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COPING WITH MIRV IN A MAD WORLD

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Coping with MIRV in a MAD World*

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One telltale sign of an institution's age, if not its vitality, is the number of myths which surround it. By this test the strategic arms limitation talks between the United States and the Soviet Union would appear to be somewhere in their adolescence--still young enough to be sensitive to the purpose and urgency of their conception and yet increasingly constrained by cynicism bred of experience, missed opportunities, and the sclerosis of past assumptions. One of the more persistent myths about SALT and a source of considerable rumination over "what might have been" is that the time is now past for the conclusion of an effective and verifiable agreement banning MIRVed weapons. According to this myth, sometime prior to 1970, before the developmental flight test program of U.S. MIRVed ICBMs had been completed and deployment of Minuteman III begun, an agreement banning MIRV was feasible. At least, the argument goes, it then would have been possible to verify a MIRV ban by national means with a high degree of confidence. Once deployed, however, short of physically inspecting the interior of a missile's reentry vehicle or examining

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it at close range with an instrument sensitive to high energy radiation, it often is assumed that one cannot determine with high confidence whether or not MIRVs have been dismantled.[1] Since both the United States and the Soviet Union now have deployed extensive MIRVed forces and given the unlikelihood that either superpower would agree to on-site inspection of its missile reentry vehicles, both critics and supporters of the U.S. position on MIRV at SALT I tend to agree that prospects for a future MIRV ban are not encouraging.[2] It may be that this pessimism is justified. Alternatively, a case may be made that MIRVed systems themselves are not inherently destabilizing, their effect on deterrence deriving primarily from the vulnerability of their launch platforms and the configuration of the adversary's strategic forces. Moreover, one might argue, an effective and practical method does exist for achieving a ban on the most destabilizing variety of MIRVs--those on land-based ICBMs.

MIRV and Deterrence Stability

Conventional deterrence logic posits that the key to deterrence stability is mutual second strike capability. That is, each side is deterred from striking first by the belief that the victim of a first strike would retain enough nuclear clout to inflict unacceptable damage upon the initiator of the exchange. Weapons capable of surviving a surprise attack, therefore, contribute to deterrence stability while vulnerable forces are destabilizing since they (1) increase pressures for rapid response (e.g., launch-on-warning); (2) encourage the belief that a first

strike might destroy a large fraction of an adversary's retaliatory capability; and (3) provide an incentive to launch a preemptive strike lest one's vulnerable forces be destroyed in their launch platforms. From this perspective of deterrence stability, therefore, there is compelling logic to the observation that "a strategic weapon's invulnerability, like a Victorian lady's good name, is its most precious asset."[3] MIRVs are destabilizing, it is argued, precisely because of the threat they pose to the survivability of an adversary's land-based missiles.

Since 1965 when the problem of verifying a MIRV ban was added to the charge that MIRV was a threat to deterrence stability, the case against MIRV has remained essentially unchanged. Although proponents of MIRV have lobbied successfully for the continuation of the U.S. MIRV program, they have rarely challenged the basic premises of the anti-MIRV case. Thus, although MIRV was defended alternatively as a cost-effective means to cover increased Soviet targets, a hedge against Soviet ABM designs, a weapon in the domestic battle over ABM, and a bargaining chip in international negotiations, the principal charge against MIRV (counterforce threat) was never seriously challenged.[4] Until very recently, the verification issue objection to MIRV also remained uncontested.[5]

The Exchange Ratio Thesis

Although significant opposition to MIRV did not materialize until 1965, the principal theoretical objection to MIRV was anticipated as early as 1962. The thrust of the argument, developed in a report by a number of scientists associated

with the Institute for Defense Analyses, was that a MIRVed ICBM force would increase significantly the potential exchange ratio between the number of adversary missiles destroyed by each missile fired. Equipped with accurate warheads, the argument went, an exchange ratio might be attained that promised a realistic first strike potential. Particularly if a MIRV capability were combined with an effective ABM system, deterrence stability might be undermined.[6]

The exchange ratio argument against MIRV is impressive because it appears to demonstrate mathematically that the survivability of an opponent's silo launched missiles is inversely related to the number of MIRVs deployed. Missile accuracy, reliability, throw-weight, and silo hardness are variables that affect the parameters of the exchange ratio. They do not, however, modify the basic principle that by increasing the ratio of warheads to opponent missiles, MIRV reduces the survival probability of land-based targets.

The anti-MIRV logic of the exchange ratio thesis, however, is less dependent on the actual magnitude of the ratio, which may vary significantly depending upon the manner in which MIRV kill capabilities are computed, than on the assumption that meaningful inferences regarding deterrence stability can be made without distinguishing between SLBM and silo launched MIRVed missiles and without reference to the composition of the opposing side's strategic forces. In other words, it is assumed that the multiple targeting capability of the reentry vehicle itself is inherently destabilizing, especially if the MIRV is extremely accurate and reliable.

In 1962-1963 when the exchange ratio argument was raised there was a clear reason for concern over projections which indicated a MIRV threat to the survivability of most U.S. and Soviet strategic forces. At that time both sides relied heavily on a small task force of strategic weapons that was vulnerable to preemptive attack. (See Table 1.) Submarine launched ballistic missiles, the mainstay of today's nuclear forces by virtue of their relative invulnerability, were then few in number and

TABLE 1

COMPOSITION OF U.S. AND SOVIET STRATEGIC FORCES*

	UNITED STATES				U.S.S.R.			
Mid-Years	ICBM	L.R.** Bombers	SLBM	SLBM % Total	ICBM	L.R. Bombers	SLBM	SLBM % Total
1975	1054	432	656	31	1618	135	784	31
1974	1054	437	656	31	1575	140	720	30
1973	1054	442	656	30	1527	140	628	27
1972	1054	455	656	30	1527	140	500	23
1971	1054	505	656	30	1513	145	448	21
1970	1054	550	656	29	1299	145	304	17
1969	1054	560	656	29	1028	145	196	14
1968	1054	545	656	29	858	155	121	11
1967	1054	600	656	28	570	160	107	13
1966	904	630	592	28	292	155	107	19
1965	854	630	496	25	224	160	107	22
1964	834	630	416	22	190	175	107	23
1963	424	630	224	18	90	190	107	27

*The Military Balance, 1976-1977, International Institute for Strategic Studies, London, p. 75.

