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AN ANALYSIS OF SOVIET MILITARY WRITING ON UNITED STATES RE-ENTRY VEHICLE TECHNOLOGY, 1965-1983

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Executive Summary

This report reviews Soviet military writing on U.S. re-entry vehicle (RV) technology and analyzes this literature in light of what it reveals concerning the Soviet military's technology assessment process. A review of over 40 Soviet military books and journal articles produced the following conclusions:

* The military's assessments consistently--over various technology areas and over the course of 20 years--focused on explaining how a given RV technology worked.

* A direct correlation existed between the Soviet military's threat perception regarding a given RV technology and how extensively that technology was assessed.

* The assessments of U.S. re-entry vehicle inertial guidance technology were anomalous.

* The assessments correlated well with the actual state of U.S. RV programs. Changes in the direction of these programs were accurately portrayed in the Soviet military literature.

* The quality and technical proficiency of the assessments improved considerably over time.

* The technology assessment process, however, changed little over the 20 year course of this study. The process has been and remains oriented to providing the Soviet military with the information needed to minimize its response time to U.S. re-entry vehicle technological innovation.

The great majority of Soviet military writing on any particular U.S. RV technology attempted to explain how that technology worked. While most military writers adopted this framework of analysis, surprisingly few sought to analyze in any detail the military significance of the various technological innovations. The foregoing suggests that the assessments were structured to address a very practical consideration: to give the Soviet military audience the information needed to formulate a response to a specific military threat.

A review of the military literature also revealed a positive correlation between the level of threat posed by a given U.S. RV technology and the extent and quality of the corresponding Soviet assessments. Of the twelve RV technology areas the Soviets examined, four were given special attention: passive radar masking (for example, penetration aids), MIRV, ablative thermal shields and maneuvering/terminally guided RVs. Three of these four technology areas (ablative thermal shields being the exception) were precisely those re-entry vehicle technological innovations which, over the 20 year period of this study, created the greatest threat for the Soviet military.

Advances in U.S. re-entry vehicle inertial guidance technology posed just as great a threat as penetration aids or MIRV, yet these systems did not receive special attention in the Soviet military literature. In fact, this technology area was virtually ignored. Three reasons can be advanced for the anomalous treatment of inertial guidance technology. For one, the improvements in this technology area may have been judged too sensitive for assessment in the open source military literature: The inertial guidance system improvements which were a part of the Mk12A RV program gave the U.S. a hard target kill capability. A second possible reason for the anomalous treatment of U.S. inertial guidance technology has more to do with the Soviet military's own advances in this technology area: The Soviets may not have wanted to draw attention to a technology area--inertial guidance--where they were making considerable progress in the latter half of the 1970s. A final reason for this unusual treatment may center on the mundane nature of inertial guidance systems--mundane at least in comparison with more exotic guidance technologies such as terminal guidance. Other reports in this series have concluded that the Soviet military often displays a bias toward more exotic systems when assessing U.S. military technologies.

Another of this report's conclusions is that the Soviet assessments responded in a fairly prompt manner both to the changing nature and direction of various U.S. RV technology programs and to changes in the overall strategic climate. The assessments accurately portrayed the broad directions of the U.S. re-entry vehicle program--from the program's early emphasis on enhancing BMD penetration capability to its more recent focus on terminal guidance. With respect to the strategic climate, the Soviet assessments responded in a logical and predictable manner to the 1972 ABM Treaty. The amount of analysis on U.S. penetration aids and RV hardening programs (technologies needed to counter an ABM system) declined considerably after 1972.

On a more general note, this study shows that the assessments improved considerably over time. The magnitude of this improvement, however, is greater than first apparent. The complexity of the U.S. technology being assessed has increased dramatically over time. It is one thing for the Soviets to assess competently the relatively simple technology of multiple re-entry vehicles; it is quite another to assess more recent and complex RV technologies like terminal guidance. Yet it was precisely with respect to these later U.S. RV technological innovations that the Soviet assessments demonstrated a higher level of technical proficiency. It must be emphasized however, that the assessments still ignored many critical questions concerning various RV technologies.

An interesting question--and one for which this study can provide no answer--is why the assessment process has improved. Is the improvement explained by the Soviet military's experience in developing its own RV technology? Or, is it simply that more Soviet military writers are being given access to western sources? Or, are the western sources themselves improving? It is quite probable that the answer is some combination of the three. This change in the quality of the individual assessments has been paralleled by a consistent and unchanging bias in the overall technology assessment process. This process has focused on the specifics of how a given U.S. RV system works; it has shunned subjective evaluations of the performance capabilities of these systems and has rarely employed worst case analyses. In sum, the technology assessment process has sought to provide the Soviet military community with the information which will best allow it to respond to the challenge of U.S. technological innovation.

CONTENTS

1. INTRODUCTION

1.1 Purpose and Organizational Structure

This paper will present a description and analysis of Soviet military assessments of United States re-entry vehicle (RV) technology since 1965. The primary objective is to gain a better understanding of how the technology assessment process of the Soviet military works. There are several facets to a technology assessment process which one can examine. The first is the question of input. That is, what is the basis for these assessments? What type of information is utilized and how is this information acquired? The second facet centers on the question of process. What is done with the information previously acquired? How--through military writings--are technological advances in U.S. RV programs presented to the military audience? If the first facet focuses on inputs, and the second on process, then the third is concerned with outputs. How does the Soviet military respond to advances in U.S. RV technology? Are there calls for technological action? For changes in force structure? For revisions to Soviet military doctrine and strategy?

The second facet--the process--will be the focus of this paper. While the first component, the input, is certainly of interest, limitations in the paper's data base do not allow this issue to be addressed properly.[1] The question of output is critical; but it, too, is beyond the scope of the present paper. One can, however, defend the paper's bias toward process over output on the grounds that what the

Soviet military does in response to particular U.S. technological advances must, in part, be a function of how these technological advances are assessed.

To better understand how the Soviet military's technology assessment process operates, it is useful to analyze Soviet discussions concerning various U.S. RV systems along four lines of inquiry:

Issue 1: Do the discussions focus on the basic physics of the RV system?

Issue 2: Is the focus on simply describing the components of the system?

Issue 3: Is the focus on the system's operational characteristics?

Issue 4: Do the discussions focus on the capabilities of the system?

The above requires further explication. Issue 1 has the most basic focus. A physicist would describe this as starting from "first principles." The focus of Issue 2 is descriptive. Here, a Soviet military writer will discuss, for example, specific technical characteristics and instrumentation. He is asking: What does the system consist of? In addressing the third issue, the writer operates at a higher level of aggregation. He brings together the various components and mechanisms which comprise the system, and asks: How does it all work? An assessment which focuses on this issue is process oriented.

Issue 4 moves one step beyond the third. After aggregating the various components and seeing how they work, one asks: What are the system's capabilities? An assessment which addresses this issue predicts performance capabilities and seeks to assess the system's military significance.

The body of the paper describes Soviet military assessments of various American RV programs. A given assessment may address more than one of the issues noted above, and different assessments of the same technology may focus on different issues. Nevertheless, for each particular U.S. re-entry vehicle technology program, an estimate is made of the primary emphasis of the corresponding Soviet assessments.

The paper's final section will summarize the results. In particular, I will examine how--if at all--Soviet military assessments of U.S. RV technologies changed over the past twenty years. Did the assessments always, on the whole, address the same issue? If differences existed, were they simply a function of variations in the technology[2] which was being assessed? Or, could differences in the assessments be ascribed to systemic considerations, that is, to improvements and/or changes in the technology assessment process over time? Several broader issues will also be addressed. For example, have the technical level and overall quality of the assessments improved over the past twenty years? Finally, drawing upon and aggregating the various military writings, I will present an analysis of the Soviet military's changing perception of the main direction(s) in U.S. re-entry vehicle development.

Three appendices supplement the body of the paper. The first gives a listing of various acronyms; the second provides background information on the various books utilized in this study. Appendix III gives, in some detail, definitions for several of the Russian phrases used in translation throughout the paper.

1.2 Methodology

A number of open source Soviet military books and journal articles concerning U.S. RV technology (see Table 1 and bibliography) were examined and, as a first step, a content analysis was performed.

Table 1
Chronological Listing of Sources

	Books	T&V	VPVO	VM	ZVO**	VZ	Z	VIZh	SVE	KZ	MS
1965				X							
1966		XXX	X								
1967											X*
1968		X	XX	XX							
1969		XX	XX								
1970											
1971	X*X*	X*X	XX	X						X*X*	
1972	X*									X*	
1973		X									
1974	X*X*										
1975											
1976									X*		
1977		X*									
1978		X*					X			X*X*	
1979								X			
1980		X			XX	XX			X*		
1981								X			
1982					XX						
1983		X*									

*Primary sources in Russian.
**Not available in U.S. prior to 1978.

Key:
T&V = Technology and Armaments
VPVO = PVO Herald
VM = Military Thought
ZVO = Foreign Military Review
VZ = Military Knowledge
Z = Znamenosets
VIZh = Military Historical Journal
SVE = Soviet Military Encyclopedia
KZ = Red Star
MS = Naval Digest

Basically, a determination was made of what the military writers were discussing. A quick glance at the table of contents suggests that the Soviet military has discussed nearly all aspects of the U.S. RV research and development (R&D) effort conducted under the aegis of the ABRES (Advanced Ballistic Re-entry Systems) program since 1962.[3] And, indeed, this is true. The reader, however, will see that the assessments of the various components of the re-entry vehicle R&D effort differ in two important respects: (1) Some R&D programs received great attention (for example, penetration aids), while others gained relatively little notice (for example, improvements in the accuracy of inertial guidance systems); and (2) The technical sophistication[4] with which the Soviet military assessed various programs differed markedly.

An important methodological issue here is how one should interpret a lack of Soviet military writing on a given aspect of the U.S. RV program. Should this be taken as an indicator that the military felt no need (and here, the question would be why) to assess a particular technology? Or, should the paucity of assessments be interpreted as a sign that a particular U.S. technology was deemed too sensitive for discussion in the open source Soviet military press. The limitations in this paper's data base (to be discussed below) do not allow me to favor one interpretation over the other. The lack of attention devoted to improvements in the accuracy of U.S. inertial guidance systems is an anomaly and certainly could be cited as evidence in favor of the second interpretation: Improvements to the inertial guidance system of the Mk.12A re-entry vehicle gave U.S. ICBMs a hard target kill capability.[5]

A second aspect of the methodology was to develop a series of issues which allowed me to disaggregate the technology assessment process. These were introduced in the previous section. The motivation behind the creation of this methodological tool was a desire to understand better how the technology assessment process of the Soviet military differed with respect to various technologies and how the process changed over time.

Finally, after analyzing the assessments and categorizing them with respect to which of the four issues they addressed, an aggregate analysis was carried out to study the overall nature of the Soviet military's technology assessment process. The purpose here was to gain a better understanding of the biases and assumptions which underlay the process.

1.3 Sources

The majority of the research material was drawn from open source Soviet military journals and books published by the military publishing house (Voyenizdat). The journals included: Tekhnika i vooruzheniye, Vestnik protivovozdushnoy oborony, Zarubezhnoye voyennoye obozreniye, Voyennyye znaniya, Znamenosets, Voyenno-istoricheskiy zhurnal, and Morskoy sbornik. The only restricted Soviet publication utilized was the journal Military Thought. In addition to the books and journals, two other sources were used: the military newspaper Krasnaya zvezda and entries from the Sovetskaya voyennaya entsiklopediya. In the bibliography, primary sources used in the original Russian will appear in transliterated form.

The fundamental constraint on the analysis and conclusions contained in this report is the limited nature of the data base. As table 1 indicated, slightly over 40 different articles and books were utilized. This number, however, is misleading for several reasons. For one, many of the articles contained only a brief reference to U.S. RV technology (sometimes a paragraph and in several instances only a sentence or two). In addition, much of the material tended to be repetitive--often changing little over the course of several years. Indeed, the author of a 1974 book on strategic rockets lifted (that's being kind) five pages concerning the past development, present status and future direction of U.S. RV technology nearly word-for-word from a 1971 journal article.[6] Finally, within a source devoted exclusively to an assessment of U.S. RV technology, one often found that the discussion was highly descriptive, and simply listed the physical parameters of the RV/ICBM system (for example, RV weight and height, range, CEP, how many the U.S. has deployed, how many the U.S. plans to deploy by a given date). Such numbers and the forecasting for which they are used, while interesting, are not germane to this report.

Given the above, each section in the second part of the paper is preceded by a chart which indicates the nature of the source material. Is the analysis based on books alone? On articles? Being explicit about the nature of the source material allows for control of various factors. For example, suppose that the source material for a certain section consists of chapters from two different books and a two page journal article. Also imagine that after describing these assessments, it is concluded that they were structured to address Issue 1, the "first principles" question. In this instance, one could infer that the conclusion was biased by the nature of the sample. Journal articles are rarely longer than ten pages, and for complex technical issues (like re-entry vehicle technology), they are often only two or three pages long. The point here is that the journal articles--simply due to space limitations--cannot probe a given U.S. RV technology with the same depth as books.[7] Thus, the conclusion--that the assessments stressed an understanding of the basic physics behind the U.S. technology--would be spurious and due to the special nature of the data base.

