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Reducing the Risk of an Accidental Launch

Pavel Podvig

Center for International Security and Cooperation, Stanford University, Stanford, CA, USA

One of the serious risks associated with the strategic nuclear arsenals of Russia and the United States is that an accidental launch might result from a false alarm or from misinterpreting information provided by an early-warning system. This risk will not be reduced by bringing down the number of strategic missiles on high alert to the level of about 500 warheads on each side because this measure will not significantly affect first-strike vulnerability of the Russian strategic forces. Other measures that have been suggested so far, namely an upgrade of the Russian early-warning system, establishing additional channels of real-time exchange of early-warning data, or transparent and verifiable de-alerting of strategic forces, are more likely to increase the probability of an accident than to reduce it. To address the problem of an accidental launch in the short term, the United States and Russia, while continuing to work toward deep reductions of their strategic nuclear forces, should develop and implement measures that would keep their entire forces at low levels of readiness without revealing their actual alert status.

After the end of the cold war, the United States and Russia undertook an effort to reduce their strategic nuclear arsenals. At the end of 2005, each side had about 3,000–3,500 nuclear warheads associated with operational strategic systems, down from more than 10,000 warheads in the early 1990s.[1] The reduction of the number of launchers and warheads is part of a broader process of transformation of strategic nuclear forces, which reflects the changes in the relationships between Russia and the United States brought about by the end of the cold war.

This process, however, has been rather slow—according to the agreement that the United States and Russia signed in Moscow in May 2002, the number of operational warheads in their arsenals will still be at the level of 1,700–2,200 by 2012. In addition, the reductions have not changed the basic structure of the strategic forces in any substantial way—both countries still rely on a nuclear triad and keep in place most of the operational practices established during the

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Address correspondence to Pavel Podvig, Center for International Security and Cooperation, Stanford University, Encina Hall E213, Stanford, CA 94305-6165. E-mail: podvig@stanford.edu

cold war. This is hardly surprising, for the current development of the strategic forces to a large extent is determined by very strong institutions (military and civilian alike) that were shaped by the cold war environment and that find it difficult to adjust to new threats and requirements.

Although it is quite likely that the United States and Russia will eventually reduce their nuclear forces to levels much lower than those agreed on in 2002, this process may take years or even decades. In the meantime, it is important to make sure that operations of strategic forces are safe and that any changes in their structure and operation practices would facilitate further reductions of the number of nuclear warheads and risks associated with them.

Some risks are inherent to nuclear weapons and therefore could not be eliminated entirely as long as countries continue to keep these weapons in their arsenals. Other risks, however, can and should be dealt with at much earlier stages of the disarmament process. Of the most significant risks in the latter category is the risk of an accidental use of nuclear weapons associated with the launch-on-warning posture and the practice of keeping strategic launchers on high alert.

The launch-on-warning strategy was developed during the cold war as an integral component of a broader strategy of nuclear deterrence that was the basis of the U.S.–Soviet relationships in the military area. By providing the option of launching strategic forces in a retaliatory strike in response to an incoming attack but before that attack can destroy its targets, launch-on-warning was believed to strengthen nuclear deterrence, for it helped ensure guaranteed retaliation. In addition to that, the launch-on-warning option removed some of the incentives for a “use them or lose them” first strike by providing an option for even the most vulnerable launchers to survive an attack.

The launch-on-warning posture, however, is associated with a significant risk. Because the time available for making the decision about launching a retaliatory strike is limited, organizational procedures for handling a warning of an attack have to be designed to favor a quick response. In addition to this, decision makers would have no choice but to rely on the information about an attack provided by their early-warning system. This combination creates a possibility that a nuclear strike can be launched by mistake, for example based on erroneous information provided by an early-warning system or as a result of an error in interpreting this information.

The United States and the Soviet Union apparently believed that the benefits of having the launch-on-warning option outweighed the risks associated with it or that they could manage those risks. At the same time, during the cold war an accidental launch was just one of the many risks that these countries were facing, which may explain the willingness to tolerate it.

With the cold war long over and the relations between the United States and Russia (which inherited the Soviet strategic forces) improved, the launch-on-warning posture has come under increased scrutiny. A number of experts suggested a set of practical measures, known as de-alerting, which were aimed at reducing the probability of an accidental launch.[2] None of these proposals have been implemented, mainly because the de-alerting measures usually required significant changes in the operational practices of the strategic forces, which the military in the United States as well as in Russia have been reluctant to undertake. In addition, consistent implementation of de-alerting measures would be impossible without a new approach to the basic principles of U.S.–Russian relationships, something that neither U.S. nor Russian political and military leadership has not been ready to consider. Specific de-alerting measures, such as removal of warheads from ICBMs or verified limits on submarine patrol areas, are sometimes criticized as cumbersome and/or unnecessary.[3]

Although the discussion of de-alerting has not resulted in implementation of the proposed measures, it introduced a number of concepts that have become almost universally accepted in the debate about reduction of nuclear forces. De-alerting proposals have also made a comeback recently, this time supported by Russian experts.[4] Specific details vary from one proposal to another, but some of the ideas, outlined herein, are common to most of them.

First, most of the currently discussed arms reduction or de-alerting proposals, although suggesting deep cuts in the number of operational warheads, accept that a certain fraction of strategic forces would remain on high alert, at least in the short term. There seems to be a consensus that at this point the United States and Russia could aim at reducing the number of warheads in the alert force to about 500. Additional warheads would be kept in reserve from which they could be returned to the operational force with some delay—from several days to several months.

It is commonly assumed that the two-tier force structure, in which only part of the force is kept on high alert, would reduce the danger of an accidental launch. Some authors also argue that at the level of about 500 warheads neither side would be capable of launching a counterforce disarming strike, eliminating the need of launch-on-warning entirely. This kind of proposal requires the status of strategic launchers to be transparent and verifiable, so neither side could be able to covertly raise the readiness level of its force and prepare for a disarming attack.[5]

Another important set of proposals that emerged from the discussion of de-alerting includes a series of measures that are supposed to help Russia to repair its early-warning system. The measures that have been suggested include direct assistance to Russia to help it launch satellites or complete construction of early-warning radars, establishing U.S.–Russian early-warning data exchange center, or augmenting the existing early-warning networks with additional sensors. The assumptions behind these proposals are that the deterioration of the Russian early-warning network after the breakup of the Soviet Union has left it without adequate warning capability and that this lack of early warning increases probability of an accident.[6]

The idea of cooperation in strengthening early-warning capabilities, whether in the form of providing Russia with assistance in completing its system or of establishing data-exchange mechanisms, has been supported by advocates of de-alerting and its opponents alike. This is one of the few proposals that came close to being implemented—in 1998 the United States and Russia agreed to establish a Joint Data Exchange Center (JDEC) in Moscow for the purposes of information exchange.[7] Although this agreement has not been implemented in practice, some authors have suggested using the framework it created for expanding U.S.–Russian cooperation in early-warning information exchange.[8]

Most of these ideas were developed in the late 1990s, when issues like negotiated bilateral arms reductions and missile defense still dominated the dialogue between the United States and Russia. Since then the relationships between these countries and the international security situation in general went through serious transformation. Shortly after the terrorist attacks of September 2001, the United States made a decision to withdraw from the ABM Treaty, which limited missile defense development. In 2002 the United States and Russia replaced the START II Treaty, which would have provided a basis for verified bilateral reductions of their nuclear arsenals, with the Moscow treaty, which places few restrictions on development of the strategic forces and does not make any provisions for verification.

Some of these developments were a direct result of the shift in priorities toward combating international terrorism that followed the terrorist attacks on the United States in September 2001. They also reflected increasing reluctance of the military on both sides to submit their strategic force modernization plans to long-term legally binding constraints. The diminished role of arms control agreements also suggests that the cold-war confrontation has all but disappeared from the U.S.–Russian relationship.

Overall, the task of reducing the danger of an accidental launch may look different today than it was in the 1990s and therefore require a different set of approaches. This article considers the key measures that are discussed in the context of the danger of accidental launch and questions their effectiveness. Moreover, some of these measures would probably increase the probability of an accident. In the conclusion we outline some measures that may help address the problem more effectively.