**A long-range bomber is considered to be a bomber with a maximum range of at least 6,000 miles. The Soviet Backfire is classified as a medium range bomber in the table above.

severely limited in range. In short, although a first strike by either party was unlikely--with or without MIRV--to disable totally the adversary's strategic forces, the presence of MIRVs in a strategic environment lacking invulnerable forces was likely to extend the appeal of and increase pressures for a first or preemptive strike posture, particularly in crisis situations.

By 1969, at the peak of debate over MIRV and at a time when it was still believed possible to effect a verifiable ban on MIRV, the strategic environment had changed and the logic of the exchange ratio thesis, at least from the U.S. perspective, was less persuasive. Although projections of improved multiple targeting accuracy, greater MIRV numbers, and higher yield resulted in calculations of reduced Minuteman survival probability, the surviving Minuteman force also could be expected to carry MIRVed warheads which multiplied their retaliatory capability. Moreover, by 1969 the number and range of U.S. submarine launched ballistic missiles had increased dramatically over the 1963 figures. SLBMs in 1969 constituted almost 30% of the launchers in the U.S. strategic triad and an even greater percentage in terms of deliverable strategic warheads.[7] Given the relative invulnerability of the sea-based deterrent and the potential to inflict massive damage even if only 5% of the Minuteman force survived, concern over the MIRV threat to land-based forces might be regarded as exaggerated, if not irrational.[8]

The logic of the exchange ratio case against MIRV in 1969 retained more validity from the standpoint of the U.S.S.R. This is less because of U.S. advantages in missile accuracy and MIRV

numbers than the fact that less than 15% of the Soviet Union's strategic force was submarine based, approximately 75% of Soviet strategic might concentrated in land-based ICBMs. In addition, superior American anti-submarine warfare (ASW) technology and a Soviet disadvantage geographically placed Soviet ballistic missile submarines in a more precarious position than their American counterparts. Political intentions aside, therefore, a basis did exist in 1969 for genuine Soviet fear of U.S. MIRV capabilities.

Today both the United States and the Soviet Union have large MIRV arsenals and the Soviet Union is on the verge of a major new deployment of MIRVs on their sea-based forces.[9] The accuracy of American and Soviet MIRVs also has improved over time as has the explosive power of MIRV warheads expressed in terms of yield to weight ratio. The question remains, however, to what extent does an increase in the ICBM exchange ratio pose a threat to deterrence stability?

One reason for discounting, in part, the alleged destabilizing effect of MIRV is the rapid increase since 1969 in the percentage of total Soviet strategic forces that are sea-based. In fact, as of 1975 the SLBM force of both the United States and the Soviet Union constituted 31% of each side's total strategic arsenal.[10] Although advances in ASW pose a threat to the long range survivability of SLBMs, both sides should retain, in the foreseeable future, a relatively invulnerable and major retaliatory capability. Indeed, one might argue that the extensive MIRVing of SLBM forces (already accomplished in the United States and underway in the Soviet Union)--as distinct from the MIRVing of ICBMs--

has contributed to deterrence stability by greatly increasing the number of warheads that would survive any first strike.[11] The relevance of missile accuracy also diminishes as the ratio of SLBMs to silo-launched missiles increases. The MIRV threat as expressed in exchange ratio terms, therefore, does not appear to be a destabilizing factor in the sense that it jeopardizes either side's capability to inflict massive punishment upon the other. As former Secretary of Defense James Schlesinger acknowledged in 1974, "even after a more brilliantly executed and devastating attack than we believe our adversaries could deliver, the United States would retain the capability to kill more than 30 percent of the Soviet population and destroy more than 75 percent of Soviet industry." "At the same time," Schlesinger added, "we could hold in reserve a major capability against the PRC."[12]

The Verification Dilemma

Prior to mid 1970 when the United States first deployed operational MIRVs, the problem of verification generally was raised by MIRV critics. They argued that unless the MIRV program was halted before the completion of extensive testing there could be no feasible means to determine whether or not there was compliance with a deployment ban. Testing of MIRVs, it was maintained could be verified by national means, deployment could not. This view was expressed most clearly by Dr. Herbert Scoville, Jr., a former Assistant Director for Science and Intelligence at the C.I.A. and MIRV testing critic. The crux of the verification dilemma, Scoville indicated in testimony before the Arms Control

Subcommittee of the Senate Foreign Relations Committee, is that:

> Since a single large warhead can be replaced, without changing the external configuration of the missile, by several smaller warheads either with or without a capability to be individually targeted (MIRV's or MRV's), it is hard to visualize how the United States could verify by national means whether a deployed missile has or has not multiple warheads. In fact even onsite inspection to make this determination would be difficult. It would require the right to inspect any deployed missile. . . on sufficiently short notice to prevent substitution of the reentry vehicle. The inspection would require access into the interior of the reentry vehicle or at very least, the use at close range of some scientific technique, such as X-rays, to determine the number of warheads present. Such inspection would almost certainly not be acceptable to the U.S.S.R. If the Soviets required similar inspection to verify that the United States was not secretly deploying MIRV's, it is doubtful that the United States could accept it.[13]

The Scoville argument, although initially emphasized by MIRV critics, became a forceful argument against a MIRV ban once both sides actually had tested MIRVed systems. After testing and deployment of MIRVed missiles, most critics of MIRV conceded, unilateral verification of a ban was infeasible, particularly if the possibility existed that tested MIRVs might fit a variety of deployed launchers. Proposals to limit MIRV, therefore, had to rely on a new approach to circumvent the verification problem.

Is a MIRV Ban Really Desirable?

Before considering several "new approaches" to limiting MIRV, it is first appropriate to address the question: Would negotiation of a verifiable MIRV ban, if still feasible, be desirable? The traditional exchange ratio argument that depicts multiple independently targeted warheads as a first strike threat is no longer persuasive given the present composition of U.S.

and Soviet strategic forces. One may object to MIRV, however, on a number of other grounds which have little to do with the general desirability of arms control. In particular, one may discern opposition to MIRV based upon the assumptions that: (1) a threat to any one of the components of the strategic triad is a threat to the deterrent properties of the strategic force as a whole, and (2) asymmetry in MIRV capability, irrespective of the total strategic balance, may be exploited politically and decrease the range of contingencies under which deterrence is credible. Arms control opposition to MIRV also may focus on the argument that regardless of the objective threat posed by MIRV, it is a weapon innovation and as such fuels the qualitative strategic arms race.