2. DESCRIPTION OF SOVIET MILITARY ASSESSMENTS OF U.S. RV TECHNOLOGY

2.1 Re-entry Vehicles

2.1.1 Types

2.1.1.1 Multiple Warhead RVs

	Sources	
	Books	Journal Articles
	2	2

The early references to multiple warhead RVs (MRV) were brief and focused solely on performance capabilities.[8] The only performance capability discussed was the ability of MRVs to increase the probability of penetrating an opponent's BMD system.[9] It was precisely for this reason that U.S. planners conceived of MRVs in the late 1950s. The paucity of references to MRVs during the mid-1960s is understandable given that the bulk of U.S. MRV R&D occurred between 1960 and 1964; in addition, any remaining Soviet interest in U.S. MRVs was, by 1967-68, being overwhelmed by concern over the next advance in U.S. RV technology: MIRV.[10]

Several sources in 1971 again pointed to MRVs as a means for facilitating a breakthrough of BMD systems.[11,12] A book published in this year made the first explicit linkage between MRV development and the ABRES program.[13] This author also noted that MRVs were of a "comparatively uncomplicated and imperfect construction designated for ejecting from the rocket three unguided warheads in a bunch."[14] While this source alluded to the drawbacks of MRVs, another was quite explicit about the limitations of such RVs. He noted that since MRVs travel along trajectories which are in "close proximity," they can all be "destroyed by one anti-rocket with a nuclear warhead." He went on to add that "thus the next step in development of multiplecharge nosecones was to give the nosecones their own control [that is, MIRV]."[15,16]

Both of the above authors were focusing on performance capabilities. The second one, in addition, perceived the decision to create MIRVs as driven by inadequacies in the capability of MRVs to penetrate a BMD system. In contrast, another author gave a more complete assessment of MRVs, and very briefly described how the system worked. After again noting that a MRV enhances the probability of penetrating a BMD system, he added that if all the "separated warheads" reach the target then the "area destroyed will be larger than for one warhead with a TNT equivalent equal to the sum of all the separate warheads." As for how a MRV works, it was noted that "multiplecharge nosecones" are those which "separate in the middle part of the trajectory (beyond the limits of the Earth's atmosphere)."[17] Admittedly, this says very little. It is, however, the only assessment where how a MRV works was given at least equal footing with explanations of this system's performance capabilities. In sum--and in terms of the four issues outlined in the Introduction, the assessments of U.S. MRV technology addressed Issue 4, that is, what are the technology's performance capabilities.

2.1.1.2 Multiple Independently Targeted RVs (MIRV)

Sources		
Books	Journal Articles	Red Star
1	3	3

The first assessment of MIRV technology appeared in a 1968 Military Thought article which, in contrast to the writings on MRVs, focused on both performance capabilities and the technical detail of how the system worked. This dual focus was a pattern followed over the next ten years by the majority of Soviet assessments concerning MIRVs. In terms of performance capabilities, this author perceived the U.S. emphasis on MIRV as dictated by the need to "overcome the anti-missile of the enemy [which] constitutes one of the main trends in the modernization and increase in the combat effectiveness of missile systems." The technical details presented by the author dealt solely with the "control systems" of the MIRV bus. It was noted that the bus would have an "improved" control system in the form of "several jet nozzles operating from a two-component liquid-gas generator." Such a control system would allow the bus to change its flight trajectory and release warheads "each of which will allegedly be guided to an individual target."[18]

Three authors, writing in the early 1970s, focused extensively on how the MIRV system would carry out its mission.[19] They sought to explain how one got from an initial state--a rocket carrying several warheads, to a final state where these warheads were striking different targets. The descriptions are essentially the same and really quite simplistic. The sequence of events the three authors outlined is given below: (i) to target the first objective, the heatshield is discarded and the nosecone's propulsion system activated;[20] (ii) the binding latch (zamok krepleniya) of the first warhead is opened; (iii) the control system motors are turned off; (iv) the warhead--now free--continues its flight along a ballistic trajectory; (v) the nosecone changes trajectory and (i) through (iv) are repeated.[21] It should be stressed that this is not a very technical analysis. The level of analysis is below that given, for example, by Herbert York in a 1973 Scientific American article.[22] Yet if one had to select the most technically inclined Soviet assessments of MIRV during the early 1970s, these three authors would be chosen.

All three devoted part of their analysis to an assessment of the MIRV's performance capabilities, with one (Anureyev) discussing them in some detail. Anureyev listed three performance criteria:

(i) MIRV will eliminate the possibility that all warheads will be intercepted by one anti-rocket;

(ii) MIRV allows several targets to be struck simultaneously;

(iii) MIRV warheads are a more effective means of hitting a target than one high yield RV.[23]

Anureyev took several paragraphs to develop the third point. He gave three examples of attacks--two were countervalue attacks against cities, the other was a counterforce attack against a soft area target (air field)--to demonstrate the utility of attacking with many low yield warheads.[24]

A 1977 article on ballistic rocket "nosecones" differed little from the above authors in its assessment of MIRV. The technical detail was no greater, but the author's description did provide a better picture of the complex interaction between the various sub-systems (for example, the guidance and stabilization systems) required to deliver a warhead to its target.[25] The Mk12 guidance system was briefly mentioned; it was described as an inertial system with three gyroscopes, accelerometers and a computer. The Soviet assessments of MIRV technology were unique among those examined for this study as it was not possible to categorize them with respect to the four issues outlined in the Introduction. Issues 2, 3 and 4 were all addressed, and if a bias existed in the assessments, then it was (but only slightly) toward Issue 3, that is, describing the system's operational characteristics.

2.1.1.3 Maneuvering RVs

Sources		
Books	Journal Articles	Encyclopedia Entry
1	4	1

In all Soviet assessments of early (late 1960s-early 1970s) U.S. R&D on maneuvering RVs, there was less discussion of specific performance capabilities than there had been in the case of MIRV. The difference may very well be explained by the differing nature of the debate over the two technologies in the U.S. With MIRV, one group in the U.S. stressed the utility of the technology as a means for penetrating a BMD system. Others, however, perceived MIRV--with its ability to greatly increase the number of warheads at relatively little cost--as a potent counterforce technology. Still others argued for or against MIRV on both accounts.

The point is that there was no broad consensus on what performance capability the U.S. was seeking with MIRV technology: enhanced BMD penetration? counterforce capability? or both? The early maneuvering RV research conducted by the ABRES program, however, left no doubt that the sole rationale for this technology was to increase the probability of BMD penetration. If the Soviet military was following the discussions of maneuvering RVs in the U.S. trade journals (as it no doubt was), it probably saw little analysis of specific performance criteria and instead much discussion of the severe demands that endo-atmospheric maneuvering placed on U.S. RV technology (two examples: the high g environment and severe RV nosetip erosion induced by maneuvers). Thus, one might expect Soviet assessments to parallel these discussions and to focus more on the specific technical characteristics and components which comprised this new technology.

In only one instance, however, was there a discussion (and even then it was very brief) of the technological barriers to be overcome in developing a maneuvering RV. Instead, the assessments focused on very brief explanations of how this new technology would work: How, for example, small fins, in combination with the aerodynamic forces created by the rapidly moving RV, would be utilized to guide the RV through several preprogrammed evasive maneuvers.[26] There was a consistent emphasis on how the maneuvers would be executed, and virtually no discussion of the impact of these maneuvers on the RV itself.[27] Along with this emphasis, there was a focus on the guidance components: the aerodynamic fins, rotating nozzles, and guidance motors.[28]

The first references to maneuvering RVs appeared in 1968. In a formulation typical of those employed by other authors, one source noted that, in terms of performance criteria, the U.S. was developing an RV "capable of carrying out an 'anti-missile' maneuver."[29] Another source also writing in 1968, focused on two specific maneuvering systems being developed by the ABRES program: the maneuvering re-entry vehicle (MRV) and the ballistic guided re-entry vehicle (BGRV). A very brief, nontechnical description of both systems was given.[30] In a different vein, this same author asserted that the MRV and BGRV were being developed for the Minuteman II and Minuteman III missiles.[31] While such a statement was not incorrect, it did give a skewed view of U.S. re-entry vehicle R&D at that time since the main development program--MIRV--was nowhere mentioned.

A 1971 article discussed the BGRV and one other maneuvering system--the maneuverable ballistic re-entry vehicle (MBRV). The description of the two systems was straightforward and nontechnical. In both cases, the author was concerned with describing how the RV executed its terminal maneuvers.[32] Both descriptions were essentially correct, although it was erroneously stated that the BGRV would accomplish its maneuvering "with the help of jet fins [struynyy rul']."[33] In fact, the BGRV, as tested in 1967, contained a propulsion system for executing its terminal maneuvers.[34] These same two RVs were described in 1977 as those U.S. RVs which "have a guided part of the trajectory in the atmosphere's dense layers."[35] It is odd that the 1977 article continued to emphasize the BGRV and MBRV programs. For several years prior to 1977 the bulk of

U.S. R&D on maneuvering systems centered on the Mk500 evader RV and the advanced maneuvering re-entry vehicle (AMARV) system.

It is only the "maneuvering nosecone" entry in the Sovetskaya Voyennaya Entsiklopediya which acknowledged the severe technological demands that endo-atmospheric maneuvering placed on a RV. It noted that the "development of MARVs [that is, maneuvering re-entry vehicles] is connected with technical difficulties more serious than building of normal nosecones," and, in addition, the "greatest difficulties arise in the creation of small (miniaturized) high accuracy guidance systems and working out the heat and erosion resistant materials" for the re-entry vehicle's body.[36] While again a nontechnical assessment, this was by far the best description of the technological challenges and instrumentation requirements generated by the development of maneuvering RVs.

The Mk500 evader RV, the longest running U.S. R&D effort concerning maneuvering technology, was mentioned explicitly only once. And in this case, the author was wrong in describing the Mk500 as a system which "will significantly increase the accuracy of the delivery of the warheads to the targets."[37] The Mk500, due to inherent design features, is incapable of achieving high accuracies.[38] The lack of attention given the Mk500 by Soviet military writers may be an example of a "mundane" technology--the Mk500--being overlooked in favor of more exotic technologies--the AMARV and BGRV, for example. Such a bias toward the exotic would be consistent with the results of other research in this series.[39]

To summarize, the Soviet assessments of American maneuvering RV technology showed a clear bias toward Issue 3; that is, these assessments focused on the system's operational characteristics.

2.1.1.4 Maneuvering, Terminally Guided RVs

Sources		
Books	Journal Articles	Encyclopedia Entry
2	4	1

Prior to 1977, the combination of maneuvering and terminal guidance technology received little attention in Soviet military books and journals. Three authors, writing in the early 1970s, noted in passing the possibility of such a combination, but gave no indication of what it would imply in terms of enhanced performance capabilities for RVs.[40] A statement typical of all three sources is the following: The U.S. is developing an RV which can "maneuver and even aim at the target after they [i.e., the RVs] enter the atmosphere."[41]

A 1977 article pointed to the crucial role that digital computers would play in any combination of maneuvering and terminal guidance technologies, and also briefly discussed both the AMARV and the precision guided re-entry vehicle (PGRV) programs. The author noted that the "use of a ETsVM (in contradistinction to electronic analog apparatus) allows for controlling the work of the control apparatus, the realization of complex maneuvers, heightened accuracy and ... a reduction in the mass and energy requirements of the nosecone."[42,43] Digital technology was emphasized and portrayed as a necessary complement to the guidance and maneuvering technology. The allusion to analog systems is interesting as the U.S., by this time, had long been using digital technology. This reference, in fact, may have been a frank recognition of the need for the Soviet Union to perfect its digital technology.

This same article described the development of PGRVs and AMARVs as part of the ongoing R&D conducted under the aegis of the ABRES program. The author observed that PGRVs would combine maneuverability and high accuracy, and noted that terminal guidance would be achieved with various sensors which used the comparison method (metod sopostavleniya).[44] This is only partly correct. The comparison method is an active means of guidance in that--similar to the Pershing II's RADAG (radar aimpoint) guidance system--a radar beam sweeps the terrain below. In the late 1970s, the U.S., however, was also actively researching various passive means (for example, IR detectors) of terminal guidance. The Soviets focused only on the active technology.[45] In terms of performance capability, it was observed that PGRVs would be able to "ensure accurate target strikes."[46] This same author, when discussing the AMARV, again focused on active means of terminal guidance. The author pointed out that "foreign specialists" consider that a guidance system consisting of "radar and optical rangefinders (altimeters)" should ensure the "required strike accuracy."[47] In fact, the guidance system the U.S. envisioned for the AMARV at that time was passive: a three-axis inertial guidance system.[48]

As before, it was the Sovetskaya Voyennaya Entsiklopediya which presented the most comprehensive assessment of how a maneuvering, terminally guided RV would carry out its mission. Curiously, here, too, only active means of terminal guidance were discussed. It observed that the RV's position in the terminal part of its trajectory was "determined with the aid of an on-board radar altimeter or a rangefinder, a microwave radiometer and other devices."[49] Admittedly, the "other devices" the author had in mind could be passive; even if this was the case, he chose not to discuss them explicitly.