POSSIBILITY OF AN ACCIDENTAL LAUNCH

There are several scenarios that can lead to an unintended launch of nuclear-armed missiles. It can be an unauthorized launch of a missile or a group of missiles (e.g., missile regiment or a submarine), a malfunction of a command and control system component that triggers missile launch, or an authorized launch in response to a warning provided by the early-warning system.[9]

There are risks associated with all these scenarios, but the one that includes a launch in response to a warning is quite different from others and is the hardest with which to deal. Regarding the first two, we can assume that a nuclear forces command and control system is designed to recognize a malfunction of its components or an attempt to get unauthorized access and to take measures that would prevent a launch in these circumstances. It is likely that a sequence of events in a case of, say, an unauthorized launch attempt, would be sufficiently different from a "normal" attack sequence to allow creators of the command and control system to consider a possibility of this attempt in advance and design protective measures that would block it.[10]

In contrast, in the case of a false or misinterpreted warning, the sequence of events would be essentially the same as during a real attack, making it much harder to recognize these events as an accident. The command and control and decision-making mechanisms would be functioning in the exact same way whether the attack reported by the early-warning system is real or not. It is generally assumed that a false warning would be sufficiently different from a real one to allow a correct assessment of the situation, but it is possible to imagine scenarios in which this difference would be quite small or even nonexistent.[11]

The short timelines and very high pressures involved in the decision-making process would substantially increase the probability of an error. In addition to this, the assessment of the situation would be influenced by a host of events that may be directly related to the accident or only remotely connected with it. It is impossible to predict what exactly these events might be and how they might influence the decision-making process.[12] Neither is it possible to foresee all possible interactions between these events and the actions that would be taken in response to the attack warning.[13]

All this makes the accidents that involve false or misinterpreted warning the hardest to recognize and deal with.[14] As long as the strategic forces keep the launch-on-warning option, we cannot completely rule out a sequence of events that would lead the military and political leadership to conclude that an attack is under way and to exercise this option. Even though an accident of this kind would be extremely unlikely, its probability is not zero even during peacetime. Given the truly catastrophic potential consequences of a nuclear strike, this probability should not be ignored or tolerated.

POLITICAL OBLIGATIONS

The United States and Russia, as well as other countries, have already undertaken some measures that probably substantially reduced the danger of an accidental launch—reductions of their nuclear arsenals and de-targeting agreements. It has been argued that a combination of these steps with a political decision not to use launch on warning as an option, which countries could make unilaterally (and not necessarily openly), would be enough to reduce the risk of an accidental launch to an acceptably low level.

Reductions of strategic forces and the transformation of the U.S.–Russian relationships that accompanied them, as well as various cooperation programs, were probably the most important and most effective steps toward reducing the risk of an accident. In addition to that, in 1994 the United States and Russia agreed to remove targeting information from their strategic missiles.[15] Later Russia and the United States reached similar agreements with other countries.[16]

Although de-targeting and a political decision not to rely on launch on warning are indeed important steps, they cannot eliminate the risk of an accident completely because they leave the technical capability to conduct a launch on warning intact. Neither of these decisions seems to have changed operational practices of the strategic forces, which include launch on warning as a possible scenario. For example, according to one of the U.S. nuclear policy documents:

> The United States does not rely on its capability for launch on warning or launch under attack to ensure the credibility of its deterrent. At the same time, the US ability to carry out such options complicates Russian assessments of war outcomes and enhances deterrence.[17]

Recent statements of the U.S. military strongly suggest that this policy of maintaining the capability to launch on warning has not been changed since this document was adopted.[18] Russia has never publicly disclosed the degree to which it relies on launch on warning in operations of its strategic forces. It does, however, continue to maintain and upgrade its early warning system, so we have to assume that the technical capability to implement a launch-on-warning strike has been preserved.

Although the United States and Russia have made great progress in transforming their relationships, we should not overestimate the extent to which they were successful in translating these changes into operational practices of their strategic forces and the assumptions about nominal adversary that guide their day-to-day operations.[19] Neither does it help that the military on both sides continue to conduct exercises of their strategic forces that include scenarios with nuclear strikes on U.S. or Russian territory.[20]

An argument has been made that in peacetime, when considered "in the context of information about the general state of relations between the potential adversaries," a warning is unlikely to be considered credible, and therefore it will not lead to a decision to retaliate.[21] This is only partially correct, because, first, an accident can be severe enough to immediately change the context and, second, understanding of "the general state of relations between countries" may be changed quite dramatically by short-term developments. Even if the general state of relationships is very good, they can occasionally suffer significant setbacks that might negatively affect the context in which the leadership would make the assessment of the situation.

In this situation neither de-targeting nor a political decision not to launch on warning could adequately protect the United States and Russia from the risk of an accident. These steps could be easily reversed in real time if the warning provided by the early-warning system is considered serious enough to trigger retaliation, as it might be the case if the system reported a large-scale attack.

FORCE REDUCTIONS AND FIRST-STRIKE INCENTIVES

Reduction of the number of strategic launchers and their warheads is the key element of the process that aims at eliminating the dangers associated with nuclear weapons, whether it is an accidental launch or proliferation of nuclear weapon technologies. This process, however, has proven quite difficult and it is likely that in the next decade or so the United States and Russia will still have more than 1500 strategic nuclear warheads on each side in their operational forces with uncertain prospects for further reductions. In this situation reduction of the number of launchers on high alert appears to offer an attractive alternative that would allow reducing the danger of an accident without undertaking serious structural and doctrinal changes that would be required in the case of genuine force reductions.

In addition, some authors argue that by reducing the number of weapons on alert, the United States and Russia would make a first disarming strike impossible, which would eliminate the need in the launch-on-warning posture altogether. Other authors, although not necessarily endorsing this argument explicitly, suggest various measures that would reduce the first-strike potential of the strategic forces. It is therefore important to understand to what extent and in what circumstances the reduction of number of weapons on high alert would affect the first-strike capabilities of strategic forces.

To answer this question, this analysis compares outcomes of a first strike executed by U.S. and Russian strategic forces against each other using the current configuration of the forces and notional 500-warhead forces. The detailed description of the analysis is given in Appendix A.

The main conclusion is that a move toward a force of 500 alert warheads on each side would not affect first-strike capabilities of either side in a substantial way. In fact, in a 500-warhead scenario fewer Russian missiles would be expected to survive a first counterforce attack than in the 2005 force (Appendix A, Table A5). This would also be true for the U.S. force (Appendix A, Table A6), but in absolute terms the difference there would not be as important because most of the survivable warheads on the U.S. side are deployed on sea-launched ballistic missiles anyway.

This result strongly suggests that if the United States and Russia believe that it is necessary to keep their forces on high alert to counter the threat of a disarming strike, their calculations are unlikely to change when they reduce their forces to the level of 500 warheads. In general, we can expect the United States and Russia to keep the launch-on-warning capability even as they reduce the number of nuclear weapons in their operational force.

It is important to note that this analysis assumes that if the United States and Russia kept only 500 alert warheads in their forces, they would do so in a way that is consistent with the practices of force reduction and modernization established in the past decade. This excludes some possible force configurations that could theoretically decrease vulnerability of the Russian forces to a first strike. For example, in some scenarios of this kind Russia would de-MIRV most of its silo-based missiles or increase the share of warheads deployed on SLBMs while increasing strategic submarine patrol rates. Measures like these, if implemented, would indeed make an effective counterforce attack significantly more difficult if at all possible.

The reason we do not take these alternative scenarios for a 500-warhead force into account is that they are extremely unlikely to be implemented. Most of the measures that are required to make them possible have been already discussed and rejected by the Russian military. For example, de-MIRVing of silo-based ballistic missiles was among the most often criticized requirements of the START II Treaty in Russia. Eventually, the ability to reject de-MIRVing was one of the major factors that made the Russian military accept U.S. withdrawal from the ABM Treaty. Similarly, the balance between sea-based and land-based missiles has been discussed by the Soviet and Russian military for a long time and nothing in this discussion suggests that we can expect a shift toward a submarine-based strategic force. Coordinated bilateral measures are also unlikely to bring substantial changes in the structure of the strategic forces or in their operational practices. The history of the START II and the Moscow treaties demonstrates that the military on both sides prefer to avoid any external constraints on their forces.