The Triad Argument

Despite public confidence in the second strike capabilities of both superpowers and the fact that the strategic triad came about more by accident than intent, many Washington decision-makers and arm chair strategists are inclined to accept or at least not rigorously challenge the argument that "a diversified deterrent composed of varying types of strategic systems. . . strengthens the overall survivability of a strategic posture."[14] It does so, presumably, by guarding against unforeseen technological breakthroughs or failures that might jeopardize any single component of the triad. If, for example, a MIRV threat to the survivability of either side's land-based ICBMs were to lead to superpower reliance upon the sea-based deterrent, this restructuring of forces might encourage the adversary to

invest more resources in anti-submarine warfare techniques.[15] Opposition to MIRV, therefore, might rest in part on the logic that MIRV accelerates the obsolescence of the land-based components of the strategic triad and provides an impetus for their phasing out.[16] Indeed, based upon the same logic it would not be irrational for support for a MIRV ban to arise among those branches of the armed services most threatened by the loss of their strategic missions.

MIRV Asymmetries

A principal issue in the 1969 MIRV debate was the first strike potential of the SS-9. MIRVing of this Soviet behemoth, Secretary of Defense Laird and others warned, might give the Soviet Union a first strike weapon against the Minuteman force. This worst case expectation did not, in fact, materialize and the SS-9 was never deployed in a MIRVed mode. Subsequent to the SS-9 series, however, the Soviets have deployed a formidable array of MIRVed ICBMs. What is of concern to many U.S. decision-makers is not that these new missiles are MIRVed, per se, but that they are much larger than their U.S. counterparts and, consequently, can deliver more MIRVs with greater payloads. In addition, there is concern, explicitly stated in Secretary of Defense Schlesinger's Defense Department Report for Fiscal Year 1975, that "the Soviets now seem determined to exploit the asymmetries in ICBMs, SLBMs, and payload. . . conceded to them at Moscow" and, in accordance with the letter if not the spirit of the SALT accords, "are considering the deploy-

ment of large numbers of heavy and possibly very accurate MIRVs."[17] This deployment itself is not regarded as a threat to the second strike capability of the United States or as an indication of Soviet designs for a massive first strike. The probability of such an attack is dismissed "as close to zero under existing conditions."[18] The critical deterrence problem, Schlesinger believes, is that the appearance of favorable asymmetries may tempt Soviet leaders to take political initiatives and limited military actions that could increase the risk of nuclear war. "It is all well and good," Schlesinger argues, "to assert that the Soviet leaders . . . would come to their senses in time to avoid fatal mistakes in such a situation and would recognize the illusory nature of their advantages. But a crisis might already be too late for such an awakening."[19]

The thrust of Schlesinger's argument is that increased research and development expenditures are necessary in order to prevent such illusions from occurring in the first place. One also might embrace his argument, however, in support of an arms control agreement that banned MIRV and thereby eliminated a principal source of perceived asymmetry.[20] Following the same line of argument, one might support a MIRV ban in order to strengthen the foundations of deterrence by making it more difficult, as one analyst puts it, for a "clever briefer" in Moscow (or Washington) to sell a scenario in which a first strike might promise victory at an acceptable cost, while hesitation could mean defeat.[21]

Fueling the Arms Race

Opposition to MIRV need not be predicated on a belief that arms control and/or disarmament in itself is a desirable end. As indicated, perception of MIRV as a threat to the viability of the strategic triad concept and fear of MIRV asymmetries, rather than MIRV per se, may be a rational basis for supporting a MIRV ban. From an arms control perspective, however, the principal danger of MIRV (assuming that it does not directly effect the operation of Mutual Assured Destruction) would seem to be that it is simply another step that accelerates the "mad momentum" of the technological arms race. To paraphrase Herbert York's observation regarding ABM, MIRV presents a technical challenge (not a political provocation) to the technologists responsible for defense. In designing around MIRV, they will probably come up with a more complex, more expensive, and more volatile defense.[22] This may take the form of increased R and D for ABM, renewed pressure for its deployment, R and D and deployment of mobile or other less vulnerable varieties of ICBMs, support for launch-on-warning, concentration of research on ASW, etc. In short, although MIRV itself should not be inherently destabilizing, it is representative of a more general category of "technologically sweet" weapon systems. Because these weapons work, and work well, it is taken for granted that they will be deployed, regardless of their actual contribution to national security.

The question previously was raised: Would negotiation of a verifiable MIRV ban, if still possible, be desirable? The answer to that question is not as straight forward as one might

expect from the extent of anti-MIRV sentiment that has developed since SALT 1. In part, an affirmative answer to the question is dependent upon the kind of MIRV ban envisioned. A MIRV ban on silo launched ICBMs, the most vulnerable component of the strategic triad, would seem to be the most desirable form of limitation. Among other positive consequences, elimination of MIRVed ICBMs would diminish whatever first strike potential the Soviets possess by virtue of their throw-weight advantage. The MIRV asymmetry argument would thus lose most of its force. A ban on MIRVed ICBMs also would remove the most accurate variety of MIRVs, increase the proportion of strategic forces least vulnerable to first strike attack, and reinforce the logic of Mutual Assured Destruction by reducing the incentives for counterforce targeting.[23] In addition, elimination of land-based MIRV forces would retard, although not halt, the growing obsolescence of the land-based component of the strategic triad. Concern over the imminent loss of a diversified deterrent, whether or not justifiable, would thus be ameliorated and military resistance to the dismantling of an operational system perhaps reduced.[24] Finally, in support of at least some version of a MIRV limitation, one must recognize the critical role of perception in the deterrence relationship. Although an assessment of the exchange ratio thesis suggests that opposition to MIRV is based to a large extent upon assumptions that no longer correspond to reality, it remains the case that if MIRVs instill fear in the minds of decision-makers and are perceived as a threat to deterrence stability, they may be destabilizing in their consequences.