Three other points made in the encyclopedia entry are worthy of mention. At several junctures, the role of digital computers was made quite clear. Secondly, the performance criteria cited for maneuvering, terminally guided re-entry vehicles were quite explicit: Such RVs could be used against "small, strongly defended targets (launch silo installations, command centers and others)." Finally, the need for trade-offs was explicitly recognized: "[c]ompromise decisions" are necessary between the capability of a maneuvering, terminally guided RV "to perfect its effective maneuvers for overcoming the PVO and the possibility of hitting the target with the given accuracy."[50]

Two articles in the last several years described the Pershing II missile and its radar aimpoint guidance system (RADAG). In only one instance was performance capability discussed, and it was in terms of the Pershing II's targeting hierarchy. The listing was much more extensive than that noted for other RVs. The Pershing II, one source noted, was designated for "striking defended and undefended targets such as command centers, surface and underground weapons depots, fuel and other supply articles, railway junctions and the junctions of important highways."[51] The assessments of the RADAG system were the best produced for any re-entry vehicle. The descriptions, however, remained nontechnical in nature. The various components of the guidance system were listed, and both authors gave a brief and understandable description of how the RADAG system sweeps the terrain below and converts these radar scans to digital form for comparison in the on-board digital computer. One author, in addition, presented an excellent schematic presentation of how the RADAG system operated.[52]

In the more recent article, the need for several trade-offs was explicitly recognized. At one point, it noted that a "decision was taken" to reduce the RV's speed by applying "aerodynamic braking upon its entry into the upper layers of the atmosphere."[53] This is a correct explanation for why the Pershing II performs a "tip-up" maneuver as it enters the atmosphere's denser layers.[54] Later on, the author described how the range of the Pershing II could be increased--without adding an additional stage--by replacing the radar guidance system with an inertial one.[55] The RADAG system is larger and more bulky than an inertial system; clearly, a Pershing II equipped with an inertial guidance system would have a greater range.

While the Platanov article was one of the better ones reviewed, it still left much unsaid. For example, with the first trade-off mentioned above, there could have been an explanation of why it was necessary to lower the RV's heat regime (in order to prevent the formation of a plasma sheath around the RV which would effectively blind the RADAG system). Another example: How does one, when constructing a "window" at the tip of the RV through which the radar sees, maintain the integrity of the Pershing II's ablative coating (and hence the accuracy of the RV)? Such questions are examples of the critical technological hurdles which the Pershing II/RADAG R&D effort had to overcome.[56,57]

In terms of the categories previously outlined, the assessments of maneuvering, terminally guided RVs addressed Issues 2, 3, and 4. The emphasis, however, was clearly on the second and third issues; that is, on explaining the "nuts and bolts" of the technology and the system's operational characteristics. The latter issue--operational characteristics--was most consistently addressed by the Soviet military writers.

2.1.2 Thermal Shielding

2.1.2.1 Heat Shields

Sources

Books	Journal Articles
2	1

The discussions of RV heat shields were brief and uniformly negative in nature. Prior to 1971, there was no mention of heat shields (or ablative coatings), but, beginning in that year, various authors noted the many drawbacks of heat shields: the requirement that they have an extremely high surface finish;[58] their excessive weight;[59] their low effectiveness relative to how much they weigh.[60] There was no technical analysis: no explanation of how the RV absorbs the thermal energy which surrounds it. Nor was it explained how the heat absorbed by an RV would be conducted into its internal systems. Instead, the focus was on the end result of such heat induction: a significant increase in the "internal temperature of the nosecone [which] can disable the control system and lead to the destruction of its explosive [podryv] system."[61]

The need to utilize materials with high thermal conductivity was recognized. The only such materials mentioned were copper, beryllium and "others."[62] At one point, it was noted that heat shields could "utilize copper coverings on which is carried a thoroughly polished thin film of nickel."[63] The need to maintain a high ("polished") surface finish was mentioned several other times. Nowhere, however, was it explained why one needed such a high surface finish: Any surface anomalies induce asymmetries in the heat transfer and ablation processes, which in turn produce asymmetries in the RV's surface. These surface asymmetries will degrade the RV's accuracy.

In sum, the few assessments which did discuss heat shields all showed a bias toward addressing Issue 2; that is, these assessments were oriented toward describing the technical characteristics of heat shield technology.

2.1.2.2 Ablative Coatings

Sources		
Books	Journal Articles	Encyclopedia Entry
2	1	1

Ablative coatings were discussed much more than normal heat shields. The use of such coatings was clearly presented as the only way to surmount the considerable drawbacks posed by heat shields. Several times, it was noted that ablative coatings were receiving intensive study in the U.S.[64] In addition, the "Golovnaya chast' rakety" entry in the Sovetskaya Voyennaya Entsiklopediya mentioned only ablative coatings when discussing RV thermal shielding.[65]

The technical analysis of how ablative coatings work was at a higher level than seen elsewhere. One author noted that ablative materials "partially absorb the thermal energy" surrounding the re-entry vehicle and "with their evaporation" transfer that thermal energy not to the nosecone but to the "gaseous wake flowing from the nosecone."[66] Writing in 1974, another author gave a good description of an active ablative coating.[67] It is interesting that the author chose to place active coatings first in the listing of various thermal shields he described. Such coatings presented, at that time, a considerable technical challenge, and the U.S. was nowhere near to deploying them on its ICBMs.[68] An active coating was, however, flight tested on a U.S. RV in late 1974--approximately six months after this author's book was signed to press.[69] Several sources cited inherent advantages in utilizing ablative materials as thermal shields. One author noted that such materials could "withstand significant thermal flows [and] they are light";[70] another claimed that "existing [ablative] materials allow the removal in the [nosecone's] outer layer--in the process of its decomposition--of nearly 50% of the heat supplied to the nosecone."[71] The same author noted that ablative materials worked so well due to their low specific conductivity. As for the materials to be employed in ablative coatings, the following were mentioned: plastics, fiberglass, silica, carbon and graphite.[72]

Although the data base is small, the assessments of ablative coatings technology were structured in such a way that three of the four issues outlined above were answered. Issues 1, 2 and 3 were all addressed, with a bias in favor of the third question--that is, the operational characteristics of ablative coatings. This technology area was one of the few instances where the Soviet military assessors addressed the "first principles" question. The reason for this, however, may simply be the nature of the sample (see box at beginning of section). Half the sources for this technology area were books; and, as noted above, it is most likely only in books that Soviet military writers have the space to probe in depth a given U.S. technology.

2.1.3 Radar Masking

Soviet military assessments of radar masking technology and the implications of that technology for ballistic missile defense comprised the most extensive and long-running body of literature encountered in preparing this study. The critical problem created by the various means of radar masking (chaff, dipole reflectors, high altitude nuclear explosions) was one of discrimination. Whether or not a given U.S. ICBM carried MIRV warheads mattered little if it was impossible (or extremely difficult) to identify even one warhead in a cloud of penaids which could easily number in the thousands. The following discussion has been divided into sections on active and passive means of radar masking (false targets in Soviet military terminology). Among the former, the Soviets include RVs equipped with radio transmitters to jam radar stations, penetration aids equipped in a similar way, and high altitude nuclear explosions. Passive means include pneumatic spheres, dipole reflectors and corner reflectors.[73]

2.1.3.1 Passive Means

Sources	
Books	Journal Articles
3	2

The first discussions of "counter-radar" operations occurred in 1966. A PVO Herald article noted an increase in such operations; their goal was to ensure the "penetration of airplanes or missile warheads through the air defense."[74] Several months later, an article appeared which gave a well-written, highly technical assessment of "anti-radar camouflage."[75] The basic techniques of anti-radar camouflage were:

(i) manipulate warhead design to reduce its radar cross-section;

(ii) utilize radar absorption materials to reduce the radar cross-section;

(iii) employ various false targets (corner reflectors, dipoles, decoy rockets).[76]

Three points need to be made about this article. First, the discussion of how the various types of radar absorptive materials work was excellent. A good Scientific American-level analysis was accompanied by instructive diagrams. As regards false targets, the listing was extensive: chaff, corner reflectors, passive electronic equipment, radar signal re-beaming, inflated metal balloons, small rocket packages, and "other devices" were all mentioned. It was recognized that, while false targets burn up in the atmosphere, they would "mask the warhead at the trajectory midpoint." In fact, false targets could hamper or preclude altogether "observation of the real radar targets."[77] Finally, the article's overall quality--while high--was diminished by one egregious error. In discussing re-entry vehicle design, the author noted that the optimal shape--pointed--for minimizing the radar cross-section was also the shape which reduced heat loads generated upon atmospheric re-entry.[78,79] A pointed shape actually maximizes the heat loads generated on the RV as it enters the atmosphere.

By 1971, the discussion of passive means of radar masking had been extended to cover several new methods, and additional detail was given on several techniques assessed earlier. One author discussed false targets covered with thermal shielding. Such shielding could protect the false targets from the heat generated upon atmospheric re-entry and therefore help to mask RVs in the final part of their trajectory.[80] The author failed, however, to note the prime drawback of such a penetration aid: its heavy weight. This same writer presented a unique opportunity to see how a western source was utilized. In the course of his text, he referred to a specific issue of the American journal Space/Aeronautics as the source for a list of various ways to protect an RV from anti-rockets.[81] Table 2 summarizes the author's listing, while table 3 is a reproduction of the western source. A comparison of the two tables reveals that the Soviet author:

(i) gave re-entry vehicle configuration/materials higher priority in his list;

(ii) dropped any reference to re-entry vehicle attitude control;

(iii) placed active ECMs in his secondary listing;

(iv) placed maneuverable RVs above multiple RVs;

(v) placed hardened RVs and high yield warheads in his secondary list;

(vi) dropped any reference to nuclear blackout and EMP.

Several interesting points follow from this comparison. For one, the fact that, in 1971, the Soviet author placed maneuvering RVs above multiple RVs is consistent with the discussion above which noted that Soviet military writers often favor the more exotic technologies in their analyses. U.S. MIRV deployments had begun the previous year (1970); maneuvering re-entry vehicles--while undergoing flight testing during this period--were still many years away from actual deployment. The second interesting point is that the Soviet author dropped the reference to nuclear blackout of BMD radars as a means of protecting an RV. A bit of speculation is worthwhile here. Given that the Soviet ABM system (the Galosh) deployed at that time would probably have blinded itself with blackout on its first shot, the Soviet author's omission of any discussion of nuclear blackout may have reflected a desire on the part of the Soviet military not to discuss weaknesses of its own systems.

Table 2

Various Methods of Defending an RV From Anti-Rockets

(i) Blow-up last stage of rocket;

(ii) False targets (pneumatic balloons and heat resistant cones, for example);

(iii) RVs with special shapes or with special radio absorbing coatings;

(iv) Dipole reflectors;

(v) Maneuvering re-entry vehicles;

(vi) Nosecones consisting of several nuclear warheads (either multiple RVs (MRV) or MIRV; it is not clear to which he refers);

Separate from the above were listed three others:

(i) Deploying electronic countermeasures against BMD radar stations;

(ii) Hardening of RVs to withstand effects of explosions by "nuclear tipped anti-rockets;"

(iii) RVs carrying high yield warheads (60-100 megatons).

Note: The above lists preserve the author's rankings.

Source: Ivanov, A. (1971). Raketno-yadernoye oruzhiye i ego porazhayushchee deystviye. (Moscow: Voyenizdat), 29-30.

