is from the reaction of dimethylamine with chloramine formed by reacting a solution of sodium hyprochlorite with ammonia.

The supply logistics of UDMH were recently described by Strunk (3). The basic raw materials for UDMH are coal or natural gas, water, and air. Salt should also be included if chlorine is used in the synthesis. Dimethylamine, one of the building blocks for UDMH, is made from methanol and ammonia, and the second nitrogen in UDMH is also fundamentally derived from ammonia. The equivalent of two moles of each of these chemicals appears in each mole of UDMH. When proceeding through the nitroso route, hydrogen is required to convert the nitroso to UDMH. In the modified Raschig process, the ammonia is oxidized by the chlorine. Both chlorine and hydrogen are fundamentally cheap, readily available chemicals which present no serious limitations on production. With regard to ammonia and methanol, the other two chemicals involved in the synthesis of UDMH, less than 1 percent of the ammonia capacity and less than 5 percent of the methanol capacity would be required to make 50 million pounds of UDMH annually. No serious scale-up difficulties are visualized, because the processes involved in the manufacture of UDMH are of the type that could be readily adaptable to large volume continuous production, if that were required.

However, by virtue of the fact that at present virtually the only use for UDMH is as a rocket fuel, it should be possible to detect manufacture and shipment of this material by adequate inspection. The raw materials could not be monitored, since they are so common, but the final product is unique and has a unique use, in contrast to the two fuels already described.

Mention has been made in the press of the so-called "high energy fuels." Recently (April, 1957) Dr. Earl A. Weilmuenster of the Olin Mathieson Chemical Corporation spoke before the Commercial Chemical Development Association on the subject of high-energy fuels. He mentioned the production of diborane, pentaborane, and decaborane. For example, diborane can be produced by the reduction of boron trifluoride etherate with lithium hydride. The production and handling of these materials is so unusual that effective monitoring of their production could probably be achieved.

Liquid Oxidizers

The two oxidizers mentioned earlier as being presently used on a large scale as liquid oxidizing agents for rockets are oxygen (used as a liquid) and concentrated nitric acid. Both of these chemicals are common articles of commerce, as will be shown below.

Oxygen can be produced by two markedly different methods. The electrolysis of water process is comparatively expensive and of little interest except under special conditions. The process widely used involves liquefaction and subsequent distillation or rectification of liquid air. The latter process is used by two basic systems: the Linde and the Claude. Both systems cool air which has been previously compressed and then depend upon gradual or self lowering of the air temperature by countercurrent cooling of the incoming gas against outgoing gas to the air liquefaction temperature. Some of the special equipment involved consists of special heat exchanges, distilling columns, expansion valves, and compressors. So-called "tonnage oxygen" plants are basically modifications of the German-developed Linde-Frankl process, and involve systems to utilize low pressure, high capacity, high speed economical compression of the air, and equipment for refrigeration.

In 1952 over 622,000 tons of tonnage oxygen were produced. The largest use for this is in chemical manufacturing involving oxidation of various materials and in some open hearth and blast furnaces, where it produces certain beneficial effects.

The other important oxidizing material, nitric acid, is again a chemical widely used in industry. The essential raw materials for the modern manufacture of nitric acid are anhydrous ammonia, air, and water. Because of the low molecular weight of the ammonia, it can be shipped economically from the large primary nitrogen fixation plants to various oxidation plants at the consuming centers. This effects a great saving in freight as well as in equipment because the anhydrous ammonia can be shipped in steel cars, whereas nitric acid must be shipped in stainless steel cars weighing five to six times the weight of the ammonia. The process essentially involves the oxidation of the ammonia with air using a catalyst. In the subsequent absorption of the oxides of nitrogen to produce the nitric acid for rocket use, the 68 percent nitric solution that is customarily made in industry and called concentrated nitric acid would have to be concentrated further to remove additional water.

This, however, can be done readily as the occasion requires.

Ammonia, the chief starting material for nitric acid manufacture, is one of the truly fundamental raw materials for modern civilization. The largest peacetime consumer of anhydrous ammonia is the fertilizer industry. Production capacity of ammonia in 1957 amounted to 4.3 million tons. In addition to its extensive use in agriculture, ammonia is the starting point for nearly all military explosives, since these largely involve nitrates. Scarcely an industry is untouched by ammonia, as it is required for the making of soda ash, nitric acid, nylon, plastics, lacquers, dyes, rubbers, and many other products.

SOLID PROPELLANTS FOR ROCKETS

Since solid propellant missiles of the Polaris type which have about a 1,500-mile range could presumably be fired from a ship or submarine, such solid propellant components will also have to be considered in the long-range missile picture.

There are two principal types of solid propellants. The first, often called a composite propellant, has two ingredients: a solid fuel and a solid oxidizer. Usually the propellant consists of crystalline, finely ground oxidizer dispersed in a polymer matrix of the fuel material. The second type of propellant, usually called the homogeneous type, consists of solid chemical materials which have both oxidizer and fuel combined in the same molecule, such as nitrocellulose or nitroglycerine. Because many of these propellants are based largely on a colloidal mixture of nitroglycerine and nitrocellulose, they are often referred to as a double-base propellant.

Solid Oxidizers

There are several families of chemicals which can be used as solid oxidizers in the composite type of propellant. The first of these is the perchlorate family, which includes sodium perchlorate, potassium perchlorate, magnesium perchlorate, and ammonium perchlorate. The perchlorates are usually produced by the electrolysis of chlorides, which are naturally available materials. The oxidizing potential of the perchlorates is generally high, and for this reason they are usually found in propellants of high specific impulse or energy. The second family largely used is the nitrates. Three nitrates are of interest in solid propellants: potassium nitrate, sodium nitrate, and ammonium nitrate. In general these nitrates are used for low-performance, low burning rate applications.

For high-energy propellant combinations, such as would probably be used for longer-range missiles, a perchlorate would logically be a preferred oxidizer. As can be seen, all that is required here is one of a number of common chemicals, and a plentiful supply of electricity. Undoubtedly such a production system would be difficult to monitor.

SOLID FUEL MATERIALS

Many different organic fuels have been used in composite solid propellants. They are selected in part for their ability to be oxidized, for adding desirable physical properties to the mixtures, and for desirable fabrication characteristics. In fabrication many fuels are mixed with a crystalline oxidizer while the fuel is in the liquid state, usually at an elevated temperature. Thereafter the fuel mixture may undergo either chemical change or a physical change to harden it to the desired shape. The materials which have been used as fuel components are as follows: asphalt-oil type, which is a very cheap and readily available raw material, but which has certain undesirable physical properties; plastic fuels which involve various thermosetting plastics such as phenolformaldehyde, styrene, and the like; rubber type fuels which consist of several types of synthetic rubber and gumlike materials. The elastic properties of the material permit simpler design provisions for thermal expansion and contraction of the propellant during storage.

The organic nitrates which are used in the so-called "homogeneous type" solid propellants are also widely used materials of commerce. As mentioned, the main material in this type of solid propellant is nitrocellulose with a liquid plasticizer material, such as nitroglycerine. Commercial nitrocellulose has much the same appearance as ordinary cotton, and is fabricated by the nitration of wood pulp or cotton linters using nitric acid as the nitrating agent. Nitrocellulose is widely used industrially as a plastic material and as a film-forming material in lacquers. Some of the liquid organic nitrates usually used are nitroglycerine or ethylene glycol dinitrate or diethylene glycol dinitrate. Nitroglycerine, the most important member of the family, is a colorless oily liquid. It is made by the nitration of glycerine using mixed acid which is a mixture of nitric acid and sulfuric acid. Glycerine is produced as a by-product of soap manufacturing, or can be made synthetically, starting with the cheap petrochemical raw material propylene and using chlorine and caustic.

As can be readily seen, all of the above materials are common chemicals of commerce, and it would be extremely difficult to detect their diversion into missile production.

SUMMARY

Types of chemicals necessary to produce propellants which might be used for long-range missiles have been reviewed. Propellants discussed include both liquid and solid types. Both fuels and oxidizers have been studied. The logistics of these materials have been briefly discussed, with particular reference to the effectiveness of possible monitoring of the use of these materials for propellants.

Liquid propellant systems actually reduced to standard rocket practice in the United States include liquid oxygen-gasoline, liquid oxygen-alcohol, and concentrated nitric acid-gasoline. Because of the fact that the form in which these materials are used as propellants is so similar to the form as used in the chemical industry, and because of the relative ease of manufacture and abundance of these chemicals as articles of commerce, it is seen that the monitoring of their production or use as propellants would be extremely difficult if not impossible.

As for more exotic fuels, such as dimethyl hydrazine or the high energy boranes, it is felt that because their unique use to date has been as fuels, an effective system of monitoring could probably be developed.

Although at present solid propellants would appear to have more application in intermediate-range missiles, they too have been studied. It is evident that the common types of solid propellant also involve common articles of chemical commerce, whose surreptitious usage for propellants would be extremely difficult to detect.

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THE DETECTION OF HIGH-ALTITUDE MISSILE TESTS[1]

by D. G. Brennan

INTRODUCTION

THIS PAPER presents a preliminary survey of the technical feasibility of detecting high-altitude missile tests, and the launching of space vehicles of any kind. The inspection envisaged here would provide world-wide coverage by a system of ground-based radars. We shall not by any means provide a detailed blueprint for such a system; a complete plan would require an engineering study of very substantial proportions and, furthermore, would be greatly facilitated by certain information that is not available for the present survey. However, it will be seen that published information alone is sufficient to establish the technical possibility of such a system beyond any reasonable doubt.

The immediate objective of such a system in connection with a program of controlled disarmament would be to retard the further de-

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velopment of long-range (1,000 miles or more) rocket-propelled missiles, and space vehicles with potential military applications. It is clear that such missiles are at present (March, 1958) in a much less advanced state of development than is the case with nuclear warheads. It is therefore probable that a ban on missile tests would be even more effective than a ban on tests of nuclear weapons, provided that such a ban could be made operative before missile technology became commonplace throughout the world.

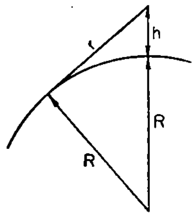
It is probably not possible, or even desirable, to stop the development of any and all rocket technology whatever. It is to be hoped that we may look forward to the peaceful development of travel in outer space. However, a radar network of the type discussed below could at least insure that international inspectors would be present at the launching of any satellites or other space vehicles, and such inspectors could insure that no satellites were launched that were not satellites merely.

The reader may ask: Why should such a system provide world-wide coverage? Why not confine it to the leaders of the current arms race? The principal reason for this is that missile tests are relatively unobtrusive, and could be conducted in any part of the world. A large rocket makes a good deal of noise, but it creates nothing like the disturbance generated by a nuclear explosion, and it does not require very elaborate launching facilities. Even now, NATO authorities (5) and others (10) are requesting sea-borne launching sites in the form of submarines, surface vessels, or floating platforms, and air-borne launching sites. At the present time, a foreign vessel could presumably sail to within a few dozen miles of New York City, Copenhagen, or Vladivostok on a foggy day and launch a missile, with a good chance of escaping undetected.

There would therefore be little point in providing any radar coverage at all if any parts of the world were to be left uncovered; it would be too easy to arrange clandestine tests in an uncovered area.

ALTITUDE REQUIREMENTS

Broadly speaking, a radar set cannot "see" around the curvature of the earth. This means that a given station could not detect a target that was located below a plane tangent to the earth at the point of the station. How rapidly does the earth "drop away" from this plane? In other words, if an object is at altitude h, what is the maximum slant range r from which a radar station could detect it, given that the station is on the surface of a smooth earth? This question is answered by the geometry indicated in Figure 1. This geometry limits the maximum possible



$$r^2 + R^2 = (R + h)^2 = R^2 + 2Rh + h^2,$$
$$r = r(h) = \sqrt{2Rh + h^2},$$
where R = radius of the earth.

FIGURE 1
Radar Inspection Geometry

spacing of the inspection stations. We shall consider a system that would detect any missile or other rocket that went above the altitude *h,* which we shall call the "detection altitude." The relation between the detection altitude and the corresponding maximum slant range is plotted in Figure 2. In all calculations presented here, such as Figure 2, we have taken the earth's radius R as $R = 4{,}000$ miles. This is slightly high. However, the fact that the index of refraction of the earth's atmosphere decreases with height leads to a "bending" effect that can be accounted for by increasing the earth's radius. On the other hand, there are practical reasons why a radar beam cannot actually scan all the way down to the horizon, and this leads to an effect in the opposite direction. We may therefore take $R = 4{,}000$ miles as a reasonable value for establishing preliminary results, with the understanding that a more detailed study might modify these results by perhaps 10 percent.

The principal question to be discussed in this section is: What should the detection altitude be? Evidently a large value of h would require fewer radar stations, but would require longer-range radar sets (Figure 2), and would provide greater opportunity for evasion. It is not a simple matter to answer this question with finality. We shall indicate the nature of certain considerations that bear on this question. These considerations suggest that the detection altitude should not be greater than 40 miles. However, this problem is one that would ultimately have to be settled by a thorough engineering study.

To begin with, D. H. Menzel has recently estimated (13) that 70 miles is approximately the minimum altitude at which a satellite might make one complete revolution. This plainly indicates that the minimum detection altitude must be less than this. In fact, serious weapons have

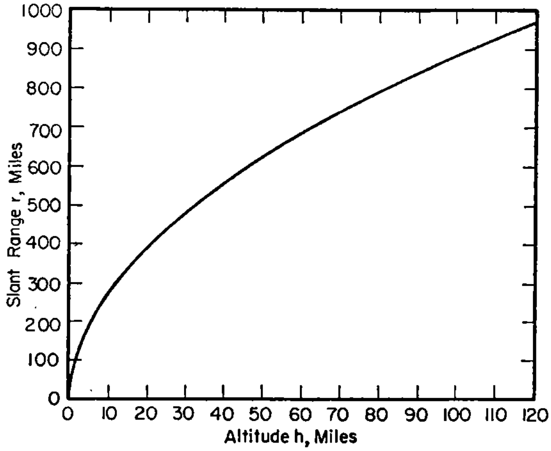


FIGURE 2
Maximum Slant Range as a Function of Detection Altitude

been constructed that did not go above 70 miles; the V-2 rockets launched against England in the Second World War had apogee heights of about 70 miles. Another consideration stems from the fact that most ionized meteor trails occur between 50 and 75 miles (4); above 75 miles, the atmosphere is so thin that little ionization occurs, while most meteors have burned out by 50 miles. It might be desirable to have at least 10 miles of coverage below the meteor zone, to have a region that would be essentially free of "clutter" from meteors. This leads to the 40-mile requirement mentioned above. However, we shall see that a system with a detection altitude as low as 10 miles would be practical, and may well prove to be desirable. Additional considerations bearing on this problem will be mentioned below.

It is of interest to compare the 40-mile requirement with the performance of the more serious types of missiles. Relevant data on the major military rockets apparently have not been published. However, as it is known that the Vanguard rocket is larger than the smaller military rockets but smaller than the larger military rockets, the Vanguard rocket may be taken as representative for this purpose. The firing program of this rocket has been published (3), and is given in Table 1. There it can be seen that, so far as missiles of this type are concerned, the 40-mile detection altitude requirement is quite conservative, and would guarantee the detection of any tests of such missiles.

TABLE 1

Vanguard Rocket Firing Program

Time from Launching (minutes and seconds)	*Altitude (miles)*	*Operations*
0 min. 10 sec.	—	Fired straight up for 350 feet, then turning starts
2 min. 25 sec.	33	1st stage burnout and release, 2nd stage fired
4 min. 18 sec.	122	2nd stage burnout, missile starts to coast
9 min. 25 sec.	261	2nd stage released, 3rd stage fired
9 min. 45 sec.	300	3rd stage burnout, satellite released in orbit

RADAR RANGE REQUIREMENTS

The range capability required for the radar sets in the inspection system increases as the detection altitude is increased, as indicated in Figure 2. (The actual range capability would be slightly greater than Figure 2 indicates, depending on how far above the horizon it was required to scan, but this fact is negligible for present purposes.) However, it is clear from Figure 2 that the range required would not in any event exceed 1,000 miles. It is therefore sufficient to establish that missile-detection radars of 1,000-mile range capability would be available.

Such radars have apparently been available for some time; it has been reported (6) that 1,000-mile missile-detection radars were in operation as early as 1955. More recently, it has been announced (11, 12) that the United States is about to construct a missile-warning network consisting of three stations in northern latitudes, each station to be equipped with missile-detection radars of 3,000 mile range. Now, the altitude h corresponding to $r = 3{,}000$ (Figure 1) is $h = 1{,}000$ miles. It follows that such targets (if any) as would be detected at 3,000 mile range by this network would consist essentially of warheads only; most missiles would presumably have shed their earlier stages before reaching any such altitude. (Compare Table 1, or the known perigee altitudes of any of the satellites launched to date.) Since the inspection network proposed here would detect rockets before they shed all of their earlier stages, and since these would make much larger targets than warheads alone, it is quite clear that the performance requirements for the inspection radars would be very moderate, relative to the demands placed on the U.S. missile-warning radars about to be constructed.

NUMBER AND COST OF STATIONS

It is relatively easy to estimate the number of stations required, assuming each station provides circular coverage. If the detection altitude is h and each station covers a circular plane disc of radius $r(h)$, where $r(h)$ is the function plotted in Figure 2, the area of this disc would be Πr^2. However, not all of this area could be counted as effective ground area. In the first place, the area on the surface of the earth obtained by projecting this disc on the earth would be slightly less than Πr^2. In the second place, it is clear that there would be appreciable overlap between adjacent stations, if no "holes" are to be left in the coverage. However, it is not difficult to see that it will be conservative if we simply assume that half of the disc area is effective, and take $\Pi r^2/2$ as the effective ground area per station. We may then estimate the number of stations required by dividing the area of the earth, $4\Pi R^2$, by this effective ground area. Thus: $N = 4\Pi R^2/(\Pi r^2/2) = 8R^2/r^2 = 8R^2/(2Rh+h^2) = N(h)$, where we have replaced r^2 by $2Rh+h^2$ (Figure 1). This gives the number N of stations required as a function of the detection altitude h. This function is plotted in Figure 3. For small values of h, say $h \leqslant 40$ miles, this function is accurately approximated by $N = 4R/h$, which is approximately $16{,}000/h$ when h is measured in miles. This may be used to estimate numbers of the scale of Figure 3; e.g., for $h = 10$ miles, $N = 1600$. It would not be very difficult to estimate the required number of stations more precisely than by Figure 3, and eventually the exact number would have to be determined by pin-pointing the stations one by one on a globe, taking due care that no station is located on the bottom of the crater of Mount Vesuvius, or any equally unfortunate site. But Figure 3 will suffice for our present purposes.

It will be noted that Figure 3 is equipped with a scale labelled "Cost, Billions of Dollars." It must be emphasized that this scale is much more flexible than the "Number of Stations" scale. Values read from the left scale are certainly not too low, and cannot be too high by more than a factor of two. No statement with this degree of precision can now be made for the "cost" scale. It seems unlikely that these values would be off by more than a factor of five in either direction, but the writer is

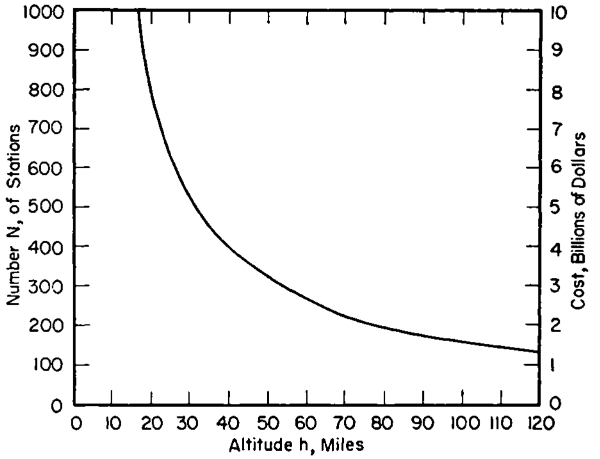


FIGURE 3
Number of Stations vs. Detection Altitude (N(10)=1,600.)
(One billion = one thousand million)

not prepared to guarantee even this rough estimate. Let us consider some of the factors entering an estimate of the system cost.

To begin with, it is helpful to have an estimate of the required power of the radar transmitters. For this purpose, we may extrapolate information published on the U.S. 3,000-mile missile-warning radars (11). Press releases appearing in the newspapers have placed the average power of these radars as "in the millions of watts," apparently specified as 5 million by the U.S. Army (14). This must be considered in conjunction with the angular width of the sector scanned. It has been reported (12) that these radars scan a sector 45 degrees wide, and a little study of a globe is sufficient to indicate that this could hardly be in error by more than a factor of three or four. Since there are eight 45-degree sectors in a circle, this would indicate that 8 x 5 = 40 million watts would be required for 360-degree coverage out to 3,000 miles range. However, the power required is proportional to the fourth power of the range (1). Taking the detection altitude h as 40 miles, one finds r = 567 miles $(3{,}000/567)^4 = (5.3)^4 = 800$, and (40 million)/800 = 50,000 watts required average power per station for a detection altitude of 40 miles. Experience with various types of communication transmitters of this power level indicates that such transmitters, produced in quantity, should not cost more than $250,000 each. Reducing the detection altitude below

40 miles would rapidly decrease the transmitter cost to an invisible fraction of the total.

Power plant costs would probably be roughly comparable to transmitter costs. For stations located in relatively inaccessible areas, it might be desirable to power them by small reactors to minimize fuel transportation costs, and these would be more expensive. In no event, of course, should these stations be powered from external sources.

It is much more difficult to estimate antenna and feed-structure cost in the absence of a detailed study of suitable antennas. However, it is undoubtedly true that three million dollars would purchase a good deal of antenna structure, including movable mounts if necessary, especially if these are to be purchased and erected in lots of several hundred. But the cost problem is complicated by the fact that it may well prove desirable to include more than one type of radar set at each station (12). It is further complicated by the necessity of providing operating spares of all components, to provide reliable operations on a twenty-four hour, seven-day basis.

All things considered, however, a preliminary estimate of the average cost per station as 10 million dollars would probably not be wildly irrational. This value has been used for the "cost" scale in Figure 3. The average cost per station would undoubtedly depend somewhat on the detection altitude, which fact is not reflected in Figure 3. The unit cost of the electronic hardware required would go down as the detection altitude was decreased. On the other hand, the corresponding decrease in the spacing required would probably mean that a greater fraction of the stations would have to be located in relatively inaccessible sites, or on floating sites, which would be more expensive.

In connection with the last problem, it should be explicitly mentioned that some stations would definitely cost more than 10 million dollars. Construction costs on the polar caps are very high, and the cost of a floating station could easily exceed 100 million dollars. But it is fortunate for this purpose that most of the oceans of the world are equipped with a plentiful supply of small islands, and the number of floating stations actually required would be relatively small.

So far as operating costs are concerned, a staff of twelve men per station, at an average salary of $8,500, would probably be adequate for most stations. This is about $100,000 per year per station, and a similar amount should be allowed for routine maintenance and miscellaneous expenses. Linear amortization of the equipment cost on a twenty-year replacement basis would lead to 5 percent of the initial cost per year; using the 10 million figure above, this would be $500,000 per year per station. These data suggest that a reasonable estimate for the total annual cost of operating the system would be between 5 and 10 percent of the initial cost.

Let us consider two specific examples of systems, using 7.5 percent of the initial cost as the annual operating cost. First, a detection altitude of 40 miles would cost about four billion dollars for about 400 stations (Figure 3), each with a required range capability of 567 miles (Figure 2). The operating cost would be roughly 300 million dollars per year. Every point on the surface of the earth would be within 565 miles (or less) of at least one station. This probably represents the smallest system that should be considered.

Second, a detection altitude of ten miles would cost about 16 billion dollars for about 1,600 stations, each with a required range capability of 283 miles. The operating cost would be roughly 1.2 billion dollars per year. Every point on the surface of the earth would be within 282 miles (or less) of at least one station. Since ten miles is approximately the upper limit of air-supported flight of contemporary jet aircraft, there is little likelihood that a detection altitude of less than ten miles would be needed for inspection purposes.

PEACEFUL APPLICATIONS OF THE SYSTEM

The cost estimate given above made no allowance for large-scale communication and data-processing systems interconnecting the stations of the network. The reason for this is that such systems would not be necessary in a network intended solely to detect isolated tests of missiles. However, the network envisaged here could also be made to serve non-military applications of great importance, at an appreciable increase in cost.

The principal application of this nature would be to air traffic control. By this, we mean control from the ground of all aircraft in certain regions, or perhaps all aircraft in certain regions that were above a designated altitude. This control would be based on information as to the location, speed, heading, and altitude of all aircraft in the region. The primary purpose of such control would be to provide safe and orderly air travel, by preventing accidents and providing more efficient utilization of air space.

The extent to which the radar inspection network could be useful in air traffic control would depend on the detection altitude. It would also depend on the "threshold" altitude taken for control purposes. Suppose we taken this to be one mile, and speak of "controlled" area as any area for which radar coverage down to one mile is provided. Then the fraction of the earth's area that would be controlled by the inspection network would be $1/h$, where h is the detection altitude in miles, if $h \geqslant 1$. For example, if $h = 40$ miles, then 1/40 of the earth's surface would be controlled; if $h = 10$ miles, then 1/10 of the earth's surface would be controlled.