The Vladivostok Approach

Ironically, it is only in the aftermath of the 1972 SALT agreements--following what most observers believe was the last chance to negotiate a MIRV ban--that Henry Kissinger and other former defenders of the U.S. MIRV program began to recant their earlier views. For some, like Kissinger, the convergence to MIRV critic appears to be based upon a gradual acceptance of the argument that MIRV has destabilizing implications for nuclear deterrence and arms control.[25] For others, less concerned with the theoretical requisites of deterrence stability, a MIRV ban is viewed wistfully as a measure that might have negated the Soviet heavy missile advantage.[26] For both varieties of critics, however, the issue of confidently verifying a MIRV limitation has proved to be a stumbling block.[27]

In order to circumvent, at least partially, the MIRV verification dilemma, U.S. negotiators recently have adopted an approach which subordinates the "shell game" philosophy of verification (i.e., counting MIRVs on the basis of identifiable reentry vehicles) to what might be called an "all or nothing" counting approach. This new strategy, central to the American interpretation of the Vladivostok limit of 1320 MIRVs, assumes that once any missile has been tested successfully in a MIRVed mode, all missiles of that type will be counted as MIRVed. For example, since some Soviet SS-18s have been tested with MIRVs, all SS-18s, including those formerly deployed with single reentry vehicles, must be counted toward the 1320 MIRV ceiling.

According to Henry Kissinger, speaking in November 1974, this principle of counting MIRVs is one which is "non-negotiable."[28]

Despite Soviet resistance, the U.S. counting procedure may be incorporated into the next SALT agreement. In any case, however, verification problems regarding MIRV remain. Jan Lodal points out, for example, that the MIRV counting rule does not enable one to distinguish "between two missile launchers which are identical, except that one contains MIRVs, and the other does not." That is, how is one to determine the number of submarines carrying MIRVed missiles if the Soviets should develop a new MIRVed SLBM which is compatible with older launchers on existing submarines?[29] Lodal notes that one possible theoretical solution to that problem--the requirement that all launchers capable of firing a MIRVed missile be counted toward the MIRV limit--is not realistic since it is at odds with current U.S. deployments in which Minuteman II silos, with only minor modifications, are capable of launching the MIRVed Minuteman III missile.[30]

Another deficiency with the "all or nothing" counting approach to a MIRV limit, at least from an arms control perspective, is that its political feasibility derives in part from the high MIRV ceiling tolerated. In other words, as Lodal points out, "the 1320 limit itself ameliorates the verification problems [since] even with a crash program, the Soviets could not approach the 1,320 limit in the number of deployed MIRVs before about 1981."[31] The limited advantage to be gained from cheating when

MIRV levels are set high also would seem to encourage compliance with the limitation.

A Confidence Flight Test Ban Approach To Limiting MIRV

Theoretically, the counting rule approach advocated by the United States at the current round of SALT is not incompatible with a MIRV limitation much more substantial than that proposed at Vladivostok. There is, however, an alternative, and in some respects preferable, method to achieve a MIRV ban that has received scant public attention. This approach relies upon the loss of confidence in the reliability of MIRVed missiles through an agreement to halt or at least substantially reduce the number of annual flight tests of strategic missiles in a MIRVed mode. Among the advantages of this approach to limiting MIRV are: (1) it is not dependent upon a high MIRV ceiling to ameliorate verification difficulties; (2) it requires no technological advances in reconnaissance capability; (3) it is applicable on a weapon system to system basis; and (4) it reinforces the principle of countercity as opposed to counterforce targeting.[32] Although a confidence flight test ban, in principle, might be applied to all MIRVed strategic missiles, it is argued below that from the standpoint of deterrence stability and political feasibility a flight test ban should extend to only MIRVed (and preferably MRVed) land-based ICBMs.[33]

The logic of a MIRV limitation by means of a ban on the test firing of missiles in a MIRVed mode is extremely simple. Indeed, considering the emphasis placed by arms control critics

of MIRV on a developmental flight test ban, it is surprising that a post deployment confidence (or reliability) flight test ban has not received more public attention.[34] The rationale underlying a confidence flight test ban, essentially, is that the United States and the Soviet Union annually conduct a series of missile flight tests in order to establish the continued reliability of missile systems under conditions that closely approximate actual operational firings.[35] Should such tests be severely curtailed there is good reason to believe that military commanders would be reluctant to continue deployment of the untested systems. To do so, various military spokesmen have testified, would seriously undermine their confidence in the reliability (and especially the accuracy) of their strategic forces. A ban on flight tests, therefore, would probably generate strong pressure to replace those missile systems affected by the test ban with ones that could be tested regularly.

How Much Testing Is Enough?

Establishment of the reliability of a missile system's performance is very much a subjective matter. This is particularly the case with respect to reentry vehicle performance because of the uncertainties of operation under actual combat conditions.[36] The refusal of the U.S. Congress to authorize test firings of the Minuteman force from operational silos further complicates the problem of estimating ICBM flight performance under realistic conditions. To date, ICBM tests are conducted only after the missiles have been removed from their

operational silos and transported across the country. Addition of a MIRV confidence flight test ban to this list of other uncertainties would appear to seriously erode military confidence in the reliability of silo launched MIRVed missiles. Precisely how many annual MIRVed missile tests are needed to retain present confidence levels, however, is extremely difficult to estimate.

Through bits and pieces of testimony before Senate and House committees addressing Department of Defense appropriation and authorization matters, one can construct a fairly clear picture of the magnitude of recent U.S. efforts to test the reliability of its land-based MIRVed missile force.[37] Apparently, operational testing and evaluation for Minuteman III (as distinguished from developmental testing and evaluation) consists of two sequential programs, both conducted by the Strategic Air Command at the Western Test Range. The first program, identified as a "Demonstration and Shakedown Operation" entailed six launches, all of which were successful. The second program, identified as "Operational Test", is an ongoing series of tests which involves the random selection from operational silos, transportation to Vandenberg AFB, and launching by SAC operational missile crews of Minuteman III missiles. As of October 31, 1975, 38 Operational Test launches had been completed with plans made to continue confidence testing at the rate of seven Minuteman III launches per year.[38] Unfortunately for the purpose of identifying the number of flight tests necessary to maintain present confidence levels, the success rate for launches in the "Operational Test" program

is classified and is deleted from published Congressional testimony. All that can be inferred confidently from the public record is that the 38 operational test launch figure includes a number of test failures in which the missile's guidance computer and propulsion system were pinpointed as the major sources of difficulty.[39]

The military importance attached to the confidence flight test programs is apparent in Department of Air Force testimony before the Senate Armed Services Committee. In response to a question submitted by Senator Stuart Symington during DOD authorization hearings for Fiscal Year 1976, for example, the Department of Air Force indicated that:

> Since 1961 the Air Force has averaged 43 missile launches per year in developing, maintaining, and assessing the reliability and accuracy of our deployed Titan II and Minuteman ICBM force. . . . If we were required to reduce this level to only 5-10 missiles a year it would have a serious impact on our ability to flight test system changes, new improvements. . ., and most important our ability to detect system deficiencies resulting from aging . . . . We would definitely have to reduce our confidence in system reliability and accuracy assessment. Low launch rates require longer periods to detect deficiencies that might degrade the entire weapon system.[40]

A similar statement is provided by the Department of Air Force in response to a question raised by Senator Barry Goldwater:

> Question: Are you fully confident that the Minuteman force could perform its assigned mission? Are you satisfied we have adequately tested Minuteman over the years to assure ourselves it will be an operationally effective system?
>
> Answer: We have high confidence in our current assessment of Minuteman reliability and accuracy. Each generation of Minuteman has been adequately tested during its deployed life to insure this confidence. However, we must continue to test Minuteman

> in its operationally deployed configuration over the life span of the system to insure that failure modes, resulting from such things as aging, are rapidly detected and corrected to prevent degradation of this high reliability of the operational force. . . . [41]

Dr. Herbert Scoville, Jr., an authority on the technical aspects of arms control, also has emphasized the importance attached by military planners in both the United States and the Soviet Union to continued testing of missile systems even after deployment. In testimony before the Arms Control Subcommittee of the Senate Foreign Relations Committee in 1970, for example, he noted that "even more than five years after development testing has been completed on the Polaris A3 MRV system, the military are claiming that additional firings of the complete system are essential to maintain confidence in its operational capability." "Based on past experience," Scoville observed,"the Soviet military are even more stringent [on test firing] than the United States."[42]

Given the history of less than perfect flight performance of the deployed Minuteman III force and the additional uncertainties that result from testing under simulated launch conditions, a substantial MIRV flight test limitation short of a total ban might generate pressure to deMIRV and, if the number were very low (e.g., a maximum of 5 flight tests per year), would almost certainly deter tests for weapon system improvements (e.g., reentry vehicles with increased accuracy, terminal guidance, and greater warhead yield). Nevertheless, if one's ultimate objective

is the dismantling of MIRVed missiles, a total ban on flight tests of long range, land-based missiles in a MIRVed mode should be sought.

Verifying a MIRV Flight Test Ban

One of the frequent objections to the MIRV ceiling set at Vladivostok is that it is much too high and encourages a build-up rather than a reduction of arms. As previously noted, one defense of this high ceiling is that it ameliorates present verification difficulties. A principal attraction of a confidence flight test ban approach to limiting MIRV (as opposed to the counting rule method currently advocated by U.S. negotiators) is that it is not dependent upon a high MIRV ceiling and, in fact, requires no technological improvements in reconnaissance capabilities. This is because it is much easier to monitor MIRV flight tests than it is to identify deployed MIRVs.

Present U.S. reconnaissance capabilities are described very clearly in several articles by Ted Greenwood. Essentially, he argues that a combination of existing land-based line-of-sight radars, over-the-horizon radars, satellite systems, and shipboard sensors provides adequate means to monitor confidently tests of strategic missiles in a MIRVed mode. According to Greenwood:

> All long-range missiles fired from test sites in the U.S.S.R. are detectable. . . . The most useful observations for monitoring long-range missile tests are those made from ships and aircraft in the region of impact of the reentry vehicle. From terminal radar and photographic observations detailed information about the reentry system can be derived . . . . If a

> powered terminal maneuver is attempted [i.e., MARV], observing radar and infrared sensors should be able to detect it. Multiple-warhead tests can be easily detected near the impact site, if they are not detected earlier by other techniques.[43]

The redundancy of present reconnaissance capabilities, Greenwood argues, would permit verification of an agreement restricting the number of missile tests with a high degree of confidence. Although not necessary to verify compliance with a flight test limitation, the task of reconnaissance would be reduced further if the flight test agreement also provided that tests of long range missiles be preannounced and conducted at specified test ranges.[44]

From a technical standpoint, the only significant question marks regarding verification of a flight test ban concern the issue of distinguishing multiple reentry vehicles (MRVs) from multiple independently targetable reentry vehicles (MIRVs).[45] To distinguish MRVs from MIRVs would be extremely difficult, Greenwood suggests, if a MIRV test involved only a small separation of the reentry vehicles. "Presumably a system that can produce wide separation could also be programmed for small separation, and could perhaps be tested without being recognized for what it was."[46] Extension of a MIRV flight test limitation to include MRVs is an obvious and desirable way to alleviate the MRV-MIRV verification problem. However, should the major asymmetries in Soviet-U.S. reliance on MRVs prove a political obstacle to negotiation of a comprehensive multiple reentry vehicle test limitation, the risks of verification evasion could be

reduced substantially by inclusion in the agreement of the previously cited suggestion requiring that flight tests be preannounced and confined to agreed upon flight paths. This would increase the probability of photographing the release stage of the reentry vehicles at which point MRVs and MIRVs are distinguishable.

Good MIRVs and Bad MIRVs

So far the feasibility of a MIRV flight test limitation has been discussed without respect to different MIRVed systems. Although a total ban on MIRV flight tests may be preferred from the standpoint of halting the technological arms race, political and other theoretical considerations may argue for a more differentiated approach toward limiting MIRV.

As indicated above, a case may be made that MIRVs are not inherently destabilizing and that sea-based MIRVs, because of their relative invulnerability, actually may contribute to deterrence stability. Theoretical reasons, therefore, may be cited in support of a MIRV flight test proposal limited to land-based MIRVed systems. A more pragmatic reason for distinguishing between land-based and SLBM MIRVed systems, however, concerns likely political-bureaucratic objections to a flight test ban agreement.

Bureaucratic resistance to any proposal that threatens the continued operation of existing systems (regardless of the systems's merits or deficiencies) may be the basis for Greenwood's pessimistic conclusion that "A prohibition against multiple warhead tests could be verified, but at the current stage of development and deployment of these systems, such an agreement seems

unlikely."[47] Graham Allison's bureaucratic politics analysis of the MIRV deployment decision also suggests that because MIRV has appealed to so many different organizational interests, it may be very hard to dismantle the system even if the original arguments in favor of deployment no longer are relevant.[48] Although restriction of a MIRV flight test ban to land-based systems would not eliminate bureaucratic opposition to a flight test limitation, such an agreement would undoubtedly be easier to defend politically than a comprehensive flight test ban.