Table 3

Penaid	Objective	Technique	Vulnerability of Anti-ICBM System	Defense Countermeasures
Booster Fragments	Overload midcourse discrimination capability.	Break-up of ICBM's booster to add hundreds of echo-producing fragments to target complex during midcourse flight. Heavy pieces reenter atmosphere.	For out-of-atmosphere intercepts; presents major problem due to lack of real-time and precise discrimination capability.	Strike for entire target-complex cloud with high-yield long-range interceptor missile to destroy as many elements in cloud as possible. Use of several interceptor missiles is advantageous. Develop discrimination capability if possible, but best countermeasure is to delay intercept until cloud reenters atmosphere.
Light Decoys (Balloons, Cones)	Deceive and/or overload midcourse discrimination and tracking radars.	Inflate multitudes of metalized balloons for release during post launch phase. Disperse light reentry-vehicles—shaped lightweight cones with good radar reflectivity.		
Chaff	Overload midcourse tracking radars, break tracking.	Release metal strips or wire cut to ½ wavelength at radar operating bands. Heavy variety can reenter. Overload tracking circuits, and discrimination computer.		
Heat Resistant Decoys	Overload or confuse terminal-phase intercept radars.	Build decoys, cone or other shapes of magnesium-thorium coated steel to resist burn-up and enter at rate approaching RV.	Can be severe depending on capability of radar systems, quality of reentry signature data, and sophistication of enemy's technology.	High power radars with high resolution can develop usable signals. Shifting radar frequency tends to negate effects of radar absorbers. Delay intercept as late as possible.
Reentry Vehicle Configuration/ Materials	Reduce wake to minimize radar signature during reentry phase.	Careful boundary layer control for minimizing shock waves during reentry. Selection of RV material to minimize plasma sheath. Cover RV with radar absorbing material.		
Reentry Vehicle Attitude Control	Minimize radar observability.	Align reentry vehicle with thrusters or aerodynamic tabs to point at radar for low radar observability.		
Active Electronic Countermeasures	Jam, confuse or deceive radar during reentry.	Generate broadband white noise, to swamp radar receiver; return false echos, delayed in time, to radar; break tracking continuity with rate-changing signals or multiple signals.	Can be severe, depending on sophistication of enemy effort.	Raise radar power, antenna gain and effective aperture to overcome high noise environment, shift radar frequency to avoid spot noise (frequency agility radar).
Multiple Reentry Vehicles	Attack several targets, or improve effectiveness against one target.	Provide multiple reentry vehicles that are discharged from a "delivery bus" during midcourse travel. Directed at one or several different targets.	Major problem to combat, but also a major task for enemy to develop and deploy.	Provide high order of multiple target tracking and interceptor guidance; intercept before reentry vehicles separate.
Maneuverable Reentry Vehicles	Avoid interceptor missiles, break radar track, select new target near end of ballistic trajectory.	Use of rockets out of atmosphere or aerodynamic surfaces in-atmosphere to maneuver primarily during reentry and strain interceptor guidance capability, and select new target after reentry. Includes technique for entering target area at very low altitude to come in below radar control.	Severe problem, but places heavy demands on enemy technology.	Improve interceptor missile maneuverability, use high capability radar with wide aperture, broadly programed capability.
Hardened Reentry Vehicle	Survive near-miss nuclear blast.	Design warhead and controls to withstand radiation from blast (gamma rays, heat), shock, electromagnetic pulse and other effects. Shield with dense (and heavy) materials, ruggedize, insulate.	Relative; depends on kill mechanism of interceptor warhead, and its guidance accuracy.	Improve guidance accuracy of interceptor, increase nuclear yield, use terminal seeker on in-atmosphere interceptor.
Very-High-Yield Nuclear Warhead	Destroy target in spite of intercept; preclude need for penetration to target.	Use of 50 to 100 megaton nuclear warhead permits detonation at 100,000 ft, out of range of terminal intercept. Use at lower altitude assures breaching defense even if intercepted.	Terminal defense system may be negated by its use.	Attack incoming warhead long before it reenters atmosphere. (Provide shelters and harden installations.)
Nuclear Blackout	Invalidate or degrade radar operation with precursor nuclear blast.	Cause attenuation and disruption of ABM radars by ionizing the atmosphere, making it opaque to signals. Effect varies with frequency and altitude, and is most severe near or in fire ball.	Can be severe enough to limit use of radars, but enemy might more profitably attack targets with bomb than seek to achieve blackout conditions.	Employ radars at several frequencies to select operation in least affected band. Use multiple phased array systems and take side looks with arrays not affected, feeding to blinded installations.
Electromagnetic Pulse (EMP)	Destroy control and communications cables, electronics components, with precursor blast.	Generate very-high intensity EMP by locating asymmetrical nuclear blast on or near ground, as secondary effect of gamma ray pulse. Weapon may be optimized for EMP.	Limited by shielding of ABM system and self-defense capability, but may easily exceed moderate levels of shielding.	Sheath cables and equipment with electromagnetic shielding material. Provide ultra-high-speed circuit surge protection of sensitive components.

*Several techniques may be combined by the enemy in his efforts to penetrate. For example, use of [illegible] decoys, radar chaff and a hardened reentry vehicle for midcourse, plus active ECM and maneuverable reentry for the terminal phase. [illegible] of the defense to be penetrated would determine the mix.

Source: Dulberger, L. (1966). "Strategic Missile and Air Defense," Space/Aeronautics. Vol. 46, No. 4, p. 75.

Anureyev, also writing in 1971, expanded the discussion of various passive means of radar masking.[82] He noted that false targets such as those with coverings of metallized plastic or metal screens could imitate the radar characteristics of ballistic missile RVs.[83] He also discussed tethered dipoles (privaznye dipoli): They would be released by the RV but not separate completely from it, and thus follow the RV to a low height.[84] If true, this is an interesting way to surmount the weight problem associated with endo-atmospheric penetration aids. Anureyev, however, did not address the real technical issue here: From what type of heat resistant and flexible materials would such tethers be made? Anureyev went on to estimate that the space covered by a cloud of false targets would be "several tens of kilometers in diameter and over 100 kilometers in length." In addition, he noted that each U.S. ICBM could carry a 200 kilogram container carrying up to one million dipole reflectors.[85]

In summarizing these assessments, it is clear that, with one exception, they were not highly technical in nature. Rather, they were concerned with how and when the passive means of radar masking would be deployed, and--most importantly--with the beneficial impact such deployments would have on the performance capability of re-entry vehicles in terms of enhancing their probability of penetrating a BMD system. With respect to the issues outlined above, these assessments at various points addressed all four. The clear bias, however, was toward explaining the operational characteristics of passive radar masking--toward explaining how such masking worked (Issue 3).

2.1.3.2 Active Means

Sources	
Books	Journal Articles
1	3

The first substantive discussions of active radar masking appeared in 1968--two years after the initial assessment of passive means. The technology involved in perfecting many active systems of radar masking (for example, anti-radar homing missiles) was complex; and at least one Soviet author, writing in 1968, recognized this fact. He noted that the use of active methods was a "radical measure."[86] He went on to mention two active means: (1) the DRADs anti-radar missile; and (2) false targets equipped with radar jammers. The DRADs (Degradation of Radar Defense Systems) missile was in fact one of the ABRES R&D efforts at that time.[87] The false targets the author described were quite exotic as each would have its own solid fuel engine. Such false targets would operate in the following manner:

(i) separate from RV, fly ahead of it;

(ii) false target next determines operating frequency or frequency ranges of BMD search radars;

(iii) false targets then jam radars.[88]

Implicit in this discussion is a good amount of high technology. Explicit, however, was only an explanation of how that unmentioned technology would be utilized to enhance the BMD penetration capability of an ICBM.

Anureyev, in 1971, devoted roughly equal space to active and passive means of radar masking. At the beginning of his section on radar masking, he made the curious claim that since U.S. RVs (in particular referring to maneuvering RVs and RVs with radar absorbing coatings) were still in a "developmental stage," the U.S. had "designated less complex mechanisms--in particular means of passive or active radio countermeasures--for overcoming anti-rocket defense systems."[89] The implication was that delays in U.S. re-entry vehicle R&D were providing the impetus for research into penetration aids. Such reasoning, however, appears flawed as the U.S. penaids program had a development history which stretched back to the early 1960s.

Anureyev discussed three active means. The first two were those noted above (that is, the DRADs missile and false targets equipped with radar jammers); the third was a high altitude nuclear explosion. He did not attempt to explain the atmospheric ionization processes triggered by a nuclear explosion; rather, he focused on the result of such explosions: radio and radar blackout. He noted that the duration of the blackout was a function of the detonation height, and cited two examples of high altitude nuclear explosions. The first, a one megaton detonation at 60 kilometers, blinded the BMD radar stations for five minutes; the second, a one megaton explosion at 100-200 kilometers, blinded long-range detection stations (operating at meter wavelengths) for 17 minutes.[90] Ivanov also referred to several active means of radar masking when he discussed the table from the journal <u>Space/Aeronautics</u> (see table 2 and listing on pages 27 above). One should note, however, how he treated the active systems. The active ECMs were placed in his secondary listing and the reference to another means of active radar masking--nuclear blackout--was dropped. One should not make too much of this, but his actions were consistent with a trend apparent in the 1970s. After about 1974, in the sources examined for this study, there was a pronounced tendency to refer only to "false targets" (making no distinction between passive and active means), and even then the discussions were very brief.

The analysis presented in two Tekhnika i vooruzheniye articles is relevant to the above point. The articles, which appeared in 1971 and 1977, were devoted entirely to re-entry vehicles.[91] There was no mention of active means of radar masking. Both articles, in discussing MIRV, noted in passing that false targets were released along with the warheads (the 1971 article specifically mentioning wire dipoles).[92] In discussing false targets, both articles described them in a negative fashion, and noted the utility of another means of passive radar masking: radar absorptive coatings for the RV. The 1971 article stressed that the use of multiple warhead RVs complicated the work of the BMD radar and therefore allowed for a reduction in the "too many and expensive false targets."[93] The 1977 article reasoned in the following way:

(i) Fact: "spherical blunting" of the RV's tip assists in braking RV upon atmospheric re-entry;

(ii) In turn, this allows thickness of RV heat shield to be reduced;

(iii) However, (i) above also "demasks" the RV on BMD radar screens;

(iv) This demasking "forces [vynuzhdaet] the use" of special materials which absorb radiation;

(v) The spherical blunting, while reducing heat shield weight, not only demasks RV but also increases time it spends "in field of view of means of PRO;"

(vi) Therefore, it is "required" that "in certain cases" the RV be masked with the aid of false targets.[94]

The critical link in this analysis is the heat shield. If one had available lightweight thermal shielding which could withstand high temperatures--in other words, lightweight ablative coatings, then the need for "spherical blunting" of the RV's tip would be eliminated. The Soviets apparently experienced great difficulty in making the transition from heavy heat shields to ablative coatings.[95]

On the whole, the Soviet assessments of active radar masking focused on operational characteristics, that is, Issue 3 was addressed. In addition, as the 1970s progressed, Soviet military writers devoted less attention to this technology area. One can adduce three reasons for this lack of interest in active radar masking technology. Most obviously, the 1972 ABM Treaty made BMD penetration (via both passive and active radar masking) less of an issue. In addition, MIRV--which resulted in a huge increase in the number of Soviet and U.S. warheads--made the protection of each warhead (via various penetration aids) a much less important issue. Finally, and related to the first reason, if the Soviet assessors were following the U.S. aerospace trade press, then the decline in Soviet discussions of penetration aids technology after 1974 was not surprising: Interest in and trade press coverage of such technology in the U.S.

dropped significantly in the latter part of the 1970s. A final note of interest: Two recent American sources claim that the USSR has never deployed pen-aids on any of its ICBMs.[96,97]

2.1.4 Hardening

Sources	
Books	Journal Articles
3	4

The year 1971 marked a major breakpoint in the discussions concerning re-entry vehicle hardening. Prior to this year, the assessments were extensive, technical in nature, and concerned with explaining the effects produced on a RV by the explosion of a "nuclear tipped anti-rocket." After 1971, only brief references were made to continuing U.S. work on RV hardening. One surmises that the change in Soviet assessments was induced by the 1972 ABM Treaty. With the treaty in force, the primary reason for hardening--the existence of nuclear-tipped anti-rockets--was virtually eliminated.

The first assessments of hardening appeared in 1969 and were concerned with explaining both U.S. advances in hardening technology and the physical principles underlying the interaction between a RV's electronic components and the various types of radiation produced by a nuclear explosion. One author noted that the U.S. was working on a fiber optics/laser firing mechanism for its RVs to increase the mechanism's resistance to electro-magnetic pulses (EMP).[98] The same author explained that shielding the entire RV to enhance its resistance to EMP was "used almost not at all" because such shielding was too heavy. Separate shielding of various components within the RV, however, was a possibility.[99]

Another author, writing in the same year, focused on the vulnerability of semi-conductor devices utilized in RVs. He claimed that such devices were "one order of magnitude less resistant to nuclear radiation than radio tubes, capacitors, resistors [and] induction coils."[100] He followed this with a good description of why semiconductors are so vulnerable to the current and voltage pulses induced in them by EMP.[101] The article was somewhat curious for what it omitted: There were virtually no references to what could be done to counter the effects of nuclear explosions (an increase in RV shielding was again rejected due to the weight increase that would result). Indeed, the message of this article could be that the less advanced electronic technologies--tubes and the like--were the proper ones to utilize in RVs. Given that at the time, the state-of-the-art in Soviet electronics was far from perfecting semi-conductor technology (vacuum tubes were in fact still widely used), this assessment of U.S. technology may have been biased by the state of Soviet technology.

A book published in 1971 devotes a chapter to the effects of high altitude nuclear explosions on re-entry vehicles. In a vein consistent with the earlier articles, there was almost no discussion of how one protected an RV from such effects. Rather, the emphasis was on understanding how the radiation incident upon the RV was conducted inward and what the effects were of such conduction. This discussion was very well informed and quite instructive. The authors of this book first discussed how soft x-rays effect an RV. They noted that such radiation was absorbed in the RV's outer layers; this absorption degraded the thermal shielding which in turn led to thermal loading and the destruction of the RV.[102] The authors then examined the problem of a neutron flux incident on a re-entry vehicle. They stated that in this case, it was not so much the RV electronics which were vulnerable as the "nuclear charge" itself.[103] The authors also noted that the kill radius (for both soft x-rays and neutrons) of an anti-rocket with a one megaton warhead was nearly 2 kilometers.[104]

Beginning partially in 1971 and totally thereafter, the references to U.S. R&D on hardening technology were very brief and no effort was made to explain how the radiation produced by nuclear explosions generated a need for hardening. The following is representative of these references:

> Basically, all research in the field of the defense of nosecones from nuclear explosions is directed most of all at ensuring the shielding of the radioelectronic apparatus, [and] the guidance and control [kontrol'] instruments of the nosecone from electromagnetic impulses and x-ray radiation.[105]

In sum and in terms of the four issues posited above, the assessments of U.S. re-entry vehicle hardening were primarily concerned with addressing Issue 1--that is, the basic physical principles behind the effects of nuclear explosions on RVs were discussed.

2.1.5 Design/Shape

	Sources	
	Books	Journal Articles
	1	2

The discussions of the design and shape of U.S. re-entry vehicles were few and brief in nature. The assessments did reflect, however, the changing emphasis of U.S. research in this area of re-entry vehicle technology.