To sum this up, reduction of the number of weapons on high alert, as well as nuclear force reductions in general, would certainly have a positive effect on the development of U.S.–Russian relationships and eventually could help reduce the risk of an accidental launch. However, these measures alone will not be able to remove incentives for launch on warning.

STRENGTHENING EARLY-WARNING SYSTEMS

An early-warning system that allows detecting incoming ballistic missiles before they reach their targets is an absolutely essential component of a launch-on-warning posture. The United States and the Soviet Union were the only nuclear states that deployed full-scale early-warning systems that included radars and satellites designed to detect an incoming attack. An overview of the current status of these systems is presented in Appendix B.

The status of the Russian early-warning system has received most attention so far, primarily because of the concerns about its deterioration. Indeed, after the breakup of the Soviet Union in 1991, Russia had to deal with a number of problems. Most of the radars were located outside of the Russian territory and some of them had to be mothballed or dismantled. The space-based system that existed in the beginning of the 1990s did not provide global coverage because it could not detect launches of sea-based missiles. Development of new satellites was held back by the economic problems during the transition of the 1990s, which negatively affected all Russian military programs. As a result, the Russian early-warning system has been operating at a fraction of its full capacity and cannot match the missile detection capabilities of the U.S. system.

There have been a number of proposals that suggested that the United States and Russia should undertake a joint effort that would improve the capabilities of the Russian early-warning system. The assumption behind these proposals is that an upgrade of the Russian system is necessary to reduce probability of an error that could lead to an inadvertent launch. This assumption, however, overestimates the degree to which the Russian strategic forces rely on early warning and underestimates negative consequences of an upgrade of this kind.

The Russian early-warning system, like its U.S. counterpart, relies on dual phenomenology—satellites and radars—to detect ballistic missiles. The basic procedures in the case of an attack are also the same—if an attack is detected, the national command authority is supposed to act on the information about it, launching a retaliatory strike if necessary. The Russian system, however, operates in quite different conditions, which means that its role in supporting launch on warning substantially differs from that of the U.S. system.

This point is illustrated by Figure 1, which shows detection timelines for a representative sample of possible attack scenarios.[22] The scenarios presented on the figure include Russian missiles attacking U.S. ICBM fields from its ICBM bases in Kansk, Dombarovskiy, and Tatishchevo, as well as from submarine patrol areas in the Arctic and the Pacific.[23] For the scenario in which the United States attacks Russia, missiles from an ICBM base or from various submarine patrol areas in the Atlantic and the Pacific target leadership and command and control targets in Moscow.[24] The bars on Figure 1 show the flight time of a missile from launch to impact. Assuming that a missile can be detected almost immediately after launch, the bars show the maximum warning time available to the attacked side. The solid portion of the bar shows the time when the missile can be detected by one of the early-warning radars.

As we can see, the most significant factors that affect the ability of early-warning systems to detect an incoming attack are the difference in geographic positions of the two countries and the deployment patterns of their offensive strategic forces.

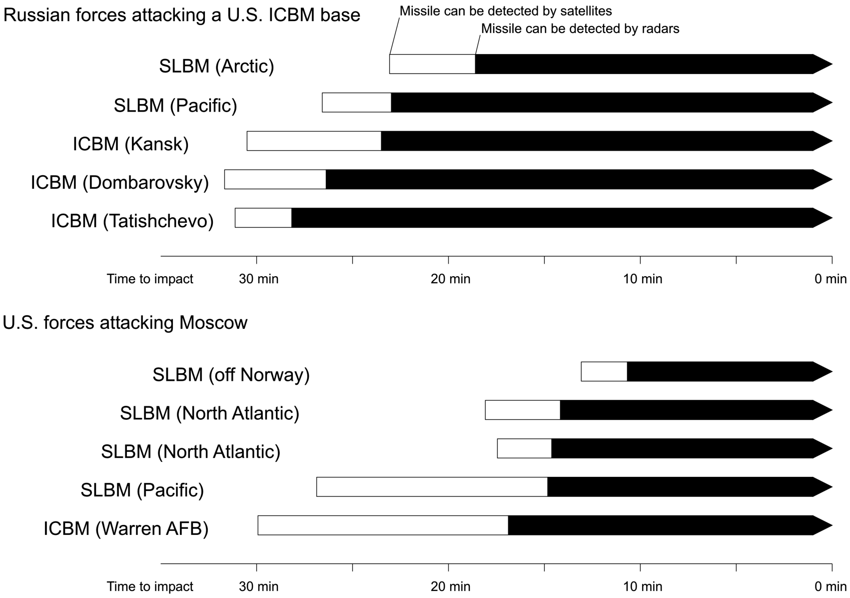

Figure 1: Missile flight and radar detection timelines.

In terms of warning time, the United States has dual advantages over Russia. First, Russia does not have submarines deployed close to the U.S. coast, so the flight time of its SLBMs is about 25 minutes. This gives the Unites States more time to detect a missile and evaluate the situation. The United States, in contrast, can launch its sea-based missiles from positions close to Russian territory, with flight time of about 15 minutes or even less. We should note also that missiles launched from the Pacific cannot be detected by the Russian early-warning satellites.

Second, geographical locations of U.S. early-warning radars allow them to detect incoming missiles quite early in the flight. Russian early-warning radars are located much closer to the targets on its territory, which means they are able to detect incoming missiles much later.

It is usually assumed that a reliable detection of an incoming attack would require a confirmation from two independent systems that operate on different physical principles—space-based infrared sensors and radars. In this case, as we can see from the detection timelines, in most of the scenarios the United States would have this confirmation about 20 to 25 minutes before the first impact. In the case of a U.S. attack against Russia, the latter may not have a detection from any source until about 20 minutes before impact. Confirmation from two independent sources may not come until about 15–17 minutes or even 10 minutes before impact.

As we can see from the detection timelines, in most attack scenarios, at the time when the Russian system would get its first chance to detect incoming missiles, the United States would have full information about an attack, confirmed by two independent sources. This creates completely different requirements for the command and control system that is supposed to act on that information. Russia would have little or no time for deliberations and transmitting launch orders to its forces unless it has been expecting an attack already.

To deal with this problem the Soviet Union is believed to have accepted a two-tier readiness approach, which assumed that an attack would be possible only in a crisis, which would give it enough time to bring strategic forces to a higher degree of readiness, disperse mobile launchers and submarines, and bring political and military leadership to protected command centers.[25] This means that in their peacetime operations Russian strategic forces cannot and do not rely on the information provided by the early-warning system to implement launch on warning.

This also means that the decline of the early-warning system after the breakup of the Soviet Union has not seriously affected the role that early warning plays in the command and control system of the Russian strategic forces, which was rather limited to begin with. Because the decline has been a slow and well understood process, the Russian military had an opportunity to further adjust their operational practices to the gradual loss of early-warning capability. The danger of a miscalculation still exists, for nothing would prevent Russia from attempting to execute launch on warning and issuing the necessary orders. However, during peacetime there will be a rather strong bias against doing so based on the information provided by the early-warning system.

The situation with the U.S. early-warning system, which is regarded as highly capable and reliable, is opposite and presents a danger of a different kind. Because of its perceived reliability, it is quite possible that if the system generated a false but credible warning, operators would not question the information provided by the system. This means that while the probability of a serious error leading to a false alarm may be significantly smaller in the U.S. system than in its Russian counterpart, the overall probability of a launch triggered by this alarm may be higher.

Attempts to upgrade or modernize the Russian early-warning system can increase the risk of an accident. The reason for this is that the decline in the capabilities of that system inevitably resulted in a loss of confidence in its performance on the part of operators and political leadership. This has probably been a positive development, for the operators would be less likely to trust the warning provided by the system whether it is a real warning or a result of a malfunction. An upgrade would inevitably boost confidence in the system, which may not be supported by the actual improvement in its performance. It would be especially dangerous if done as part of a one-time attempt to "repair" the system, for in this case the operators would not have the opportunity to adjust their confidence in the system according to their experience, as would be the case during normal deployment and modernization process.