In the first place, continuation of MIRVed SLBM flight tests would appease those critics concerned about the rapid loss of R and D resources (money and personnel) tied to MIRV technology.[49] Political decision-makers in the United States and Soviet Union also would avoid the embarrassing and politically risky situation of abandoning a major defense program on the verge of its completion (i.e., Soviet MIRVing of their SLBM force and U.S. development of the Trident missiles).[50] A flight test ban on silo launched MIRVs, moreover, might be defended as in the best organizational interest of the apparent target of the ban--the Air Force--since a loss of confidence in the most accurate variety of MIRVs, those launched from silos, would enhance the survivability (and rationale for continued deployment) of land-based ICBMs.

Finally, with respect to the political feasibility of a MIRV flight test ban, limitation of the ban to land-based systems would appear to be consistent with several major U.S.

and Soviet strategic objectives. In particular, a ban on testing of silo launched MIRVs would alleviate a major fear of U.S. decision-makers--the Soviet throw-weight advantage. Most likely, elimination of confidence flight tests would lead to the deMIRVing of Soviet heavy missiles. Even if the Soviets decided to retain their MIRVs without testing, however, the reliability and accuracy of the systems would deteriorate as would their counterforce capability. A test ban on land-based MIRVs also would be consistent with the Soviet desire to minimize the strategic dividends of the American advantage in MIRV technology. Although the test ban would not apply to SLBMs, the counterforce threat of the most accurate variety of MIRVs would be checked. Moreover, and perhaps most significant from the Soviet perspective, the principal strategic asymmetry in favor of the United States--nuclear warhead numbers--would become less relevant as the size of the more secure and less threatening sea-based deterrent force increased relative to its more vulnerable land-based counterpart.[51]

Contingent Conditions

An important long term objective of a confidence flight test ban may be the actual dismantling and/or destruction of MIRVs. Movement toward that goal, assuming a flight test agreement, is apt to be affected by a number of factors. The subjective, idiosyncratic character of "confidence" in missile system performance already has been mentioned. In addition, the strategic doctrines of the two parties, as well as their

present force structures, are apt to influence post-flight test ban deployment decisions.

So long as a nation's strategic policy is defined primarily in terms of countercity and Mutual Assured Destruction objectives as opposed to counterforce and warfighting capabilities, there may be little incentive from a strategic standpoint to replace MIRVed missiles rapidly with single reentry vehicles. This is because a loss of accuracy, while critical to the kill coefficient for "hard" targets such as missile silos is much less significant for "soft" countervalue targets such as population centers. Alternatively, a desire to minimize the loss of MIRV's counterforce capabilities (or at least the appearance of disarming) might lead to rapid replacement of MIRVs with larger single reentry vehicles.[52] Because of the subjective nature of missile performance confidence levels it is impossible to identify the rapidity with which present U.S. counterforce capabilities would deteriorate given a halt in MIRV flight testing. It is unlikely, however, that a counterforce capability, once lost through a halt in MIRV testing, could be easily or quickly reacquired simply through the resumption of testing.[53]

Force structure also is an important parameter likely to affect the pace of deMIRVing; the more modern and extensive currently deployed single reentry vehicle missile systems, presumably, the less urgent the need to replace MIRV systems with new single reentry ones. Because of asymmetries in dependency on MIRVs (the U.S. strategic force and particularly its more modern

components is more reliant upon MIRVs than is its Soviet counterpart), the United States might propose that implementation of a flight test ban be extended over a period of years to allow development of new single reentry vehicle missile systems or conversion of present systems to a single reentry vehicle mode.

Conclusion

It is unrealistic to assume that what has long been accepted as fact--the impracticality of a MIRV ban after completion of developmental testing and deployment--will be recognized readily as a myth. The prospect of moving from recognition of the technical feasibility of deMIRVing to policy advocation to actual implementation of the policy is even less sanguine. Bureaucratic opposition to the dismantling of operational systems regardless of their contribution to national security and the potential economic burden of converting from technologically sweet MIRVs to technologically old fashioned single reentry vehicle missile systems are obstacles that proponents of a MIRV flight test ban must expect to encounter. A test ban agreement without a limitation on strategic anti-submarine warfare also may provoke opposition from arms controllers wary lest a limitation on MIRVs rechannel the arms race into another, possibly more dangerous, area.

Despite these objections, however, the logic of a flight test ban approach to limiting MIRV is compelling. In particular, this approach avoids the substantial verification difficulties of other MIRV reduction schemes and requires no technological advances in reconnaissance capability. Its applicability on a

weapon system to system basis, moreover, recommends it as an adjunct to alternative MIRV reduction proposals should bureaucratic resistance to a comprehensive MIRV flight test ban prove insurmountable.

It is too soon to judge whether the formative years of the strategic arms limitation talks between the United States and the Soviet Union will be remembered as a period of innovation and irreverence to past myths and immobilities or a time of missed opportunities. If history is to avoid the latter verdict it is now time to cope with MIRV.

FOOTNOTES

1. This assumption was especially widespread prior to August 1973 before it became apparent that the Soviet Union intended to MIRV its new SS-17 and SS-18 missiles rather than the SS-9 (Cf. Ted Greenwood, Making the MIRV: A Study of Defense Decision Making (Cambridge, Massachusetts: Ballinger Publishing Co., 1975), p. 111 and Herbert Scoville, Jr., Testimony during the Hearings before the Senate Subcommittee on Arms Control, International Law and Organization of the Committee on Foreign Relations, April 14, 1970, p. 228). After 1970 but prior to the initiation of the Soviet MIRV testing program a common explanation for the presumed non-negotiability of a MIRV limitation was Soviet reluctance to be frozen into a position of technical inferiority.

2. Subsequent to the realization that the Soviets were not likely to MIRV their SS-9s, some arms control experts have suggested that a MIRV ban is again feasible, if unlikely. The method to effect a MIRV ban, they maintain, is acceptance of a counting rule principle which provides that once a missile is flight tested in a MIRVed mode, all missiles of the same type must be counted toward the MIRV limit. Other authorities, however, continue to insist that "a complete MIRV ban can no longer be verified." (Cf. Gerard Smith, "SALT After Vladivostok," Journal of International Affairs, Spring 1975, p. 9.) The merits of two alternative, new approaches to limit MIRV are discussed in detail below.