Two authors, writing prior to 1972, discussed RV design only in the context of how that design affected the RV's effective radar cross-section. That is, re-entry vehicle design was considered in the context of how it could maximize the "radar masking" capabilities of the RV. Writing in 1966, one author noted that the optimal nosecone design was a "pointed" one since such a design would reduce the RV's radar cross-section.[106] Implicit in this author's discussion was the assumption that RV design could be manipulated to enhance the probability of penetrating a ballistic missile defense. Five years later, Anureyev explicitly linked his discussion of RV design with the "possibility of overcoming an anti-rocket defense system."[107] He contrasted an RV which had a "blunting" (prituplennaya) form with one which was more "sharply shaped." He stated that while a blunting form was considered advantageous for manned travel through space, such a form on a RV led--upon atmospheric re-entry--to the creation of an "intensive track of ionized air" behind the RV. Such a track was a "demasking sign" which would be detected by a BMD radar station. In addition, he noted that a "more sharply shaped RV is conducive to radar masking."[108]

It is not surprising that both authors--writing prior to the 1972 ABM Treaty--focused on the manipulation of RV design as a means to minimize the RV's radar signature. During the late 1960s, the emphasis in the

U.S. re-entry vehicle R&D effort was to enhance the probability that a BMD system would be penetrated by a given RV. Enhanced penetration probabilities were sought in a number of ways--one of which was manipulation of warhead design.

The one assessment of U.S. RV designs which appeared after 1972 reflected a change in emphasis which was consistent with the shifting focus of the U.S. research effort. Throughout the 1970s and particularly after 1974, re-entry vehicle R&D in the U.S. has focused on both enhancing terminal maneuver capabilities and improvements in terminal accuracy.[109] As a result, in addition to the earlier stress on manipulating RV design to decrease vulnerability to BMD intercept, the U.S. has placed equal (or at least substantial) emphasis on utilizing changes in design to minimize the dynamical loading (due to endo-atmospheric maneuvering) placed on the RV's delicate terminal guidance apparatus. Not surprisingly, the Soviet author, writing in 1977, now discussed several criteria, in addition to concern over BMD, which governed U.S. re-entry vehicle design considerations. He noted that RV designs should ensure: minimal drag effects, the minimal possible effect of heat flows on the RV's internal apparatus, the withstanding of "maximal shocks" during maneuvers, and also the "firm[ness of the RV] to the influences of the explosions of anti-rockets."[110] The concern with BMD was still evident, but it was now seen as only one of several considerations which guided U.S. R&D into re-entry vehicle design.

The assessments of U.S. re-entry vehicle design and shape clearly had two purposes: to describe this technology and to assess how it would influence the performance capabilities of U.S. RVs. With respect to the four issues, these assessments addressed the second and the fourth.

2.1.6 Guidance Systems

Sources		
Books	Journal Articles	Encyclopedia Entry
2	2	1

It is useful to divide Soviet assessments of U.S. re-entry vehicle guidance system technology into two sections: assessments which examined inertial guidance systems and those which analyzed terminal guidance technology. The former were universally brief in nature and highly descriptive; in short, the Soviets showed little interest in assessing inertial systems. Terminal guidance technology was, however, another matter. As was noted in section 2.1.1.4 above, and as will be discussed below, the discussions of terminal guidance were several of the best encountered in preparing this study.[111]

The most extensive description of an inertial guidance system appeared in 1977. The author noted that a nosecone guidance system "usually" consisted of "an inertial system for measuring angular coordinates and automatic orientation, an electronic digital computer (ETsVM), a transformer-amplifying unit, [and] guidance organs."[112] Descriptions by other authors of the Minuteman II and Poseidon C3 guidance systems said even less. For both systems, the only element of the guidance apparatus discussed was the digital electronic computer. In neither case was it even mentioned that the guidance systems were inertial.[113]

The first Soviet discussion of further advances in U.S. guidance technology appeared in 1974. At this time, it was noted that U.S. research to increase ICBM accuracy was proceeding along two tracks. The first involved "improving existing systems" by creating "new on-board guidance systems with more sensitive measuring elements." The second track consisted of guidance systems which were "being constructed with the calculation of the rocket's guidance not only in the period of its active flight, but also with its entry into the atmosphere's dense layers."[114] The first statement was an apparent reference to the guidance system improvements which were a part of the Mk12A RV program (more on this below); the second was a clear allusion to a terminal guidance system--most probably to the maneuvering ballistic re-entry vehicle (MBRV) program which had been active since 1966.[115] The MBRV program apparently utilized terminal sensors in several of its test flights.[116] This author, however, appeared to be "jumping the gun" somewhat as the first serious U.S. R&D effort which focused on terminal guidance did not begin until 1975-6.[117]

With terminal guidance systems, there was some discussion of performance capabilities, but much greater attention was devoted to explaining how the technology worked.[118] As already noted, these analyses were informative and understandable. To say this is not to imply that these assessments touched on all the critical issues involved in the development of terminal guidance technology. One example of a critical technology area which received virtually no attention is guidance system miniaturization. Only one Soviet source mentioned this issue, and even then it was only in passing.[119] Miniaturization of various guidance system components was a major hurdle which the U.S. terminal guidance research program had to overcome. Re-entry vehicles are not large objects, and if individual RVs are to be equipped with terminal guidance equipment, then it is essential to make that equipment as small as possible so as not to force reductions--for example, in warhead size.[120]

For inertial guidance systems, little effort was made to assess performance capabilities or to explain how such systems operated. This is surprising given that the only new guidance technology the U.S. actually deployed in the 1970s was the improved inertial guidance system which accompanied the Mk12A re-entry vehicle. Perhaps this technology area was deemed too sensitive for open source assessment due to either: (1) analogous advances in Soviet re-entry vehicle guidance technology beginning with the deployment of their fourth generation ICBMs in 1975;[121] or (2) the hard target kill capability which the Mk12A RV would possess.[122]

Overall, the Soviet assessments of U.S. inertial guidance were clearly biased toward addressing Issue 2 of the four posed above--that is, what were the technical characteristics of this technology? With respect to terminal guidance systems, the Soviet assessments were more detailed and oriented to addressing two issues: how did this technology work (Issue 3), and what were its performance capabilities (Issue 4).

2.2 Impact of RV Technology on Ballistic Missile Defense Systems[123]

As will be discussed below, throughout much of the period covered by this study the Soviet military perceived the main impetus driving U.S.

re-entry vehicle R&D as the need to increase the possibility that a given RV would penetrate a BMD system. The deployment of various penetration aids and to a lesser extent the development of multiple warhead RVs posed a critical problem: discrimination.[124] How did one select a re-entry vehicle from a cluster of hundreds or thousands of penaids? The writings which addressed this issue presented several of the most explicit calls for action seen in researching this study. The writers focused on two technology areas: computer systems and detection technology. The emphasis on computer technology had a single focus: the need to employ computers capable of rapid data acquisition and processing--that is, digital systems. The writings on detection technology had a dual emphasis. There was a stress both on improving BMD system detection capabilities (for example, radar and infrared) and also on gaining a better understanding of the basic physical processes which governed the interaction between a re-entry vehicle (or penetration aid) and the atmosphere as the RV (or penetration aid) approached its target.

Before addressing the particular technology areas, it is important to understand how Soviet military writers perceived the threat posed by the above mentioned advances in RV technology. Writing in 1968, one author noted:

> the destruction of a considerable mass of ballistic missiles at the initial (primarily active) segment of the trajectory facilitates the conditions for intercepting the warheads at the terminal segment of the trajectory and will not require the solution of a difficult problem--selection, since the release of dummy warheads is technically feasible only at the end of the active section or at the start of the passive section [of the flight].[125]

Ostensibly, this writer was discussing trends in U.S. BMD. The lesson to be drawn for Soviet BMD, however, would not be lost on the readers of this particular journal (PVO Herald). Four months earlier, the readers of this same journal had been told that the U.S. was planning to utilize large numbers of false targets.[126] The lesson was clear: To avoid the problem of "selection" and hence maintain the effectiveness of one's BMD system, either exo-atmospheric or perhaps even space-based means of BMD had to be considered along with endo-atmospheric/terminal defenses.

Anureyev, writing in 1971, advocated a less radical response to the improvements in U.S. RV and pen-aids technology. Anureyev noted that at the present time a "universal means" of identifying RVs "does not exist," and therefore it was necessary to combine several identification methods in order to increase the probability of detecting a RV among false targets.[127,128] He went on to conclude that the optimal BMD system was that which obtained the greatest quantity of data about the targets in a time which would give the possibility of taking measures for striking the incoming RVs.[129] Thus, in the course of three years, one had both a possible call for changes in force structure to counter the threat posed by a proliferation of targets and an explicit call for technological action--from Anureyev--to meet that same threat. While one should avoid drawing conclusions on the basis of two data points, it is worth noting that the two calls for action did not conflict and in fact complemented one another. If for nothing else, one should take these calls for action as an indicator of the seriousness with which the Soviet military viewed the threat posed by radar masking (passive and active) and MIRV.

2.2.1 Detection Technology

The need for improvements in radar technology was recognized as early as 1968. One author, writing in that year, noted that as the U.S. began to utilize radar absorbing materials on its RVs, it would be necessary to increase the radiating power of BMD radars.[130] Anureyev, focusing more on the multiplicity of targets than on the ability of one target to conceal itself, stated that BMD radar stations needed to have high resolving power in order to obtain information on all the targets.[131]

Anureyev, also presented a technical analysis of the various ways in which a BMD system could attempt to detect an incoming RV. Before undertaking his analysis, he noted that the

> examination of the characteristics of targets is presently considered to be of paramount [vazhneyshiy] importance since the radiation and reflection of energy and also the interactions with the surroundings depend on exactly the basic form of these characteristics.[132]

Here, he made a basic point: Before investing heavily in R&D for various detection methods (radar, IR, etc.), one should understand what it is one expects to detect. Anureyev's use of the phrase "paramount importance" is suggestive of the importance he attached to this kind of basic research. Anureyev next outlined the various possible detection methods. His analysis proceeded in the following order:

(i) radar detection;

(ii) detection by IR means;

(iii) detection by identifying an object's electromagnetic signature (this detection to be carried out by "special" radar stations);

(iv) detection by measuring doppler shift;

(v) detection of RVs by examining the composition of their plasma wake.

He noted that the first two methods required a "very large" amount of time and therefore did not ensure timely detection of the target.[133] "Even" the fifth method, he concluded, did "not answer the contemporary demands of ensuring the dependable identification" of RVs. Anureyev finished by noting that "work on the modernization of already operational methods [of detection] and the development of new methods is continuing" and foreign countries were allocating large sums for such research.[134] In the context of the analysis he presented, these words appeared to present a call for action. It was a call not for changes in force structure or doctrine, but for technological action: both at the theoretical (that is, basic research) and applied levels (that is, utilizing the results of the basic research to enhance BMD detection capabilities).

2.2.2 Computer Technology

Several authors were unambiguous in noting the demands placed on the computer hardware of radar stations by the appearance of multiple and maneuvering RVs and, in particular, of penetration aids. In 1971, one author noted that the timely detection of distant targets meant "primarily to reduce time spent on obtaining and processing radar information to a minimum." In order to obtain this "minimum," computers were necessary which would not only process the radar data input, but also analyze the data, and determine the type of the target "be it an aircraft, missile or artificial earth satellite."[135] Writing in 1969, another author noted that the U.S. TacMar BMD radar was connected to an electronic computer which allowed for rapid, high speed target acquisition, tracking and interception. In addition, when several targets were detected this computer determined "whether or not they are the warheads of an ICBM or false targets." He went on to note the importance of the redundancy built into the TacMar's information processing system.[136] Redundancy was critical because of the need to respond with "exceptionally high speed" to an incoming ICBM strike. Thus, if one system failed there must be a backup ready to replace it immediately.

3. SUMMARY AND CONCLUSIONS

3.1 The Nature of the Soviet Military's Technology Assessment Process

Before summarizing the results of the paper's second section, it is useful to look more closely at the issues utilized to probe the nature of the technology assessment process of the Soviet military. For reference, I will again list the four issues:

Issue 1: Do the discussions focus on the basic physics of the RV system?

Issue 2: Is the focus simply on describing the components of the system?

Issue 3: Is the focus on the system's operational characteristics?

Issue 4: Do the discussions focus on the capabilities of the system?

Several examples will demonstrate the analytic utility of disaggregating the Soviet assessments in this manner. As a start, one can ask why the Soviet military would structure its assessments of U.S. technology in such a way that Issue 1 was primarily addressed. One possibility is that a given U.S. technology was poorly understood within the Soviet military establishment. This lack of understanding could very well arise because the military community had not yet mastered the Soviet counterpart to this U.S. technology. In a pedagogical sense, too, it would make most sense for Soviet military assessors to address Issue 1. As any teacher knows, the best way to educate your students is to start from first principles. Space considerations and the uneven educational background of the Soviet military, however, might deter military assessors from structuring their assessments in this manner. Issue 2 is the easiest one for a Soviet military analyst to address. Assessments which focus on this issue are descriptive in nature. The military writer need not be a scientist or physicist to write at this level; in addition, he need not be given great amounts of possibly classified information on western weapons systems. His job is to describe the nuts and bolts of the technology, its technical characteristics. This is a relatively easy task.