Along with proposals to repair or upgrade the existing early-warning system, some authors suggested augmenting it by sensors and communication links that would help reliably detect ballistic missile launches or provide assurances that a launch has not occurred.[26] Among specific measures that have been mentioned is deployment of acoustic or video sensors next to missile silos or real-time sharing of early-warning data.

Measures of this kind should be treated with extreme caution, for they are as likely to cause an accident as they are to prevent it. Introduction of new elements into the already complex early-warning and command and control systems would not only bring additional complexity, but would also create new links between the many components of these systems. It is virtually impossible to predict how the new elements would interact with the existing systems or how the new links would affect the nature of interaction between the existing components.[27]

For example, instead of providing reassurance about the absence of an attack, the lack of warning from a silo-installed sensor may in some circumstances lead to suspicions about tampering with the sensor. Similarly, a data exchange arrangement can easily create misunderstanding if one side detects an attack that is not reported by the other, even though this is exactly the situation the exchange is supposed to deal with. In normal circumstances conflicts like these could be easily resolved, but in a crisis there would be no guarantee that the arrangements that are put in place to prevent misunderstanding would work as intended.

An analysis of possible developments during a crisis brings another set of important questions. Even though in peacetime Russia cannot rely on its early-warning system to implement a launch-on-warning strike, it does seem to have an option of doing so in a crisis (in fact, this is most certainly the primary mission of the system). It has been argued, therefore, that an upgrade of the Russian early-warning system is still necessary, for a better functioning system would have a stabilizing effect in a crisis situation. For example, in a crisis the early-warning system could reduce incentives for a preemptive "use them or lose them" strike by providing a certain degree of assurance that the country is not under attack. Information provided by the system could also be used to ensure proper attribution of an attack, which in some circumstances might prevent a retaliatory strike. However, the benefits that an early-warning can provide are marginal and do not offset the additional risks outlined earlier.

First, it is far from clear that having an early-warning system would help make a crisis more manageable, let alone more stable. It is true that early warning can provide additional information that can influence the decisions made during a crisis. However, absence of that information would not necessarily lead to inadequate decisions, especially if the decision-making process is not designed to take that information into account. Lack of early warning is not a problem if the command and control system does not rely on any kind of warning.

Second, it can be argued that a crisis, while potentially dangerous, is a deliberate political tool. A country that gets involved into a crisis presumably pursues certain policy goals and therefore should be ready to bear the risks associated with that crisis. What matters in this situation is not whether a country has certain crisis-management tools in its disposal (an early-warning system in our case), but whether the risks of the crisis are properly understood. These risks should include the ones associated with countries not having early-warning capability or having inadequate capability.

Finally, the notion that a reliable early-warning system would help manage a crisis can make the crisis more likely, precisely because of the belief that it can be managed.[28] As a result, the overall risk of an accident (or deliberate use of nuclear weapons) might increase quite substantially.

To summarize, if countries have concerns about reliability of early-warning systems, these concerns should be dealt with by removing these systems from the decision-making process. Attempts to upgrade, repair or augment the existing early-warning systems would only increase complexity of the systems, which is more likely to increase the probability of an accident involving these systems.

POSSIBLE PRACTICAL MEASURES

As we can see, dealing with the risk of an accidental launch is a very challenging task. None of the methods that have been suggested so far seems to provide an adequate solution to the problem. Neither a political decision nor partial de-alerting can prevent a launch of a substantial number of strategic launchers in a serious system accident. Force reductions are unlikely to affect the U.S. first-strike capability and provide strong new incentives to take forces off alert. And, finally, improvements in early-warning systems or reliance on data exchange mechanisms can potentially make accidents more, not less, likely.

Part of the problem is that the launch on warning posture is an integral part of nuclear deterrence strategy, which the United States and Russia still recognize as one of the primary missions of their strategic forces. Even though the value of deterrence in the current U.S.–Russian relationships can be questioned, neither country is willing to forgo it completely. To some extent this problem can be dealt with by continuing the efforts to improve the U.S.–Russian relations by expanding the current arms reduction process and by creating the institutional and legal framework for cooperation and transparency in military relations. In the long run, this would be the most reliable and most effective way of reducing the risk of an accidental launch, as well as most of the risks associated with nuclear weapons.

This approach, however, has its limits. First of all, the United States and Russia have been steadily improving their relationships for almost 15 years now and they still have been unable to negotiate reductions of their strategic arsenals beyond the level of 1,700–2,200 warheads agreed in Moscow in 2002. Moreover, this process has demonstrated the lack of powerful incentives to introduce transparent and verifiable arms control or arms reduction measures and the reluctance of the military on both sides to commit to measures of this kind. Transformation of strategic forces is increasingly driven by internal considerations, which in many cases have nothing to do with the U.S.–Russian relationships.

This means that although it is true that the United States and Russia commonly justify their force levels and operational practices by pointing at the size and structure of their respective strategic arsenals, they could easily find other justifications. Threats from third countries as well as some yet unknown emerging threats have already been mentioned in the context of justifying various strategic force modernization programs, so we can expect that these arguments will be used in the future as well. As a result, there is no reason to believe that the United States and Russia will discontinue the practice of keeping their forces on high alert even after they reach the point at which they would no longer consider nuclear deterrence to be part of their relationships.

Finally, the process of building mutual confidence and trust, although effective in the long run, cannot address the problems that exist today, when the United States and Russia still have sizable strategic forces that follow operational practices inherited from the cold war.

Ideally, the measures that aim at reducing probability of an accident should not depend on the level of trust between the countries or on legally or politically binding agreements between them.

Another consideration that should be taken into account is that attempts to include transparency, verification, and other confidence-building mechanisms into the measures designed to reduce risks may make the latter harder to implement and potentially destabilizing.

One example of the contradiction between risk reduction and transparency is de-alerting. It is generally assumed that if weapons are taken off alert, it should be done in a transparent and verifiable manner. This, however, creates a possibility of a dangerous re-alerting race during a crisis, which in some circumstances can create an instability that might be worse that the one de-alerting was supposed to stave off.[29]

It is important to note, however, that neither transparency nor verifiability plays any role in reducing the risk of an unintended launch. If one side takes its missiles off alert to prevent them from being launched by an accident, it will not be able to launch them regardless of whether the other side can see status of the missiles or verify the fact that they have been de-alerted. In short, the task of reducing the risk of an accident is quite separate from the one of confidence-building and it should be treated as such. Decoupling of these two tasks would remove the most serious objections to de-alerting—that it creates additional instabilities and that it is cumbersome and hard to implement.

In the absence of transparency in de-alerting, it is possible to aim at taking off alert the entire strategic force. Should an accident occur, no launchers would be available for an immediate attack, allowing enough time to recognize the error.

One possible objection to non-transparent de-alerting is that once taken off alert to guard against an accident, strategic forces would not be able to respond to a real attack as well, which potentially opens a possibility of a surprise attack against a de-alerted force. This possibility, however, should not be overestimated. If the forces can be taken off and on alert covertly, the attacker could never determine the right moment for his attack. Both sides would have to assume that the forces of their adversary are on full alert.

As a practical step, the United States and Russia could introduce a policy of keeping their forces off alert most of the time. This can be done as a coordinated measure or unilaterally, or, in fact, without a declaration or agreement of any kind. In any event, countries should reserve the right to bring them back to alert status and regularly exercise this right. Doing this covertly would most likely require development of de-alerting measures different from those discussed so far, but there is no reason to believe that it cannot be done, even though development of specific measures may require knowledge of the command and control systems that goes beyond that available in public domain. It should be noted here that large fraction of U.S. and Russian strategic forces have already been de-alerted in this manner. Strategic bombers on both sides are no longer kept on high alert. Strategic submarines on patrol can also be considered de-alerted. This leaves land-based ICBMs as the only component of the strategic force that would be seriously affected by de-alerting measures.