More generally, the inspection network would provide coverage down to k miles altitude (where k may be less than one) for a fraction of the earth's area equal to k/h. But the examples above are sufficient to indicate that, although the missile inspection network would probably not provide all the air traffic control that might be desired in some areas, it could nevertheless provide control for non-trivial areas. In particular, each station could provide coverage down to one mile in a circle of about 90 miles radius, which is about 25,000 square miles. By locating the stations judiciously, the inspection network could therefore provide a "skeleton" air traffic control system of substantial proportions. If the system were originally designed with this objective in view, it would be a simple matter to fill in this "skeleton" when and where it became necessary to provide additional control. Many areas, such as the vicinity of the South Pole, would not require much additional control for some time to come.

Various compromise designs would also be possible. We have been discussing a network with a uniform distribution of stations, but there is obviously no intrinsic need of this. The system could well be designed for a detection altitude of ten miles throughout most of the world, and for a detection altitude of four miles in those areas where control is desired—including in particular a world-wide system of air traffic lanes. This would make it possible for all regular transport aircraft to remain within the control system continuously.

It should be emphasized that we are here discussing a system of vast proportions, and an adequate analysis would require many dozens of man-years of engineering time. The foregoing remarks in this section should be regarded only as a tentative indication of various possibilities. And it should also be noted that the imposition of air traffic control requirements on the inspection system would increase the cost substantially, perhaps by a factor of two.

Additional applications of the system stem from the fact that the same stations used for the radars would presumably also house the personnel and facilities for the acoustic, seismic, electromagnetic, and radioactivity detection of nuclear bomb tests, as discussed by Orear elsewhere in this book. The system would therefore provide a world-wide network of stations for gathering and transmitting meteorological and seismic data of all kinds. The additional cost of this activity would be negligible, and it would provide a permanent continuation of the International Geophysical Year. Floating stations could gather oceanographic data as well.

EVASION TECHNIQUES AND SYSTEM GAPS

The only "gap" in the system considered here is easily discussed, but not easily solved. It stems from the fact that not all missiles are high-altitude ballistic missiles. Some, such as the U.S. "Snark" (2), are what are known as "air-breathing" missiles, and consist simply of pilotless aircraft. The German V-1 missiles—called "buzz bombs"—launched against England were of this type. Such missiles fly at speeds and altitudes comparable to ordinary aircraft, and are indistinguishable from such aircraft so far as radar techniques are concerned. A sufficiently tight air traffic control system might possibly detect tests of air-breathing missiles that were specifically designed as such; ultimately, however, the only components required for such missiles are airplanes of any type, and a guidance system. The best thing that can be said for such missiles is that they are relatively vulnerable to modern weapons of defense, in comparison to high-altitude rocket-launched missiles.

The principal evasion technique one might envisage for rockets would be the use of coatings to reduce the radar reflectivity of the rocket (1). Such coatings are of two types, a thin-film interference-type coating and an absorption type of coating. The interference-type coatings are effective only at certain frequencies, and would easily be defeated by staggering the radar frequencies over a range of two to one, and then periodically changing the frequencies of individual stations. The same technique, in conjunction with a suitable choice of frequencies, would probably require an absorptive coating of prohibitive thickness if it were to be sufficiently effective.

Ultimately, however, one would rely on the fact that a rocket has a hot exhaust—so hot that it would lead to appreciable ionization of the trail, which would thus provide a fine radar target all by itself. One might wish to supplement the radar with infrared detection (7) for this purpose, but there seems little doubt that the rocket plume alone could provide a sufficiently reflective target. This is one of the principal reasons for requiring a fairly low detection altitude, to enable detection before burn-out. Ten miles would certainly be low enough for this purpose, and forty miles might be. This question is also not unrelated to the problem of detecting high-altitude nuclear bomb tests; evidently one could not test a bomb at thirty or forty miles altitude without first putting it up there.

CONCLUSIONS

We have seen that it is technically and economically feasible to construct a world-wide network of radar stations that would:

(a) enable detection of clandestine tests of long-range, rocket-launched missiles;
(b) insure that no satellites or other space vehicles were launched that were not properly inspected;
(c) possibly serve nonmilitary applications of great importance;
(d) provide additional means of detecting high-altitude bomb tests.

Furthermore, if the stations of the network were equipped with suitable bomb-test detection facilities of the type discussed elsewhere by Orear, the resulting system would be highly reliable for detecting tests of significant nuclear bombs.

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ON THE FEASIBILITY OF CONTROL OF BIOLOGICAL WARFARE

by Vincent Groupé

INTRODUCTION

THIS REPORT is based upon the assumption that it is possible to develop cultures of various bacteria, viruses, or fungi whose virulence for man, animals, or plants would be sufficiently great to establish infection in the field in a short period of time. It should be emphasized that this is by no means an easy task. In fact, it is the common experience of bacteriologists that the continued cultivation of various strains of microorganisms on artificial media in the laboratory leads to loss of virulence due to variation and mutation of the cultures. Any nation faced with the problem of developing an *effective* offensive program in biological warfare would probably divide the effort into two parts: (a) research and development, and (b) production and field trial. The various phases of research and development could be carried out in

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university, industrial, and governmental laboratories already in existence, and it would be virtually impossible for any inspecting team to differentiate such work from the usual programs in the fields of public health and agriculture. However, the second and equally essential phase of such a program, namely, production and field trial, would be more difficult to conceal. This phase would involve both large-scale operations capable of handling large quantities of highly dangerous material and proving grounds located in areas of the country where, if an infection got out of hand, it could be controlled. It is common knowledge that such a proving ground exists in Dugway, Utah, and that one of the major centers for biological warfare is Fort Detrick in Frederick, Maryland. Both of these installations are large and could be observed from the air.

Specific recommendations for inspection will be given in Section 5 of this paper. It should be emphasized that such inspection would detect only the production and testing phase of a biological warfare program, so that the equally important research and development phase could continue unabated. However, control of the former phase should be sufficient to cripple an *effective* offensive program.

RESEARCH AND DEVELOPMENT PHASE

The difficulties that would confront any inspecting team in detecting this phase of biological warfare can be illustrated by my own experience. I have been associated with Rutgers University for over eight years and have a reasonable knowledge of the activities in my own field, microbiology, throughout the university. However, if someone were to ask me whether or not any work on biological warfare was currently in progress in my own university, and even in my own building, I could not answer one way or the other. Support for research comes not only from Foundations and the Public Health Service but also from the Army, Navy, and Air Force. Throughout the university extensive programs are being carried out with a wide variety of bacterial, viral, and fungal pathogens. Presumably, such work is being carried out along beneficial lines. However, in the development of a vaccine, for example, it is essential to obtain cultures of the greatest virulence in order that the resulting vaccine will have the highest potency in protecting the individual. It thus becomes impossible to separate offense from defense in research and development.

Various bacteria, viruses, and fungi that might prove useful in the development of a biological warfare program are being isolated daily in various hospitals, agricultural experiment stations, medical schools, and governmental research centers, in the normal course of events. Culture collections sponsored by various organizations are found over the entire country. It is entirely possible for any nation to carry out an extensive research and development program in biological warfare that even the most astute inspection team would find almost impossible to detect.

PRODUCTION AND FIELD TRIALS

The problems presented by this phase of the operation are entirely different from those encountered in research and development. The differences are both quantative and qualitative. Essentially, it would be the difference between the amount of work which Sir Alexander Fleming put into the discovery of penicillin in his small laboratory in Scotland and the tremendous industrial effort made during the Second World War in the development and production of usable penicillin in sufficient quantities to be of value. Indeed, in the development of an effective offensive program in biological warfare, many problems would be encountered that would be somewhat similar to those encountered in the antibiotic program. For example, the methods, procedures, and culture media employed in the production of a small quantity of either an antibiotic or a pathogen are entirely different from those encountered when one increases the scale of production. It is impractical simply to replicate laboratory test tubes and flasks. New equipment must be designed, and the behavior of the various bacteria must be studied in great detail in their new environment. In addition to the difficulties faced by the manufacturer of antibiotics, the biological warfare unit would also have the difficulty of the disposal of large quantities of hazardous material.

It is as pointless to produce an atomic bomb that does not explode as it would be to manufacture a "bug" bomb which does not initiate infection and *disease* in a short period of time. Indeed, should such an ineffective bomb be set off in enemy territory the first result would be one of panic that would subside in a short time. However, should the enemy have effective bacteriological bombs at its disposal, it would obviously not hesitate to retaliate. It becomes essential to conduct extensive tests under field conditions, showing that such a bomb would have every reasonable chance of success. The magnitude of such an operation is great, and extensive measures would have to be taken to prevent the spread of the pathogenic microorganisms outside of the proving grounds.

Needless to say there is a wide choice of various bacterial, fungal, and viral pathogens affecting man, animals, and plants available for use in biological warfare. In every part of the world there are problems caused by infectious diseases of man, animals, and plants. Recent advances in knowledge of the genetics of microorganisms have clearly indicated that it is possible to develop highly virulent strains of various microorganisms which in their present state are relatively harmless.

DEVELOPMENT OF DEFENSE MEASURES

It is obvious that the development of an effective offensive biological warfare program must be accompanied by an equally effective defense program. The pathogen that one country seeds into another can spread back to its place of origin. In the majority of instances, the development of such defense measures would fall in the province of the public health laboratory and the agricultural experiment station, and as such would be extremely difficult to detect. However, extensive investigation into the development of vaccines or therapy for diseases that are not currently endemic or threatening a given nation might be more easily detected. For example, an extensive research program on the prevention and therapy of bubonic plague would seem out of place in the National Institutes of Health in the United States.

SCIENTIFIC ASPECTS OF INSPECTION

The role of the bacteriologist in an inspecting program would of course be essential. However, this role would be primarily advisory, and, numerically, bacteriologists would constitute a very small percentage of the total personnel. Individuals experienced with military affairs and intelligence would do the bulk of the work. Nevertheless, an experienced bacteriologist should be a part of each inspecting team. It would also be advisable to have an International Scientific Advisory Board. The work of the various inspecting teams could be facilitated considerably by requiring each nation to maintain a registry of the location of certain large and essential pieces of laboratory and pilot plant equipment, such as autoclaves, incinerators, centrifuges, spectrophotometers, fermentors, and stills. In addition, a registry of qualified bacteriologists and other professional specialists and their current location of employment would be of value to the inspecting team. Adequately staffed and trained inspecting teams probably could not detect every single laboratory or unit engaged in the production of infectious material to be used for offensive purposes. However, such teams could probably sufficiently cripple any such effort as to render it ineffective as an offensive weapon.

Unfortunately, detection of clandestine activity by sampling the working materials and wastes of biological laboratories is impractical and could easily lead to a false sense of security. Most highly virulent pathogens such as those required for effective biological warfare will grow only on culture media and under environmental conditions peculiar to that particular substrain. The commonly used culture media would not support their growth and would lead to a negative test, even though the pathogen were present in abundance. Knowledge of the specific culture media and appropriate environmental conditions for such highly virulent pathogens would be limited to the laboratory engaged in such work, and the inspecting team would be at a very serious disadvantage.

ATTEMPTED CONTROL OF RABBITS IN AUSTRALIA THROUGH USE OF MYXOMATOSIS VIRUS

To illustrate the complexities of the development of an effective program in biological warfare, an excellent example is found in the recent attempt to control the rabbit population in Australia through the use of the myxomatosis virus. It is well known that in Australia the rabbit population presents a real problem to the sheep-raising industry. In fact, it has been said that in Australia a rabbit count of 200 per acre is regarded as "rather high." In an attempt to alleviate this condition, myxomatosis virus, which is lethal for rabbits, was produced in large quantity, and strains of high virulence were developed. In the first attempt a large number of infected rabbits were placed in a field with a very high rabbit population in the hope that the virus would spread. A small epidemic did develop, but then disappeared. A second attempt was tried the following year with somewhat similar results. However, in the third year, before another attempt was made, the virus was found many miles from the site of the original seeding. Later, it was found that the virus was carried by certain species of mosquitos. Only when the infection had been established in Australia over a period of three years did the disease begin to spread with any rapidity.

On the other hand in France, a physician who was interested in keeping rabbits out of his backyard, foolishly placed an infected rabbit in his yard and this infection spread rapidly throughout the country, much to the consternation and dismay of the populace, since in France rabbits are shot and used for food.

Thus, the same virus placed in two different environments yielded two completely different results. These two experiences point to the importance of extensive field trials that simulate the environmental conditions of the locales of possible utilization of biological warfare weapons.

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SOME ASPECTS OF CLANDESTINE ARMS PRODUCTION AND ARMS SMUGGLING

by Gershon Rivlin

[Note: One of the main dangers to a system of inspection for disarmament is the attempt to evade the system by methods that emphasize an ideological commitment of the arms producers. The operatives for an evasion effort could be screened for devotion to nationalist or other goals of a country. If that commitment were strong enough, and had substantial popular support, it might insulate a clandestine effort from almost any scrutiny—whether technical or based on inspection by the people. Such a possibility cannot be excluded. The present paper contributes to the analysis of the technical as well as the social-psychological requirements for effective clandestine systems of production. It is an authentic statement of the point of view and style of operation which underlie clandestine military operations. —Editor.]

GENERAL PRINCIPLES

THIS PAPER deals with the activities of an underground movement from the point of view of members of such a movement. It should be stated, at the outset, that an underground movement has a special code of morality. The nature of an underground movement prevents it from operating openly, by legal means, and it is obliged to employ "criminal" methods such as using forged documents, smuggling, cover stories, etc. It must be stressed, emphatically, that such "criminal acts" are carried out by members of an underground movement *for the sake of the movement* and would not, under any circumstances, be executed for

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their personal benefit. A loyal member of the movement feels that he must give everything he can to his movement, but that the movement, as such, owes him nothing.

Before the subject of underground movements is discussed, a distinction should be made between two kinds of such movements: (1) the underground movement based on ideological aims, and (2) the criminal underground, i.e., a grouping (usually of short duration) for the execution of criminal acts (robbery, theft, forgery, etc.).

This paper is not concerned with criminal movements, but is confined to the lessons learned from "ideological-activist" movements.

No active underground movement can operate without accepting to a certain degree the motto: "The aims justify the means." This maxim also expresses the actual difference between a public social-political movement on one hand and a criminal or personal underground movement with vested private interests on the other. While the latter is prepared to accept this maxim without reservations, the former type of movement will usually confine the principle to the absolutely essential and will always act with reservations.

History shows very few liberation and underground movements which abstained from terrorism. Those movements that did abstain regarded foreign soldiers and policemen as instruments of their rulers. They therefore considered the principal struggle to be against the very attitude and actions of their leaders and rulers. Such motives were important, to a certain extent, in the passive resistance movement of Gandhi in India, the "Sokol" of Masaryk, and the "Hagana" in Palestine.

In order to attain a position of power, the underground movement needs arms to train its men and equip them. The illegal acquisition of arms and their use for training purposes under the eyes of a hostile police force depends on the successful solution of problems of transportation, storage, caches, and security. The training as such, and the use of weapons, are part and parcel of the above-mentioned problem, since without training and exercise the arms of the underground movements would be of no use.

GENERAL ORGANIZATION

There are two ways in which an underground movement can protect its own security. It can police the loyalty of its members and take steps to see to it that a complete picture of the movement is held only by a limited few, or it can employ the threat of terror against informers. Although the members of the underground may number thousands, and at times even scores of thousands, only very few know the arms caches, the industrial plants, the means of transportation, etc. Of these few only a small number know more than one link of the chain, and this latter group is selected from the most trusted and loyal members, about whom there can be no doubt whatsoever. Accordingly, the structure of the underground movement is different from that of normal bodies which have administrative and operational organizations. Underground movements are usually built on lines of communication from bottom to top, without interchange across one level. Thus, a driver only knows where he received the truck and where he will hand it over to a colleague, so that the line which leads from the place of origin to the destination is broken several times without the two ends meeting. The people at the two ends do not know each other or their locations.

PRODUCTION ORGANIZATION

The organization of production under the Hagana in Palestine during British rule covered the whole range of industrial activity.

Raw Materials. Materials were purchased most frequently through regular trade channels, using established firms as "covers." This was facilitated by the location of arms production within the framework of plants that produced normal goods.

Factories. The earliest factories were small workshops, some of them literally underground. After the end of the Second World War, the size of the plants was increased and the more important method became the use of a public covering operation, surrounded with sufficient early warning, signalling systems to permit quick changes of appearance should the police appear. This was possible mainly in parts-producing plants, where arms components were among various products. Arms assembly plants had to be carefully concealed, for in these the identity of the product was unmistakable.

Labor Force. Workers for special arms plants were carefully selected after extensive security checks on their backgrounds, behavior, etc. Since their occupations had to be kept secret, they were encouraged to form their own social milieu as well. This limited contact with others offered less opportunity for security leaks. Very high morale and strong ideological allegiance was characteristic of these people.

Management. The top management of arms production was in the hands of a few men who knew the locations and operational features of the various plants, and controlled the movement of work among plants. The head office was located within one or another office of some large enterprise and had a cover title. Records of arms production and financial transactions were carefully maintained—in code. Thus, each military item had its cover name for this purpose. Officers of the arms system were also employees of firms or other institutions and were paid as such. These units were reimbursed for salary payments in indirect ways, from various sources—for example, for various services rendered.

The cooperation of regular firms included arrangements whereby a firm in textiles, for example, might order textile machinery. Delivery would be in special arms-producing machines or in some armament components. Payment to the textile-ordering firm was arranged in some indirect way for goods or services received from them. Thereby, all financial books of account were in good order.

Arms Storage. All types of devices were used here. The range was from concealed arms or equipment in parts of household furniture, to large caches of arms in reinforced concrete, underground storage chambers. These involved problems of temperature and humidity control, and camouflaged means of ventilation.

Transportation is a sphere of underground activity that is especially sensitive as a test of efficiency in clandestine operations.

SEEING THE WORLD THROUGH THE ENEMY'S EYES

The ability to know how the world looks in the eyes of the opponent is a primary requirement of successful clandestine evasion. This is demonstrated by a few examples concerning plant location and transportation: the latter is especially important, for the products of underground operations are then relatively exposed.

Plant Location. One basic rule of underground production is fitting the actions to the circumstances in such a manner as to make them appear "natural." When a workshop for illegal arms is set up, it has to be situated in an area in which small and medium sized workshops are located, i.e., an urban industrial area, preferably a densely populated region where the appearance of additional men will not be noticed, even by curious people. Such workshops should be maintained openly, with offices, reception desks, bookkeeping which is subjected to auditors and to the income tax controls, etc. The owner of the factory should be somebody well known to the workers and to the neighbors. It is desirable for such a workshop to produce legitimate articles, apart from the illegal production, so that in case of sudden inspections, controls search, etc., production processes can be switched over to the "civilian" orders and continue normally, without arousing suspicion.

Transportation. The Hagana maintained a transportation center as well as an assembly plant for weapons, parts of which were produced all over the country. It was located less than 100 meters from the Headquarters of British Forces in Tel-Aviv, near a power station and a central bus station, in the vicinity of garages and automobile workshops, where day and night truck traffic was normal and natural and did not rouse the suspicion of anyone.

As far as the transportation of weapons or their parts is concerned, there, too, no definite rules exist. The means of transportation and the wrappings must be fitted to circumstances. Agricultural implements were employed as containers for arms to be transported in rural areas, while compressors, gas cylinders, asphalt sprayers, and other industrial machinery served the same purpose in urban and industrial areas. Then again, during the orange season, arms-carrying trucks were covered with thick layers of oranges, grapefruit, etc. The latter is a usual and normal cargo and has the advantage that fruit rolls into any hole which may be made to inspect the cargo. An illegal cargo may be covered by tarpaulins with a layer of fresh fertilizer on it—preferably with a disagreeable odor. Policemen, well-dressed and with polished boots, will hardly insist on a full inspection of such a cargo, which would require them to climb up the back of the truck.

Military goods, by the truckloads, were frequently shipped in the containers and trucks of well-known firms whose products (like beer) were shipped everywhere and in bulk.

It will be easily imagined that a heavy truck, moving under the auspices of a traffic policeman mounted on a motorcycle will not arouse suspicion. Heavy machinery can be inserted in large industrial equipment such as funnels, huge cylinders [large enough to contain missiles! —Ed.], cement pipes of large dimensions, or any other product which fits the cover story. Such a truck, showing the insignia of a well-known transport firm, moving along the road with a mounted traffic policeman preceding it, and moving from a well-established factory, will hardly be considered suspicious by security people. They will most likely help to grant it priority on the road. Thus, if no technical hitch should occur, such heavy "illegal" equipment would safely reach its destination under the very auspices of the "keepers of the law."

The success of transportation operations depends on the daring and initiative of the group charged with it. In one case a lorry was stopped on the road for inspection, a sudden road block having been established. The inspecting team did not satisfy itself with the examination of the relevant documents and was about to inspect the cargo, when the car accompanying the truck suddenly jumped out of line and lightly struck a British constable. Everybody's attention was immediately diverted to the "fresh native" who had dared to hit a British constable. The driver of the escort car was arrested and taken to the nearest police station. He later explained that he never had such a good feeling on being arrested as on that particular occasion, especially when he saw the truck continue on its way unhindered as a result of his "accident."

Understanding the mentality of the opponent, knowing his train of thought and habits, often facilitated the transportation of arms. One of the drivers of illegal arms trucks advises that when traversing areas where uniforms and polished buttons are particularly respected, the best way of assuring a "peaceful" passage was to invite a constable into the car and make him sit beside you—also, of course, on top of the cargo. Similar tactics were also useful under different circumstances: A group of policemen, led by an officer, appeared one day in a flat shortly after a shooting incident. Since there was no time left, weapons were quickly hidden in a couch in the living room. The chances looked rather bad and the confiscation of weapons almost inevitable. The search party was politely received by the owner of the flat, but with feigned surprise. He did not offer any resistance to the search. On the contrary, doors and cupboards were opened for inspection, and the officer was invited to sit on the very couch in which the arms were hidden. Polite, non-political conversation was in progress while the search party looked for the weapons, in cupboards, behind doors, and underneath tiles. They searched everything in the house except the couch which held both the officer and the illegal arms. It never occurred to the disciplined police constables to ask their officer to rise and enable them to inspect the couch.

Joining convoys carrying military equipment to the legal forces was an accepted practice. In this manner it was possible to travel hundreds of miles and to pass any road blocks with no check at all. It was, of course, necessary at times to make certain telephone calls and inform commanders of road blocks that a convoy which would pass included two or three lorries of another unit (which was usually expressed in abbreviations), which were to be added to the routing instructions of the convoy commander.

A good example of the "penetration of the mind of the enemy," as a result of which an underground installation was able to exist over a period of two years in a foreign country, will be told here. With the end of the Second World War, there was a flow of displaced persons from Germany, Poland, Hungary, and other countries towards Palestine, without the permission of the British. At the time it was impossible to move on roads or obtain petrol and spare parts without a special license. It was not easy to obtain such licenses in liberated countries, and there was little doubt that no such permission would have been granted in Allied-occupied Europe to Jews from Palestine. It was imperative, though, to maintain the transports and draw petrol and rations en route.

Under these circumstances, the team which was charged with illegal immigration established a British military camp in the vicinity of a town in British-occupied territory. The "military camp" was a typical British camp, complete with badges, insignia, notices, etc. A large plot was "requisitioned" for this purpose near the town. Sidewalks were marked in white, traffic arrows erected, and a guard posted. Authentic military spit-and-polish was in full view. The camp was also given an identification number in accordance with the practice of the British military camps. Local laborers were employed and given the tasks which British and Americans normally assigned to local labor in occupied territory. The relations between "officers" and "other ranks" were far from the usual Hagana relations of comradeship, but were based on the British Army system of distance and respect. Whenever a lorry became available (by one means or other) it was immediately given an army number and recorded on the lists of the camp. Drivers were equipped with proper orders for requisitioning petrol, rations, and any other requirements and needs which they were able to draw along their way—from the official army depots. This "camp" moved and fed many thousands of people, and was able to exist for over two years, arousing no suspicion that it was not a proper "army camp" similar to all its neighbor camps in the zone. On the contrary, the camp had a reputation of being exceptionally well organized, its soldiers well disciplined, and the commanding officer was known as "not issuing even a drop of petrol without proper orders."

INTELLIGENCE

No underground movement which begins to hoard arms on a more or less permanent basis can hope to be successful, even in its first steps, unless it develops an efficient and suitable intelligence network. After a short while it will be found that such an intelligence service has to be divided at least into two sections. The first is positive intelligence, whose aim is to discover the plans of the enemy, its order of battle, movements, etc., in order to make planning possible and to support the active operations of the movement. This section is in no way different from the structure and character of similar organizations of legal forces. The second, security, or negative, section, will principally aim at safeguarding the movement and take the necessary precautions to prevent leakages of information and give due warning of events which may affect members, installations, equipment, and the carrying out of actions. The activities of the security section will, of course, have the characteristic traits of an underground movement and its objective will be to prevent misadventures which may stem from action under illegal conditions. It must study members of the regime whose duty it is to combat the underground, in order to discover their weak points (ideological, moral) and "indoctrinate" them. Experience has shown that considerable success can be achieved in this field.