The third issue is the most obvious one for a Soviet military writer to address. Clearly, these assessments play a role in the Soviet military's response to U.S. technological innovation; when the assessments explain how a given technological innovation works, this is certainly the best way for others in the Soviet military community to formulate a response to the U.S. technological challenge.

It is more difficult to understand what might lead a Soviet military analyst to address only Issue 4. One possibility, however, does come to mind. Issue 4 deals with outcomes, that is, with the performance capabilities of specific technologies. This is the issue an assessor addresses when he wants to know: "what is the military significance of this technology?" Given this, an assessor interested in developing worst case scenarios or playing for propaganda advantage would benefit from structuring his assessment about Issue 4. He has moved away from the objective technical facts addressed by Issues 2 and 3 to the more subjective analysis of performance capabilities raised by Issue 4.[137]

It is somewhat of an oversimplification, but one can summarize the above as follows:

*Issue 1 is the most logical one (in a pedagogical sense) for a Soviet military writer to address;

*Issue 2 is the easiest one (in a practical sense) to address;

*Issue 3 is the most obvious one (in a security sense) to address;

*Issue 4 is the most tempting one (in a propaganda and worst case scenario sense) to address.

With these considerations in hand, one can proceed to analyze the Soviet military's technology assessment process as it has operated with respect to U.S. re-entry vehicle technology over the past 20 years. Table 4 summarizes the results of Part 2. What is immediately obvious from the table--and not at all surprising--is that the overwhelming majority of the assessments were structured to address Issue 3--the most obvious one to consider from a security point of view, and the one which best equips the Soviet military community to formulate a response to U.S. technological innovation. The three technology areas (MRVs, hardening and inertial guidance) where the bulk of Soviet assessments did not emphasize operational characteristics can plausibly be explained as anomalous.

Table 4: Categorization of Soviet Military Assessments

Key: X = some assessments in this category
XX = majority of assessments in this category

Date of Initial Soviet Assessment	Technology	Physical Principles Involved	Technical Charac-teristics	Operational Charac-teristics	Performance Capability
Mid-1960s	MRV				XX
1966	Passive Radar Masking	X	X	XX	X
1966	Design/ Shape		X		X
1968	MIRV		X	XX	X
1968	Inertial Guidance		XX		
1968	Active Radar Masking			XX	
1968	Maneuvering RVs		X	XX	
1969	Hardening	XX	X		
1971	Heatshields		X		
1973-4	Ablative Coatings	X	X	XX	
1974	Terminal Guidance			XX	X
1977	Maneuvering, Terminally Guided RVs		X	XX	X
		<u>Issue 1</u> Focus on basic physics of RV	<u>Issue 2</u> Focus on describing components and instru-mentation?	<u>Issue 3</u> Focus on system's operational and system character-istics?	<u>Issue 4</u> Focus on system's capability and military significance?

With respect to MRVs, this study--with its 1965 starting date--most likely missed the bulk of Soviet assessments concerning this technology. For hardening technology, the emphasis I found on physical principles is quite possibly due to the nature of my data base: Three of the seven sources were books (where there is sufficient space for consideration of "first principles"). As for inertial guidance, I have already suggested several times that this technology's sensitive nature (that is, the MK12A's hard target kill capability) may have resulted in the Soviet military adopting a "hands off" approach to assessments of this technology in the open military press.

The table has several other interesting features. Issue 2--the "easiest" one to address--is in fact utilized most often: The assessments for nine of the twelve technology areas touch upon this issue. The table also shows an interesting--and strong--correlation between the level of threat posed by a given U.S. technological innovation and the "richness" of the Soviet assessments ("richness" being defined as assessments which address at least three of the four issues). The assessments in four technology areas--passive radar masking, MIRV, ablative coatings, and maneuvering, terminally guided RVs--meet the "richness" criterion. It can be argued that three of these four technology areas (ablative coatings being the exception) were precisely those re-entry vehicle technological innovations which the Soviet military felt most threatened by over the 20 year period of this study.[138] Passive radar masking--that is, penetration aids--and MIRVs, in the space of a few years, increased the Soviet BMD detection and tracking target set by at least four orders of magnitude. Maneuvering, terminally guided RVs--specifically, the Pershing II--have put important control nodes and nuclear facilities in the European part of the USSR (including Moscow if one is to believe Soviet military writers) at risk to short time-of-flight, highly accurate strikes.

In sum, what the table says about the nature of the Soviet military's technology assessment process is that it is focused on achieving results. In this sense, results means the assessments are optimized to allow the Soviet military to respond quickly to U.S. technological innovation. Thus, the great bulk of the assessments fall in the middle two columns --which are oriented toward providing the Soviet military with the tools and information it requires to formulate a response to American technological innovation. The two outer columns (Issues 1 and 4) are clearly accorded lower priority in the Soviet assessments. The low priority, however, makes sense if the goal of these assessments is to maximize the rapidity of the Soviet response to U.S. technological innovation. When either Issue 1--with its building block, pedagogical approach--or Issue 4--where less emphasis is placed on objective technical detail and more on subjective evaluations of performance capability--is addressed alone, the military community will not be provided with the kind of information it needs to formulate adequate responses to U.S. technological advances.

3.2. Soviet Military Perceptions of Main Direction(s) in U.S. RV Development

In attempting to analyze Soviet perceptions of the main direction(s) in U.S. re-entry vehicle technology, the following chronology of Soviet statements on the topic is helpful:

1968	Improving capability to overcome antimissiles constitutes "one of main trends" in modernization of missile systems
1971	Penetration of ABM; more reliable hit probability on area targets; higher hit probability on hard, point targets
1971	"Basic direction:" means for overcoming PRO systems
1971	Development of maneuvering, multiply charged nosecones and creation of other means in order to overcome PRO system
1971	Creation of multiplecharge RVs in order to: (1) facilitate penetration of PRO; (2) enhance effectiveness of the rocket's actions at the target; (3) allow one rocket to strike several targets
1972	Proper accuracy to hit designated targets; need to have means for overcoming PRO; need to withstand opponent's nuclear strike
1972	Creation of multiplecharge RVs is "one of the leading directions" in ICBM development in U.S.; "vast program of work underway" to increase accuracy of MIRV guidance system; terminal guidance as way to increase strike accuracy
1974	Development of "maneuvering, multiple-charge RVs" and other means for overcoming PRO
1977	Improve maneuverability; perfect guidance systems; decrease radar profile of RVs; harden RV against effects of PRO; equip RVs with active ECMs.[139]

All the above listings preserve the order given by the respective authors.

What can one conclude from the above? For one, the Soviets consistently perceived--through 1971--the need to enhance BMD penetration capability as the prime driver behind U.S. re-entry vehicle R&D. In four instances--1971, 1972 (twice) and 1977--accuracy improvements were also perceived to be impelling re-entry vehicle research.[140] Thus, in broad terms, one saw a consistent Soviet emphasis on BMD penetration as a driving force behind U.S. RV research. This emphasis was played down--but not eliminated--by 1977. As the 1970s progress, the Soviets perceived accuracy improvements as gaining in importance. The increased emphasis on accuracy did not, however, come at the expense of the elimination of the BMD penetration priority; both were present.

The critical question to ask is how these changes in Soviet perceptions correlated with changes in emphasis in actual U.S. re-entry vehicle R&D work. The short answer is that the correlation is pretty good. The sole emphasis on BMD penetration in the 1968 assessment is not entirely accurate, but is understandable, given that an extensive debate in the U.S. press over the merits of MIRV as a BMD penetration technology versus MIRV as a target coverage/counterforce technology did not occur until 1967.[141] Thus, it is not surprising that, in terms of performance capabilities, MIRV was perceived as a direct follow on to multiple re-entry vehicles (MRVs). One should also recall that the only rationale in the U.S. for developing MRVs was to enhance BMD penetration probabilities. The 1977 assessment, with its dual focus on seemingly incompatible technologies (maneuverability and accuracy improvements), is correct. One western source (Aviation Week & Space Technology--a source the Soviets were sure to be reading) noted in 1976 that the emphasis in the ABRES program "has switched to stress evasion (i.e., maneuverability) without sacrificing any accuracy achievable with the Mk 12."[142]

3.3 Nonrecognition/Recognition of Need for Tradeoffs

Table 5 is a chronological listing of those trade-offs which were either explicitly recognized within a given assessment or ignored. The table is admittedly of limited utility, but it does serve to reinforce a point which became evident as this paper was prepared: These assessments, for the most part, were not worst case analyses. The Soviet military writer--if he had been writing from a worst case perspective--could easily have converted nearly all the "yes's" in Table 5 to "no's." As was noted above, one can plausibly argue that a Soviet military writer would have a greater incentive "to worst case" those assessments which focused on performance capabilities than those which answered the question "how does this technology work?" In this context, it is worth recalling that the majority of the assessments examined were more concerned with explaining how a given technology worked than with assesssing performance capabilities.

Table 5

Year	Trade-Off Involved	Recognized?
1969	Shielding RV from EMP vs increase in RV weight required by such shielding	Yes
1971a	Terminal RV maneuvers vs increase in time spent in "field of view" of BMD due to such maneuvers	Yes
1971b	False targets which follow RV through dense layers of atmosphere vs increased weight of such false targets	No
	Increase in number of pen-aids carried by bus vs decrease in number of RVs on bus	No
1977	Utilizing aerodynamic principles to execute terminal maneuvers instead of propulsion system due to severe size constraints on RV	Yes
1978	Terminal maneuvers producing some degradation in terminal accuracy	Yes
1983	In order to increase Pershing II range most likely need to replace RADAG guidance system with inertial system	Yes

Sources: 1969--Chuprin (1969, 51) and F. Fedorov (1969, 42); 1971a--Anureev (1971, 58); 1971b--Ivanov (1971, 29-30); 1977--Aleksandrov (1977, 47); 1978--Sovetskaya Voyenna Entsiklopediya (1978; Vol. 5, 119); 1983--Platanov (1983, 36).

3.4 Final Remarks

3.4.1 The Changing Nature of the Soviet Military's Technology Assessments

The question to ask is not whether Soviet assessments of U.S. re-entry vehicle technology have changed over the past 18 years. Some change and improvement are virtually inevitable. The critical question, however, is one of degree: How much have the assessments improved? In answering this question, it is important to keep in mind that the complexity of the technology being assessed by the Soviet military has increased dramatically over the past two decades. It is one thing to understand the technology of mutiple re-entry vehicles; it is quite another to assess competently the complex technology involved in, say, a maneuvering, terminally guided RV. The first question to ask, therefore, is whether the Soviet military assessments have kept up with the rapid pace of technological advance? The answer is yes; in fact, they have done a little better than simply "keeping up." As noted earlier, several of the best assessments were those which dealt with a very complex technology: maneuvering, terminally guided RVs. There is still, however, great room for improvement. As this report has shown, many critical issues involved in a given advance in U.S. RV technology were ignored in the assessments.

An interesting question is why the assessment process has improved. Is the improvement explained by the Soviet military's experience in designing, testing and deploying its own re-entry vehicle technology over the past decade and a half? Or, is it simply that more military writers are being given access to western sources? Or, are the western sources themselves improving? One could hazard a guess that the answer is in fact some combination of the three.

In addition to the improvements in the Soviet military's technology assessments over the past 18 years, this report has also shown that shifts of emphasis in these assessments correlate well with changes of emphasis in U.S. re-entry vehicle R&D programs. The assessments were not based on worst case analyses and for the most part were concerned with explaining how a given technology worked. As that technology has grown in complexity, the Soviet assessments have become more comprehensive and certainly have at least met the challenge of keeping pace with advances in U.S. re-entry vehicle technology.

3.4.2 The Unchanging Nature of the Soviet Military's Technology Assessment Process

As Table 4 shows, the nature of the military's technology assessment process has changed little across technology areas and over the course of 20 years. This process has consistently focused on explaining how a given technology works. While the technology assessment process has had an unchanging focus, it was shown in Section 3.4.1 that the individual technology assessments have changed and improved considerably over the past 20 years. Indeed, the improvements in the individual assessments have enhanced the capability of the overall technology assessment process to provide the Soviet military community with the information which will best allow it to respond to the challenge of U.S. technological innovation.

APPENDIX I: ACRONYMS

American

ABM	Anti-ballistic Missile
ABRES	Advanced Ballistic Re-entry Systems program
AMARV	Advanced Maneuvering Re-entry Vehicle
ASMS	Advanced Strategic Missile Systems program (the successor to the ABRES program)
BGRV	Ballistic Guided Re-entry Vehicle
BMD	Ballistic Missile Defense
CEP	Circular Error Probable
DRADs	Degradation of Radar Defense Systems
ECM	Electronic Counter-measures
EMP	Electro-magnetic Pulse
ICBM	Intercontinental Ballistic Missile
MBRV	Maneuverable Ballistic Re-entry Vehicle
MIRV	Multiple Independently-targeted Re-entry Vehicle
MRV	Multiple Re-entry Vehicle (early 1960s)
MRV	Maneuvering Re-entry Vehicle (late 1960s)
PGRV	Precision Guided Re-entry Vehicle
RADAG	Radar Aimpoint Guidance system
R&D	Research and Development
RV	Re-entry Vehicle

Soviet

ETsVM	Electronic Digital Computer
PVO	Anti-air Defense
PRO	Anti-rocket Defense
PKO	Anti-space Defense

APPENDIX II

BACKGROUND INFORMATION

This appendix provides supplementary information on the Voyenizdat (military publishing house) books utilized in the paper. The entry for each book is standardized, and is of the following form:

Author(s):

Title:

Editor:

Technical Editor:

Date Signed to Press:

Tirage:

Summary Statement:

The categories are self evident except for the last one. What I call the "Summary Statement" is a two or three paragraph summary of the book which is printed immediately prior to the "Introduction" or "Foreword." The summary typically provides an overview of the book's objectives, a reference to its intended audience and a brief statement concerning source materials used in writing the book.