Taking weapons off alert in a non-transparent way would allow to significantly reduce the probability of an accidental launch or even completely eliminate it. At the same time, the lack of transparency would ensure that de-alerting does not introduce new instability in a crisis. Implemented this way, de-alerting would not be able to add to confidence-building between the United States and Russia, but in this case reducing the danger of an accident should clearly take precedence.

To summarize, one of the reasons the United States and Russia have been slow and reluctant to introduce measures that would reduce risk of an accidental launch is that the measures that have been considered so far were designed to achieve several different goals at once—from addressing the risk to building confidence and promoting cooperation and to facilitating deeper reduction of nuclear arsenals. This created a significant threshold on the way to implementing these measures and in some cases raised serious concerns about their side effects.

As this analysis demonstrates, some of these concerns are quite real and in general nuclear states should be very careful about taking steps that may affect their established command and control procedures. At the same time, there are practical measures that can substantially reduce the risks associated with accidental launch without creating new instabilities and concerns. These measures would not require any special negotiated arrangement or binding political commitment of any kind. Taken unilaterally or even hidden from public view, they would be just as effective in preventing an accidental launch. This means that there is nothing that prevents the United States and Russia from implementing these measures without delay.

NOTES AND REFERENCES

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2. Bruce G. Blair, *Global Zero Alert for Nuclear Forces* (Washington, The Brookings Institution, 1995). Bruce G. Blair, Harold A. Feiveson, Frank N. von Hippel, "Taking Nuclear Weapons off Hair-Trigger Alert." *Scientific American* (November 1997): 74–81. Harold A. Feiveson, ed., *The Nuclear Turning Point* (Washington, The Brookings Institution, 1999).

3. Thomas H. Karas, "De-alerting and De-activating Strategic Nuclear Weapons," Sandia National Laboratories, SAND2001-0835 (April 2001). Kathleen C. Bailey and Franklin D. Barish, "De-alerting of U.S. Nuclear Forces: A Critical Appraisal." *Comparative Strategy*, 18 (January–March 1999): 1–12. More recently, skeptical view of de-alerting was expressed in John Deutch, "A Nuclear Posture for Today." *Foreign Affairs* (January/February 2005).

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5. This argument is central to the proposal outlined in Rogov et al., *op. cit.*

6. A set of specific measures was outlined in Geoff Forden, "Reducing a Common Danger: Improving Russia's Early-Warning System." Cato Policy Analysis no. 399, May 3, 2001. See also Mosher et al., *Beyond the Nuclear Shadow*.

7. "Joint Statement of the Presidents of the United States of America and the Russian Federation on the Exchange of Information on Missile Launches and Early Warning."

September 2, 1998, http://www.fas.org/news/russia/1998/98090208_tpo.html, accessed on February 9, 2006 and "Memorandum Of Agreement Between The United States Of America And The Russian Federation On The Establishment Of A Joint Center For The Exchange Of Data From Early Warning Systems And Notifications Of Missile Launches." June 4, 2000, http://www.fas.org/nuke/control/jdec/news/000604-warn-wh2.htm, accessed on February 9, 2006.

8. Rogov et al., *op. cit.* as well as Arbatov and Dvorkin in *Revising Nuclear Deterrence* suggest various ways to implement the information exchange described in the JDEC agreement.

9. For a discussion of different scenarios see, for example, Karas, "De-alerting and De-activating Strategic Nuclear Weapons." 13–15.

10. For example, the Russian command and control system, known as Signal, allows the Strategic Rocket Forces Command Center to monitor status of individual silos, detect malfunctions, and, if necessary, block attempts of unauthorized access. Valery E. Yarynich, *C3: Nuclear Command, Control, Cooperation*, Center for Defense Information, Washington, DC, May 2003, p. 143.

11. The November 9, 1979 false alarm in the United States was a result of an accident in which training tapes that simulated a massive Soviet strike were inserted into the computers that processed data from early-warning radars. The U.S. Strategic Air Command was able to recognize the event as an accident by looking at the data supplied by early-warning satellites (see, for example, Geoffrey Forden, Pavel Podvig and Theodore A. Postol, "False Alarm, Nuclear Danger." *IEEE Spectrum*, 37 (3) (March 2000). It is quite possible that had the training tapes affected both channels—radars and satellites—the Strategic Air Command would have made a decision to launch a retaliatory strike. Accidents of similar kind occurred in the Soviet early-warning system as well. Mikhail Pervov, *Sistemy raketno-kosmicheskoi oborony Rossii sozdavalis tak*, 2nd edition (Moscow, Aviarus-XXI, 2004): 416.

12. One example of unforeseen interaction of this kind is the exercise that was conducted by the Russian strategic aviation on the day of terrorist attacks against the United States on September 11, 2001. The exercise included flights of strategic bombers in the direction of the United States and Canada. The flights were cancelled after the Russian General Staff learned about the events in the United States. Yuri Golotyuk, "Yadernyi conflict otstavit." *Vremya novostey*, September 12, 2001. In another coincidence, on the same day, the NORAD was scheduled to conduct an exercise, known as Vigilant Guardian, "which postulated a bomber attack from the former Soviet Union"; *Report of the National Commission on Terrorist Attacks Upon the United States*, note 116, http://www.9-11commission.gov/report/911Report_Notes.htm, accessed on June 11, 2006.

13. For a detailed discussion of interactions in nuclear weapon command and control systems see Scott D. Sagan, *Limits of Safety: Organizations, Accidents, and Nuclear Weapons* (Princeton, N.J.: Princeton University Press, 1993), especially chapter 3.

14. This does not mean that the dangers of an unauthorized launch or a malfunction of the command and control systems can be ignored. They do, however, present a different set of challenges and should be considered separately.

15. Moscow Declaration by President Clinton and Russian President Yeltsin, Moscow, Russia, Jan. 14, 1994.

16. Russia reached similar agreements with the United Kingdom in February 1994 and with China in September 1994. In May 1997, president of Russia announced that Russia will not target NATO countries. The United States reach an agreement with China in 1998. See "Mutual De-targeting News." Federation of American Scientists, http://fas.org/nuke/control/detarget/news/, accessed on February 16, 2006.

17. “Nuclear Supplement to the Joint Strategic Capabilities Plan for FY 1996.” CJCSI 3110.04, February 1996. Quoted in Hans Kristensen, “The Joint Strategic Capabilities Plan (JSCP) Nuclear Supplement.” Nuclear Brief, June 16, 2005, http://www.nukestrat.com/us/jcs/jscp.htm, accessed on February 14, 2006.

18. Wade Boese, Miles A. Pomper, “Strategic Decisions: An Interview With STRATCOM Commander General James E. Cartwright.” *Arms Control Today* (June 2006).

19. For example, during the terrorist attacks against the United States on September 11, 2001, U.S. military pilots assumed that the attack came from Russia. One of the fighter pilots who were scrambled into the air that day testified later, “I reverted to the Russian threat—I'm thinking cruise missile threat from the sea. You know you look down and see the Pentagon burning and I thought the bastards snuck one by us.” Testimony of Philip Zelikow, National Commission on Terrorist Attacks upon the United States, Twelfth Public Hearing, June 17, 2004, http://www.9-11commission.gov/archive/hearing12/9–11Commission_Hearing_2004-06-17.htm, accessed on February 14, 2006.

20. William Arkin, “Russia Nukes the United States.” *Early Warning*, October 31, 2005, http://blogs.washingtonpost.com/earlywarning/2005/10/russia_nukes_th.html, accessed on February 16, 2006. Nikolai Sokov, “Chronology of Significant Military Maneuvers.” NTI Research Library, August 2004, http://www.nti.org/db/nisprofs/russia/weapons/maneuver.htm, accessed on June 11, 2006.

21. Thomas H. Karas, “De-alerting and De-activating Strategic Nuclear Weapons.” p. 15.

22. An attack against U.S. command and control network would have to involve a strike against targets inside the U.S. territory, so an ICBM base rather than the national capital was chosen as a representative target. In the case of an attack against Russia, detection timelines for an attack against ICBM bases are similar to the ones for an attack on Moscow, presented on Figure 1.