SIMULATION

The span of life of an underground movement, the size of its actions, and its success depend substantially on its ability to conceal and to simulate. This includes the ability of its members to guard secrets and act in accordance with circumstances, to understand their opponents

—divine their train of thought, penetrate their minds. Here again experience has shown that this is feasible. They must see themselves as the enemy sees them, in order to plan successful actions, and take into account the enemy's view of such actions, as well as his probable reaction. Members of an underground movement, and especially the veterans, automatically conduct themselves in their daily life, in their conversation, dress, etc., in such a manner as to give the impression of being "respectable" and "reasonable." Such people even adopt a way of behavior which the opposite side would consider "correct" by its own standard.

One of the principles of war—surprise—is often advantageously put to use, as an aspect of simulation. In every military operation the element of surprise is of the utmost importance, especially for a small force operating against a larger one. In underground actions this importance cannot be exaggerated. The pinnacle of surprise is reached when it appears as though the element of surprise has not been employed at all. It must be admitted that such actions require a great deal of daring, but such daring often assures success. Surprise must be a characteristic of the action, its timing, its circumstances, its location and, of course, the choice of target, too. The transportation of weapons, arms, and men to the appointed place must be carried out in a manner fitting to the element of surprise. Thus, surprise sometimes means the clever use of normally accepted behavior forms and operations. A unit was once assigned the task of blowing up a fortified police station, located at a considerable distance from a populated area, on the seashore. Early reconnaissance of the area in which the action was to take place was carried out by a couple, a boy and a girl who "accustomed" the policemen of the station to see them daily leaving the bathing area and passing the police station along the seashore. The constables became used to them, and the dog in the station also got to know them and stopped barking as soon as he recognized his "friends."

In another case a saboteur had to penetrate a closed harbor area and go on board a ship in order to sabotage it. He went on board as a bricklayer, an assistant to an expert on ovens, whom the trade union had been asked by the port authorities to send, in order to make urgent repairs to the ship's bakery. Thus, things went "normally." The ovens were repaired to the complete satisfaction of the authorities, but the mission of the underground movement was also carried out to their complete satisfaction.

PUBLIC SUPPORT AND CHARACTER OF AN UNDERGROUND

The very existence of an underground movement, the success of its actions, the well-being of its members, and its degree of influence (both on its own people and on the enemy), depend to a large extent on the adherence and loyalty of its members to the aims of the movement, and also on the sympathy and support extended to them by the population of the country in which it operates. The decent and moral behavior of its members in daily life, by respecting its principles, property, and funds, are essential in order to raise the public sympathy and support which are vital for the "backing" of the underground, its actions, and its training. Voluntary donations, hiding and housing its members who have participated or who are about to participate in actions, or who are being searched for by the police, hiding arms and equipment as well as obliterating traces, etc.—all these depend on the good will and affection of the public towards the underground movement.

The cooperation between the underground movement and the public is easier if the public is educated and cultured. On the other hand, the risk of failure is considerable if for some reason or other the underground is unable to hold the allegiance of the intellectual and more politically active portion of the population. It is interesting to note in this connection that the greater success of underground movements in Nazi occupied territory was in the densely populated and developed areas. Note the Maquis operations in Paris and in other urban centers of France, and the achievements of the underground in Dutch and Belgian cities, and in the Scandinavian countries. It may be of interest to note that the secret radio stations in France in the days of the German occupation, which operated with the backing of a friendly public, managed to transmit almost uninterruptedly. On the other hand, the clandestine stations which transmitted after the liberation of France were immediately discovered, owing to the fact that the French public attributed their existence to collaborators who were fleeing the country.

The history of the underground in Palestine includes a very large number of instances in which the underground activists were shielded from arrest by spontaneous aid from the public.

The help of the man in the street and his loyalty are often decisive factors for the success of operations. When the need arose for a section of a street to be darkened, it was sufficient to pass the word: "The boys are in need of some darkness," and within minutes the particular part of the street would be pitch-dark.

Another example of the cooperation of the public: A unit of the British Army once discovered one of the workshops of the Hagana. The staff of the shop was able to escape in time. The British sealed the door and put a guard there. In accordance with the tradition that "no weapons of the underground shall ever fall into the hands of the government," an attempt was made to empty the workshop. The soldiers, whose duty it was to guard the doors during the night, were most probably astounded at the disharmony and noisiness of the inhabitants of that quarter. All radios, gramophones, and similar instruments were turned on at full volume during that night; a number of cars made extensive noises. In brief, the guards were unable to hear, in the resulting tumult, how the rear wall of the building they were guarding was broken down during the night and all arms, equipment, machines, etc., brought to safety. On the following day, when the Criminal Investigation Department and Police arrived, equipped with a valid warrant for seizure, the place was empty. All the equipment had been successfully evacuated with the aid of the inhabitants of that particular quarter.

An underground movement which has a well-organized and efficient intelligence service can no doubt warn its members of impending danger. This is especially so if the service is able to gain the trust and active friendship of the population within which it operates, and, at times, even within the executive arm of the force whose task it is to combat the movement.

EFFICIENCY OF OPERATIONS

All problems connected with illegal arms, their production, transportation, storage, assembly, etc., require very careful and thoughtful planning, in order that these operations should be successful. The possible methods for this purpose are infinitely varied.

From the thirty-year experience of the Hagana in Palestine, it can be learned that if things are worked carefully, failures are rare and happen only because of accidents. For example, secret arms were disclosed when a case dropped from the sling of a crane in a port, and broke; or fire broke out on a truck carrying ammunition, because of a failure in the motor; or a soldier opened a tap to drink water and discovered that it was a ventilation pipe for a secret arms store. Failures were comparatively few. During the thirty years of activity of the Hagana, considerable quantities of arms were produced and transferred from town to town through densely populated and agricultural areas, as well as smuggled in from faraway countries. The arms included large quantities of ammunition, small arms, and even heavy weapons. There is no record of successful interception of major arms transports by the British inspectorate.

There are many opportunities to employ civilian workshops and factories for the production of "illegal" products. On the eve of the Israel war of independence, over 100 factories and workshops in the small country worked for the Hagana. The possibilities of camouflage have already been mentioned.

It is also possible to camouflage the components of military products. Thus, a certain part can be marked with a well-known trade-mark of a factory. Such a part may be looked at suspiciously at first, perhaps as being part of a weapon. However, when the eye registers the trademark of the factory, this suspicion will be lessened, since the particular part may also serve another purpose. Capsules for explosives could, for example, be marked "Bayer—Medicine." In this manner scores and, in big countries, hundreds of plants and factories can be put to work producing clandestine products with little chance of discovery.

It would almost seem that in order to combat an underground movement, an anti-underground movement would have to be established and developed, which would be able to supervise the activities of the former. Its members would have to be trained accordingly and implanted with the special underground movement sense. The main achievement of such an organization would be to isolate the clandestine movement and prevent its growth. The number of possible devices in the field of clandestine arms production is practically unlimited and, if space would permit, a book could be written here of examples of how it was done by underground-minded people.

DISARMAMENT AND CLANDESTINE REARMAMENT UNDER THE WEIMAR REPUBLIC

by E. J. Gumbel

[Note: This paper bears especially on the role of government in a clandestine rearmament effort that followed disarmament by law, and on the nationalist atmosphere which surrounded and supported this effort in Weimar Germany. E. J. Gumbel writes on this subject with special competence. He was one of the small group of pacifists who exposed the illegal rearmament and the terrorism connected with it. For this activity he was three times charged with high treason.—Editor.]

ILLEGAL REARMAMENT in Germany following the First World War is a classic example of the use of governmental powers to evade a disarmament agreement.

In this paper the crucial role of government will be emphasized. The actions of government, however, were made feasible by the presence of several essential social and economic conditions. Public support for the illegal rearmament was based upon the widespread resentment against the unilateral military restrictions of the Treaty of Versailles and

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reinforced by the manifest impoverishment after the First World War, due to the largest inflation of all times.

The re-creation of the military machine was made possible by: (a) the existence of substantial popular backing for the evasion effort, (b) the presence of a group of men dedicated to evasion of the Versailles Treaty, a group composed of parts of the military forces and their highly nationalist political supporters, who later backed the Nazi party, and (c) the availability of adequate technical methods for the clandestine rearmament. Each of these major aspects of the German clandestine rearmament will now be considered.

THE ARMY AND ILLEGAL REARMAMENT

Within the government of the Weimar Republic the army organization was decisive in organizing the illegal armament effort. Under the emperor the army had been a "community of its own," a virtual state within a state, with large budgets, tightly-knit social groups, and elaborate connections with industrial management circles. The Republic, born out of defeat, never tried to create a Republic-minded officer corps. Instead, it accepted the monarchist-minded officers. Owing to this general characteristic, it was possible for the military to carry out the illegal rearmament despite the specific antagonism of an important sector of German society—the Center, Democratic, and Socialist parties which formed the government and had their base in the industrial working class and parts of the bourgeoisie.

The methods used by the limited *Reichswehr* of Versailles Treaty creation to transform itself into a formidable military machine required extensive government complicity at all stages of the operation. The feudal origin of the army put this institution on a higher moral level than any other government institution. It identified the imperial army with the state, whose chief, himself, claimed a specific divine grace.

Although national unity has been an ideal of the bourgeoisie, feudal powers played a larger role within Imperial Germany than in other contemporary liberal states. The army, where the higher echelons were chosen from the aristocracy, was a strong political force. The emperor was, first of all, the Chief of the Army. Thus, the army had been identified with the empire. Its very continuation under monarchist-minded officers was a contradiction to the Republic. The army was a body foreign to the socialist, and later liberal, aims of the Republic. As a sign, the army never accepted the black-red-gold colors of the Republic, taken from the Revolution of 1848. *The whole history of Weimar is characterized by the antagonism of the army and civilian powers.* The secret armaments were a tool by which the army tried to regain its power.

Defeat, and widespread hatred of war and bloodshed, had deprived the army of its respectability. Now, by definition, every national army is invincible and, since the defeat was evident, it had to be disproved. Different fictions are available for such purposes. Usually, traitors are found in the government and in the army. This time, it was the Fatherland which had betrayed the army. Thus, the legend of the "stab-in-the-back" was invented. The civilian power, derived from these traitors, was therefore illegal. The army was the only remnant of the legal government. For many weeks no officer had dared to show his insignia. The desecration cried for revenge. The leaders of the revolution had to be punished. The workers, the basis of the Republic, had to be restored to their "proper place." Thus, the important elements of the new army saw their task as the restoration of order and justice by plotting crime and murder.

The reduction of the army as foreseen in the Versailles Treaty was based on the premise of a defeat. It was therefore the alleged right of the army to regain its power lost through treason. Any illegal expansion of the army was thus the true legality of a hidden, invisible, but real government.

Within the framework of defeat and drastic reduction in manpower and resources, the army maintained a tight core of officers whose first loyalty was to the grand political role of the German army and its continuation in politics. For these men there was no possibility in society other than to recreate the army and its "just" position as a leading element of a renascent German imperial state. Toward these ends, the officer group contrived a military machine that could be readily expanded from a small nucleus, and could maintain itself with legal as well as illegal sections.

THE ARMY AS A CENTER OF EVASION EFFORT

The disarmament prescriptions of the Versailles Treaty consisted of four parts. First, the demilitarization of a border line adjacent to the

Rhine. This was carried out. Until the occupation of the Rhineland under the Nazi government in 1936, no German soldier existed in the demilitarized zone and no illegal armament took place there. Second, certain heavy weapons, tanks, and military airplanes were prohibited. Third, the number of ships for the navy and their size were limited. Fourth, the army was to be reduced to 100,000 men.

At the beginning of the Republic, during the demobilization and the formation of the new troops, there was no clear distinction between legal and illegal parts of the army. This distinction became clearer when the reduction was enforced by the federal government under pressure of the Allied powers.

The army reaction was in two phases: first the Kapp Putsch, then the systematic illegal rearmament. The Kapp Putsch in 1920 was an open revolt of army officers. Threatened by demobilization, parts of the army, led by an East Prussian Junker, Kapp, General Ludendorff, and Captain Ehrhardt, seized Berlin. The Minister of War, Noske, a Socialist, had vouchsafed in parliament the loyalty of the same troops which overthrew the government. The Kapp government declared military law and instituted the death penalty against strikers. No military action against the rebels was possible, since no loyal troops were available. The Kapp Putsch was finally defeated by a general strike.

The failure of the Kapp Putsch brought a change in the illegal methods of the army. Instead of engaging in open revolt, it worked at undermining the Republic from within, especially through organizations which it dominated, financed, trained, and equipped with arms, such as the Free Corps, border patrols, home guards, patriotic (i.e., anti-Republican) organizations, and innocent-looking youth organizations with ever-changing names, headquarters, forms, admitted and non-admitted aims.

The official army (*Reichswehr*) consisted of 4,000 officers, 20,000 noncommissioned officers, 38,000 *Gefreite,* and 38,000 soldiers. Of course the army took advantage of any loophole that existed or could be constructed in the Versailles disarmament rules (14). Each company continued the tradition of an imperial regiment and got the corresponding numbers and colors. Since four companies make up a battalion, the battalion corresponded to a division and the regiment to an army corps. Thus, the *Reichswehr* threw a shadow, and the shadow was the larger of the two. The meaning of this shadow was the image of the Imperial Army.

The officers in the *Reichswehr* served longer in the same ranks, sometimes up to two and a half times the length of service in the Imperial Army. Thus, the average officer was actually a higher-ranking officer in the shadow army. Reserve officers were illegally trained and advanced in a legally nonexisting reserve. Fifty-eight thousand noncoms were able to train a much larger army which existed, partly on paper, in the patriotic organizations forming an illegal reservoir, and in illegal parallel military formations. The instructions in official manuals were based on the strength of arms and munitions of a great modern military power and not on the legal 100,000-man army. Since the soldier had to sign up for twelve years, 8,000 could leave after each twelve years and 8,000 new soldiers could then be enrolled. In reality, various devices such as unforeseen illnesses were used to justify large, premature dismissals and new entrants. New soldiers were introduced under the identification of legal soldiers, so that the formal number remained constant.

The legal army maintained close liaison with various groups which trained men in arms, and had a variety of "cover" identities to shield them from view as military groups. The *Stahlhelm,* for example, was a nationalistic, middle-class organization which advocated the merit of military life and agitated publicly for restoration of the German military machine. Unlike the Nazis, the *Stahlhelm* was not a terroristic body. The Nazis started as a movement of the outcasts of society, the *Lumpenproletariat*—long-standing unemployed. This movement, originating with desperate men who had little to lose, took on a politically fanatic and terroristic character. Here, military methods were important for use in the party's struggle for political supremacy.

Finally, the illegal military groups included an array of fanatic terroristic organizations, small in size, but important for their work of political assassination in eliminating first the leaders of the Revolution, then prominent Republicans, and finally the enemies of the illegal rearmament.

THE LEGAL AND ILLEGAL ARMIES

The position of the officers in the legal army was clear, open, and unambiguous. They enjoyed the income and social status which their official occupation gave them. In the illegal army, however, such rewards were hardly possible. This was a major source of conflict between the two elements in the illegal rearmament effort. Also, the connection between the illegal military groups and the Nazi political parties was a source of open struggle between them and the *Reichswehr*. Thus, the legal and the illegal army were not always on good terms. "If you succeed you will get no honor, if you fail no help." This is the permanent procedure applied by any army to this type of friend. The officers in the illegal army wanted recognition and the pension of the regular officers and this was exactly what the legal army could not grant them.

PUBLIC SUPPORT FOR ILLEGAL ARMAMENTS

Within the German population, especially during the inflation period, substantial popular backing, or acquiescence, was given to the evasion of the Versailles Treaty. For the nationalists of all shades, these efforts were necessary for restoration of national honor.

The Economic Stake in Rearmament. Disarmament shares certain properties of demobilization. The army is always one of the greatest buyers and represents a secure market for certain products, ranging from the essentials for the bare living of the soldiers and for the good living of the officers up to the most elaborate technical materials. Therefore, the existence of an army is deeply embedded in the national economy. The disappearance of the largest single buyer entails deep social changes. The classical argument of the socialists that big industry has an interest in armament and is therefore to blame for the political tensions thus created, was valid at times when armament played only a minor economic role. The argument becomes invalid as soon as armament provides the livelihood for large masses. The millions employed in military production have a vested interest in maintaining their jobs. Disarmament, as well as demobilization, means a threat of unemployment until the economy has been transferred to a peacetime status. Such transformation may be simple, quiet, and without many social repercussions, if machinery for civilian production is available and a large-scale market, based on accumulated desire and ability to purchase goods, leads to a new start of production. In the absence of such favorable conditions, unemployment caused by disarmament must create powerful movements of discontent.

The nationalist political ideology of the army officers found ready acceptance among a part of an impoverished population, especially the lower middle class. After the military defeat of the First World War, and abortive revolutionary attempts by German communists, the country experienced a disastrous inflation which impoverished a substantial part of the middle class.

The war had been financed by inflation. The Republic continued inflation, which lasted up to 1923. It reached unheard-of dimensions. From 1917 to the beginning of 1923, the dollar rose from 4.20 to 10,000 marks. However, in the single year 1923, it rose from 10,000 to 4.2×10^{12}. In other words, in five years, the mark fell to the 10^{12th} part of its original value. This created moral degeneration, wide-spread corruption (a new phenomenon in German history), and new riches of doubtful origin and aims. It made large parts of the population hostile to the government.

Inflation meant the complete impoverishment of people living on fixed incomes, the pauperization of government employees and vast parts of the bourgeoisie. It alienated the juridical apparatus from the Republic. The counterpart of inflation was the gain of the great debtor. The big estates, the seats of the feudal powers, paid the mortgages accumulated during decades with the price of a match. The exporting industry flourished because of the difference between wages paid in marks and the payment for goods in hard currencies.

The main result of inflation was general unrest: the wide-spread belief that a government which produced the inflation could only be illegal. Consequently, the Republic lacked a Republic-minded population. The youth, devoid of hope, looked for new ideals and found them in National Socialism. The older people continued to long for the virtues of the "good old times" of the Kaiser to restore order and justice.

Terror as an Instrument for Enforcing Support for Illegal Armaments. During the period of illegal German rearmament, terrorist methods were wielded against the opponents of rearmament. These included acts of personal violence carried out by the terroristic nationalist groups supported by the manipulation of the legal system.

Altogether, there were about four hundred political assassinations of the nationalists' foes. A considerable literature was published in Germany which detailed such charges. In reply to these charges the Federal Minister of Justice published a brochure in 1923 (2) full of details which officially confirmed the nature and the actions of the terrorist campaign against the opponents of the rearmament, and the fact that the murderers, with few exceptions, were not brought to justice.

The nationalist terrorists who enforced acquiescence in the rearmament of the Reich included many of the men who later became Hitler's trusted adjutants for overseeing the mass extermination program which the Nazis carried out during the Second World War.

Many of the nationalist terrorists were at the same time members of different organizations. Therefore, it is not always possible to fix the higher responsibilities. Since the victims were "traitors to the national cause," the murderers did not try, as a rule, to hide their responsibilities. On the contrary, there were even imposters who claimed to have engaged in such activities without having done so. In their memoirs the different terrorists, such as Salomon (who participated in the assassination of the foreign minister Rathenau), never showed the slightest trace of repentance, a fact which strongly speaks for the sincerity of their convictions. Nationalist terrorists have their code of honor like the members of any other criminal organization. The first rule is that no appeal to legal institutions is permissible. The second rule is that its arms must be protected from those who are deemed to be traitors. "Traitors" existed everywhere: law-abiding citizens who realized that the Republic was threatened by the military gangs; the Republic-minded Prussian police; profiteering merchants dealing in arms; agents of competing organizations; agents of the Communist party; agents of foreign powers attracted by payments in hard currency—all fell under the heading of "traitors."

A reliable administrator of secret arms cannot ask the legal authorities for aid; he cannot ask his illegal or semi-legal superiors' advice. Faced with the danger that the whole organization may blow up, he has no choice but to administer justice as he sees it. Such was the case with the illegal arms in Germany. "Traitors" had to be eliminated at all costs, with the tacit or explicit approval of the legal superiors. Military orders which clearly indicated that traitors should be eliminated were produced in court at the law suits against some of the murderers.

The Role of the Law Courts. The political assassinations committed by the members of the former Imperial and the secret armies put a heavy burden on the administration of justice. The murderers had to be acquitted and the victims had to be shown as guilty. This task was fulfilled by the employment of military courts which sided with military men when they were accused of murder, by the slowness of the justice-enforcing agencies, by inability to find the guilty, by issuance of false papers of identity by the police, etc.

Another procedure consisted in accepting at face value the claim of the accused murderer that the victim had tried to escape. Since arrest by an illegal gang was legal, the victim had to bear the consequences of his resistance by "trying to escape."

For the protection of secret armaments, the law courts, following the Supreme Court, introduced a new notion: high treason committed by the press. In English the phrase "high treason" has two aspects. First, to prepare for revolution or to aid the enemy in time of war. This corresponds to *Hochverrat* in German. Second, stealing secret documents with the intent to transmit them to a present or potential enemy foreign power. This corresponds to *Landesverrat* which, of course, was a rare crime. Now, public opinion, as expressed by the leading newspapers, was strongly opposed to the secret rearmament. However, such publications, aimed at stopping illegal actions committed by branches of the government, were interpreted as high treason.

Accusation of "high treason" was the big weapon of defense of the illegal rearmament effort. Even the spread of well-known news and publication of facts concerning the relation between the army and the military groups, especially the Nazis, led to a lawsuit of "high treason." As a rule, no proof of the illegal activities was admitted in court. By this procedure, the Supreme Court could affirm at the same time that secret armaments did not exist and that any publication of such a fact was a crime. To insure sentences, officers of the *Reichswehr* responsible for the secret armament were called as witnesses of the prosecution. In order to terrorize the public, many more trials were started than could ever be completed.

TECHNIQUES OF CLANDESTINE REARMAMENT[1]

The techniques used by the German government, and by quasi-governmental and private organizations, to conceal weapons covered an extremely wide range. In the following summary only the principal devices are noted, because they have important implications for any disarmament inspection system.

[1] This section was prepared with the assistance of Mr. John E. Ullmann of the Department of Industrial and Management Engineering, Columbia University.

In 1919 the victorious powers instituted an Inter-Allied Control Commission. It was authorized to make payments for reports leading to discoveries of arms caches. Some rewards were claimed. The extra-territoriality of the Commission was never clarified and its personnel was left without protection. Individual inspectors were physically molested at times.

From its beginning the Commission was handicapped by the failure of the Allies to maintain a common front. In general, the French were the most interested in disarmament and the British the least. The French members of the Commission, especially General Nollet, objected to the fraternization between British Commission officers and German liaison personnel. This is borne out by Guhr, who successfully sabotaged Commission work in Silesia and commends the British attitude. After the Franco-Belgian Ruhr occupation in 1923, the German authorities refused to furnish liaison personnel to the French members and enforcement was further hindered.

War material was defined in an unpublished Blue Book of the Inter-Allied Control Commission. War weapons were to be destroyed and convertible equipment converted. Of course, a widespread effort was made to prevent the destruction of military equipment. Many thefts, especially of small arms, took place. Some arms were concealed. The actual level is hard to determine, but finds such as 600 105 mm. gun barrels were made (11).

Plant inspection visits could generally be made only with German liaison personnel present. Visits were also often prevented by management refusal to "guarantee safety" of visitors. Factory inspections were resented as commercial espionage (20). Guhr reports (6) that the French General LeRond refused liaison officers and, by making impromptu visits, discovered a great deal of illegal manufacturing. In one case, the management claimed that the arms had been smuggled in by a disgrunted employee who then reported them to the Commission. The Commission, at Guhr's request, eventually accepted this story. In Silesia, the chief problem was small arms manufacture. At the time German and Polish border patrols engaged in continual raids in preparation for the plebiscite, and thereafter.

The few approved factories for arms were not allowed to make anything else and had to be kept small. The separation from peacetime production was to hinder sudden conversions and to facilitate inspection.

A further criterion of approved plant selection was that no space for expansion at the plant site was available. A control commission was maintained at Krupp's factory until 1932 but much of Krupp's equipment had been shipped to Holland for safekeeping at the end of the war (15). In addition, Krupp owned a part of Bofors, in Sweden, and produced arms there (1).

Another technique was the maintenance of a floating stock of arms in constant transit. There were many lonely branch lines in Germany's railroad system.

Permitted quantities in authorized plants were widely exceeded. By 1924 the Control Commission estimated that Germany could, within a year, produce arms at First World War rates. The industrial base had been increased and several wartime bottlenecks eliminated (1, 12).

With regard to specific equipment, the German authorities maintained that flame throwers were necessary for insecticide spraying and range finders to determine cloud heights (17). There were also dispersals and physical removal of unusually large aggregates of machines harmless in themselves but usable in numbers for large-scale war production.

The growth of the automobile industry provided an opportunity for development of cross-country vehicles, tractors, etc., thus setting the base for some tank manufacture.

In 1926 the Inter-Allied Control Commission was replaced by a conference of ambassadors which had always exercised a right of veto over its decisions. Thereafter effective control ceased. At the time Britain was most alarmed over Russia and less concerned with illegal German acts.

ARMAMENTS PRODUCTION AND TRADE

German export trade flourished with arms to China, the Baltic states, etc. Corporate ties between German manufacturers and Skoda (Czechoslovakia, partly owned by Schneider-Creuzot), Schneider-Creuzot itself, Vickers-Armstrong, Hotchkiss, etc., facilitated this trade.