A final note: Within a given entry, the order in which the authors are listed is identical to that given in the book.

Authors: Aleshkov, M.N. (Candidate of Technical Sciences)

Zhukov, I.I. (Doctor of Technical Sciences)

Savin, N.V. (Engineer)

Kukushkin, D.D. (Candidate of Technical Sciences)

Markov, O.P. (Candidate of Technical Sciences)

Fomin, Yu. G. (Candidate of Technical Sciences)

Title: Fizicheskiye osnovy raketnogo oruzhiya

(Physical Principles of Rocket Weapons)

Editor: Peremyshlev, V.I.

Technical Editor: Makarova, N.Ya.

Date Signed to Press: 26 May, 1972

Tirage: 11,000

Summary Statement:

The book presents the principles of the combat application of rocket weapons, the elements of flight theory, the physical principles of jet engines; rocket engines and fuels, systems for the control and guidance of various classes of rockets are described. Descriptions are given for the principal equipment of rockets of various designs and of their basic aggregates; also described is the groundbased and testing equipment of rocket complexes. A classification of rocket weapons is given.

The book is based on materials of the open home and foreign press.

Author: Anureyev, I.I.

Title: Oruzhiye protivoraketnoy i protivokosmicheskoy oborony

(Weapons of Antirocket and Antispace Defense)

Editor: Morozov, K.V.

Technical Editor: Zudina, M.

Date Signed to Press: 6 April, 1971

Tirage: 16,000

Summary Statement:

The book examines rocket-space means of attack, the properties of these means and the problems of struggle with them. On the basis on foreign models, weapons of antirocket and antispace defense, their equipment and operation are described; tactical-technical data are given for antirocket and antispace defense systems developed abroad.

The book is based on foreign press materials.

The book is intended for a wide circle of military readers of the Soviet Army and Navy; other readers, who wish to acquaint themselves with questions of antirocket and antispace defense in contemporary conditions, will also find much of interest in the book.

Authors: Ivanov, A.

Naumenko, I.

Pavlov, M.

Title: Raketno-yadernoye oruzhiye i ego porazhayushchee deystviye

(Rocket-Nuclear Weapons and Their Strike Effects)

Editor: Kader, Ya. M.

Technical Editor: Konovalova, E.K.

Date Signed to Press: 23 December, 1970

Tirage: 60,000

Summary Statement:

The authors popularly explain the physical principles and equipment of rocket-nuclear weapons and their strike factors. The book introduces data on the equipment of atomic and thermonuclear munitions and rocket-carriers, on the means for calculating the strike zone and on measures of defense from rocket-nuclear attack. The reader is acquainted with the plans of the imperialists for the utilization of cosmic means of struggle, he learns about the strike effects of cosmic nuclear explosions. The book is written using materials published in the open Soviet and foreign press and is intended for military and civilian readers, agitators, propagandists, lecturers, and teachers who are interested in rocket-nuclear weapons.

Author: Morozov, N.I.

Title: Ballisticheskiye rakety strategicheskogo naznacheniye

(Ballistic Rockets of Strategic Designation)

Editor: Morozov, K.V.

Technical Editor: Konovalova, E.K.

Date Signed to Press: 24 April, 1974

Tirage: 10,000

Summary Statement:

The book illuminates the general principles of the equipment of ballistic rockets of strategic designation; a classification of these rockets and their means of flight control are presented; the use of these rockets in combat operations on land and at sea is recounted.

The book is based on materials of the open home and foreign press, and questions of the combat use of rockets are presented via the views of foreign specialists. The book is intended for a wide circle of military and civilian readers who are interested in military rocket equipment.

Authors: Velikanov, V.D.

Galkin, V.I.

Zakharchenko, I.I.

Koposhilko, Yu. I.

Malyutin, A.S.

Mikhaylov, L.V.

Title: Radiotekhnicheskiye sistemy v raketnoy tekhnike

(Radio-technical Systems in Rocket Equipment)

Editor: Sterligov, V.L.

Technical Editor: Konovalova, E.K.

Date Signed to Press: 22 April 1974

Tirage: 10,500

Summary Statement:

The book contains a generalized and systematized presentation of the views of foreign specialists on the role and place of contemporary radio-technical equipment in the design of military systems of defense and offense. On the basis of foreign models, elements of the complexes of strategic rocket weapons, phased array radars and the kinds and types of interference equipment for the defense of rocket nosecones are discussed. The book is based on materials of the open foreign and home press. It is intended for a wide circle of military and civilian specialists who work in the field of radar and other applications of radio-electronic apparatus. The book is also useful for teachers, students and auditors of the radio-technical departments of schools, universities and academies.

APPENDIX III

DEFINITIONS

This appendix will provide further explication of several Russian words which are used--in translation--throughout the paper. I will start by giving the U.S. government translation of these terms, and then proceed to cite extensively from Soviet sources in order to place these translations in a broader context.

Golovnaya Chast'

The U.S. government translates this phrase as "nosecone." This translation is adequate for discussion of a single warhead atop a three stage ballistic missile. In this instance, one imagines the "nosecone" separating from the missile's last stage and proceeding along a ballistic trajectory until the warhead is detonated. No confusion occurs: The translation does no disservice to the original Russian text. Confusion arises, however, when one examines re-entry vehicle configurations more complex than, say, a single warhead atop a ballistic rocket. When Soviet military writers, for example, discuss MIRV technology, to what does the term"golovnaya chast'" refer? The post-boost vehicle which separates from the ballistic rocket and dispenses individual warheads? Or, to the individual warheads each now following its own ballistic trajectory? To clear up this confusion, I will utilize the Sovetskaya voyennaya entsiklopediya and its entry for "Golovnaya Chast' Rakety." In what follows, I will not quote word for word; instead, I will give an accurate paraphrase of the encyclopedia's definition.

The golovnaya chast' is a special, technical piece of equipment which is located on the forward part of ballistic rockets. It is designated for the direct striking of targets. The golovnaya chast' consists of a body, one or several combat charges, and various systems which ensure the normal functioning of the golovnaya chast' during the rocket's launch and flight through space. The golovnaya chast' also contains systems which ensure that the combat charge is detonated at the proper point. A golovnaya chast' with one combat charge is called a single-charge or monobloc golovnaya chast'; a golovnaya chast' with several combat charges is a multiple-charge or separating (razdelayushchaya) golovnaya chast'

Several sentences later, the separating golovnaya chast' is explained in great detail.

A separating golovnaya chast' is best thought of as consisting of several monobloc golovnaya chast''s which are now called combat elements. The dimensions and mass of these combat elements are relatively small in comprarison with those, of a single monobloc golovnaya chast'. There are four types of separating golovnaya chast'.

Type 1: The combat elements are dispersed around a chosen aim point. In this case, the golovnaya chast'--along with its combat elements--separate from the ballistic missile when the missile's last stage stops firing. The combat elements separate from the golovnaya chast' in a manner which ensures their dispersal about the aim point. This kind of golovnaya chast' can be employed against large-scale targets protected by antirocket defenses.

Type 2: The combat elements are consecutively aimed at the objectives of the strikes. In this instance, the golovnaya chast' resembles a special stage of the ballistic rocket. After separation from the ballistic missile, the golovnaya chast' continues along a ballistic trajectory for a certain period of time. Then, upon a command from the control system, the first combat element separates from the golovnaya chast'. This combat element completes its flight along a ballistic trajectory. Next, the propulsion system on the golovnaya chast' is turned on in order to change its trajectory. This ensures that when the second combat element is released, it will strike a different target. This sequence continues until all combat elements have been released. The separation between the targets that each combat element hits ranges from tens to hundreds of kilometers.

Type 3: The combat elements are individually guided to their targets. The feature of a golovnaya chast' equipped with individually guided combat elements is that each element contains its own control and propulsion system. This allows the combat element to complete a guided flight in accordance with the program placed in its control system. This type of golovnaya chast' can be employed against small-scale, shielded targets.

Type 4: The combat elements maneuver along the final part of their trajectory (that is, in the dense layers of the atmosphere). A golovnaya chast' with maneuvering combat elements has a control system and actuating organs (wings or fins) which ensure that the combat elements execute a programmed aerodynamic maneuver in the atmosphere's dense layers. This significantly increases the combat capabilities of the combat elements in overcoming the opponent's antirocket defense.

To summarize, and to place things within the context of U.S. re-entry vehicle programs and U.S. government terminology, one has the following:

With a Type 1 separating nosecone, the nosecone is essentially a passive carrier of the nuclear warheads (that is, the combat elements). The nosecone has no special properties and simply follows the ballistic trajectory established by the rocket. In terms of U.S. programs, a Type 1 nosecone would dispense multiple re-entry vehicles (MRVs).

A Type 2 separating nosecone plays an active role in dispensing the nuclear warheads (combat elements). The nosecone contains a propulsion system and deviates from the original ballistic trajectory established by the rocket. In American terminology, the nosecone is the post-boost vehicle which dispenses multiple independently targeted re-entry vehicles (MIRVs).

A Type 3 nosecone is similar to a Type 2 nosecone--only now each combat element has a terminal guidance capability. In terms of U.S.

programs, a Type 3 nosecone would dispense precision guided re-entry vehicles (PGRVs).

The Type 4 nosecone again resembles the Type 2. In this instance, each combat element--while lacking a terminal guidance capability--can execute preprogrammed maneuvers once it has entered the atmosphere. The U.S. system which envisages this combination of nosecone and combat elements is the maneuvering re-entry vehicle program.

The above makes clear that the phrase "golovnaya chast'" has several distinct but related meanings. It is the context in which the term is used that defines its precise meaning. Several examples illustrate this point. In 1967, a writer discussed U.S. plans to develop a "maneuvering nosecone." Taken by itself, such a phrase would lead a U.S. analyst to the mistaken conclusion that the reference was to early U.S. work on manuevering re-entry vehicles. The context, however, makes clear that the writer was discussing the postboost vehicle which would dispense MIRV warheads. The lesson here--besides the importance of context--is that the phrase "golovnaya chast'" should never be translated as "re-entry vehicle." The military writer was in fact perfectly correct in talking of a "maneuvering nosecone." For him, the nosecone was more than simply a re-entry vehicle; in this instance, it was the entire postboost vehicle. The postboost vehicle does execute trajectory changes while dispensing the MIRVs; in this sense, it is indeed "maneuvering."

Another author, again assessing MIRV technology, wrote in 1972 of a "MIRV-type nosecone." Is this a reference to the individual re-entry vehicles, or what? Once the author noted that such a nosecone contained several nuclear warheads and its own guidance system, it became clear that his "nosecone" was the postboost vehicle. To reiterate: The context is critical to a proper understanding of the phrase "golovnaya chast'."

Sources: Sovetskaya Voyennaya Entsiklopediya (1976; Vol. 2, 593-4)
Sergeyev (1967; 95)
Petrov (1972)

* * *

Lozhnaya Tsel'

The U.S. government renders this phrase as "false target." Strictly speaking this is correct. My own research, however, suggests that the term is best thought of as the Russian language equivalent of "penetration aids." Soviet military writers often use the phrase "lozhnaya tsel'" by itself--without further explication--when discussing U.S. attempts to facilitate a nosecone's penetration of a BMD system. A 1977 article devoted to "Ballistic Rocket Nosecones" mentioned "lozhnaya tsel'" on at least three occasions, but the term was never defined. This example and numerous others indicate that the phrase lozhnaya tsel'/false target is used in a general and generic sense to denote a wide range of penetration aids.

A book published in 1974 included a chart which confirms that Soviet military writers include many "interference means" under the rubric lozhnaya tsel'. The chart--while difficult to interpret-- provides a glimpse of how the Soviet military organizes its thinking regarding the full array of penetration aids. The original chart is reproduced in Appendix Table 1; Appendix Table 2 is an English translation of the Russian.

The chart is both confusing and interesting. The confusion stems in part from the use of the dotted lines: What do they signify? It is also odd that a nuclear explosion in the atmosphere is considered a passive interference means (this, however, may simply be the result of sloppy artwork: On the page previous to the chart in the book, a nuclear explosion is listed as an active interference means). What makes the chart interesting is its comprehensive nature. As far as can be determined by examining U.S. sources, the chart's various categories cover nearly all aspects of U.S. penetration aids research through the early 1970s.