3. John Newhouse, Cold Dawn: The Story of SALT (New York: Holt, Rinehart and Winston, 1973), p. 265.

4. Given the surge of public anti-MIRV sentiment after 1969 it is interesting to note Ted Greenwood's observation that "as late as 1965 MIRV was perceived by almost everyone to be beneficial, not detrimental, to unilateral arms control and was essentially irrelevant to the subjects under active discussion in international arms control negotiations" (Op. cit., p. 108). An alternative explanation for the lack of early arms control opposition to MIRV is that few members of the arms control community were aware of MIRV prior to 1964 because of the extreme secrecy surrounding the program.

5. Although one may argue that the post 1973 "counting rule" approach promises to reduce some of the difficulties of verifying a MIRV limitation, other verification problems persist. Nor does available evidence support Henry Kissinger's November 1974 assertion that the U.S. has always regarded verification of MIRV as a soluble problem. (See Press Backgrounder, Secretary of State Henry Kissinger, Tokyo-Peking Flight, November 25, 1974, Part 1, p. 3.)

6. Greenwood, op. cit., p. 109.

7. If one counts warheads on U.S. bombers as four to a bomber (approximately one warhead per 8,000-9,000 kg. payload), submarine-based warheads constituted over 32 percent of the total number of U.S. strategic warheads in 1969.

8. The most widely quoted estimate of the number of Minutemen that would survive a Soviet first strike in the late 1970s was 5 percent. See, for example, testimony by Dr. Albert Wohlstetter before the Senate Armed Services Committee, May 23, 1969.

9. The Soviet Union reportedly tested its first MIRVed SLBM (the SS-NX-18) in November 1976 (See Washington Post, November 24, 1976).

10. In terms of warhead numbers, however, the percentage of the U.S. strategic force at sea was substantially greater than that of the Soviet force. The U.S. total in 1975 was approximately 55 percent, the Soviet total 26 percent.

11. A rather different argument in support of MIRVs is articulated by Henry Rowen who regards the adoption of MIRV as beneficial in that it works toward a reduction in the average and total warhead yields in the Soviet force. See Rowen, "The Need for a New Analytical Framework" Review of Security in the Nuclear Age, International Security, Vol. 1, no. 2 (Fall 1976), p. 143.

12. Secretary of Defense James R. Schlesinger, Annual Defense Department Report, FY 1975, p. 35.

13. Herbert Scoville, Jr., op. cit., pp. 228-229.

14. Jerome H. Kahan, Security in the Nuclear Age (Washington, D.C.: The Brookings Institution, 1975), p. 210.

15. The result, John Newhouse suggests, may be that a gesture designed to encourage stability actually has the opposite effect (op. cit., p. 20). It remains to be convincingly argued, however, that a "more eggs in a single basket" philosophy necessarily compromises deterrence stability. The most frequently cited negative factor of a SLBM concentrated retaliatory force is the problem of command and control.

16. Alternatively, Lawrence Weiler suggests that a major argument likely to be raised should a substantial MIRV limitation be considered is that MIRV serves as a useful hedge against violations or abrogation of the 1972 ABM Treaty which might lead to development of an effective anti-ballistic missile system. (Personal communication, January 1977).

17. Schlesinger, Annual Defense Department Report, FY 1975, p. 43.

18. Ibid., p. 38.

19. Ibid., p. 43.

20. From the Soviet perspective, of course, the important asymmetries involve missile accuracy and number of warheads--areas in which the U.S. has superiority.

21. Morton H. Halperin, "Clever Briefers, Crazy Leaders and Myopic Analysts," The Washington Monthly (September 1974), pp. 42-49. See Also Kahan, op. cit., p. 204.

22. Herbert F. York, Race to Oblivion (New York: Simon and Schuster, 1970), p. 179.

23. One might contend that although incentives for targeting land-based forces are diminished, incentives for ASW actually are increased. Although an ASW limitation would acquire increased importance as the proportion of sea-based strategic forces increased, retention of MIRVed SLBMs--at the same time that land-based MIRVs are banned--would increase the number of warheads likely to survive any first strike.

24. As will be discussed later, bureaucratic resistance rather than verification difficulties is the Achilles' heel of a MIRV ban.

25. Kissinger implied at several frank press conferences during 1974 that he wished he had thought through the implications of a MIRVed world more fully in 1969 and 1970 than he did. See, for example, Department of State News Release, Press Conference by Secretary of State Henry A. Kissinger, Moscow, July 3, 1974 and Press Briefing by Secretary of State Henry A. Kissinger, December 3, 1974.

26. Senator Henry Jackson is a prime example of this second variety of critic. See, for example, his harsh criticism of the high MIRV ceilings accepted at Vladivostok.

27. In the case of Kissinger it appears that by 1974 he personally believed that the MIRV verification problem was soluble, but recognized that others within the administration would continue to use the verification issue to block a SALT II agreement. See Kissinger November 25, 1974 Backgrounder, op. cit., pp. 3-4.

28. Kissinger Backgrounder, op. cit., Part 2, p. 1.

29. Jan Lodal, "Verifying SALT," Foreign Policy, No. 24 (Fall 1976), p. 52. This verification difficulty may be less severe than Lodal suggests if one assumes that the Soviets would be reluctant to deploy a weapon system without fully testing it in its operational mode. More likely, the real problem would be a political and economic one. That is, although one could still apply the MIRV counting rule, the number of MIRVs encompassed by the rule might increase dramatically and confront decision-makers with the choice of abrogating or revising upward the MIRV limitation or undertaking a major dismantling of other MIRVed systems.

30. Ibid., pp. 52-53. Although theoretically Lodal is correct in asserting that a launcher counting rule is at odds with current U.S. deployments, it may be that the problem is principally cosmetic (i.e., drafting treaty language that does not appear to be one-sided). Kissinger implies that this is the case in a November 1974 backgrounder. He notes that although the Soviets "will try to make us count things by our yardsticks," "we have no capacity of deploying significant numbers of MIRVed missiles secretly. We cannot procure them, we cannot deploy them, and therefore if they want to scuttle what was achieved in Vladivostok, that is exactly what they will do." (November 25, 1974 Backgrounder, op. cit., Part 2, pp. 1-2.)

31. Lodal, op. cit., p. 51.

32. From an economic standpoint one might cite a fifth advantage of a confidence flight test ban approach. It is probably less costly in terms of conversion from multiple to single reentry vehicle missile systems than is a MIRV counting approach dependent upon the construction of new missile launchers as well as new missiles.