The League of Nations convention against arms shipments was not ratified by a sufficient number of countries. (The U.S.A. did not do so, for example.) This fate was typical of the fruitless and interminable disarmament negotiations of the 1920s. By 1929, League of Nations statistics listed Germany as the major arms supplier of thirteen countries. France and Belgium gave Germany as their chief foreign source. In addition to the discrepancies in the League of Nations statistics themselves—imports and exports reported never balanced—so much trade was camouflaged under false customs declarations, etc., that estimates range up to five times the reported figure.

In all major countries the aircraft industries have always been grossly overexpanded relative to any conceivable need of civil aviation. Government subsidies have been the rule. In Germany the government guaranteed the interest on bonds of individual manufacturers and set up a cartel to standardize products. Junkers, Heinkel, Dornier, and the *Bayerische Motorenwerke* were all active in the production of engines and air frames, and several smaller companies made air frames only. In 1930 the export of war planes started, especially to China for use against the Japanese and between rival war lords (1). In 1930 the first German tests of rockets and missiles were made, including liquid fuels and solid propellants (5). The large German aircraft of 1925-1935 were actually intended as prototype bombers, e.g., the JU-52 and the Junkers G-38, the first flying wing type aircraft. There were many flying clubs and by 1930 Germany had 1,000 planes, of which 500 were convertible for war purposes (1).

In the chemical industry war and peace products are often almost identical. Nitrates, ammonia, etc., are well-known examples. After the First World War the Germans held on to their plants successfully, although Nollet (15) warned of their war potential and even foresaw "energy released through disintegration of matter." By 1926 Germany made a third of *all* nitrates in the world, having in effect eliminated the Chilean natural product. Hydrogenation of coal, synthetic rubber, etc., were all started in the first instance because of autarchy objectives and military needs.

An explosion in a chemical factory in Hamburg in 1928, causing the death of eleven persons, proved that poison gas had been produced —for use by the army.

Germany also maintained large powder factories for "sporting arms" and by 1924 was DuPont's greatest competitor in Europe (20). Because of the convertible products involved, control over filling facilities and delivery vehicles is paramount in the control of chemical weapons (12).

Many of the major German arms manufacturers had subsidiaries in the countries neutral in the First World War, particularly Sweden, Holland, Switzerland, and Spain. These served as branches of the German parent companies engaged in armament production, research, and development. Thus the Swedish branch of Junkers, A. B. Flygindustri, in 1931 tested a pioneer two-seater fighter. A Dutch subsidiary of Pintsch made torpedoes. German advisers were sent to Spain, Turkey, and Finland, and organized arms production there for the regimes of Primo de Rivera, Kemal Ataturk, and Mannerheim. Shipping companies were formed under flags of convenience to serve naval rearmament (5, 23). Submarines were also made in Holland, according to Raeder's testimony at Nuremberg. The German government used neutral banks to lend government funds to its own industries, as in the case of a loan to Krupp's via Holland (20). Austrian industry collaborated both with German and with Swiss (Solothurn) and Dutch interests to continue illegal arms production.

After the First World War, Austria was under military restrictions similar to those imposed on Germany, in accordance with the treaty of St. Germain. The so-called "Hirtenberg-St. Gotthard incident" is a good example of operation of "inspection by the people." A group of social democratic Austrian railroad workers halted shipments of Italian arms to the Austrian government because these arms were suspected to be meant for the use of Austria's fascist militias. An attempt was made to bribe railway workers to divert the shipments to a line which loops briefly into Hungarian territory, so that the arms could be unloaded in Hungary. Such a shipment to Hungary would have violated the Treaty of Trianon, which restricted Hungarian armaments. Under pressure from Britain and France the intercepted arms shipment was finally returned to Italy.

THE RUSSIAN PHASE OF GERMAN REARMAMENT

The use of neutral facilities was in addition to the large scale collaboration with Russia. It extended beyond manufacturing to the clandestine training of army personnel.

Starting their collaboration with the Rapallo Treaty (1921), the contracting powers, the Russian government and the German Army, had different aims. The Russians wanted to profit from German industrial technology and were keen on getting an armament industry of their own to be built by the Germans. The German Army had an interest in producing weapons and munitions which could not be controlled by the power of Versailles.

This connection led to the construction of an air force. The Junkers airplane factory in Dessau built airplane factories in Russia. The costs were, of course, to be provided by the army. Other airplane factories were built near Moscow, and in Samara (Kuibyshev) and Saratow. Military air personnel got their instruction in Russia. To this end, German officers dismissed from the army went to Russia as civilians and, after a period of training there, returned to the army with a higher rank. In addition to airplanes, the army built a poison gas factory. Krupp had a firm in Russia which produced heavy artillery, especially howitzers (13).

In October, 1926, three Russian ships landed in Stettin with about 350,000 illegal grenades. But the workers became suspicious and wanted to know the content of the cases. Thus, it became known that grenades had been introduced for illegal uses by the *Reichswehr* from Russia. (The Communist Party denounced this news as false, since it could not admit that Russia had collaborated with the illegal *Reichswehr.*)

In the Moscow purges of 1936, one of the main accusations was the collaboration of Russian officers with the German army identified with the Nazis. The defendants had collaborated, but on official orders of the Russian government.

FINANCING THE CLANDESTINE REARMAMENT

The nationalist supporters of illegal rearmament received funds from big industry and the feudal estates, difficult to trace, except for the subventions paid by Thyssen. But the main source was the army's budget.

About 25 percent of the military budget consisted of amounts which could be transferred, i.e., used for purposes different from those they were intended for. Another source of income was the fantastically high prices that were charged for munitions, far exceeding the real costs. Surplus funds were thus made available. Large amounts were at the disposal of the military for aims not specified. A further source was the private funds which the army collected through its public relations. The army sent agents to big business and asked for contributions to defray the costs of secret armaments, from which industry profited. Certain military items appeared in the budget as innocent-looking civilian needs. From all these sources the army disposed of enormous sums for which it did not have to account. In 1929, this led to so large a surplus that illegal army funds were invested in films, real estate, shares, ships, and aviation. But the investments were bad. The secret fund lost 28 million marks, about $7 million, which had to be reimbursed from the legal budget.

EPILOGUE

The Weimar Republic was killed by the great depression, which brought a revival of illegal party armies and their fight for power. When the Nazis took over, the secret armament stopped because armament became legal; the great powers had accepted the Nazi breach of the Versailles Treaty. The secret armament under the Weimar Republic is a link between the defeat of 1918 and the holocaust of the Second World War.

CONCLUSIONS

From this account of aspects of clandestine rearmament under the Weimar Republic several general inferences may be made:

1. Secret rearmament in conventional weapons is possible if a large reservoir of trained soldiers, especially with war experience, is available; if it is supported by some parts of public opinion; and if secret production or illegal importation of arms is available. Complicity of at least a part of the government is an essential condition for successful illegal rearmament and terroristic activity, its consequence.

2. Reliance cannot be placed merely on the existence of groups which oppose rearmament. Reporting of illegal rearmament efforts to an international authority must be regarded as both legal and praiseworthy. This condition is possible if a non-monopolistic, competitive free press exists. International authority must supersede national authority. The personal safety of those giving information to a disarmament control commission must be legally assured.

3. No law has any force if its violation is encouraged by habit, vested interests, economic powers, or by the law enforcing agencies. If disarmament is legal, rearmament must be illegal. This distinction

must be firmly embedded in the minds of the citizens and the law-enforcing agencies. Any illegal act by any part of the government should be a crime.

4. In formulating and implementing a disarmament agreement, the identification of war materiel and its destruction are likely to be extremely difficult, and fraught with risks of evasion unless the agreement has substantial support from the general population. The production of arms is difficult to control in the absence of surveillance of international trade in arms. Disarmament must be universal, i.e., no countries may be left out of the control setup.

5. The more comprehensive a disarmament agreement, the simpler is its implementation, and the more difficult and elaborate must be the methods used for its evasion.

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ON THE FEASIBILITY OF USING A MULTIPLE LINEAR REGRESSION MODEL FOR VERIFYING A DECLARED INVENTORY

by Cyrus Derman and Morton Klein

[Note: International agreements for limiting or prohibiting arms production would certainly require a declaration of the stocks of weapons already produced. The problem of an international inspectorate would be: How can one check on the inventory figures that are so declared? How could one test for the possibility that a part of past production has been concealed in a secret, undeclared inventory?

This unusual kind of inventory problem was explored by several men in terms of the developing technology of inventory theory and methods of control. Their finding was that none of the available modes of analysis for inventory control could cope with this kind of problem.

Exploration of conceivable methods yielded the suggestion that this problem might be approached through an attempt to measure past production of industrial plants on the basis of an analysis of current relations between several inputs and output. If this could be done with acceptable accuracy, then the past (estimated) output of a plant could be compared with the declared output, as represented by a declared inventory of weapons on hand. This comparison would be a check, by this reasoning, on the accuracy of the declared inventory.

In order to test the feasibility of this approach, the editor secured the cooperation of the management of a firm producing a product that is well suited in many respects for such a test.

The results, largely negative, are important for the present purpose. If further research does not disclose ways of solving this problem of verifying a declared inventory, then this area stands as one of major weakness for inspection methods that rely solely on the direct control of materiel.—Editor.]

ONE ASPECT of a disarmament inspection program is that of verifying stated inventory figures of critical components of weapons systems. The purpose of this memorandum is to investigate the feasibility of verifying such inventory data on the basis of a short period of observation on the system used to produce these components.

Assume that the observations are used to develop a mathematical model which describes the relationship between certain basic input variables and the output of a production system. Then, it may be possible to use the model, together with input figures for some fixed past period, to check the validity of data purported to represent the number of components added to inventory during this period, by a comparison of the data supplied with the number given by the model. If the past period under study includes the start of production, the total inventory statement may be verified.

In order to see whether an actual production system could be expected to be stable enough to permit this approach, the production data supplied by a Midwestern plant, which manufactures a small motor driven precision product, were analyzed.

A multiple linear regression model was considered to be a suitable first approximation to the potential mathematical relationship between the input variables and the output of the plant.

The inputs were:

X_1 = man-hours/week
X_2 = kwh/week
X_3 = lbs. steam/week
X_4 = cu. ft. air/week
X_5 = gal. H_2O/week
X_6 = lbs. scrap/week
X_7 = time, in weeks, from start of some observation period.

The output was:

Y = Number of units produced/week.

The model considered was of the form

$$Y = B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + e$$

where e is assumed to be a random variable, which has a mean value equal to zero and a variance, equal to σ^2, which is independent of the input.

The usual least squares methods, based upon thirteen weeks of

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observation, resulted in the following estimates of the regression coefficients:

$$\begin{aligned} \text{Estimate of } B_1 &= .974 \\ B_2 &= -16.9 \\ B_3 &= 16.1 \times 10^{-7} \\ B_4 &= 9.17 \times 10^{-3} \\ B_5 &= 3.96 \times 10^{-4} \\ B_6 &= -.362 \\ B_7 &= 58.1 \end{aligned}$$

The estimate of σ^2 was 875,333. The actual observations are shown in Table 1.

For present purposes, *assume* that the above estimates are actually the true values and that e has a normal distribution. Then, a prediction interval, having a high likelihood of being correct, e.g., having a probability equal to .954 of including the true output of a given week, would have a width equal to 4 σ. In this case, this is equal to $4(935) = 3{,}740$. This quantity is approximately 25 percent of the maximum weekly production during the period observed.

It should be noted that since the values used in the computation are in fact estimates, the above interval, in reality, would tend to be wider. Actually, this interval, although optimistically obtained, is large enough to discourage consideration of this kind of model for purposes of detecting a specified quantity of items unreported in a week's production record. The chances of detecting the same quantity, if withheld over a longer period, will be even smaller.

The use of only thirteen weeks' observations, which was considered to be reasonable in terms of an inspection program, may have resulted in an overestimation of the variance (σ^2). However, even if σ is halved the resulting interval is still rather large for the purposes of interest. Clearly, at best, a different and probably more extensive analysis of the production system is required. At worst, the system is such that the variation in the output is excessive no matter what reasonable analysis is used.

It should be further noted, that even if the error had been very small, if systematic caching of output is practiced continually (including during the period of observation), then the above model would not be effective.

It may be observed that although the example and data utilized

TABLE 1

Input-Output Data for a Certain Production System

OUTPUT	INPUTS						
Number of Units Produced Y	*Man-Hours* X_1	*Power (KWH) (000)* X_2	*Steam (Lbs.)* X_3	*Air (Cu. Ft.)* X_4	*Water (Gal.)* X_5	*Scrap (Lbs.)* X_6	*Time* (Weeks)* X_7
16,126	28,638	359	3,528,996	17,625	7,350,000	9,397	01
9,092	20,097	323	3,352,485	16,875	7,350,000	6,670	02
10,691	21,388	317	3,267,468	19,559	4,934,672	4,701	03
13,494	21,935	316	3,581,526	20,396	4,865,739	5,537	04
10,045	19,631	318	3,950,103	15,144	5,005,771	5,315	05
12,464	22,264	311	4,136,457	19,500	4,912,613	4,680	06
15,045	24,147	334	4,640,490	21,560	4,933,879	5,455	07
9,225	18,025	328	4,298,076	20,378	5,038,826	4,795	08
15,808	24,210	295	3,890,688	18,603	4,624,238	5,728	10
12,084	20,756	323	4,752,384	22,502	5,263,835	4,723	11
18,857	29,894	338	5,375,961	24,098	6,423,949	8,774	12
15,380	27,531	323	5,280,700	22,306	6,300,310	10,204	13
16,536	27,279	337	4,524,159	22,167	5,326,496	8,740	14

* Data for the ninth week were incomplete. Hence, the entire week was omitted.

above may be considered as representative of the production of a high output "civilian" commodity, it is not necessarily characteristic of precision-manufactured, low output, closely controlled weapon components. It is conceivable that the inherent variation in data associated with such a system could be of a much lower order of magnitude. This would naturally facilitate the possibility of postdictions of the kind which would be useful for inspection purposes.[1]

[1] We are indebted to the Watson Scientific Computing Laboratory, Columbia University, for making an IBM 650 computer available for this study and to Miss S. Guimaraes for carrying out the computations.

THE USE OF SAMPLING IN DISARMAMENT INSPECTION

by Herbert Solomon

[Note: There are several areas of inspection for disarmament which are important, but costly to inspect by monitoring each unit. Such sectors include the thousands of metal-working plants, biological laboratories, government accountants, scientific personnel, and possibly other areas of this type. Therefore the problem arose: How could one devise rational systems of sampling inspection according to the specific features of the industry or other sphere involved?—Editor.]

THE PRIMARY PURPOSE of the ability to inspect in any disarmament program is the encouragement it gives to all sides that disarmament programs will be carried out in good faith. However, one can always hope for the best, but prepare for the worst. Such preparation assumes that evasion will take place and calls for feasible strategies to detect such action. Appropriate inspection strategies will, of course, have to be based on methods of evasion. For example, evasion can occur through the sheer negligence of the inspection function by the responsible authorities or by connivance with such authorities. The main purpose of this paper is to consider the detection of evasion not under such circumstances but in less dramatic situations.

Suppose it were possible to inspect any and all factories, laboratories, and government records. Hordes of trained officials and staff would be required for one hundred percent inspection, and this in and

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of itself would not be enough to guarantee detection of evasion. Any reasonable estimate of the costs involved in manpower, money, good will, and other intangible resources immediately suggests a prohibitively high figure for one hundred percent inspection. Morover, it may be a physical impossibility to find enough adequately trained personnel. This raises the question whether anything less than complete inspection is feasible in terms of sufficient protection against evasion. The immediate question to be resolved is: Is it possible to have partial inspection which would provide a high degree of protection against evasion and yet not assume astronomical costs? One way of achieving a partial inspection whose risks can be evaluated is by probability sampling. A beneficial by-product of sampling is that fewer inspection personnel will be required. These can be trained in inspection skills so that, while all potentialities will not be inspected, those that will be inspected will be done accurately.

What follows in this paper is an a priori assessment of some sampling designs for inspection purposes. This assessment employs a few facts drawn mainly from published United States sources, and also employs much conjecture to produce other numbers employed in the analyses. Thus, its results are based on the partially guessed numbers employed, but the rationale can be employed for any set of figures. One can employ one's own numbers if the approach has any merit and see how the final estimates differ from those in this paper. In short, there will be much subjective judgment used in giving values to population parameters in the sampling designs. On the other hand, we are in an unexploited subject without access to many facts.

We will consider two areas for inspection to illustrate our approach: (1) metal-working plants, which could produce, among other things, say, gyros for missiles, and (2) biological laboratories, which could produce biological or chemical agents deleterious to mankind.

Suppose we consider metal-working plants in the United States. In 1954, there were approximately 12,000 such plants which could be stratified into three groups according to the ease with which a critical destructive item could be both produced and then hidden from an inspection team. Group 1 consists of those plants with the best chance of achieving evasion; Group 2 those with a reasonable chance of doing so, and Group 3 those with the smallest chance. There are $N_1 = 2{,}500$, $N_2 = 5{,}500$, $N_3 = 4{,}000$ plants in the groups (the subscript identifies the group as belonging to one of the categories in the previous sentence).

Assume it is approximately twenty times as probable that a plant in Group 1 will be successful in evasion as will a plant in Group 3; approximately five times as probable that a plant in Group 2 will be thus successful. If we let N_i' be the effective size in each stratum, N′ the sum of the N_i's, then the effective strata sizes are computed by multiplying N_i by these weights to obtain:

$$N_1' = 50{,}000,\ N_2' = 27{,}500,\ N_3' = 4{,}000,\ N' = 81{,}500.$$

Let $p_i = \frac{N_i'}{N'}$, then $p_1 = .61$, $p_2 = .34$, $p_3 = .05$.

Let the standard deviations of the variable measuring success in evasion in each of the three strata S_1, S_2, S_3, be as follows: $S_1 = 5S_3$; $S_2 = 2S_3$. What we are essentially saying here is that the easier it is for a plant to practice evasion, the bigger the variability in whether or not evasion is practiced. Obviously, if evasion is always practiced or never attempted the variability is zero. (The variability is also zero if evasion is always practical, but we are assuming that the probability of evasion in Group 1 is realistically not greater than .5.) It is possible to select an optimum sample size, where optimum means maximizing the precision of estimate of the inspection team as to whether or not evasion is practiced. From the theory of stratified sampling, the optimum sample size from each stratum is

$$n_i = n \frac{p_i S_i}{\Sigma p_i S_i}$$

where n is the total sample to be taken from the 12,000 plants.

$$\text{Thus } n_1 = n \frac{.61(5S_3)}{.61(5S_3) + .34(2S_3) + .05(S_3)} = .80n$$

Likewise

$$n_2 = .18n$$
$$n_3 = .02n.$$

Assume now that the number of man-days necessary to inspect a plant completely is the same for a plant in any of the three categories and is equal to, say, 10 man-days per plant. Let a man-day cost \$50 (salary and overhead), then total cost C_o is

$$C_o = 500n \text{ or } \frac{C_o}{n} = \$500,$$

where *n* plants are inspected over the three categories according to the stratum allocations just determined, namely .80n, .18n, .02n.

If we wish to spend \$500,000 for an inspection, then $n = 1{,}000$ and $n_1 = 800$, $n_2 = 180$, $n_3 = 20$.

If we wish to spend $1,000,000, then $n = 2{,}000$ and $n_1 = 1{,}600$, $n_2 = 360$, $n_3 = 40$.

We can construct the following table:

Total Cost of Inspection	*Total Sample* n	n_1	n_2	n_3
$ 500,000	1,000	800	180	20
1,000,000	2,000	1,600	360	40
2,000,000	4,000	2,500[a]	1,350	150
3,000,000	6,000	2,500	3,150	350
4,000,000	8,000	2,500	4,950	550
5,000,000	10,000	2,500	5,500[b]	2,000
6,000,000	12,000	2,500	5,500	4,000

[a] Should be 3,200 but 2,500 is total in this category; remainder is allocated to n_2 and n_3 in proportion, namely 9:1. This procedure is continued in succeeding rows in the table.

[b] Total of 5,500 is exceeded, remainder given to n_3.

This table indicates the optimum protection one can obtain for a fixed dollar cost. One can easily see that the added protection that $2,000,000 provides is quite different within a range of, say, one to three million than in a range of four to six million, since the latter addition results primarily in the examination of all plants in Group III, a group which is not as vital as the other two for our purposes.

A similar approach can be attempted for biological laboratories. In the United States there are approximately 9,000 biological laboratories; 7,000 of these are in hospitals, 1,000 are large installations devoted to immunology, pharmaceuticals, etc., and 1,000 are installations in such places as milk stations, agricultural experimental stations, etc. Let $N_1 = 1{,}000$ (labs), $N_2 = 7{,}000$ (hospitals), $N_3 = 1{,}000$ (milk stations), and assume their relative worth as before is 20:5:1. Then

$N_1' = 20{,}000,\ N_2' = 35{,}000,\ N_3' = 1{,}000$, and

$p_1 = .36,\ p_2 = .83,\ p_3 = .01$

Now let $S_1 = 10S_3$, $S_2 = 5S_3$, and allocate the total sample size n such that again

$$n_i = n\,\frac{p_iS_i}{\Sigma p_iS_i}$$

We get $$n_1 = n\,\frac{.36(10S_3)}{.36(10S_3) + .63(5S_3) + .01S_3} = .53n.$$

Likewise

$$n_2 = .46n$$
$$n_3 = .01n.$$

Assume now that it takes 50 man-days to inspect completely each plant in each of the three categories and that the cost per man-day is $100. Then if C_o is the complete cost

$$C_o = 5000n \text{ or } \frac{C_o}{n} = \$5{,}000$$

If C_o is $1,000,000, then $n = 200$ and $n_1 = 106$, $n_2 = 92$, $n_3 = 2$. We can now construct the following table:

Total Cost of Inspection	*Total Sample* n	n_1	n_2	n_3
$ 1,000,000	200	160	92	2
3,000,000	600	318	276	6
5,000,000	1,000	530	460	10
7,000,000	1,400	742	644	14
9,000,000	1,800	954	828	18
10,000,000	2,000	1,000[a]	978	22
15,000,000	3,000	1,000	1,958	42
20,000,000	4,000	1,000	2,940	60
30,000,000	6,000	1,000	4,880	120
45,000,000	9,000	1,000	7,000	1,000

[a] Should be 1,060 but 1,000 is total in this category; remainder is allocated to n_2 and n_3 in proportion, namely 46:1. This procedure is continued in succeeding rows in the table.

Suppose we now consider evasion through camouflage attempts in budget procedures. The United States General Accounting Office (GAO) is composed of a headquarters and nineteen field activities, employing about 6,000 people. A working rule in audit control is to employ about five percent of the accounting staff for that purpose. Therefore a maximum of 300 trained fiscal and budget experts should be sufficient. For this situation it does not appear necessary to consider sampling techniques as we did for the previous two situations, although it is quite possible that some sampling may have to be done by each individual auditor in deciding what accounts to pursue in detail.

Let us now consider the implications of the use of sampling in the metal-working plants and the biological laboratories. If no evasion is practiced, then the sampling will not uncover any evasion and the decision of no evasion on the basis of the sample will not have harmful effects. Similarly, if evasion is practiced in every installation, the sampling will establish evasion. Where evasion is practiced in some plants and laboratories but not in others, there will be risk attached to the decision given by the sample. This risk can be lessened by increasing the total sample size and, therefore, the cost. The sample size will therefore depend on some external knowledge about the nation undergoing inspection. However, even if the sample size required is high, the total cost given in the two tables does not seem extraordinarily high for so important a subject.

AN INTERNATIONAL PUBLIC OPINION POLL ON DISARMAMENT AND "INSPECTION BY THE PEOPLE": A STUDY OF ATTITUDES TOWARD SUPRANATIONALISM [1]

by William M. Evan

[Note: To counteract efforts to evade a disarmament agreement, various methods of inspection are needed. One method recommended by this book, "Inspection by the People," takes advantage of the fact that every major evasion effort requires a large number of man-hours in many occupations. It is, therefore, critical to have an indication of public attitudes toward inspection for disarmament and an estimate of the readiness of a cross section of the population to oppose clandestine armament.—Editor.]

INTRODUCTION

INNOVATIONS in science are now generally valued, whereas in other social institutions they are often depreciated. And yet cultural and social innovations deemed utopian in one epoch may become part of social reality in another. The proposal advanced by Professor Seymour Melman to include "Inspection by the People"[2] as part of a disarmament inspection system entails a cultural and a social innovation. If methods of *physical* inspection do not afford adequate safeguards against evasion of an international disarmament agreement, then the suggestion to com-

[1] The writer is indebted to Professor Paul F. Lazarsfeld for valuable comments and criticisms.

[2] See his General Report, pp. 38-44.

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plement them with a *social* inspection system, namely, "Inspection by the People," assumes special significance.