23. Missiles are assumed to follow minimum energy trajectories. The coordinates used in the calculations were 41.2N 104.8W for the target (Warren AFB), and 50.8N 59.5E (Dombarovskiy), 56.0N 96.1E (Kansk), 51.7N 45.6E (Tatishchevo), 85N 45E (Arctic), and 45N 165E (Pacific)—for launch points.

24. The coordinates used in the calculations are 55.8N 37.6E (Moscow) for the target and 65N 0W (off Norway), 55N 25W (North Atlantic), 65N 30W (North Atlantic), 50N 165E (Pacific), and 41.2N 104.8W (Warren AFB)—for launch points.

25. For a description of the Soviet command and control system see Igor Sutyagin and Pavel Podvig, “The Structure and Operations of Strategic Nuclear Forces.” in Pavel Podvig (ed.), *Russian Strategic Nuclear Forces* (MIT, 2001).

26. See, for example, Mosher et al. *Beyond the Nuclear Shadow.*

27. Introduction of additional elements would increase “complexity” of the system as well as the degree of “coupling” between its components. Charles Perrow, *Normal Accidents* (Princeton, N.J.: Princeton University Press, 1999): 72–100. A similar point was made by Scott Sagan in *Limits of Safety*, 273–274. For a detailed discussion of various problems associated with interactions see Scott Sagan, “The Problem of Redundancy Problem: Why More Nuclear Security Forces May Produce Less Nuclear Security.” *Risk Analysis*, 24 (4) (2004).

28. See the discussion of this effect, known as overcompensation, in Sagan, “The Problem of Redundancy Problem.”

29. All authors who discuss de-alerting assume that should be done in a transparent manner. For a detailed discussion of various methods see Arbatov and Dvorkin, *Revising Nuclear Deterrence.* The argument about instability associated with de-alerting is made, for example, in Bailey and Barish, *op. cit.*

APPENDIX A: FIRST-STRIKE CAPABILITIES OF U.S. AND RUSSIAN STRATEGIC FORCES

Composition of the Strategic Forces

According to START Treaty data exchange, in July 2005, the United States had 1,225 strategic delivery systems that could carry 5,966 nuclear warheads. Russia had 955 strategic systems and 4,380 nuclear warheads associated with them. These warheads are deployed with land-based intercontinental ballistic missiles (ICBM), sea-launched ballistic missiles (SLBM) carried by strategic submarines, and strategic bombers that can carry either air-launched cruise missiles or gravity bombs.

The numbers presented in this section take into account that not all systems listed in the START Treaty data exchange are operational and the number of warheads deployed with some of the launchers is different from the one reported in the treaty. The result is the 2005 baseline force configurations described later. The "first-strike forces," which include only those delivery systems that can be kept on constant high alert and therefore can take part in an offensive strike with little or no notice.

Also presented are notional 500-warhead force configurations. As the name implies, in these configurations each side is allowed to have only 500 operationally deployed warheads. "Operationally deployed" is a term defined in a way that would allow both sides to accommodate their force development plans and to keep those systems that they consider valuable. This is consistent with the approach that the United States and Russia agreed on in the Moscow treaty of 2002. Similarly to the baseline scenario, each 500-warhead force configuration includes a "first-strike force."

The United States

In 2005, the land-based component of the U.S. strategic force consisted of 500 Minuteman III silo-based missiles.[1] These missiles carry 1,050 warheads of two different types—W62 and W78.[2] The numbers of missiles and warheads are listed in Table A1.[3] Some W62 warheads will be replaced by the W87 warheads,

Table A1: The U.S. first-strike force.

		Number of missiles/warheads or submarines/missiles/warheads	
	Warheads	**2005 baseline**	**2005, 500-warhead force**
ICBMs			
Minuteman III	1 or 3 W62	200/300	
Minuteman III	2–3 W78	300/750	116/116
Minuteman III	1–3 W87	—	—
SLBMs			
Trident II/D-5	up to 8 W76	2/48/288	2/48/192
Trident II/D-5	up to 8 W88	2/48/288	2/48/192
Total warheads		1626	500

which have been deployed on MX/Peacekeeper missiles. The replacement, which is scheduled to be completed in 2009, will include an upgrade of the guidance system that will improve accuracy of the missile to about 100 m. In this analysis we assume that no W87 are deployed, but if they are they would increase the counterforce capabilities of the U.S. forces.

The strategic submarine force of the United States includes 14 nuclear-powered submarines that carry sea-launched ballistic missiles (SLBM). These submarines are based in the Pacific at Bangor, WA, and in the Atlantic at King's Bay, GA. Older submarines that initially carried Trident I/C-4 missiles are being converted to carry Trident II/D-5. The conversion is almost complete—all 14 ballistic-missile submarines will be equipped with D-5 missiles by 2008.[4]

For the purposes of this analysis we will assume that two submarines will be in overhaul at any given time, so the number of operational submarines will remain at twelve, as it is today. Of these twelve submarines about eight would be at sea on patrol or in transit.[5] This means that at least eight submarines and their weapons could survive an attack. On the other hand, we will assume that only four submarines, those that are not in transit, can participate in a first strike. This assumption is made to take into account those de-alerting proposals that call for disabling SLBMs during transit.[6] We should note that if these submarines were to take part in a first strike they would substantially increase its effectiveness.

Trident II missiles can carry two types of nuclear warheads—W76 and W88. The latter was developed as a counterforce weapon—it has higher yield and a fuse that allows it to attack hardened targets. The W76 warhead was reported to undergo an upgrade that would increase its counterforce capability as well.[7] Both warheads can be delivered with very high accuracy.[8] In our analysis we will assume that half of the Trident II missiles are equipped with W76 and half with W88 warheads.

Table A1 shows the total number of SLBM warheads in different scenarios. It assumes that the missiles are currently carrying six warheads each.[9] In the 500-warhead force scenario the number of submarines and missiles will remain the same, but they will carry four warheads instead of six.

In addition to land-based ICBMs and strategic submarines, the United States has 115 strategic bombers that can carry about 1,000 nuclear weapons (air-launched cruise missiles and gravity bombs).[10] These weapons are not included in the first-strike force.

Russia

The Strategic Rocket Forces, which has traditionally been the strongest component of the Soviet and Russian strategic nuclear triad, currently operate land-based ICBMs of four different types. The core of the force are silo-based missiles with multiple independently targeted reentry vehicles

Table A2: Russian first-strike force.

		Number of missiles/warheads or submarines/missiles/warheads		
	Warheads	**2005 baseline**	**2005 500 warhead silo force**	**2005 500-warhead mobile force**
ICBMs				
SS-18/R-36MUTTH	10	45/450	0/0	0/0
SS-18/R-36M2	10	40/400	40/400	10/100
SS-19/UR-100NUTTH	6	120/720	0/0	0/0
SS-25/Topol	1	279/279	60/60	279/279
SS-27/Topol-M	1	40/40	40/40	40/40
SLBMs				
SS-N-18/R-29R	3	6/96/288	0/0/0	0/0/0
SS-N-23/R-29RM	4	3/48/192	0/0/0	1/16/64
SS-NX-30/Bulava	6	—	—	—
Total warheads		2369	500	483

(MIRVs)—SS-18 (R-36MUTTH and R-36M2) with ten warheads each and SS-19 (UR-100NUTTH) missiles with six. In addition to these, Russia has two types of single-warhead missiles—road-mobile SS-25 (Topol) and silo-based SS-27 (Topol-M). The number of deployed ICBMs is shown in Table A2.[11]

The Russian strategic fleet currently includes submarines of two types—older Delta III/Project 667BDR ships, which carry SS-N-18/R-29R missiles, and newer Delta IV/Project 667BDRM submarines with SS-N-23/R-29RM missiles. Not all submarines are operational, though—three out of six Delta IV submarines are in overhaul. Of the six Delta III submarines, only one has undergone an overhaul, which may indicate that the other five may be facing withdrawal from active service.[12] For the purposes of this analysis, however, we assume that all Delta III submarines are operational. Russia has been developing a new sea-based missile, known as Bulava, but it will not be ready for deployment until at least 2008.

Russian strategic submarines do not go on patrol on a regular basis, but because they have the capability to launch their missile from the port, all operational submarines theoretically can participate in a first strike.[13]

In addition to land- and sea-based missiles, Russia has 78 strategic bombers that can carry about 800 nuclear air-launched cruise missiles.[14] These weapons are not counted as part of the first-strike force.