33. Although it is convenient to refer to the flight test limitation as a "confidence flight test ban" approach to limiting MIRV, the limitation is intended to apply to all test firings of missiles in a MIRVed mode. Besides being extremely difficult to verify, a separate ban on confidence (as opposed to developmental) flight tests would probably be non-negotiable since the United States, unlike the Soviet Union, does not test ICBMs at full range from operational silos. (See footnote 35.) A useful collateral missile flight test agreement would be to restrict the number of SLBM tests in a MIRVed mode to a low enough number (perhaps 5-10 per year) to inhibit the possible transfer of MIRV reentry vehicle technology improvements from SLBMs to ICBMs. I am thankful to Sidney Drell for calling my attention to the MIRV technology transfer problem.

34. The germ of the idea certainly may be inferred from the writing of Ted Greenwood and the Congressional testimony of Herbert Scoville, Jr. The October 1973 issue of The Arms Control Association Newsletter also suggests, in passing, "that the key to controlling MIRVs is not in controlling the numbers deployed, which would not be verifiable, but rather in controlling tests, which would" (p. 3). These sources, however, stop short of proposing a confidence flight test ban as a means to deactivate MIRVs already deployed and instead focus on ways to prevent development of more accurate MIRVs. My inquiries to senior American and Soviet arms control and defense counselors also indicate that although a confidence flight test ban approach to limiting MIRV is not entirely virgin territory, until very recently it has received little attention in Washington and Moscow. A brief, general statement of the arms control merits of limiting missile test firings, not confined to the issue of MIRVs, is provided by Sidney D. Drell in "Testimony on National Security and Arms Control Implications of Current U.S. Strategic Options," Senate Committee on Foreign Relations, January 19, 1977, pp. 18-19. See also Sidney D. Drell, "Discussion Paper on Limitations on Missile Test Firings," Mimeo, Stanford, California, December 6, 1976.

35. U.S. land-based ICBMs, it should be emphasized, have never been fully tested in operational silos, although SLBMs have been fired from operational submarine launchers. The Soviet Union, by contrast, has conducted extensive testing of their ICBM force from operational silos. See Hearings before the Senate Armed Services Committee, Fiscal Year 1976 Authorizations for Military Procurement, Research and Development and Active Duty, Selected Reserve and Civilian Personnel Strengths, April 1975, pp. 5310-5311 for a discussion of the desirability of shifting to an "Operational Base Launch" program.

36. Wolfgang Panofsky, for example, emphasizes that "it is very difficult to predict precisely how in a heavy attack one missile will affect another. . . ," "The Mutual Hostage Relationship Between America and Russia," Foreign Affairs, Vol. 52, No. 1 (October 1973), p. 114.

37. The author wishes to thank John C. Baker and Herbert Scoville, Jr. of the Arms Control Association for their assistance in locating Congressional source material.

38. These figures do not include approximately 20 Minuteman III test launches programmed through FY 1978 designated as weapons improvement tests. See Senate Hearings before the Committee on Appropriations, Department of Defense Appropriations, FY 1976, Part 4, February 26, 1975, pp. 205-206.

39. Hearings before the Senate Armed Services Committee, Fiscal Year 1977, Authorization for Military Procurement, Part 11, March 19, 1976, p. 6528. See also Senate Hearings before the Committee on Appropriations, Department of Defense Appropriations, FY 1977, April 26, 1976, pp. 391-397.

40. Hearings before the Senate Armed Services Committee, Fiscal Year 1976, Authorization for Military Procurement, Part 2, February 20, 1975, p. 828. My emphasis.

41. Hearings before the Senate Armed Services Committee, Fiscal Year 1976, Authorization for Military Procurement, Part 10, April 11, 1975, p. 5310. My emphasis.

42. Scoville, op. cit., p. 230.

43. "Reconaissance and Arms Control," in Arms Control: Readings from Scientific American (San Francisco: W. H. Freeman and Co., 1973), pp. 230-231. My emphasis. Although the focus of Greenwood's article is on U.S. reconnaissance capabilities, he indicates that the Russians have comparable observation satellite systems (p. 233).

44. Greenwood, "Reconnaissance, Surveillance and Arms Control," Adelphi Paper No. 88. London: International Institute for Strategic Studies, p. 20.

45. Another verification issue raised by Greenwood, the possibility of circumventing a MIRV flight test limitation by testing a MIRV with only one warhead at a time, does not appear to be a real difficulty. Release of even a single reentry vehicle from a MIRV bus could probably be detected and firing of a MIRVed missile without activation of the bus would not provide a test of the entire missile system's reliability.

46. "Reconnaissance and Arms Control," p. 232.

47. "Reconnaissance, Surveillance and Arms Control," p. 22. Greenwood does not elaborate on this point.

48. Graham Allison, "Questions About the Arms Race: Who's Racing Whom? A Bureaucratic Perspective," Paper prepared for the 6th International Arms Control Symposium, Philadelphia, November 1973. See especially p. 25.

49. This loss, of course, also might be cited by arms race critics of MIRV as a major accomplishment of a MIRV flight test ban.

50. U.S. decision-makers would still have to contend with opposition from proponents of the new MX missile and MK-12A warhead. Opposition to these programs, however, has been substantial even without the benefits of a MIRV flight test ban. Soviet decision-makers, on the other hand, would have to contend with defenders of the SS-16, SS-17, SS-18, and SS-19 programs.

51. Because of American superiority in ASW technology and a Soviet disadvantage with respect to forward basing of submarines, the Soviets would probably insist that some form of an ASW limitation accompany a ban on MIRVed ICBMs.

52. Another disturbing possibility which, fortunately, would probably not be tolerated by Congress is to compensate partially for the loss of reliability in the MIRVed systems by increasing the number of deployed MIRVs. This alternative, in fact, was hinted at by the Air Force in response to a question by Senator Symington regarding the effect on the U.S. ICBM program of a hypothetical limitation of missile tests to 5 to 10 per year. See Hearings before the Senate Armed Services Committee, Fiscal Year 1976, op. cit., p. 828.

53. There is considerable debate within the scientific community over the number of tests necessary to acquire, maintain, and/or reacquire different missile performance characteristics. I have been informed by one U.S. technical expert that at least 40 to 50 tests would be necessary in order to regain present U.S. counterforce capabilities. For a discussion of relevant statistical assumptions see Nancy R. Mann et. al., Methods for Statistical Analysis of Reliability and Life Data (New York: John Wiley & Sons, 1974).