According to this proposal, an international agreement would make it the legal duty of the citizens of all signatory countries to report evidence of violations in their country to an international inspection authority. Such an agreement implies that nations would relinquish a measure of sovereignty in favor of an inclusive and transcending collectivity of the nation-states of the world or of mankind for the purpose of preserving peace. The *cultural* innovation of the proposal for "Inspection by the People" lies in the acknowledgment that for the purpose of securing peace, loyalty to a supranational entity or to mankind is a higher value than loyalty to nation. The *social* innovation lies in implementing this value by devising open, two-way channels of communication[3] between the peoples of the signatory countries and the international inspection authority. Such an international agency would necessarily create new social relationships and new rights, privileges, and immunities, as well as new duties, for the peoples of the countries which are parties to the disarmament agreement.

Present obstacles—of a political, economic, legal and cultural character—to a system of "Inspection by the People" are, of course, numerous and formidable. This paper is not, however, concerned with a general analysis of these impediments. Rather, it is a study of one possible obstacle: the climate of opinion regarding the proposed innovation in international law as it relates to disarmament.

In polling public opinion on disarmament and "Inspection by the People," the assumption was made that attitudes or latent views toward supranationalism were being explored. A supranational, as distinct from an international, orientation to world affairs acknowledges that individual citizens—not merely governments—have rights and duties with respect to an entity transcending the nation.

With reference to these considerations, this paper seeks to answer two questions: (1) What is the current climate of opinion regarding disarmament and "Inspection by the People" in selected countries? and (2) What are some sociological and social-psychological factors associated with opinions about disarmament and "Inspection by the People" in these selected countries?

To answer these questions, a specially designed poll was conducted

[3] *Ibid.*

in six nations: the United States, Great Britain, France, West Germany, India, and Japan. Samples of respondents were personally interviewed from March 7 to March 13, 1958, by the staffs of the American Institute of Public Opinion and its affiliates[4] in Great Britain, France, West Germany, and India. In Japan, the Research Department of the national newspaper, *Yomiuri,* conducted the poll from March 13 to March 29, 1958.[5]

THE FINDINGS

In order to measure attitudes toward disarmament and "Inspection by the People," the following three questions were asked:

1. Would you favor or oppose setting up a world-wide organization which would make sure—*by regular inspections*—that *no* nation, including Russia and the United States, makes atom bombs, hydrogen bombs and missiles?
2. If this inspection organization were set up, would you favor or oppose making it each person's *duty* to report any attempt to secretly make atom bombs, hydrogen bombs and missiles?
3. If you, yourself, knew that someone in (name of country) was attempting to secretly make forbidden weapons, would you report this to the office of the world-wide inspection organization in this country?

The first question refers to a somewhat abstract proposal for disarmament, which presumably evokes attitudes toward peace. Since it demands little from the respondent in the way of a sacrifice of values, it was anticipated that a relatively high proportion would express approval. In contrast, Question 2 involves a concrete proposal which imposes a unique legal duty on all citizens to participate in the enforcement of a disarmament agreement. Thus it does potentially entail the sacrifice of one or more values by requiring a citizen to report damaging evidence against a friend, a neighbor, or his own government. Hence an appreciably lower proportion of favorable responses was expected. This is even more true of Question 3, since it asks the respondent if

[4] British Institute of Public Opinion, Institut Français d'Opinion Publique, Emnid, Institut für Markt- und Meinungsforschung, Indian Institute of Public Opinion, Ltd.

[5] For information regarding the validity of the poll data, see Appendix: The Strengths and Weaknesses of the Poll Data.

he personally would accept the duty of reporting to a world-wide inspection organization any evidence of violations in his own country, thus raising a potential conflict of values between loyalty to nation and loyalty to a supranational or "trans-national" body. Consequently, it was anticipated that the favorable response to this question would be even smaller than that to Question 2.

In short, it was expected that the aggregate responses for a country would have a monotonically declining pattern from Question 1 to Question 3. Moreover, it was expected that those who answered Question 3 positively would be more likely to answer Question 1 positively than those whose answers to Question 3 were negative. Conversely, those answering Question 1 positively would be more likely to answer Question 3 positively than those answering Question 1 in the negative. Otherwise put, it was hypothesized that the three questions measuring attitudes toward disarmament and "Inspection by the People" are interrelated.

National Climates of Opinion

In view of the above set of expectations, the over-all results of the poll in the six nations, as shown in Table 1, are indeed striking. The high level of affirmative responses to all three questions in all six nations underscores the widespread support for a system of disarmament inspection in general and "Inspection by the People" in particular. To the extent that favorable public opinion regarding a disarmament agreement is a necessary condition for its workability, the findings suggest that "Inspection by the People" is not considered as visionary a proposal as one might have thought.

How shall we interpret this overwhelmingly positive response to the three questions in all six countries? What meaning did respondents read into the questions, and what meaning may we read out of their answers?

One interpretation is that Question 1 presents a proposal manifestly concerned with ensuring peace, a proposal which has been debated in the United Nations for over a decade. Questions 2 and 3 raise a novel and hypothetical proposal. The high level of approval may be taken as a measure of readiness to participate personally in implementing a disarmament agreement.

TABLE 1

Opinions about Disarmament Inspection in Six Selected Nations

Questions	*United States* (N:1,610) %	*Great Britain* (N:1,000) %	*France* (N:287) %	*India** (N:250) %	*West Germany* (N:282) %	*Japan** (N:200) %
Would you favor or oppose setting up a world-wide organization which would make sure—by *regular inspections*—that *no* nation, including Russia and the United States, makes atom bombs, hydrogen bombs, and missiles?						
Favor	70	72	85	78	92	91
Oppose	16	10	6	1	1	8
No Opinion and No Answer	14	18	9	21	7	1
If this inspection organization were set up, would you favor or oppose making it each person's *duty* to report any attempt to secretly make atom bombs, hydrogen bombs, and missiles?						
Favor	73	54	74	71	86	80
Oppose	11	15	13	2	4	16
No Opinion and No Answer	16	31	13	27	10	4
If you, yourself, knew that someone in (name of country) was attempting to secretly make forbidden weapons, would you report this to the office of the world-wide inspection organization in this country?						
Yes	80	50	63	63	73	83
No	6	17	18	6	11	5
No Opinion and No Answer	14	33	19	31	16	12

* See the Appendix for a statement of the limitations of the sample.

TABLE 2

Opinions about Disarmament Inspection in Two Validation Groups

	Group of Federation of American Scientists (N:32)	*Group of American Legionnaires* (N:76)
1. Percent in favor of inspection for disarmament	97	53
2. Percent in favor of making it each person's duty to report violations	78	59
3. Percent who would personally report violations to world-wide inspection organization	84	59

Another facet of this interpretation is that these questions are uncovering a possibly higher receptivity to supranationalism than is generally assumed to exist in a world rife with conflicting nationalisms. To ascertain whether these questions are being interpreted along the dimension of nationalism-supranationalism, it was decided to validate the meaning of the questions for the United States sample on two contrasting "known" groups for the purpose of establishing upper and lower limits of a supranational orientation.[6]

It was assumed that the Federation of American Scientists, which for over ten years has publicly advocated international control of atomic weapons, would score fairly high on a national-supranational scale. At the other end of this hypothetical continuum might stand the American Legion, with its emphasis on military preparedness, national security, and patriotism. The opinions of two groups of members from New York City branches of these organizations were obtained.[7] As shown in Table 2, the response patterns of these groups are indeed different. Whereas 97 percent of the group of members of the Federation of American Scientists approve of Question 1 and 84 percent approve of Question 3, 53 percent of the group of American Legion members are in favor of Question 1 and 59 percent are in favor of Question 3. The relatively high level of favorable responses of the group of American Legion

[6] The writer wishes to express his gratitude to Professor Eugene Litwak of Columbia University for the suggestion that a validation procedure be used.

[7] The respondents for this validation study were selected groups rather than samples, because of the assumed homogeneity in the attitudes of the members of these organizations.

members to Questions 2 and 3 would suggest that supranationalism is not necessarily a dominant meaning given by respondents to these questions. Confronted with an unfamiliar or unstructured situation, people tend to turn to familiar concepts in an effort to structure the situation. Thus, when presented with Questions 2 and 3, respondents may have had recourse to familiar concepts, such as general ideas of peace or of doing one's legal duty, since these conceptions represent widespread values in modern societies.

It is, nevertheless, reasonable to assume that respondents who answer all three questions—which as predicted are interrelated—positively, would have a more pronounced supranational orientation than those answering only one or two questions positively. If we construct such a disarmament inspection score, ranging from zero to three points, the distribution of scores for F.A.S. and the Legion is indeed different: 78 percent of the respondents affiliated with the F.A.S. have a score of three, i.e., are positive on all three questions, as compared with 34 percent of the group of Legionnaires. These two proportions, as Table 3 shows, represent the upper and lower boundaries for the distribution of disarmament inspection scores in all six countries.

A second unanticipated feature of the over-all poll results in Table 1 is that the predicted monotonic decline in response patterns is generally borne out, with the notable exception of the United States, where the pattern of response is completely reversed: 70 percent are in favor of Question 1; 73 percent are in favor of Question 2; and 80 percent answer question 3 in the affirmative.

TABLE 3

Comparison of High Disarmament Inspection Scores among Six Selected Nations and Two Validation Groups

Nations	*Percent Who Have a High Disarmament Inspection Score (who answer all 3 questions positively)*
Japan	72
West Germany	71
India	60
France	57
United States	56
Great Britain	44
Validation Group	
Federation of American Scientists	78
American Legion	34

A clue to the reason for the reversal is provided by the spontaneous verbatim comments of some of the respondents. A recurrent justification for opposing the proposal for the disarmament inspection system in Question 1 is that "Russians couldn't be trusted." The comments offered in support of Question 3 have as their major theme obedience to law, e.g., "If it's a law, it's a citizen's duty to report"; "Law should be obeyed"; "It would be our duty as a citizen"; "Should obey the law of the land." A strong commitment to law-abidingness as a value emerges, which is not nearly so pronounced in the spontaneous comments of respondents in the other countries. James Bryce's observation about America in the nineteenth century may well apply to America in the twentieth century: "Feeling the law to be its own work, the people is disposed to obey the law" and ". . . Americans are specially eager to claim [credit for] being a law-abiding community."[8]

Although the verbatim comments throw some light on the anomalous pattern of responses in the United States, how may we account for the over-all national differences in attitudes toward disarmament and "Inspection by the People"? As shown in Table 3, Japan has the highest positive score on disarmament inspection, Germany is second, India is third, France is fourth, the United States is fifth, and Great Britain is sixth. This rank order of favorable attitudes toward disarmament is largely explainable either in terms of the military experiences of these countries in the Second World War or their present military position. As militarily vanquished countries, Japan and Germany may be particularly interested in maintaining peace. Japan's memory of Hiroshima is still fresh and radioactive fall-out from nuclear tests by both the Soviet Union and the United States has been provoking anxiety. Germany's vulnerablity to invasion by the Soviet Union in the event of another war may be a contributing factor to the German interest in disarmament. At the opposite end of the rank order is Great Britain, a victorious country whose possession of nuclear weapons may afford a measure of subjective—apart from objective—security against the outbreak of another world war. France and India are in an intermediate position in the order, the former possibly because of its deteriorating military and political fortunes, the latter because of its neutralist position both politically and militarily. The United States, although a victorious country and an atomic power, occupies a position closer to France than to Great Britain.

[8] Bryce, *The American Commonwealth* (London: Macmillan, 1888), III, 340.

This is due to the high proportion of positive responses to Question 3, which is discussed above in terms of the value of law-abidingness.

In the absence of other poll data to check the validity of these interpretations of the rank order of attitudes toward disarmament inspection, they would be at best merely plausible. However, one question was included in this poll on the assumption that it was a determinant of responses to the three disarmament inspection questions. This question measures the degree of anxiety about the likelihood of a world war in which nuclear weapons would be employed. It reads as follows: "How worried are you about the chance of a world war breaking out in which atom bombs and hydrogen bombs would be used—very worried, fairly worried, or not worried at all?"

TABLE 4

Comparison of Rank Order of Six Selected Nations on High Disarmament Inspection Scores and on Perception of Threat of War

Nation	*Rank Order on High Disarmament Inspection Scores*	*Rank Order on "Very Worried" about War*
Japan	1	1
West Germany	2	4
India	3	2
France	4	3
United States	5	6
Great Britain	6	5

The rank order of the countries on the proportion of respondents who say they are "very worried" is as follows: Japan is first, India is second, France is third, Germany is fourth, Britain is fifth, and the United States is sixth. It is evident, as Table 4 makes clear, that this order closely corresponds to the previous order on high disarmament inspection scores. Japan, which ranks high on favorableness toward disarmament inspection, also ranks high on the perception of threat of a world war; and Great Britain, which ranks low on favorableness toward disarmament inspection, also ranks low on the perception of threat of a world war.

Sociological Factors Associated with Attitudes Toward Disarmament

Apart from the social-psychological variable of the perception of threat of a world war, what is the relation of such sociological variables as occupation, sex, education, etc.—which locate people in different segments of the social structure—to attitudes toward disarmament and "Inspection by the People"? On theoretical grounds we should expect some of these variables to be related to attitudes toward disarmament inspection. However, since the six countries differ substantially in their systems of beliefs and patterns of social relationships, the effect of a particular variable on attitudes toward disarmament would not necessarily be uniform in all countries.

Of the seven social background questions asked in the poll, space permits an analysis of but three: sex, occupation, and party affiliation or vote in the last election. With respect to the first of these variables, sex differences in opinions about disarmament inspection are negligible in the United States and Great Britain (see Table 5), where it may be

TABLE 5

Willingness to Report Violations and High Disarmament Inspection Scores among Men and Women in Six Selected Nations

	WILLING TO REPORT VIOLATIONS				HAVE A HIGH DISARMAMENT INSPECTION SCORE			
	Men		*Women*		*Men*		*Women*	
Nation	%	*N*	%	*N*	%	*N*	%	*N*
United States	78	(781)	82	(821)	57	(781)	56	(821)
Great Britain	52	(470)	48	(530)	46	(470)	43	(530)
France	67	(131)	60	(156)	63	(131)	51	(156)
West Germany	77	(127)	69	(155)	75	(127)	67	(155)
India	69	(189)	44	(61)	66	(189)	37	(61)
Japan	79	(102)	88	(98)	66	(102)	78	(98)

surmised that the sexes have moved farthest toward a position of relative social equality and a consequent convergence in opinions pertaining to various spheres of life. In France, Germany, and India, sex is correlated with attitudes toward inspection, with a higher proportion of males than females expressing readiness to report violations and having a high disarmament inspection score. This difference may be due to a more traditional relationship between the sexes in these countries; occupying a subordinate position in the family and in other areas of life, the woman is discouraged from venturing new opinions. The reluctance to express an opinion on a controversial issue is reflected in the higher proportion of "don't know" answers to Question 3 among women than among men in these countries. In Japan, on the other hand, a higher proportion of women than men approve of reporting violations and have a high disarmament inspection score. This is probably due to the fact that family obligations are more likely to take precedence over traditional, militaristic, and nationalistic obligations among women than among men.

The second sociological variable to be considered, occupation, is commonly found to correlate with social, political, and economic opinions. With the exception of France and Japan, a higher proportion of nonmanual workers than of manual workers is willing to report violations and has a high disarmament inspection score (see Table 6). This may

TABLE 6

Willingness to Report Violations and High Disarmament Inspection Scores among Manual and Nonmanual Workers in Six Selected Nations

	WILLING TO REPORT VIOLATIONS				HAVE A HIGH DISARMAMENT INSPECTION SCORE			
	Manual Workers		*Nonmanual Workers*		*Manual Workers*		*Nonmanual Workers*	
Nation	%	*N*	%	*N*	%	*N*	%	*N*
United States	78	(888)	83	(514)	55	(888)	59	(514)
Great Britain	47	(520)	54	(349)	41	(520)	47	(349)
France	65	(131)	62	(154)	59	(131)	55	(154)
West Germany	71	(147)	75	(95)	68	(147)	74	(95)
India	59	(97)	67	(138)	56	(97)	64	(138)
Japan	92	(47)	81	(153)	81	(47)	69	(153)

very well be due to such occupationally correlated factors as education and level of information, particularly with respect to the possible hazards of nuclear radiation. The reversal of this relationship in Japan may be accounted for by the fact that more than one half of the manual workers in the Japanese sample are fishermen—an occupational group which may be especially aware of the dangers of radioactive fall-out. In France the reversal is probably due to the differential impact of the leftist parties on manual and nonmanual workers.[9]

The attitudes of two specific occupational groups, engineers and scientists, toward disarmament inspection are particularly crucial, since these groups not only have access to the production and testing of nuclear weapons, as do other occupations, but they also possess specialized knowledge which would enable them to identify clandestine production in violation of an international disarmament agreement. Hence, their disposition to comply with the duty to report violations is of great significance to the question of the feasibility of a disarmament inspection

[9] See footnote 10 below.

TABLE 7

Willingness to Report Violations and High Disarmament Inspection Scores among Scientists and Engineers and All Other Respondents in Six Selected Nations

	Scientists and Engineers in the Six Nations		*Non-Scientists and Non-Engineers in the Six Nations*	
	%	*N*	%	*N*
Would Report Violations	84	(51)	69	(3,578)
High Disarmament Inspection Score	67	(51)	55	(3,578)

TABLE 8

Willingness to Report Violations and High Disarmament Inspection Scores by Party Affiliation or Vote in Six Selected Nations

Nation [a] *and Party Affiliation or Vote*	*Willing to Report Violations*	*Have a High Disarmament Inspection Score*	
	%	%	*N*
Great Britain			
Conservative	52	47	(371)
Liberal	60	48	(25)
Labor	55	48	(341)
United States			
Republican	85	59	(693)
Democratic	79	59	(481)
West Germany			
Christian Democratic Union (plus CSU, DP, FVP, FDP, DVP, *Bayernpartei*)	74	71	(124)
Center and BHE	54[b]	54[b]	(13)
Social Democratic	79	78	(92)
Japan			
Liberal-Democratic	82	73	(127)
Socialist	87	70	(69)
Communist	75[b]	75[b]	(4)
India			
Jan Sangh	50[b]	50[b]	(4)
Congress	65	62	(114)
Praja Socialist Party, Communist, Independent	81	81	(21)

[a] The French Institute of Public Opinion did not include a question on party affiliation or voting behavior in its poll.

[b] The N is too small for meaningful statistical inferences. However, the percentages are shown for general comparative purposes.

system in general and of "Inspection by the People" in particular. An examination of Table 7, which compares scientists and engineers in the six countries with all other respondents in these countries, shows the former more willing to report violations to a world-wide inspection organization and more likely to have a high disarmament inspection score. Their direct role in the production of such weapons, combined with their knowledge of the destructive power of nuclear weapons, may give them a greater appreciation of the importance of an international disarmament agreement. In addition, the scientist's search for laws transcending time and space, and the need for communication across national boundaries, may be conducive to a supranational orientation.

The third sociological variable, party affiliation or vote in the last election, has relatively little bearing on attitudes toward disarmament inspection in four of the six nations (see Table 8). In Germany and India, where leftist opposition parties have taken a strong stand on the cessation of nuclear testing, a higher proportion of respondents affiliated with leftist parties, as compared with other parties, both indicate willingness to report violations and have a high disarmament inspection score. In the other four countries, attitudes toward disarmament cut across party lines.[10]

[10] It is noteworthy that, on the assumption that occupation (or economic status) determines party affiliation or party vote, several of the findings of Tables 6 and 8 seem inconsistent.

Since a higher proportion of nonmanual workers than manual workers, except for France and Japan, is in favor of inspection for disarmament, one would expect that those liberal or leftist parties with a predominantly manual-worker membership would be less favorable toward disarmament than other parties with a preponderance of nonmanual workers. This expectation is borne out in the United States but not in Great Britain, where a slightly higher proportion of Labor Party voters is in favor of disarmament inspection than those voting for the Conservative Party; nor is it borne out in Germany, where a higher proportion of those affiliated with the Social Democratic Party than those affiliated with the Christian Democratic or allied parties is in favor of inspection.

Further cross-tabulation of the data for Great Britain, holding occupation constant, still shows a slightly higher proportion of Labor Party voters in favor of inspection, although the difference is substantially higher among nonmanual workers than among manual workers. A similar analysis of the data for Germany discloses that, among manual workers, party difference in attitudes toward inspection disappears entirely, whereas among nonmanual workers party difference tends to be reversed, namely, a slightly higher proportion of voters in Christian Democratic and allied parties is in favor of inspection for disarmament.

The problem raised by these considerations, that is, the role of occupation relative to other factors in party affiliation as it bears on attitudes toward disarmament, is obviously beyond the scope of this paper.

TABLE 9

Willingness to Report Violations and High Disarmament Inspection Scores by Perception of Threat of World War in Six Selected Nations

Nation	WILLING TO REPORT VIOLATIONS						HAVE A HIGH DISARMAMENT INSPECTION SCORE					
	Very Worried		*Fairly Worried*		*Not at All Worried*		*Very Worried*		*Fairly Worried*		*Not at All Worried*	
	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*
United States	85	(228)	81	(675)	80	(658)	62	(228)	61	(675)	53	(658)
Great Britain	62	(154)	53	(387)	49	(345)	57	(54)	49	(387)	41	(345)
France	70	(142)	65	(76)	51	(45)	65	(142)	58	(76)	47	(45)
West Germany	79	(131)	75	(99)	68	(33)	79	(131)	74	(99)	64	(33)
India	82	(143)	64	(52)	36[a]	(11)	79	(143)	56	(52)	36[a]	(11)
Japan	87	(139)	79	(57)	25[a]	(4)	80	(139)	56	(57)	25[a]	(4)

[a] The N is too small for meaningful statistical inferences. However, the percentages are shown for general comparative purposes.

In contrast to the three sociological variables which correlate differently with attitudes toward disarmament in the six countries, the social-psychological variable of perception of threat of war correlates uniformly in all countries: the greater the degree of "worry" about a world war, the higher the proportion of respondents who are willing to report violations and the higher the proportion of respondents who have a high disarmament inspection score (see Table 9). This finding suggests that the fear of nuclear war may prove to be a powerful force making for supranationalism.

CONCLUSIONS

The public opinion poll discussed above yields the surprising finding that at the present time the majority in all six countries supports the proposal for a disarmament agreement with a system of "Inspection by the People." Does this result provide us with a reliable prediction as to how people would behave if such an agreement were actually reached, and if an inspection system were established? This raises the general and critical question of the relation between attitudes and behavior or verbal behavior in the present and nonverbal behavior in the future.[11]

Among the conditions making for a close correlation between attitude and behavior are the strength and importance of the attitudes expressed. The greater the strength and importance to a respondent of an opinion, the greater the likelihood that the opinion is predictive of his behavior. In the case of the disarmament questions of this poll, two (Questions 2 and 3) are fairly novel and hypothetical in character. Hence, we might conservatively infer that the strength and importance of the opinions expressed about them are relatively low. If this were so, we could not confidently take the high disarmament inspection scores as predictive of what people are likely to do in the event that an international agreement is reached, obligating citizens to report violations to an international inspection authority.

On the other hand, two factors argue in favor of the possible predictiveness of the attitudes reported in this paper, assuming, of course, that these attitudes are maintained in the future. First, the

[11] Cf. Patricia L. Kendall and Paul F. Lazarsfeld, "Problems of Survey Analysis," in Robert K. Merton and Paul F. Lazarsfeld, eds., *Continuities in Social Research: Studies in the Scope and Method of "The American Soldier"* (Glencoe, Illinois, Free Press, 1950), pp. 179-82.

public opinion poll results in conjunction with the responses of the validation groups suggest that underlying the opinions expressed is a commitment to the values of peace and supranationalism. This indicates that the peoples of the countries that are parties to a disarmament agreement would probably comply with the provision to participate in a system of "Inspection by the People"—at least in the six countries in which the poll was conducted. Moreover, if we suppose that a clandestine system of production of nuclear weapons, or the practice of other large-scale evasions, requires a strong nationalistic orientation of a large segment of the population, then it is reasonable to predict that an effort to evade the agreement would not enjoy popular support in these countries.

A second consideration which enhances the prospects of action in line with expressed opinions is the fact that law generally legitimizes the commission or omission of an act. Since an international disarmament agreement would have the force of law in the signatory countries, it would encourage and facilitate the translation of favorable opinions about "Inspection by the People" into action. Following the establishment of such an agreement, the level of support for disarmament and "Inspection by the People"—barring government efforts to undermine the agreement—may even exceed that found in this poll. Such a response may be anticipated because of the finding by social scientists that after the enactment of a law there tends to be an increase of public opinion favorable to the law in question.[12]

Another important result of this poll is that the variation in national climates of opinion regarding disarmament inspection within the six countries is correlated with the perception of threat of war. This helps to account for differences in favorable attitudes toward disarmament inspection. It suggests that if the fear of war increases, favorable attitudes towards disarmament and "Inspection by the People" will increase unless they are counterbalanced by an effort to achieve collective military security.

Yet another important finding is the relationship between occupation and attitudes toward disarmament: engineers and scientists, two strategic occupational groups, express more willingness to comply with

[12] Cf. Paul F. Lazarsfeld, "Public Opinion and the Classical Tradition," *Public Opinion Quarterly,* XXI (1957): 46-47; Hadley Cantril, *Gauging Public Opinion* (Princeton, N. J., Princeton University Press, 1944), p. 228.

a disarmament inspection agreement than non-engineers and non-scientists.