If Russia were to configure its strategic forces to keep only 500 nuclear warheads in full readiness, it would have a choice between two basic scenarios. One of these would keep silo-based missiles as the core of the strategic forces whereas another would rely primarily on mobile missiles. Although it can be argued that mobile missiles might be less vulnerable than silo-based ones and therefore could allow building a more stable strategic force, the choice between these two options is far from certain. The debate about relative merits of mobile missiles and generally more capable (e.g., in their throwweight and therefore the ability to penetrate missile defenses) silo-based missiles has been in progress in Russia for several decades and the current status of the land-based missile forces indicates that it has failed to reach a conclusive outcome. There is no reason to expect that this issue would be resolved one way or another should Russia decide to reduce its strategic forces to the level of 500 warheads. In particular, Russia might be reluctant to remove from service its SS-18/R-36M2 missiles and the recently deployed silo-based SS-27/Topol-M missiles.

To take both possibilities into account, we will consider two scenarios, outlined in Table A2. The "silo" scenario assumes that Russia keeps all its SS-18/R-36M2 and silo-based SS-27/Topol-M missiles. This would leave 60 road-mobile SS-25/Topol missiles. In the "mobile" scenario Russia would keep all its SS-25/Topol missiles and reduce the number of SS-18/R-36M2 to 10. In this scenario, in addition to land-based missiles Russia could keep one submarine in high degree of readiness.

Theoretically, Russia could reduce the number of warheads on alert by reducing the number of warheads carried by silo-based missiles. For example, in addition to its mobile missiles, Russia could preserve almost all of the SS-18 and SS-19 missiles by de-MIRVing them. This would help Russia maintain a relatively large "target base," making a counterforce attack much more difficult. At the same time, implementation of this measure requires removal of warheads from missiles, which would seriously disrupt standard operations of the Strategic Rocket Forces units and would severely limit force reconstitution capability.[15] This means that in practice this scenario is extremely unlikely to be realized.

First-Strike Scenarios

A counterforce strategic strike would have to destroy several categories of targets. One category would include political and military leadership, objects of command and control infrastructure, communication networks, and other targets of this kind. The exact number of targets in this category, their characteristics, and therefore the number of weapons required to destroy them is difficult to estimate, but these would not change with changes in composition of the strategic forces, so we can assume that they are constant for all attack scenarios.

Another category would include missile silos and individual launchers, missile, submarine, and bomber bases, and other facilities of the strategic forces. The number of targets in this category (and their characteristics) would generally depend on the number of deployed strategic launchers or the number of weapons on alert. This means that it is this category of targets that would account for most of the difference between effectiveness of various first-strike attack options. We can further limit variations between different scenarios by observing that certain targets in this category are essentially "fixed," just like those in the leadership and command and control category. For example, at the current force levels the number of strategic bomber bases or submarine ports would not depend on the number of warheads on sea-based ballistic missiles or on strategic bombers.

In practice, the variables that would determine the size of target base are the number of land-based missiles in silos and on mobile launchers. In our assessment of first-strike scenarios we will compare effectiveness of various attack options by estimating the capability of strategic forces to destroy land-based missile force of the opposing side. The number of weapons required to attack the leadership and command and control targets as well as submarine and bomber bases is assumed to be about the same for all scenarios.

For Russia, an estimate of the number of weapons that would be required to attack targets in this category can be derived from a study done by the Natural Resources Defense Council in 2001.[16] The study estimated that destroying submarines in ports would require 30 warheads,[17] whereas attacking strategic aviation facilities would require 19 warheads.[18] According to the study, an attack on command and control facilities would require about 175 warheads.[19] Overall, the United States would probably need to have about 200–250 warheads that it can use on targets other than land-based ICBMs. We will assume that this number would be comparable in those scenarios where Russia attacks the U.S. strategic forces.

In considering effectiveness of an attack, we need to know the probability of a weapon system destroying the target it is assigned to attack. This number, usually known as kill probability, P_{kill}, is determined by several factors. The most important ones are the yield of the warhead delivered by the weapon system, the accuracy of delivery (which may be affected by uncertainty in target's location), and the target's ability to withstand an attack.[20]

A missile silo is a fixed target whose hardness is usually characterized by the overpressure in the air shock wave at the distance at which the silo can survive the blast. Estimates of silo hardness, quoted in literature, vary quite significantly. During the cold war, some U.S. sources assumed that the silos built by the Soviet Union have been hardened to 5,000 psi or even to 25,000 psi.[21] However, the information that is available today from various Russian sources does not support these assumptions. According to the Russian literature, the most hardened silos that were built in the Soviet Union can withstand effects of a nuclear blast at a distance that corresponds to overpressure of 100 atm, which is equivalent to about 1,500 psi.[22] This is the value that we will use in our analysis for hardness of all silos, whether U.S. or Russian.[23] We should note that even though the U.S. targeting plans probably still assume that Russian silos can withstand very high overpressures, the Russian military would assess

Table A3: Counterforce capabilities of the U.S. missiles.

				Against a silo		Against mobile missiles	
	Warhead	Yield, kt	Accuracy (CEP), m	R_{kill}, m	P_{kill}^{2-1}	R_{kill}, km (HOB, km)	Warheads per missile group
ICBMs							
Minuteman III	W62	170	220	230	0.715	3.5 (1.8)	6
Minuteman III	W78	335	120	290	0.982	4.4 (2.0)	5
Minuteman III	W87	310	100	280	0.985	4.4 (2.0)	5
SLBMs							
Trident II/D-5	W76	100	100	190	0.963		
Trident II/D-5	W88	455	100	320	0.985		

vulnerability of its forces based on their knowledge of silo hardness, not on U.S. assumptions about it.

Once the hardness of a target is known, we can calculate kill radius R_{kill} of various warheads against a silo—the distance at which a warhead generates overpressure that exceeds hardness of the target. This distance depends on the warhead yield and the altitude of the nuclear burst. For a hardened target the maximum probability of kill is achieved with a ground burst, which is assumed in all calculations of kill probability against missile silos. Estimates of the kill radii for specific strategic systems against missile silos are presented in Table A3 for U.S. systems and in Table A4 for Russian systems.[24]

To estimate the probability of destroying a fixed target we have to take into account accuracy of the delivery system. If we assume normal distribution of warhead landing points around the target, the probability of miss distance r being larger than R is given by the following equation:

$$P(r > R) = 2^{-(R/R_{CEP})^2}$$

Table A4: Counterforce capabilities of Russia's missiles.

			Against a silo	
	Yield, kt	Accuracy (CEP), m	R_{kill}, m	P_{kill}^{2-1}
ICBMs				
SS-18/R-36MUTTH	750	400	380	.650
SS-18/R-36M2	750	220	380	.946
SS-19/UR-100NUTTH	750	400	380	.650
SS-25/Topol	550	390	340	.590
SS-27/Topol-M	550	350	340	.665
SLBMs				
SS-N-18/R-29R	200	900	240	.083
SS-N-23/R-29RM	200	500	240	.242
SS-NX-30/Bulava	100	400	195	.249

where R_{CEP} is the common measure of missile accuracy, known as CEP.[25] For the target to be destroyed the miss distance should not exceed kill radius R_{kill}. For a given kill radius the probability of a target being destroyed in a one-on-one attack is

$$P_{kill}^{1-1} = a \cdot (1 - 2^{-(R_{kill}/R_{CEP})^2}),$$

where a is a factor that accounts for reliability of the weapon system and its components. If each target is attacked by two warheads, the probability of kill would be

$$P_{kill}^{2-1} = 1 - \left(1 - (1-b) \cdot P_{kill}^{1-1}\right) \cdot \left(1 - P_{kill}^{1-1}\right),$$

where b is the fratricide rate—the probability that the second warhead is destroyed by the first one. In this analysis we assume that reliability of missiles is 90 percent and the fratricide rate is 5 percent.