Sources: Aleksandrov (1977; 46-7) Velikanov (1974; 156-7)

Appendix Table 1

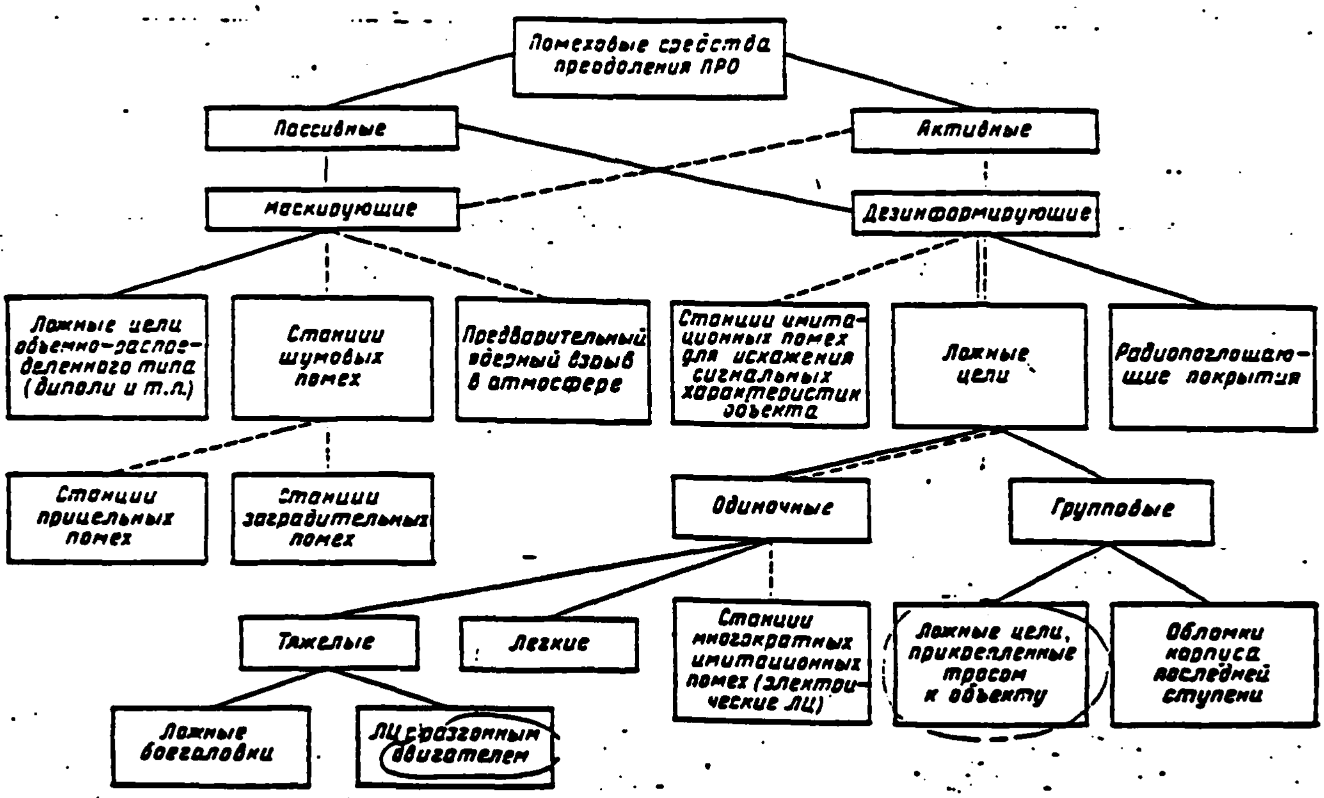
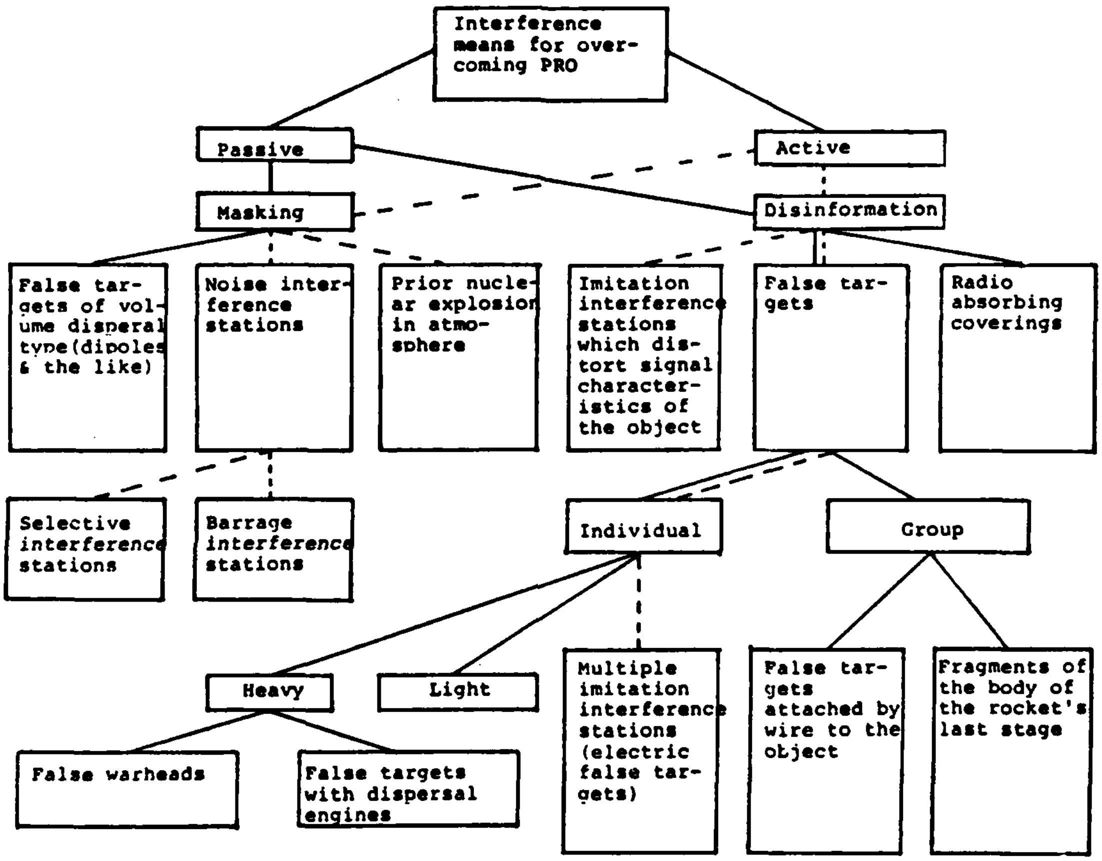


Рис. 3.3. К классификации радиолокационных помеховых средств преодоления ПРО

*Source: Velikanov, V. (1974). <u>Radiotekhnicheskiye sistemy v raketnoy tekhnike</u>. (Moscow: Voyenizdat), 157.

Appendix Table 2



A Classification of Radar Interference Means for Overcoming PRO

NOTES

1. What I can say--after examining over 40 books and articles published by the Soviet military--is that these assessments rely heavily on western trade journals. Soviet military writers are not especially good at citing their sources, but in those instances when they do, the citations are a who's who of western aerospace trade journals: Aviation Week & Space Technology, Flight International and the like.

2. That is, were the differences due to variations in the complexity of the different technologies--for example, in the extent to which new technologies built on previous ones (the MIRV program building on the MRV program) or represented radical new technological advances (the ablative coatings thermal shielding program).

3. In 1982, ABRES was renamed the Advanced Strategic Missile Systems (ASMS) program.

4. Admittedly, this is a highly subjective concept. Nevertheless, after analyzing various books and articles, one gains a feel for when a particular author "knows his stuff;" that is, he understands the technology being described and--most importantly--has the ability to explain that technology through his writing.

5. Still another possible reason why the Soviet military devoted little attention to U.S. inertial guidance technology may have been that the Soviets were actively engaged in research on their own inertial guidance systems.

6. The author is N. I. Morozov (1974). Pages 170-175 of his book were taken from a 1971 Tekhnika i vooruzheniye article by K. Morozov (see K. Morozov [1971]).

7. To give the reader a better feel for the nature and intended audience of the books utilized in this study, I have included the "summary statement" sections in Appendix II.

8. See, for example, Fayenov (1968; 110).

9. BMD, here and elsewhere, is synonymous with the Soviet military acronym for anti-rocket defense: PRO.

10. For a brief overview of the impetus behind MRVs and their R&D history, see Greenwood (1975; Ch. 1).

11. Ivanov (1971; 30), K. Morozov (1971; 46), Anureyev (1971; 51).

12. It is interesting that of the four sources for this section, three appeared in 1971. This was the year that the Soviet military began to deploy its first MRV (the SS-9 Mod. 4). Prior to deployment, the Soviet MRV was flight tested 22 times between August, 1968, and November, 1970. [On these points, see Baker (1982; 104-5) and Wright (1985; Vol. 2, 239)]. Thus, the assessments in this section may reflect and be biased by the Soviet military's experience with its own MRV technology.

13. The "program 627A" to which the author referred (Anureyev [1971; 51]) was, at least through 1969, the numerical designation for the ABRES program.

14. Anureyev (1971; 51).

15. K. Morozov (1971; 46).

16. Here, as elsewhere, I have translated golovnaya chast' as nosecone. For further discussion of this phrase, see Appendix III.

17. Ivanov (1971; 30).

18. Yakovlev (1968; 80).

19. Anureyev (1971; 51-53), K. Morozov (1971; 47), Petrov (1972). The drawing which accompanies both the Morozov and Petrov articles is taken from p. 52 of Anureyev's book.

20. The heatshield (teplovoy ekran) mentioned here is apparently a protective covering which shields the MIRV bus as the ICBM/bus ascends through the atmosphere; it is not a reference to the thermal shielding on the individual re-entry vehicles.

21. Anureyev (1971; 51-2), K. Morozov (1971; 47), Petrov (1972).

22. York (1973; 18-19, diagram on 20-21).

23. Anureyev (1971; 51-2), K. Morozov (1971; 47), Petrov (1972).

24. Anureyev (1971; 51).

25. Aleksandrov (1977; 46).

26. K. Morozov (1971; 46).

27. Fayenov (1968; 114), K. Morozov (1971; 47).

28. Aleksandrov (1977; 47).

29. Yakovlev (1968; 80).

30. Fayenov (1968; 114).

31. Fayenov (1968; 114).

32. K. Morozov (1971; 47).

33. K. Morozov (1971; 47).

34. Defense Market Service Market Intelligence Report (1969; 10).

35. Aleksandrov (1977; 47).

36. Sovetskaya Voyennaya Entsiklopediya (1978; Vol. 5, 119)

37. N. Morozov (1974; 185).

38. For a general description of the Mk500, see Bunn (1984; 39-41).

39. See Meyer (1983; 16)

40. Aleshkov (1972; 226), Anureyev (1971; 53), K. Morozov (1971; 47).

41. K. Morozov (1971; 47).

42. ETsVM is the Soviet acronym for digital electronic computer.

43. Aleksandrov (1977; 47).

44. Aleksandrov (1977; 47).

45. While the focus on active over passive technology is difficult to explain, it is interesting to note what the active/passive distinction implies in terms of BMD detection capabilities. An active terminal guidance system like the RADAG, "broadcasts" (via its radar beam sweeps of the terrain below) the presence of the Pershing II warhead to the BMD system. In contrast, a passive terminal guidance system--for example, IR sensors--would not "broadcast" the warhead's presence.

46. Aleksandrov (1977; 49).

47. Aleksandrov (1977; 47).

48. On this point, see "Guidance Systems" (1976; 41) and Bunn (1984;43). In fairness to the Soviet author, there was apparent confusion in the U.S. during the period 1976-78 as to the type of guidance system (active or passive) envisioned for the AMARV. While "Guidance Systems"--writing in 1976--stated that the AMARV's guidance would be passive, Congressional testimony in the period 1976-78 suggested that the U.S. was exploring both active and passive guidance systems for the AMARV. (I am indebted to Matthew Bunn of M.I.T.'s Arms Control and Defense Policy Program for this information).

49. Sovetskaya Voyennaya Entsiklopediya (1978; Vol. 5, 119).

50. Sovetskaya Voyennaya Entsiklopediya (1978; Vol. 5, 119).

51. Platanov (1983; 36).

52. Ignat'yev (1982: 50).

53. Platanov (1983; 36).

54. On this point, see Bunn (1984; 60).

55. Platanov (1983; 37).

56. A final comment on the Platanov article: His figure 2 (Platanov [1983; 37]) is lifted detail-for-detail from the same western source used by Arkin, et al (see Arkin [1983; 294]).

57. The criticism of Platanov is perhaps unjustified. Many--although not all--of the American defense journals and aerospace weeklies are written at the same level as Platanov's article. Since these publications in all probability were Platanov's source material, it may be asking too much for the Soviet assessor to go beyond his American counterparts.

58. Ivanov (1971; 28).

59. N. Morozov (1974; 75).

60. Aleksandrov (1977;47).

61. Aleksandrov (1977; 47).

62. Aleksandrov (1977; 47), N. Morozov (1974; 75).

63. N. Morozov (1974; 75)

64. Ivanov (1971; 28), Aleksandrov (1977; 47).

65. Sovetskaya Voyennaya Entsiklopediya (1976; Vol. 2, 593).

66. Aleksandrov (1977; 47).

67. An active coating is one where a liquid is continually flowed over the RV's surface. As the liquid flows over the hot surface it evaporates and transfers thermal energy to the air surrounding the re-entry vehicle. For the Soviet description, see N. Morozov (1974; 75).

68. This may be another case where the attention of Soviet military writers was captured by an "exotic" technology. See Note 39 above and the discussion which precedes it in the text.

69. Miller (1976; 23).