Finally, in an effort to explain the unexpected reversal in the pattern of responses to the three disarmament questions in the United States poll, it was found that obedience to law is highly valued by many respondents. Although commitment to the value of law-abidingness may vary from one country to another, it is highly probable that, like the value of peace, it too transcends national boundaries. Commitment to the values of peace and law-abidingness is a potential basis for the participation of individual citizens of the nations of the world in a new social institution: "Inspection by the People."

APPENDIX: THE STRENGTHS AND WEAKNESSES OF THE POLL DATA

The first and most apparent limitation of the poll data of this study is the number of countries included and the status of those excluded. Of the ninety-odd independent nation-states in the world, six, to be sure, is a tiny proportion. However, limited financial resources made it impossible to increase the sample of nations. Especially regrettable is the omission of the Soviet Union and its allied countries in Eastern Europe and Asia, due primarily to the problem of inaccessibility of the peoples of these countries. On the other hand, the six countries included in the poll are among the major political forces in the world.

Another limitation of the poll data pertains to the sample size and sample design. Again because of the limited financial resources of this study, rather small national samples were selected in four of the countries.[13] The smallness of the sample does not necessarily lead to non-representativeness—providing the sample is designed properly. However, small samples, regardless of sample design, have the disadvantage not only of increasing sampling variance, but also of limiting the statistical analysis because of the dwindling of cases when sample subgroups are compared.

The sample design employed differed in the six countries. In Germany, France, and Great Britain, quota samples were drawn from among

[13] The sample sizes are as follows: 200 in Japan, 250 in India, 282 in West Germany, 287 in France, 1,000 in Great Britain, and 1,610 in the United States. The statistical-minded reader will realize that the size of the sample depends not on the size of the population but rather on the desired level of precision.

TABLE 10

Comparison of Sample and Population Characteristics of the Six Selected Nations, in Percentages*

Characteristics	UNITED STATES		GREAT BRITAIN		FRANCE		WEST GERMANY		INDIA		JAPAN	
	Sample	*Population*	*Sample*	*Population*	*Sample*	*Population*	*Sample*	*Population*	*Sample*	*Population*	*Sample*	*Population*
Sex												
Male	48.5	47.8	47.0	48.1	45.6	48.3	45.0	47.1	76.0	51.4	51.0	49.1
Female	51.5	52.2	53.0	51.9	54.4	51.7	55.0	52.9	24.0	48.6	49.0	50.9
Age												
Under 30[a]	15.3	18.2	25.6	23.6	62.4[b] (Under 30 and 30-49)	23.4	20.5	20.8	22.8	32.6	34.5	31.2
30-49	46.6	44.1	43.6	37.8		35.3	40.2	39.1	56.4	44.4	45.5	40.8
50 and over	38.1	37.7	30.8	38.6	37.6	41.3	39.3	40.1	20.8	23.0	20.0	28.0

[a] The minimum age of the poll respondents in the six countries is as follows: the United States, 21; Great Britain, 16; France, 18; West Germany, 20; India, 20; Japan, 20.

[b] Poll data on age were pre-coded in categories which overlap with those used in this table.

* Source: For the United States, U.S. Bureau of the Census, *Current Population Reports: Population Estimates,* December 18, 1957, Series P-25, No. 170, Table 3. The remaining figures come from the U.N. *Demographic Yearbook,* 1956 and 1957 (forthcoming). Those for Great Britain, France, and Japan are 1956 estimates, that for West Germany is a 1955 estimate, and that for India is from the 1951 census.

sampling units—ranging from 52 in France to 80 in Great Britain—distributed throughout the country. This method of sampling predetermines the selection of the categories of respondents to be interviewed so as to represent correct proportions of the adult population according to such background characteristics as age, sex, occupation, region, etc. A quota sample was also employed in Japan in six cities and their surrounding rural areas, representing the nine regions into which the country is divided.

In India, a probability sample was drawn from electoral registers; however, the poll was confined to five areas in which the Indian Institute of Public Opinion has interviewing staffs. The sampling areas comprise two states out of a total of fourteen—Uttar Pradesh and West Bengal—and one of the six territories, Delhi. The combined population of the sampling areas is approximately one fourth of the population of India.

In the United States, a modified probability sample was drawn by dividing the country into twenty-six regions and subdividing these areas down to the block level in the larger cities, groups of blocks in smaller cities and towns, and segments of townships in rural areas. Within these blocks and segments, 160 interviewers were given a preselected starting point and required to follow a given direction in their selection of households. The choice of respondent within a household was controlled by a systematic but not probability procedure and by male-female quota assignments.

In each of the six nations an attempt was made to draw a representative sample. The success with which this was accomplished differs from country to country, as can be seen in Table 10, which compares the samples and populations on two available characteristics—age and sex. In the United States, Great Britain, France, and West Germany, the samples appear to be fairly representative. In India, women are grossly underrepresented, due to the fact that relatively few women appear in the electoral registers from which the sample was drawn. In Japan, apart from the underrepresentation of the fifty-and-over age group, less educated, rural, and manual worker groups are underrepresented. For example, 43 percent of the sample are college graduates.

The third limitation of the data has to do more with difficulties of interpreting the results than with the generalizability and validity of the data. Once again because of the limited financial resources, only four opinion questions and seven social background questions were asked.

Thus, we are dealing with a poll rather than a survey, which normally consists not only of a large battery of questions, including items designed to test anticipated interpretations of the data, but also of questions varying in degree of directness and seeking to ascertain not only what opinions people hold but the strength and importance of the opinions expressed.

Notwithstanding these limitations, the body of data presented here is highly relevant for the problems with which this book is concerned. It also unquestionably provides a more reliable guide to action than common sense, guesswork, or intuition.

SOME COMMENTS ON PSYCHOLOGICAL ASPECTS OF EVASION AND DISARMAMENT

by Alberta B. Szalita

[Note: This paper is a comment on certain aspects of "evasion mentality" as seen from the vantage point of a clinical psychiatrist.

Evasion of inspection for disarmament by a part of a government, for example, would need two main elements: first, a technically feasible weapons system; and secondly, a driving will to evade among many people, as well as an allied justification of the evasion effort as just and laudable. This will to evade is a necessary condition for an evasion effort. Similarly, the will for peaceful living is a necessary condition for sustained disarmament.

It is significant that this entire investigation starts from the assumption that mistrust and evasiveness are central conditions of the problem of disarmament. Such attitudes may be readily justified in the light of recent history, which includes both domestic and international tensions. It is the editor's opinion that sustained and extensive disarmament may diminish such tensions and replace an "evasion mentality" by a positive will for peaceful living.

Scientists and engineers are especially important for any evasion effort. This is indicated from the reports of the Evasion Teams. Therefore, the knowledge of factors that generate or mitigate evasiveness is highly relevant to these occupations.

Broadly, a knowledge of conditions that encourage or discourage an "evasion mentality" is important for ensuring the successful operation of inspection for disarmament.

After taking counsel with psychiatrists, the editor wishes to indicate that evasion of disarmament involves complicity in acts whose pathological character, in destructiveness and in denying the value of human life, may be masked by certain available, socially validated psychological mechanisms. These are widely used to diminish responsibility toward other human beings. Four such mechanisms are identified here: (1) the relative guiltlessness of the psychopathic personality;

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(2) the identification with moral aims that are socially-approved; (3) the "obedient employee"; (4) the dehumanized perception of inhuman effects.

The psychopathic personality lacks a development of moral responsibility. People with such a personality are able to commit inhuman, destructive acts without a sense of guilt, or of wrong doing. (Psychopaths who act "on their own" in being destructive for personal needs are not relevant to this discussion.)

Identification with goals that are socially approved and that even imply moral sanction may be used as a masking mechanism for destructive behavior. Thus, goals such as patriotism and protection of family and country against an aggressor can be used to support preparation for mass destruction or to justify behavior which is in violation of an established international agreement to disarm. In this way, destructive acts are clothed with the respectability of socially validated goals.

The role of the "obedient employee" has also been widely used as a rationalization for "doing the job" whose duties, ranging from the operation of death camps to bomb-sight designer, are justified as being done "in order to make a living." Responsibility, by this mechanism, is vested in the employer or higher authority whose orders are merely being properly executed.

The last of these psychological devices is perception in a dehumanized way of the inhuman effects of war preparation. This is done by excluding feelings ("emotional anaesthesia") and focusing on abstracted technical aspects of the work in hand, while selectively ignoring the human consequences which will occur from the application of the technical principles. The design aspects of elaborate mechanisms, for example, are held in focus, while the effects of their application are ignored. Problems of maximizing killing power are translated into mathematical language, in whose terms problems of formal reasoning receive central attention, while no symbol for inhuman effects is allowed to appear.

By means of these evasive devices, often used in combination, highly destructive acts can be carried out, the effects of which are concealed from the perception of the actor. People who use these devices can simultaneously act in complicity toward destructive ends and live in the conscious belief that these acts are oriented toward constructive goals of the society.

Displacement of responsibility enables the people involved to express indirectly their own destructiveness, and their yearning for power over people. Even apparent passivity can be a cover for acting out aggressive tendencies. The actor shields himself from awareness of his destructiveness by selective inattention to the consequences of his acts—thereby maintaining an innocent picture of himself.

This report provides knowledge of both the methods and rationalizations for irresponsibility for human life as seen in evasion of disarmament. A general dissemination of these facts will deprive potential members of an evasion effort of the excuse of ignorance of these psychologically evasive mechanisms. Therefore, they will have no basis for justifying a claim of no responsibility for the inhuman effects of complicity in such evasion.—Editor.]

INTRODUCTION

THIS STUDY of the ways of implementing and evading disarmament agreements has pointed out a number of difficulties. It indicates, in fact, that the success of a disarmament agreement project depends substantially on the reduction of the atmosphere of fear and uncertainty which leads to what is termed, in this study, an "evasion mentality." I think the difficulties of such an enterprise should not be underestimated.

In addition to the remarkable ingenuity that the human mind exhibits in making infernal inventions for destruction, there is the long-standing tradition and training in developing and keeping secret all kinds of weapons and perfecting the ways of outwitting the so-called "enemy." It is also very important to keep in mind that, because these practices are held in great esteem, acts that would otherwise be considered criminal are treated as acts of higher morality. They have been considered heroic and highly regarded for such a long time that a considerable change of values would have to take place and equivalent goals be found before one could ensure the success of such an enterprise as world disarmament. What support does evasiveness have in socially validated behavior and in the psychological potential of man?

There is a long international tradition of finding ways of by-passing agreements rather than adhering to them. Governments participating in international disarmament agreements can look for ways to by-pass, ostensibly as a means of defense. They can anticipate that the opponent may also use such techniques and thereby will project to the opponent their own aggressive character.

There is also a tradition of using an external threat as an outlet for internal dissatisfaction and as a means for creating social cohesiveness.

Even in the short run, the operation of inspection for disarmament would be greatly facilitated if we had answers to questions like: Is man capable of sustained peaceful living? Is warlike behavior inevitable in man? Does man possess psychological equipment for disarmament as well as for evasion?

With some justification the problem may be viewed from a psychological standpoint. However, there is no sufficient basis for assuming that a psychiatrist, busy with clinical work, can make a decisive contribution to the deeper understanding of this problem, unless and until there is an interdisciplinary effort on the part of sociologists, psychologists, psychiatrists, and members of allied professions to elucidate the relationship between individual and mass psychology. Such an effort would enable us to shed light on the specific elements and steps involved in the preparation and implementation of a project of this magnitude.

While these remarks are based primarily on clinical experience with single persons, the elements discussed here represent common human features. It should be emphasized, however, that social psychology is not a sum of individual traits; such traits become modified as group phenomena. It is not clear whether it is only quantity that changes the quality. Thus, it is quite possible that social pressures narrow the range of alternatives that are conceivable to an individual. Social pressures give social validation and justification. Thereby, such pressures intensify, selectively, certain of the ranges of behavior of which people are capable. Action within the framework of governmental bodies, political parties, and the like gives social validation to the actions of participants and frequently relieves them of problems of responsibility, thus freeing them from guilt.

The following remarks are offered with a full awareness of their incompleteness and fragmentary nature, and with the reservation that they are derived mainly from experience with individual human beings. The topics to be discussed here are: (1) secrecy, mistrust, and evasion as aspects of personality; (2) major causes of evasiveness and related tendencies; (3) peaceful and destructive potentials; (4) human potentials for peace; and (5) science and scientists.

SECRECY, MISTRUST, AND EVASION AS ASPECTS OF PERSONALITY

It should be stated first that political reasons for mistrust between governments and possible reasons for evasion will be excluded from our consideration, in order to simplify matters. It is evident that such a division is artificial, for similar psychological principles may operate with governments and with people. It is legitimate to assume that governments base their decisions on necessities determined by the type of information they have of the strength and plans of their opponents. It is also plausible to assume that some, if not many, of the decisions are prompted by personal needs and the nature of personality characteristics of some government representatives. The presence of people with such characteristics may be due to a selective preference for such people for given posts. Thus, it is known that psychological tests have been used to select persons with particular traits to occupy governmental posts.

Those who practice psychiatry know from clinical experience that evasion, or evasiveness, a tendency toward secrecy, self-deception, deceptiveness, mistrust, and suspicion are common human features. A revaluation of values takes place in psychotherapy, which diminishes and sometimes eliminates the above tendencies, when they appear in disproportion. As a result, the distance between the subjective and objective experiences is narrowed, and undue suspiciousness and mistrust become redundant. When an individual is able to make a distinction between a feeling, a thought, and an action, and when obscure feelings and motivations become integrated, he acquires insight into the fact that his previous reaction was in disproportion to the event that precipitated it, and was misplaced.

CAUSES OF EVASIVENESS

What are the conditions that cause a disproportionate degree of evasiveness and related tendencies? The principal causative factors are loneliness, threats to one's security, lack of love, humiliation, helplessness, and the feeling of uselessness. Fear is the outcome and concomitant feature of all these states. In therapy we observe that the freer the individual becomes to make his own choices and take responsibility for them, the less fearful he becomes.

Yet, as psychotherapists, we realize that evasiveness is itself a necessary outcome of conditions under which it was produced. Likewise, evasion may be considered a necessity on the part of the group that employs it. In the present state of world mistrust, it is obvious that such attitudes will not be surrendered, any more than they are surrendered in the case of individuals, until the basis for mistrust is eliminated. The more secure the individual (and this may apply to larger groups), the readier he is to share information.

If one were to apply this observation to the problem of evasion as presented in these studies (and as related to an inspectorate of disarmament), it could be expected that the greater the participation and the responsibility on the part of a large segment of the world's population in the decisions of the governments, the less the need and possibility of such evasion.

Despite the prevalence of evasiveness, our knowledge of man's potentials includes the basis for an optimistic prognosis as to man's capability for peaceful living. This means that an ideology in which the maintenance of peace could represent a primary loyalty has a basis in the nature of man. Each government in representing its people would have to represent this ideology. Under such conditions governments represent a state in which, to quote Hegel,[1] "that will which obeys law is free; for it obeys itself. . . . The contradiction between Liberty and Necessity vanishes."

To bring this about an extensive change in educational values would have to take place: for example, increased security as against the glorification of uncertainty, achievements in knowledge and aesthetics as superior values to military achievement. Such effects require more knowledge on the causes of evasiveness as a mass phenomenon. While there are some vantage points for such inquiries, for example, in the known relation between insecurity and evasiveness, it would be useful to be able to define the social phenomena which encourage and discourage evasiveness and the mechanisms of such effects.

PEACEFUL AND DESTRUCTIVE POTENTIALS IN MAN

In connection with this entire subject, a question may be raised: Can the human race exist without wars? It is true that the history of civilization is an almost continuous history of warfare. War does have, as J. C. Flugel points out,[2] "a peculiar combination of moral and instinctive appeal," such as that of adventure, increase in social unity, freedom from certain worries and restrictions, provisions for outlet for aggression, and expression of virility. (Of course, in the light of the latest technological achievements, the possibilities for personal expression in war are immeasurably reduced.)

There is another peculiarity of the human mind which is worth mentioning here. People at large harbor a notion that somehow they will escape death in case of war. As Freud put it, "the idea of our own death is inaccessible to our unconsciousness."[3] It would appear, however, that this self-deception or illusion no longer holds in an atomic age.

While none of these elements can be discarded, we shall concentrate here on the problem of aggression as one of primary importance. Unsatisfied aggression has long been considered as the ultimate source of the appeal of war. War is, in fact, morally authorized aggression.

[1] Georg W. F. Hegel, *The Philosophy of History* (New York, Wiley Book Co., 1944), p. 51.

[2] J. C. Flugel, "Psychoanalysis and Morals" and "The Problem of War and Peace," in *The Yearbook of Psychoanalysis* (New York, International University Press, 1946), II, 195-229, *passim.*

[3] Sigmund Freud, "Thought for the Times on War and Death," in *Collected Papers* (London, Hogarth Press, 1948), IV, 316 and *passim.*

Clinical experience proves the presence of strong destructive tendencies in every individual. Actually, whether destructiveness is primary or secondary is an unresolved question. However, it is generally agreed that the stronger the helplessness, frustration, dependency, uselessness, and above all, fear, the greater the destructive tendencies. When such phenomena become widespread, fearfulness and mistrust are immediate concomitant features and the stage is set for uncertainty and receptivity to evasive behavior. Nothing contributes more to one's sense of security, self-respect, and well-being than the *feeling of being needed and useful.*

In psychotherapy we find that the destructive drive is reduced as the patient finds better and more satisfactory ways of self-realization.

Our experience teaches us that no matter how desperate or destructive a person may be, the constructive tendencies preponderate over the homicidal and suicidal ones. People want to live—not to die.

William James once offered a grim, though witty, description of human nature, in order to challenge an opposing view. "Our permanent enemy," he wrote, "is the rooted bellicosity of human nature. Man, biologically considered, and whatever else he may be into the bargain, is the most formidable of all beasts of prey and, indeed, the only one that preys systematically on his own species. We are once for all adapted to the military status . . . , and a function so ingrained and vital will never die out without resistance." James proceeds to state that, while the military ideals are as strong as ever, they are confronted by "reflective criticisms which sorely curb their ancient freedom," and concludes that "international rationality" could stop war, since "a war becomes absurd and impossible from its own monstrosity. . . ."[4]

HUMAN POTENTIALS FOR PEACE

It is altogether possible that such tendencies as suspicion, mistrust, deception, secrecy, and the like, while natural human feelings, develop in exaggerated form only under certain conditions. Such conditions may start in childhood as a reaction to parental attitudes, or untoward relations in home and school, or may be the outcome of political insecurity, such as is the case with racial or minority groups. Successful psychotherapy is effective in reconditioning such states. Since psychotherapy is

[4] Margaret Knight, *William James* (Harmondsworth, Penguin Books, Ltd., 1950), pp. 240, 248. (Extracts quoted are from "Remarks at the Peace Banquet" and "The Moral Equivalent of War.")

in a large degree a reeducational process, it would follow that by reeducation (taking various forms) such traits may be minimized in individuals as well as populations. A study of history convinces us that such an expectation is justified. No major humanistic movement was accepted without effort and struggle. Hegel, for example, speaks of "training into religion," assuming that there is a foundation for it in the human mind.[5]

The need for peace is not alien to the human mind. Hence, the possibility and necessity for training people *into peace*. Training in war has become so sustained, extensive, and normal that large military budgets and their allied technical efforts have come to be taken for granted.

Reeducation into peace depends on many conditions, among which exact information may play a predominant role. Such is the case in psychotherapy, where an attempt is made to face all aspects of our nature. Perhaps the development of uncertainty is due in great measure to the lack of proper information. Diplomatic secrecy, and the helplessness on the part of the rest of the population of exercising any judgment, not to speak of influencing their destiny, are perceived by people as an insult. A child feels similarly when parents make plans and decisions without notifying the child about it. This raises a very important question of the necessity on the part of large groups of people to participate in some way in the making of major decisions. Information must have purpose and direction, and be devoid of demagogy, otherwise it causes confusion and uncertainty. Since not everyone is capable or desirous of assuming responsibility, public servants are called to do so in the role of "opinion leaders." Such "opinion leaders" should be, in the words of Harry Stack Sullivan, "people who respect themselves for the serious care with which they sift facts from prejudice, and study the probable consequences or alternative course of action."[6]

SCIENCE AND SCIENTISTS

There is a perplexing problem connected with the role of the scientists in the project of world disarmament. On the one hand, their achievements have laid the basis for nuclear wars. On the other hand,

[5] Hegel, *The Philosophy of History*, p. 51.

[6] Harry Stack Sullivan, "Remobilization for Enduring Peace and Social Progress," *Psychiatry*, X (No. 3, 1947): 239-52.

they are key people for implementing and maintaining disarmament agreements.

It would be of little use to present here a clinical discussion of the little-understood nature and motivation of the creative process. No conclusive data are really available, apart from the fact that most human feelings appear in more intensified form among scientists.

In my experience, one of the basic motivations is the rebellion against limits to our power and, above all, limits to our life. The strongest motivation seems to be inacceptance of death and aspiration for immortality. Why does man use the acquired knowledge for destruction, when it is produced out of a striving against self-destruction? There is a seemingly paradoxical situation here. One type of immortality involves living in the memories of those who survive us. But what if no one survives? The scientific knowledge which we could utilize for our welfare also makes our extinction possible.

The recent advances in science and technology have changed the conditions of human existence. The discoveries of pure science, frequently made without any concern about their application, are the necessary conditions for technical advances. These in turn contribute to further advances in pure science. These two forms of science correspond to two aspects of human nature—spirit and matter—Psyche and Soma,[7] both indispensable for its existence.

This process of search for truth cannot be stopped. If reason is natural to men, one may hope that reason will reign over madness.

Scientists can cooperate in an attempt to maintain peace in the world, by finding a way of sharing responsibility in the decisions relating to the application of their discoveries. That is not an easy task. For, in my experience, scientists are people of great intensity of feelings. Thus, the tradition of their occupation partly leads to exaggerated secrecy and competitiveness. Scientists must have freedom of creativity. Efforts should be made to assure them the best conditions for their work. They must also, however, be encouraged to assume responsibility for international cooperation rather than envious competition. "The Free Man, we may observe, is not envious, but gladly recognizes what is great and exalted, and rejoices that it exists."[8]

[7] Louis de Broglie, *Savants et Decouvertes* (Paris, Editions Albin Michel, 1951), p. 377-82.

[8] Hegel, *The Philosophy of History*, p. 31.

SUMMARY

The success of a disarmament agreement depends upon trust among peoples. Mistrust and evasiveness in individuals are the outcome of fear, loneliness, threats to security, lack of love, humiliation, helplessness, and the feeling of uselessness. When a society generates such effects as common conditions of life, then evasiveness and its concomitant ways become widespread and even acceptable features of behavior.

Similarly, the need for, and hence receptivity to, "evasive" behavior and destructiveness can be mitigated. This occurs when conditions of living generate a widespread feeling of being needed and useful, and the allied senses of security, self-respect, and well-being.

Under such changed conditions, evasiveness and destructiveness would become unnecessary.

These comments suggest the worth of extended inquiry into the relation between individual and social behavior. Such inquiry and expanded knowledge would serve the implementation of disarmament and peaceful living.

REPORTS OF EVASION TEAMS

[Note: Three groups, of varied occupational composition, were organized in order to gauge the force of the inspection methods that were outlined in the draft of this report. Each of these evasion teams was given the Terms of Reference that follow. Revisions of the specifications in the Terms of Reference were made by the evasion teams, who found that the most promising evasion opportunities lay in the organization of secret armaments schemes during the early stages of disarmament agreements. Their reports are given below. These reports were most valuable for improving on earlier conceptions of appropriate systems of inspection for disarmament.—Editor.]

TERMS OF REFERENCE FOR EVASION TEAMS

1. The objective of the evasion team is to prepare a strategic plan, outlining—within a memorandum of fewer than ten pages—the main organizational and technical methods for attaining a military production objective in violation of a disarmament agreement, under the conditions given below.
2. There is an international disarmament agreement of all the governments of the world, which prohibits the production of all weapons of warfare—nuclear explosives and their delivery systems, as well as "conventional" weapons and biological warfare weapons. All such arms are to be destroyed.
3. The international agreement establishes an inspectorate with ample budgets to serve this function. The inspectorate includes people of the highest caliber and conducts its own research laboratories in all the fields of knowledge of interest to the inspectorate staff.
4. The inspectorate has unrestricted access to places and to people.
5. Citizens of all countries are obligated, under the international

agreement, to report evidence of violation of the disarmament agreement to the inspectorate.

6. A judicial and penal system is allied to the inspectorate, by which people found guilty of violating the disarmament agreement can be punished as felons.

7. The directorate of the movement for evasion of the disarmament agreement consists of senior military men, industrial executives, and one cabinet member. The evasion team is the planning group of the evasion effort.

8. The production objective of the evasion effort is the preparation of 200-400 intercontinental-type missiles (of an existing design) in state of readiness for use. This clandestine effort is desired in the conviction that the country is unsafe without this—either for international bargaining, or for carrying out a surprise military stroke.

9. Ample funds for the evasion effort can be obtained by diversion of government funds.

REPORT OF EVASION TEAM A: PROBLEMS OF CLANDESTINE PRODUCTION

The problem is to produce 200 to 400 atomic missiles secretly. While the production problems posed by this form the major subject of this report, it is believed that they cannot be divorced from certain significant political and strategic questions. For example: What is the objective of producing the missiles? If they are to be used against specific targets, they will have to be of high quality. If they are to be used for diplomatic bluff, then accuracy is of much less importance (dummies might be enough in some cases) and certain key production problems are eliminated.

If the missiles are usèd, what is the nature of the follow-up? It seems hardly feasible merely to launch a destructive attack, with much territory turned into a radioactive wasteland, without some sort of occupation or control over what is left. This would require certain conventional build-ups, in addition, with all the difficulties inherent in concealing large quantities of materiel. The examples of Israel and Germany are not relevant in this connection, since in Israel the fighting was mostly with light weapons and, in Germany, six years of full scale Nazi rearmament and the capture of Czechoslovakian materiel were needed before the war could be started.

There are also propaganda questions involved here. How can an attack be justified before the world? Some ideological preparation would be required here, in addition to that needed to secure the necessary staff for the project within the attacking country.

What opposition would such an attack have? If there are no fighters or other antiaircraft weapons, then a Piper Cub carrying an H-bomb could get through. If fighters *are* available, opportunities for disguising missile development are greatly enhanced, especially in connection with air frames. If "defense" missiles are permitted, the problem is even simpler; in fact, very little extra work would be needed to make offensive missiles since most of the larger defense weapons themselves carry nuclear warheads.

It should be realized that most of the problems described in the following analysis could be eliminated if a systematic policy of concealment were to be followed during the period of disarmament negotiations, or once an agreement is in clear prospect. Similarly, if missiles are ready and emplaced when the agreement is ratified, there is very little chance of discovery by such methods as aerial inspection, and perhaps even by "inspection by the people," if remote regions have been used. This does not apply to manufacture or assembly, however. Sudden bursts of activity, transport, or human movement in a remote area would excite suspicion and could probably be detected by aerial inspection. Aside from concealment by "floating inventory," industrial operations would probably have to be carried out in established industrial areas.

The warheads are the principal problem in parts production. Otherwise, the security problem is most important. Every one of the above additional steps would need more people working on the project, and so would complicate the task. It would not be desirable to have any leaks to the inspectorate since, even if parallel efforts are being carried out, the discovery of one would probably bring a vastly increased army of inspectors down on the offending country, thus increasing the difficulties of carrying out the other systems successfully, perhaps at a time when assembly is taking place and hiding parts is more difficult.

Security and Personnel

These questions are closely related. It is believed that in countries where a substantial part of the national economy has been depending on arms production there will be widespread economic dislocation, with unemployment rife among certain specialists unable to adjust to other occupations. Many of these specialists can undoubtedly be persuaded to take part in a clandestine effort on economic grounds. At the same time, and especially under conditions of free speech, it is possible that political groups might seek partisan advantage by means of charges of "treason" against the government which signed the disarmament agreement. Such efforts might be made by industrialists whose organizations have depended on war production and have had their existence threatened as a result of disarmament. It seems, therefore, that sufficient unemployed engineers, scientists, military men, skilled workers, and administrators would probably be available for the task. However, the scale of the production task itself, as well as the additional problems noted here, will need many such people, and the problem of maintaining secrecy will no doubt be crucial. Under these conditions, certain ideological currents could be utilized to support an evasion effort. Nationalist agitation, coupled with rearmament propaganda, could be useful to this end, especially in police states where popular cooperation with an inspectorate may be scanty unless disarmament is strongly backed by the government.

Financing

Sufficient funds are assumed to be diverted from the government, perhaps supplemented by the gifts of "patriotic" industrialists. The economic dislocations of disarmament will no doubt result in large public works and other "pump priming" expenditures, some of which will be rather loosely monitored.

Choice of Missile Type

Ballistic missiles are highly complex mechanisms and, depending on the nature of the defenses, their use would probably be best avoided, in favor of air-breathing missiles. Both types will be considered in the components analysis presented here.

The choice is also influenced by the nature of the aircraft industry. If "peaceful" spaceships are built, their plants will no doubt be closely controlled by the inspectorate. However, in missiles generally, much material is "scrapped" during production for one reason or other, and this is a rich mine of clandestine parts. The existence of a space rocket industry in any form complicates the arms control process and thus simplifies the task of evasion.

Treatment of the Inspectorate

Violence towards the inspectors will probably have to be avoided for fear of repercussions. There are many demoralizing ways of annoying, harassing, and hindering inspectors, depending upon their status in the country in which they are located. The inspectorate could also be kept busy with a continuous stream of false reports of clandestine activities. This saturation would have to be carefully planned to eliminate any suspicion of "planning." It goes without saying that every attempt should be made to place secret operatives inside the inspectorate, perhaps by means of "allied" nationals among the inspectors. Advance notice of visits and other information could thus be obtained.

Surplus Disposal

The destruction of armaments which would follow on a disarmament agreement would provide opportunities for faked surplus disposal and subsequent repurchase of the valuable parts by the clandestine organization. This would, in fact, be a great financial help to the organization, since it would save a great deal of money. At times, as is well known, whole weapon units such as bombsights, infrared scopes, etc., have been sold on Canal Street, in New York City, and in similar war-surplus centers.

Raw Materials

The supply of certain strategic raw materials might be controlled. In order to circumvent this, a company would have to establish itself as a bona fide user of the material concerned, if necessary in products where it might not pay. The cost difference could be made up by the organization. (On the other hand, the inspectorate might be skilled in discovering such devices.) In this case (and perhaps anyway) smuggling, etc., à la Rivlin would have to be resorted to.

Labor

It seems probable that the inspectorate will maintain a registry of all skilled scientists and key workers able to work on missile projects and allied tasks. Any address and job changes might have to be reported to the inspectorate; sudden concentrations of such personnel would excite suspicion. Wholesale fakery might have to be resorted to in such situations.

Production and Quality Control

This is a very complicated problem because each ballistic type missile contains up to 30,000 parts.[1] Assuming that the quality problem would be surmounted by producing three times the actual parts required and then inspecting and selecting the few parts meeting the specifications, this would mean keeping tabs on 30,000 x 400 x 3 or 36,000,000 parts. Even in assemblies, the situation is difficult. Assuming that only twice as many are made as are required for the 400 missiles and again selected by inspection, 10,000[2] x 400 x 2 or 8,000,000 assemblies are needed. The assemblies are perhaps more difficult to disguise than parts which can be labeled something else. All this is a major control task and would call for the keeping of records, no doubt on microfilm or even in more miniature fashion.

Scientific Product Problems

Structure. Some difficulty may be expected in assembly, since parts are hard to disguise. However, "peaceful" work on spaceships and "sports" aircraft may be used to hide some of the missile structural work. If fighters are still made, this problem is much simplified. However, since fighters are not much use against missiles, they would therefore most likely be discarded. There should be enough fighter planes in the world now for "police purposes" for many years to come. Otherwise, such methods as hiding the structure in the form of chemical tanks, mixers, etc., would have to be resorted to. Mathematical disguises might have to be used (e.g., fudge factors) to prevent identification of analytical methods that are used for designing. However, this might be difficult once transonic speeds were reached.

Guidance. No problem should be experienced with the electronic components. It should be possible to use any special miniaturized parts in industrial controls, and this immediately gives methods for faked scrap production and diversion to the clandestine effort, even without the paper work type of smuggling.

[1] *American Machinist,* February 24, 1958, p. 87.

[2] *Ibid.*

The use of ultra-accurate bearings, gyros, etc., could probably be avoided by using electronic guidance (Doppler correction, for example) to correct missile flight, especially if air-breathing weapons are used. If not, it should be possible to hide the necessary parts prior to disarmament inspection. Again, the impossibility of verifying past scrap would be most helpful. The inspectorate would probably check carefully into any intended uses for the "super-accurate" parts. The inspectors would probably not accept their use in commercial aircraft gyros. If, somehow, this could be assured, the company producing the instruments would possibly have to be reimbursed for the cost difference between conventional and accurate components.

Engine. There should be relatively little difficulty in the engine itself, since many of the "critical" parts can somehow be disguised as commercial jet or gas turbine parts. If solid fuels are used, of course, or even ram jets, the engine becomes very simple in design and might be made almost in any reasonably well-equipped welding job shop able to handle aluminum and stainless steel.

Fuel. Most liquid fuels are common materials and no effective control would be possible. The sole exception is to be found in the "exotic" group, e.g., the boranes, trimethyl aluminum, etc., and these will probably now be de-emphasized anyway in favor of solid rocket fuels (some of which may also contain boranes, however). The latter are also made of fairly common materials, but the final processing of the fuel has to be carried out with considerable precautions against explosions. This type of operation, similar to a shell-filling plant, may present some difficulty, but could perhaps be decentralized in many plants able to compound and mix chemicals, especially premixed plastic materials, rubber, etc.

The plants now doing this kind of work are quite elaborate, large complexes, and this would have to be revised, if necessary, by developing small mixing units. Undoubtedly severe controls would be exercised over the existing facilities, perhaps including the dismantling of most of them.

Warheads. Warheads are the most crucial component problem, not only because their clandestine production is difficult, but also because fewer design alternatives exist for them than for their method of delivery. In this section nuclear warheads will be considered.

The following analysis attempts to deal both with the problem of concealment prior to the agreement and with subsequent pilferage. The results give the accuracy with which past production will have to be estimated in order to prevent concealment (cf. the paper by Derman and Klein) and with which future production has to be supervised to prevent accumulations after the agreement.

Once the agreement is signed, all warheads would probably have to be contributed to a common pool for disposal or conversion under sufficiently wide international control to render pilferage extremely difficult. The first problem is what delivery quota to set for each possessor of atomic weapons.

The characteristics of reactors and their known life make estimates of past plutonium (Pu-239) production much easier than the discovery of past production of U-235, which is a natural isotope of uranium and thus a product of the mining and refining process. If there are 10,000 warheads, each of 50 kg. U-235, 50.10^4 kg. U-235 are needed. U-235 is about 1 percent of U-238, the natural material, and the average uranium ore grade in the United States is 0.25 percent U_3O_8. If the warheads are all of U-235, therefore, a total of

$$\frac{50 \times 10^4}{.01 \times .0025} = 20.10^9 \text{ kg. or } 20.10^6$$

metric tons of ore would be needed to produce this.

Suppose 400 warheads have been concealed. They would require

$$\frac{50 \times 400}{.01 \times .0025} = 8.10^8 \text{ kg. ore.}$$

To prevent concealment, therefore, the assessment of past production would have to be $8.10^8/2.10^8$ or 4 percent accurate. This is likely to be workable in the chemical process industries, in which inputs and outputs can be more objectively measured and in which the process is likely to have fewer major short-run changes (cf. the findings of Derman and Klein in mechanical manufacture). Of course, if only 100 or 200 warheads are concealed, the control would have to be 1 and 2 percent accurate, respectively. However, an analysis of this type might possibly lead to the setting of rather high delivery quotas and their enforcement as the price of other countries' acceding to the agreement.

The problem of stealing from sanctioned peacetime uranium production is much more complicated, unless the pilfering process is prolonged over many years. The uranium-processing plants are such large aggregations that it would be extremely difficult to conceal them. The removal of fissionable material would, therefore, have to be done under the eye of the inspectorate. The future peacetime uranium requirements of the United States have been estimated at up to 30,000 tons a year by 1980.[3] If the warheads are to be accumulated within two years, 200 must be acquired each year, requiring $200 \times 50/.01$ or 1,000 metric tons (1,100 S.T.) of uranium. This would need an output control 3.7 percent accurate, which is probably feasible in a closely monitored chemical plant. The clandestine organization might, of course, be able to divert some of the material stream, using such devices as faked inputs to mass flow meters (by wire taps, for instance). But such methods would have to be carefully employed with a view to the whole process. This in turn might require a whole clandestine computer. Besides, only the end product is of any value.

The possibility of securing the warheads, therefore, rests on the exact nature of the production level variance, as suggested by Derman and Klein, applied to the production of uranium. Similarly, it is assumed that both plutonium plants and uranium refiners, as well as thermonuclear reactors, would be sufficiently closely monitored to prevent pilferage *at the rate required.* Of course, if the lead time for the project is extended, the problem of acquisition is technically simplified, but chances of discovery due to personnel failures here or elsewhere in the whole operation are correspondingly heightened. The probability of using a combination of pre- and post-agreement acquisition is also to be considered and would probably prove highly effective.[4]

Chemical-Bacteriological Warfare. Professor Groupé's comments on this lead one to the conclusion that the production, testing, and delivery of large quantities of such agents are not easily carried out in a clandestine manner. However, might not slow methods of delivery suffice? Let it be assumed that agents of the enemy infect the water supply of most of the large population centers, or start an epidemic in another way. The attacker, on hearing news of the actual outbreak of the plague, immediately bars all travel to the afflicted country, as would, no doubt, most other countries. With crocodile tears, a "research effort"

[3] K. Cohen, "Charting a Course for Nuclear Power Development," *Nucleonics,* February, 1958, p. 66.

[4] If acquisition of warheads takes a long time, changes in delivery techniques in the meantime might simplify (or complicate) the whole operation beyond the present "state of the art."

is started even in the attacking country, but principally with a view to having enough antidote on hand in case the disease should happen to get back. With the victim's population decimated or debilitated, political and economic concessions can then be demanded, again perhaps in company with other countries, all of whom might have scores to settle.

This method would, of course, have to use existing biological warfare agents. However, there are Edgemoor Arsenals and Dugway Proving Grounds in many countries. The chief reason for this, as Groupé points out, is the fact that large-scale poison production, and especially testing, tends to be hard to conceal. Again this is a matter for pre-agreement concealment. Since the technical feasibility of determining prior production is limited, this is believed to represent a fruitful area for clandestine evasion efforts.

CONCLUSION

The organization of a clandestine armament effort must be designed for maximum probability of evading the inspectorate, which could use 100 percent inspection at some points and sampling methods elsewhere.

Beyond this, however, the problem is one of security—within the inspectorate, the arming organization, and the "inspectors among the people." With respect to the first, the organization will endeavor to penetrate the inspectorate.[5]

Within the arming organization, the security problem is most acute. First, it is clear that the production of 200 to 400 modern missiles under clandestine conditions would require a substantial and highly skilled work force. Economic dislocations would facilitate the accumulation of sufficient numbers of effectively motivated malcontents. At present, economic pressure would probably be sufficient to recruit those operatives who have to be told what is going on. This task would become progressively more difficult as working on instruments of death ceased to be regarded as a fine exercise for the scientific mind or manual skill and was instead looked upon as a grave offense against society. As long as nationalist and similar sentiments can be used to rationalize clandestine arms production, or moral questions on the subject can be disre-

[5] Immunity of the inspectorate from local pressures is therefore essential. J. Edgar Hoover has recognized such immunity as a principal advantage of the FBI compared with local law enforcement. The inspectorate might, therefore, have to be a strongly mobile force, supplementing the various field officers.

garded entirely, it would appear from the foregoing that chances for a successful clandestine arming operation are quite favorable, even in the presence of a very large inspectorate.

Conversely, the more widespread sentiment against arms production becomes, the more effective help will be given the inspectorate by "the people," *provided* that the security of informers can be guaranteed. The legal and civil rights implications of this are considered to be beyond the scope of this paper. Paradoxically, it seems that a politically divided population is a good guarantee against a clandestine effort of the kind described here. (Cf. the Hirtenberg-St. Gotthard incident described in the paper by Gumbel.) The old patriotic motto might have to be revised to read "United we blow up, divided we (i.e., the human race) stay alive."

REPORT OF EVASION TEAM B: PRE-INSPECTION PREPARATION

Problem and Approach

This report is submitted in response to a proposal calling for the development of an evasion effort to circumvent a proposed disarmament inspection plan. Thus, it has been supposed that the probability and feasibility of various means of evasion has an important bearing on the adequacy of the design of an armament inspection system. Since the proposed plan of inspection has been sketched out in only essential detail, the possibilities of evasion dealt with here will be correspondingly simplified, both as to assumed circumstances and illustrative means of accomplishment. The entirely hypothetical nature of the problem and the limitations of knowledge available on critical technical and political assumptions argue against an attempt to deal with other than the most obvious possibilities.

Furthermore, it is the sober reflection of the persons who attempted to carry out this assignment that the conditions assumed in the instructions tend to dispose of some of the most serious opportunities for evasion while focusing attention on less likely alternatives. Specifically, a most plausible and dangerous threat to the disarmament plan is contained in falsification of both the quality and quantity of the weapons inventory available to the countries immediately prior to the adoption of the plan. The possibility of ex post facto *development* and/or *production* of complex weapons systems capable of a significant surprise military stroke seems somewhat more remote. Accordingly, the report which follows places major emphasis on the crucial problem of evasion by inventory falsification, and only after considering this takes up the more difficult case of evasion by clandestine production and deployment of weapons after the effective date of an inspection plan. Finally, an alternative type of disarmament agreement, which is less vulnerable to misplaced confidence and successful evasion, will be outlined.

Inventory Falsification

Any assumption that the United States and Russia can move from the present position of armed hostility and suspicion to a situation of accomplished disarmament must anticipate a transitional period during which the pros and cons of each intermediate step are elaborately considered and debated. This, therefore, would provide both sides with every opportunity to direct both the extent and pace of the disarmament movement in such a manner as to permit the optimization of residual retaliatory power. Bearing in mind that various schemes calling for aerial inspection and cessation of nuclear weapons testing have been under discussion for over a year without tangible progress, it seems reasonable to assume that the full transition from the present to a condition of accomplished complete disarmament would take many years. This being so, it would be very possible and therefore likely for both countries deliberately to develop a variety of weapons explicitly conceived to answer the security requirements of a transitional and post-inspection plan period.

New Weapons

A different threat is contained in the likelihood envisioned above of explicit government preparation for maintenance of armed capacity during an interval of disarmed inspection. It will be seen that the criteria for an ideal "inspection peace" weapon are not seriously removed from current technological capability. Such an ideal weapon would:

1. Be capable of maintaining a readiness state for approximately five years without servicing, and be capable of remote testing for readiness and modular servicing when defective;
2. Be capable of remote firing by appropriate sonic, thermal, or radio signal, with the destination either preset or determined while in flight, and the whole missile capable of detonation while in flight if called for;

3. Finally, be capable of establishing its own point of origin, and of integrating this information with the preset or in-flight destination instructions, so that the need for precise location of the weapon or even precise knowledge of its location might be eliminated.

Given such a weapon in the form of an intercontinental ballistic missile armed with a nuclear warhead, the whole encased hermetically in an appropriate titanium capsule, it would be possible during the transitional negotiating period for this country to deposit an enormous store of these missiles at the bottom of the sea, in the wastes of the polar extremes, in the remote deserts and jungles, and even perhaps within neutral or "enemy" territory itself. Certainly, the delivery of these missiles to appropriate location by egg-laying submarines, or by merchant vessels equipped to carry them suspended under the hull, could be accomplished without knowledge of the crews. On appropriate remote signal, the missiles would rise to the surface, determine their own location, aim, fire, respond to predestination, or be given in-flight revised destination, and finally be capable of in-flight self-destruction, if countermanded by appropriate secret signal.

Manpower Implications

For a country intending to provide against unforeseen elaborations of inspection activity of unknown effectiveness, the development of such a weapon would have the highly attractive consequence of locating all the costly and personnel consuming development, testing, production, and deployment activity during the pre-inspection period when, with foresight and cunning, appropriate falsified records could be set up to effectively conceal from post-inspection discovery the true nature, duration, extent, and potential of the latently emplaced weapons system. Thereby, literally a handful of men, needed chiefly to oversee the maintenance of the hidden firing equipment (such as a small radio transmitter) and to properly control the rationality of the firing decision, might constitute a formidable military establishment with the capacity to annihilate many continents. The weapons would, of course, be capable of conspicuous demonstration, should negotiation by threat be more appropriate than attack by surprise. And it would not be unthinkable that many extra hundreds of such weapons would be emplaced around the world to allow for malfunction, or for the giving away of a part of the emplacement to the inspection team as a show of compliance in case of partial discovery of the undertaking. Thereby, the post-inspection discovery of these weapons systems could be made to provide an accounting "mask" for a still remaining lethal number of operational missiles and their small remote firing facilities.

Other Weapons

Perhaps more fantastic, and considerably more demanding on technology, would be the proposal that the inventory of explicitly contrived weapons designed for the inspection period should be continuously orbiting around the earth with the capacity to be directed into a military path at any time. Perhaps even more remote is the suggestion that the inventory of missiles should be emplaced on the moon. These, however, are all details of minor importance to the central point, which is that the advance preparation for the consummated disarmament period would cover such a protracted interval of time as to permit many elaborate alternate weapons systems. Since all envisioned development and production activity related to these special weapons systems would be completed prior to the point at which such activity became illegal, the management of the project and the training of personnel could proceed under the control and protective cloak of the military establishment, relying on the great complexity and diversity of modern weapons systems to provide an adequate smoke screen to prevent contemporaneous discovery, and further relying on advanced preparation and foresight to sufficiently obliterate evidence that ex post facto inspection would fail to uncover any trail. As a last resort—and this was pointed out above—a certain quantity of such weapons systems might be deliberately given away in order to divert a too-pressing inspection effort.

Development and Production

Turning now to the case in which the further development of weapons systems was forbidden—both as to warhead and means of delivery—before the technical problems implied in the "ideal" weapons system had been solved, and assuming further that the destruction of all existing weapons has been ordered, the question must be faced: Given the strong possibility that a sizable number of powerful warheads (nuclear, poison gas, germ warfare, etc.) probably could be withheld from destruction and cached at places known only to a small number of individuals, how could a means of delivery for these warheads be devised which would not pose impossible problems for concealment with regard to production and training activity? For example, assuming that at the time of the total inspection ballistic missiles are both too large in size and too few in number to permit any real possibility of withholding an adequate inventory of these delivery systems, one then can scarcely imagine concealing the new production of such weapons during a period of active inspection, nor even conceive of the training of personnel in the maintenance and firing of these missiles under such conditions.

Delivery Systems

Accordingly, while the presumed existence of a great number of grapefruit-sized atomic warheads may reasonably be said to provide an opportunity for holding out a lethal destructive potential, the means of delivery of these warheads is the more critical problem, and its solution can be imagined along two quite different routes:

1. By open manufacture of dual purpose components, innocent by themselves and with a legitimate nonmilitary use, which, in a very brief period of time, could be assembled into an operational weapons system capable of delivering the atomic warheads and penetrating any enemy defenses.
2. By a fifth column activity which secretly transports the destructive warheads to the enemy country many time periods in advance of the readiness point, which further supposes an elaborate secret communication system to guard, maintain and, when necessary, fire the emplaced weapons.

Illustrative Plan

Of the two foregoing approaches, the former is more economical with respect to the number of persons who must be informed of the secret plan for evasion of the inspection effort, and its operational requirements are considerably more familiar and therefore believable. For example, we can imagine a plan which intends to use the civilian air transport systems as a means for the delivery of the atomic warheads. Let us assume that in the interests of flight safety the Civil Aeronautics Board promotes the development and installation of automatic pilots with capability for taking off, flying, and landing aircraft, employing an inertial guidance system immune to jamming but also potentially sensitive to discovery of other flying objects and evasion actions, while at the same time constantly under the control of ground signals from a suitably occult frequency.

Let us further assume that the Civil Aeronautics Board, in the interests of increasing the productivity of the civil air transport operation, promotes the use of pod type luggage carriers to be fastened under the belly of the planes, similar to the type which several of the airlines already have employed. It is not then fantastic to imagine that several hundred pods are produced, in which atomic warheads are secretly placed, and deployed at appropriate remote air fields to which all civilian aircraft of appropriate type are ordered on an emergency signal, the pods then being affixed and the planes fueled and flown to target destinations by remote control. Obviously, more elaborate systems requiring the remote aiming and dropping of the bombs and the return of the aircraft to their point of origin could be developed, the necessary guidance and control equipment being contained in the pods, but such activity would greatly increase the strain on concealment during production.

The central management of this entire evasion project during the post-inspection period when all weapons stocks have presumably been destroyed and all military establishments reduced might well be located in the Civil Aeronautics authority itself, because it would have control over the design of the necessary systems, the operation and deployment of aircraft, the training of crews, and so on. Since none of the produced components as such need be concealed, the only personnel with a secret function would be those charged with the concealment of the withheld inventory of warheads, those concerned with the diversion of pods to warhead assignments and their emplacement and maintenance at appropriate airfields, and the over-all management group and its communication system. Conceivably, it might become necessary to include appropriate airlines executives and certain public officials outside the Civil Aeronautics authority in the scheme, in case their objections to required technical modifications of automatic pilot and related equipment began to seriously compromise the evasion effort.[1]

[1] It is even possible that a political party (perhaps one of those now existing) might identify itself openly and aggressively during this transition period with a position advocating rejection of the inspection plan and reliance on armed preparedness. At each stage of gradual increase in the sovereignty of the international organization, the existence of such a vocal political party contesting the very issue of human rights on which it relied for its own survival would provide a most troublesome and difficult problem for both the international organization and the

By and large, however, a more difficult problem would arise in providing the central management of the evasion effort with an adequate intelligence organization to describe what was going on in the enemy country, what was going on within the inspection organization and what was known to it, so that impending threats from the enemy country and the continuing danger of discovery of the clandestine activities by the inspectorate might be effectively acted upon by the central management group.

In summary, then, it is obvious that even while begging the question as to the design and development of a delivery system, and as to the availability of a secret stock of warheads, the manpower required merely to assemble, deploy, maintain and, above all, decide to use and fire this "home made" clandestine weapon poses a formidable problem in concealment. A moment of reflection on the task of recruiting the needed skills and locating them in the required places, while not betraying to an alert informer by cumulative minor disclosure the whole existence of the plot, is enough to suggest that the flaws in the inspection operation would have to be grotesque to give this sort of activity much chance for success.

Fifth-Column Delivery Plan

Assuming now the situation in which either the activities of the inspection group or the general political circumstances frustrate the effective penetration and exploitation of a government organization such as the Civil Aeronautics Board, it then might be necessary for those who had withheld an inventory of atomic or other lethal warheads to devise a delivery system entirely devoid of modern technical devices. Furthermore, it is probably consistent to assume that, in a situation where effective exploitation of top government officials is impossible, the group in possession of these warheads probably would have many of the characteristics of a fanatic movement. These characteristics would be indispensable to what is now proposed, as we must assume that this fanatic group, without any social sanction, will attempt to obliterate millions of people in the "enemy" country. Such a motivation is essentially criminal in character, and might succeed only if criminal types of persons were available to carry it out. Such persons normally are not present in our military establishment in large number, and it therefore is suggested that

federal government. Such a party could maintain among the public a will to resist, a focus for their efforts, and have ready a plan for the marshaling of all resources in event of a need for concerted military action.

the persons who would withhold the nuclear warheads and the persons who later would use them would be two different generations and kinds of fanatics, separated in time by perhaps five years, during which the character of the evasion movement deteriorated from the military to the criminal level. It is likely that there now exist, or soon will exist, suitcase-sized weapons in the kiloton range. There are atomic cannons of less than twelve-inch bore. Thermonuclear weapons have recently been reduced in size to the point where fighter planes may carry them. Future developments may well lead to a megaton weapon which would be suitcase-portable. Other illustrative weapons which might be suited to fifth-column activity are mentioned in the appendix that follows.

It has been observed in the inspection plan report that successful clandestine revolutionary activity requires popular approval, but here we have taken up the case of clandestine criminal activity, directed against the government, the inspectorate, and the "enemy" all at the same time. This, therefore, is the extreme case that the report assumes has no chance of success, and with this estimate we concur because it appears that a very large number of "agents" would be required to supervise, emplace, guard, and operate the weapons, and all governmental groups—especially those in the "enemy" country—would be in active opposition. If we try to meet these objections and bring such an activity under the assumed direction of our present Central Intelligence Agency, we then must further note the essential unreliability of the resulting military capacity except as a retaliatory machinery of "last resort." As a demonstration or surprise attack system for negotiation or aggression, the fanatic fifth-column approach would have serious shortcomings, due to problems associated with "setting off" the weapons in a dependable manner.

Third Party Evasion

A closely related problem is contained in the case where citizens of a nation not having modern weapons are assumed to steal or otherwise obtain a small supply of warheads and some means of delivery (aircraft, ship, etc.). While stocks of warheads and delivery systems presumably are closely guarded, the history of revolution and conflict within and among small nations is starred with many examples in which stolen or secretly procured weapons play a major role. Perhaps at some point Russia or this country may deliberately arm a small nation, placing the resulting inventory of military potential to some degree beyond all effective control and accounting. In any case, the explosion of a nuclear weapon of uncertain origin in the wrong place at the wrong time could set off a war involving the whole world, and the possibility that stocks of such weapons have already become so widely dispersed as to be unaccountable per se must be given sober consideration. Indeed, one might wonder what would result from the announcement by a major belligerent in the pre-inspection period that quantities of its atomic weapons had been stolen. Such a claim would gravely undermine confidence in the feasibility of any inspection plan.

Alternative Disarmament Agreement

The preceding analysis suggests that, although effective development or even production of large scale weapons and delivery systems might be virtually impossible *after* the full inspection program begins, it is equally unlikely that all prior existing military capability could be eliminated by the inspectorate. If the existing accumulation of inventories of nuclear weapons and the likely design of specific "inspection period" weapons makes successful evasion of an inventory declaration type agreement a foregone conclusion, does it make sense to try to achieve any agreement at all? We think it does, because any agreement looking toward limitation on future weapons developments and production is a highly desirable achievement in and of itself. Its adoption and subsequent application would constitute a revolutionary step in breaking down barriers among countries. As countries open themselves to each other, mutual understanding would grow and fear-breeding suspicion would diminish. The creation of even a small measure of international allegiance among people would be an achievement of immeasurable importance.

To be sure, hidden away there would still be the threat and the potential of mutual nuclear destruction. However, if the agreement succeeded in preventing the continued development and production of new weapons, it would relieve the countries of the world of the burden of supporting the spiralling weapons race now springing from fast-breaking advances in science and technology which open apparently limitless possibilities. If military technology were frozen as of today, the military and political leaders of different countries would know pretty well with what weapons a war would be fought, and could plan for their country's security consistent with such knowledge. Everyone would, we think, breathe a good deal more easily if things were to be stabilized, even though it were a second-best kind of stability, embodying the real possibility of mutual destruction with hidden nuclear arms.

The foregoing, however, suggests a modified type of disarmament agreement. Why not accept the fact that the inventory of existing stocks cannot be checked, and that mutual destruction capabilities—sometimes called mutual deterrence capabilities—will continue to exist in the United States and the USSR, no matter what agreement is signed? Why make it necessary for either country to evade the agreement to keep such retaliatory power (as cannot be prevented in any case)? Instead, sanction its existence.

Let the disarmament agreement be concerned wholly with the effective prevention of *further* weapons development, production, and accumulation anywhere in the world. The prize to be won by such a modified agreement would be the stabilization of the East-West military power struggle, and the elimination of the great threat that, before too long, stocks of nuclear weapons will be built up in countries of the world other than the three that now possess them. Furthermore, if acted on promptly, such an agreement might circumvent the inevitable development of ultimate weapons of a type which are explicitly designed to be uninspectable, and which therefore would doom the world to eternal anxiety and hatred.

Appendix: Possible Fifth Column Weapons

1. Germ warfare or psychologically debilitating agents used as warheads of missiles or as fifth-column weapons in lieu of nuclear armament.

2. Crop or animal poisoning of a cumulative and permanent type to create mass starvation, delivered by ecological chain reaction (poisoning of mice, bees, plants, etc.) or by aerial or wind dispersion.

3. Radioactive invisible paint to be fifth-column-applied by micro aerosols to movie seats, subway seats, toilets, etc., to genetically deform and depopulate the enemy. Desired action: slow enough not to be discovered until too late. Alternate: radioactive strontium, etc. in public water supplies, cigarettes, gum, liquor, food, etc.

4. Narcotic addiction established by latent inclusion in aspirin tablets, popular candy, liquor, etc. with subsequent disclosure. Narcotic should be a new synthetic unknown to enemy or a natural substance unavailable in large quantity.

5. Drug causing sterility after several exposures—tasteless, odorless, etc.—included in common pills, food items, etc., to bring about depopulation. Better yet: Include this in an infrequently used food product to defy detection.

6. Insect or rodent invasion of ecological chain reaction type to upset crop balance, or spread rabies, bubonic plague, etc.

7. Campaign of incendiary white phosphorous letters which burn when completely dry to destroy contents of mail boxes, post offices, airplanes, mail cars, etc., and disrupt communications. Letters cannot be identified as dangerous except by opening.

8. Corrosive lubricating oil to destroy power generators, turbine, locomotives, automobiles, machinery, etc. Two reagents used in separate batches of oil, so that after "priming" exposure, application of oil containing second chemical causes precipitous deterioration, but no evidence will appear until second chemical is added, etc. A year might be devoted to "priming" all oil uses, followed by a three-month idle period, then by the trigger dose. Before damage could be arrested, the country would have to shut down either for want of clean oil or for want of operative machinery. The oil industry would be the first to be "triggered."

REPORT OF EVASION TEAM C: EVASION BY A SECOND-RANK POWER [1]

Conditions of Disarmament

The practicability of evading a disarmament agreement backed by inspection, in the view of this group, depends more upon the nature and sanctions of the agreement than upon the form of inspection. The terms of reference that the group was invited to consider postulate a technically competent inspectorate, to which people everywhere would be obliged by law to report anything apparently tending to contravene the disarmament agreement. In our view, this begs a primary question: What ultimate power of enforcement would such an inspectorate, or the international organization for which it would act, be assumed to possess?

We have considered the possibility that disarmament might be backed by some overwhelming assembly of ultimate weapons. This could, at least in name, be an international police force. It could be,

[1] This report on possibilities for evasion by "second-rank" powers was prepared by a group in Great Britain, including a physicist, two engineers, and two economic and political journalists.

and perhaps effectively would be, in any case, the ultimate military force of the two existing superpowers, the USA and the USSR. We do not consider such a possibility more remote than that of any complete disarmament agreement in itself, which in any case would have to abrogate national sovereignty and impose overriding laws upon existing national laws and loyalties. Indeed, we lean towards the opinion that the only practical possibility of any significant agreement over full disarmament in the near future may lie in the duopoly of ultimate military power shared by the USA and the USSR, and their possible unity of interest, in spite of bitter mutual distrust, in denying all other aspirants the power to wage world war. These are the only two nations whose agreement is effectively required for disarmament: if they could ever reach some horse-trading agreement, they could readily impose that agreement upon all other nations, while their military power remains overwhelming—whether or not it might purport to be used, vis-à-vis all other nations, in the name of some international organization.

If a disarmament agreement were backed by some such assemblage of military force, we think evasion would lose all conceivable political meaning for other nations. No national force organized in clandestine conditions could practically be used, either as a fact or as a threat in international bargaining, if action would bring down upon it immediate and automatic attack from a force fully equipped, strategically deployed, and constantly alert to carry out punitive action. Evasion of a disarmament agreement could have political meaning for use against other nations either wholly disarmed or at most possessing what secret force they too might have organized; the risks could be acceptable. But the idea of organizing a force in secret that would, moreover, have to withstand a punitive force armed and equipped under none of the disadvantages of working in secret seems to us transparently hopeless: we cannot conceive of any practical political group's considering it worth while.

Disarmament backed with such military sanctions, therefore—and as a group we consider this the kind least unlikely to be achieved—would write off evasion for any except the two superpowers. Moreover, if the military backing for an agreement were sufficiently centralized and organized for automatic action immediately violation was discovered, the political practicability of evasion even for either of these two could be immensely reduced.

Disarmament backed by such force is not, however, generally admitted to be under discussion in current international negotiations. Nor does it seem to be the kind postulated in the Terms of Reference submitted to us, which set down that under international agreement all nuclear, major conventional, and biological warfare weapons "are to be destroyed." We have, therefore, considered the possibility of evasion of a disarmament agreement backed by no such sanction, leaving undefined the kind of pressure that a disarmament inspectorate lacking punitive power could be assumed to bring upon breakers of the peace. (The Terms of Reference assume that "people found guilty of violating the disarmament agreement can be punished as felons," which clearly deals with discovery of the evasion arrangements before these were put into force. Once the clandestine force was put into action, however, the felons would be effectively concealed in the nation concerned; "punishment" of a different order would be required.) In particular, we have considered the possibility of evasion by countries other than the two superpowers.

Evasion by Second-Rank Powers

We believe that "the preparation of 200-400 intercontinental-type ballistic missiles" under clandestine conditions in countries of the size and present industrial capabilities of, say, Britain or Western Germany would be impossible. Whether or not the superpowers yet have "existing designs" of such missiles, these other powers have not. Nor have the second-rank powers yet gained sufficient experience or competence in designing or building such missiles as they are developing (which, owing to geographical location, need not be intercontinental) to go into production, even openly, without a large continuing development and testing effort. We do not believe that such development or testing could be concealed from an inspectorate technically qualified to know what it was looking for. Nor do we believe that production that makes such widespread and searching demands upon the precision-engineering capacity of countries of this order could successfully be organized in secret.

We doubt, moreover, whether it would be practicable to abstract sufficient quantities of fissile material for nuclear warheads from current production of fissile material in nuclear reactors, or processing plants, or conceivably from experimentation with controlled fusion reactions, provided that a technically competent inspectorate was constantly on watch for such clandestine withdrawals from current output. What we know of nuclear engineering suggests that the critical conditions of operation, the health hazards, the extremely detailed programs necessary for changing location of fuel elements, etc., and for control of the build-up of waste products, make for most precise accounting indeed in the very area where the evasion group would need the accounting to be systematically falsified. Technically competent inspectors with full access to the operating records of nuclear plants, backed with the ability and knowledge from comparable operations elsewhere to carry out various forms of cross-check, could in our opinion detect such unaccounted-for withdrawals from the current production (or by-production) of fissile materials.

We have assumed that the inspectorate would in fact be very largely recruited from technicians of every kind now engaged in the production, research, and development of weapons of all kinds, and would have the service of scientists of the highest rank, completely aware of the state of actual and potential development of military science up to the moment of agreement to disarm. These technicians, we feel, would be competent to keep watch upon areas of activity where similar development would possibly continue for peaceful purposes—e.g., rocket development, supersonic flight, controlled fusion (which could for example be used for the production of large quantities of fissile materials), nuclear marine propulsion, heavy water, etc. We do not feel that research, in spite of the fact that at any time it will contain a vast number of projects that few people will be qualified to recognize, offers a particularly profitable ground for evasion, particularly on the large scale immediately under consideration. It might be utilized to refine technical points of design—guidance systems, for example, could be improved within a general program of instrument development. It could not be used to mask production or ordering of equipment on anything like the scale envisaged.

Moreover, disarmament would automatically outlaw the concept of national "military security" which at present, with varying degrees of effectiveness, shrouds the activities of some scientists from others in the same field. We doubt whether it would be possible to build up any alternative concepts of commercial or industrial security "in the national interest" that could effectively inhibit the fairly constant contact and broad awareness of what other individuals in the same field are doing that, even under military security, still exists in scientific affairs. Every kind of political and philosophical opinion, of course, is to be found among scientists, but we feel that the very widely distributed leavening of personalities who might be expected to react violently against anything that they might suspect to constitute evasion of a disarmament agreement would make this field a risky one for organizers of an evasion effort to operate in, on any large scale.

Production is one thing: the hiding of some of a country's existing stock of weapons or nuclear explosive is another. We believe that it would be difficult, but not impracticable, to hide, and to expunge from records existing at the time when a disarmament agreement came to be signed, some small percentage of a country's stock of ultimate weapons. We are not aware of the way in which such records are maintained in any country's defense organization, or of the numbers of people likely to have access to them. If some marginal falsification of records had to be carried through all their ramifications in a short period when disarmament became imminent, it would be difficult and dangerous, though by no means impossible. Effective disarmament backed by the legal obligations set down in the terms of reference, we have assumed throughout, would automatically abrogate all laws of official secrecy pertaining to government employees' knowledge of facts that might affect disarmament. Short-term falsification of records, therefore, would be endangered by the memories of everyone who had ever had access to the relevant record before they were changed, but who was not privy to the evasion effort. It could be, of course, that systematic under-recording of production and stocks was already the practice of the responsible authorities, for one reason or another. This would obviate the dangers of the short-term falsification, though knowledge that something of the sort was usually going on might be more broadly diffused among government officials and hence available to the inspectorate.

The possibilities of hiding away a sizable margin of weapons and fissile materials from stock depend, obviously, upon the size of the stock any nation possesses. This again, in our view, would limit anything on the scale laid down in the terms of reference to the two superpowers. We doubt whether any other country has at present enough weapons or enough nuclear explosive to be able to hide away tens, let alone hundreds, of nuclear weapons.

"Small-Scale" Evasion

Evasion on that scale, we therefore consider, would not be worth while attempting in powers of the second rank, particularly those with strongly developed democratic processes. But we do not think this precludes less demanding and ambitious evasion. We understand that nuclear devices of quite small dimensions can now be made, of destructive powers that can be considered "small" only in terms of today's megaton weapons. We think it probable that a practicable number of weapons of this size, if they were already being manufactured in quantity, would probably be hidden away with a reasonable chance of escaping detection in such countries, and possible, if this were not done, that enough nuclear explosive could be hidden away from existing stocks to enable a small number of such weapons to be manufactured in clandestine conditions.

Once stored, we think delivery of these nuclear weapons would be practicable, by merchant ship, civil aircraft, or diplomatic bag. Most simple, perhaps, would be delivery of such weapons hidden in exports of perfectly genuine equipment. The kind of weapon "that can go in a briefcase" could certainly go in, say, the main casting of even a small item of capital equipment of the kind that in conditions of disarmament would enter into East-West trade, for example, much more widely even than it does today. Plutonium does not emit gamma radiation, and can readily be completely shielded. Nor would removal of the nuclear device at the destination, placing, and fitting such a weapon to go off present insuperable difficulties; it would need only, say, two or three technicians, among much larger teams than this who constantly visit foreign industrial locations for the assembly on site and running in of complex equipment.

A particular advantage, for the organizers of evasion, of such weapons and procedure would be that the numbers who would need to be concerned in the project could be greatly reduced—in contrast, for example, to the very large-scale and hardly concealable coordination of many groups and individuals required in the industrial effort of manufacturing or even of launching, ballistic missiles. (The chances of success in evasion would clearly become rapidly attenuated as the number of people and organizations that had to be drawn upon, even unknowingly, increased.)

Evasion on this scale—a small number of small weapons which might be delivered as the occasion came in "custom-built" concealments, though these might possibly go into perfectly standard machines assembled and supplied quite innocently—would require only a very few persons to be fully "in the know." Access to some engineering capacity, to some exporters of equipment, and to a few technically trained and devoted workers would be the nucleus of such an operation; all of this "evasion capacity," over the years of concealment, would of course operate perfectly genuinely as what it purported to be. The experience in espionage that most governments possess could, we think, reasonably be counted upon to overlay such organization with the refinements of "cover plans" and the like to have a fair chance of escaping detection even by an equally expert inspectorate.

Circumstances Surrounding Evasion

In some ways, however, evasion would be markedly more hazardous than normal espionage. Countries accept the fact that other countries practice espionage; they are concerned to frustrate its operations, not to arraign it. A disarmament inspectorate discovering that disarmament was being evaded would be concerned to publish the guilt of nationals of a country, even if these were naturally completely disowned by the government concerned. Whether any "punishment" or sanctions could be devised against a country in which evasion was shown to have taken place, even though no use had been made of the weapons, would depend upon the nature of the disarmament agreement: but clearly discovery of evasion, even if immediately disavowed, would be likely to have severe political consequences internally for any government in power. Moreover, we have been struck by some of the peculiar circumstances that would seem to surround the conduct of evasion as a backing of national power in a world which at least purported to be completely disarmed. Until the fact of armed strength were disclosed—and thus the "crime" of evasion admitted—this strength would neither deter any aggressor nor add any weight to the nation's bargaining power. It could hardly be used, therefore, except in a direct attack or at any rate in a demonstration attack calling for surrender. Its use as an open threat, even accompanied by demonstration, might open endless patterns of bluff between nations each of which had some clandestine force, but did not know how much others possessed. In particular, it might be difficult to use against the main alternative form of attack or offensive that Western nations might be expected to preserve it for—subversion at home or in spheres of influence abroad.

Moreover, time is of considerable importance in two ways. At present, only two powers can be assumed to have sufficient stocks of ultimate weapons, or to have been making nuclear explosive for long enough, to make hiding away a large stock of such weapons practicable; few as yet have any weapons at all. As time passes, and the scale of such weapons is reduced, more nations will steadily acquire more of them. The sooner a disarmament agreement could be achieved between the nations, the simpler the problem of inspection. While it is not, time works for evasion. But once an agreement were achieved, time would begin to work against evasion. The longer a disarmament agreement lasted, and the longer that people everywhere had to get used to the idea of peace that was not, on the face of it, instantly terminable, the greater would be the chance of developing the effective international loyalties to the idea itself that are envisaged in the concept of "inspection by the people." In the crudest terms of conspiracy, clandestine arrangements that might have been formed around, say, a group of permanent government officials would grow more difficult, as the years wore away, to pass on to selected successors. The flow of different politicians through every cabinet post in democratic countries, with the years, would again increase the chance that the one minister in any new cabinet whom the group might have to select as a supporter to count on might turn out to disappoint or disavow them. Moreover, with the passage of time it might become increasingly more difficult for politicians, or even for evaders, to be sure of the kind of international issue that would justify the use of armed force. (The Terms of Reference we have been given do not specify whether such an evasion team would be presumed itself to take such decisions, or to break secrecy and disclose the stock of weapons at a crucial time to a cabinet that might or might not then decide to use it.)

We have not considered in elaborate detail the "tactical" arrangements that an evasion group might seek to make to facilitate its task. It would obviously be essential to infiltrate the disarmament inspectorate, if possible at its highest levels as well as in the "field force" (where individuals would presumably be employed outside their own country, and the evader-inspector could usually do a conscientious job, learning as much of other people's evasion, and techniques, as possible on the side). Eventually, however, he might be called upon to assist delivery of a nuclear weapon there. It would be advisable, and we should think not difficult, to influence the press towards skepticism about the value of an inspectorate which would necessarily be universally interfering, and which, if disarmament was succeeding, would appear to be interfering to no result. The "planting" of stories that evasion was going on unchecked in other countries, as well as giving the inspectorate there extra work, might be used to weaken as far as possible the development of readiness to "sneak" among one's own people. (Britain, for example, has a firm tradition of believing that it is the only country which ever sticks quite to the letter of any agreement it signs with others.) In the extension of government support of civilian research that would almost certainly have to follow upon abandonment of the impetus that defense has recently given technology, it might be advisable to establish some pockets of specialized knowledge or technique, accustomed to placing orders for "prototype work," to facilitate the small-scale production of clandestine weapons that we have envisaged. It might be advisable to develop electronic reading or scanning methods that could possibly be inserted under suitable cover somewhere in the postal pipeline serving the disarmament inspectorate—though this would need to be backed by intelligence from within the inspectorate about "cases" being considered.

Special Cases for Evasion

We believe that all measures of evasion would become less difficult in totalitarian countries—except, indeed, that the condition of free access to the inspectorate for all the population would in itself require even more fundamental changes in the relation of the citizen to his national government in such countries than in all others. There are a number of cultures, moreover, which are traditionally held to be less readily penetrable by the foreigner (even if he is a disarmament inspector) than others. China, for example, comes into the first category, and may well come into the other; its size would also facilitate concealment, though we do not know whether its industrial capabilities could yet make it a practicable "evasion area."

We have, above, excepted the two superpowers in considering possibilities of evasion. Both, we assume, would find evasion practicable on a scale impossible elsewhere, if only because of their far greater existing stocks of weapons. We should consider it immensely more difficult in the United States with its strong traditions of democracy, checks and balances of power, and critical scrutiny of all institutions, than in Russia. The rigid loyalties of Soviet citizens to their state power, the one-party monopoly and its claims to the right to investigate the political views of any citizen, and the existence of a far wider "area of security" within political and economic affairs, would all tend to make evasion easier. We have been told that during a considerable recent period para-military and even full military forces were not only organized and controlled but even largely equipped by the NKVD, from economic resources which went wholly unrecorded in official statistics, even those available within the country's planning organizations. The weakness of statistics in many of the countries of eastern Europe and Asia (and incidentally in some of the industrialized countries of the West) would in itself hamper inspection.

Conclusions

Consideration of the special case of the superpowers brings us back to our first premise—that the least unlikely kind of disarmament agreement might be one imposed jointly upon the world by these two powers, and backed, in one way or another, by their continuing and overwhelming military force. We do not believe that evasion of such an agreement would be worth attempting for any other country.

We believe that "small-scale" evasion of less powerfully backed disarmament—using small nuclear devices, delivered by concealment in exports to the selected destination, for assembly, timing, and detonation there—would be practicable, though difficult, for any powers of the second rank which, at the time disarmament was agreed upon, had sufficient stocks of nuclear explosive for diversion of a small percentage to provide the fissile elements for such small weapons.

We think that the longer a disarmament agreement is delayed, the more widespread the chance of evasion will become, but that, once it were signed, evasion would gradually but steadily become more difficult over time.

We think evasion would be significantly easier in totalitarian countries than in democratic. Nevertheless, disarmament could simply not be achieved without radical changes in national loyalties and legal obligations in totalitarian as well as in democratic nations. In particular, it would require abolition of the whole concept of official secrecy on a national scale.

This, in our view, merely emphasizes how vast a distance still separates the world from genuine full disarmament. But if it could, nevertheless, eventually be reached either by stages or at one leap, then the replacement of national loyalties by international allegiances that would have to have been accepted in the decision could give disarmed peace strong chances of viability.

Meanwhile, a superpower prohibition of nuclear weapons everywhere else, enforced by a Baruch-type control [2] of all nuclear activities on behalf of UNO, would avoid a critical increase in the danger and would give all countries a very necessary experience of enforceable peaceful coexistence—including the opportunity to evolve means of altering the status quo without relying on effective threats of force.

[2] The "Baruch plan" refers to "The United States Proposals for the International Control of Atomic Energy, Presented to the United Nations Atomic Energy Commission by the United States Representative, Mr. Bernard M. Baruch, June 14, 1946." This document is contained in: U. S. Department of State, *The International Control of Atomic Energy: Growth of a Policy*. Washington, D. C., U. S. Government Printing Office, 1946. Publication 2702 (pp. 138-47).