Data on accuracy of U.S. and Russian missiles are presented in Table A3 and Table A4, which also give kill probabilities against missile silos in a two-on-one attack.[26]

The Russian strategic forces include a number of ground-mobile ICBMs that would have to be destroyed in a first strike. Survivability of mobile missiles depends on uncertainty of their locations rather than on hardness of their launchers. Transporter-launcher of the SS-25/Topol missile is a soft target with hardness not exceeding 5 psi.[27] As can be seen from Table A3, the kill radius of modern U.S. missiles against a target of this kind is on the order of several kilometers.[28]

However large, this kill radius is small compared to the size of missile patrol area, which can be several hundred kilometers across. During the START Treaty negotiations, the Soviet Union agreed that during normal time mobile missiles will stay inside designated deployment areas, which cannot exceed 125000 sq. km in size (most of these areas are rectangles of about 300×400 km).[29] Each missile division, which can include from 18 to 45 missiles, has a separate deployment area associated with it.[30] It should be noted that according to the treaty, missiles can go beyond their regular deployment areas during "operational dispersals," but there was an understanding that these dispersals would be rare and conducted "only for national security purposes in time of crisis."[31]

Within a division, missiles are organized into regiments of nine missiles each. Each regiment has its own base ("restricted area" in the START treaty language) with permanent shelters, where missiles stay when they are not on patrol. The missiles go on patrols in units of three launchers that apparently share command and control and communication equipment.[32]

If the mobile missiles are dispersed over their deployment areas and locations of patrol units are unknown, they can be considered essentially invulnerable. As we can estimate using the data presented in Table A3, "barraging" just one deployment area would require about 2,000 warheads, which rules out a "brute force" attack. However, an attacker could still try to mount a successful attack, exploiting the fact that peacetime deployment patterns may increase vulnerability of mobile missiles.

The information on deployment patterns of mobile missiles is very scarce. However, they seem to be spending most of the time in stationary shelters at the missile regiment base. The shelters, in addition to protecting missiles from the elements, provide the capability of launching the missiles in fully automatic mode (including in a launch-on-warning strike).

In estimating the mobile missile patrol rate we will assume that as a general rule each missile division that consists of four or five regiments would be expected to keep one regiment (nine missiles grouped into three mobile units) on patrol at any given time. Smaller divisions will be grouped together to maintain the same patrol rate—one regiment on patrol for every four or five operational regiments.

In 2005 the Strategic Rocket Forces included two five-regiment mobile missile divisions, four four-regiment ones, and one with two and three regiments each (the total of 31 regiments).[33] For those scenarios in which the current structure of the mobile force is preserved we will assume that there are seven regiments on patrol at any given time. This corresponds to 21 mobile units, each representing a separate target. In addition to these, the attacker would have to target all 31 garrisons. For the scenario in which the number of mobile missiles is reduced to 60, we will assume that there are 2 regiments (6 mobile units) on patrol and 7 garrisons that would have to be targeted.

Stationary shelters in garrisons are relatively soft targets that offer little additional protection to missiles. In practice, all missiles stationed in a garrison can be destroyed with a single warhead.[34] We will assume that each garrison is targeted by two warheads. To target a mobile missile unit on patrol, the attacker must know its location before launching an attack. Although mobile missile units certainly employ a variety of techniques to prevent detection, they are still vulnerable to detection by space-based reconnaissance means because unlike submarines they do not have a body of water to protect them. Detection is further facilitated by the fact that during normal peacetime operations the missile transporter movements are most likely constrained by a set of predetermined routes and positions along the existing road network. Moreover, for the 15 years the mobile missiles have been in service, they almost certainly developed detectable patrol patterns that can help determine their locations and predict their movements.

The vulnerability of mobile missiles to detection from space has been recognized by the Soviet and Russian military. The information about operational deployment procedures of mobile missiles suggests that the military did not consider mobile launchers to be undetectable and therefore invulnerable during their normal peacetime operations. For example, the procedures for generating the force in a crisis included dispersal of mobile missile launchers beyond the regular deployment areas.[35]

Finally, even though some mobile missile units can avoid detection for some of the time, in a first-strike scenario considered here an attacker would have the choice of time for the attack, so he could wait for the moment when location of all mobile units is known with adequate certainty.

Once the location of mobile units on patrol is determined, the attacker would have to take into account the possibility that they would change their location between the time of detection and arrival of attacking warheads. In our analysis we will assume that the attacker would have to cover a stretch of road of about 40 km around the projected location of a mobile missile group. This implies that the maximum speed of a mobile group is 40 km/h and the attacker has about one hour to execute the attack. This is a conservative estimate, for it is unlikely that mobile units will be on the move—they are usually stationed in predetermined locations along their patrol routes. Because attacking mobile missile units on patrol would require adaptive targeting capability, we assume that sea-launched ballistic missiles cannot be used in an attack of this kind. The number of ICBM warheads required to target a mobile missile unit is given in Table A3.

The results of modeling first-strike attacks in which U.S. forces target Russian strategic forces are given in Table A5. The numbers presented in the table (and in the similar table for the Russian attack on U.S. forces) should be treated with caution.[36] They are expected values, not outcomes of a particular attack scenario. The number of significant digits of the values presented in the table also should not be interpreted as an indicator of an accuracy with which these values are known. The main purpose of this table is not to predict an outcome of a specific attack, but rather to compare different scenarios, which

Table A5: Estimated outcomes of a U.S. first strike against Russian forces.

	2005 baseline		**500-warheads silo**		**500-warhead mobile**	
	Total missiles	**Expected to survive**	**Total missiles**	**Expected to survive**	**Total missiles**	**Expected to survive**
ICBMs						
R-36MUTTH/SS-18 R-36M2/SS-18	85	1.3	40	0.6	10	0.1
UR-100NUTTH/SS-19	120	2.0	—	—	—	—
Topol-M/SS-27	40	0.7	40	0.6	40	0.6
Topol/SS-25	279	3.4	60	0.8	279	3.4
SLBMs						
R-29R	96	0	—	—	—	—
R-29RM	96	0	—	—	16	0

is possible because the basic assumptions remain the same for each scenario considered here.[37]

The 2005 baseline attack on the Russian forces assumes that SS-18 silos are attacked by Trident II/W88 warheads, SS-19 silos—by Trident II/W88 and Minuteman III/W78 warheads, SS-27 silos—by Minuteman III/W78 warheads, SS-25 garrisons—by Trident II/W76, and mobile SS-25 units—by Minuteman III/W78 warheads. In this scenario, after attacking the targets listed in the table, the United States would still have 969 operational warheads.

In the 500-warhead scenarios, silos of SS-18 and SS-27 missiles are attacked by Trident II/W88 warheads. SS-25 garrisons are attacked by Trident II/W76 warheads, while mobile units—by Minuteman III/W78. After hitting these targets, the United States would still have 296 warheads in the "silo" scenario and 233 warheads—in the "mobile scenario.

As we can see, the number of warheads that would still be available to the United States after an attack on land-based missiles would be sufficient to simultaneously destroy leadership and command and control targets, as well as submarine and bomber bases. We therefore assume that none of the strategic submarines and bombers can survive the first strike.

As we can see from Table A5, reduction of nuclear forces to the level of 500 warheads would negatively affect the ability of the Russian strategic forces to withstand a first disarming strike. The number of missiles that would be expected to survive an attack would be lower than it is today. The situation would be even worse in terms of survivable warheads, for the missiles that would be affected the most by the reductions would be multiple-warhead R-36M2/SS-18 and UR-100NUTTH/SS-19.

As we can see, the U.S. forces can destroy most of the Russian strategic launchers in a surprise counterforce attack. In contrast, Russia's first-strike capability is virtually nonexistent. Table 6 shows estimated outcomes of an attack of the Russian strategic forces against the United States that illustrate this point.

In the 2005 baseline scenario Minuteman silos are attacked by all 85 SS-18 (R-36MUTTH and R-36M2) missiles and some UR-100NUTTH missiles. After a strike of this kind, Russia will still have 1369 missiles on its ICBMs and SLBMs. In both 500-warhead scenarios, the Minuteman silos are attacked by R-36M2 missiles. In the "silo" scenario there are enough missiles of this type to execute the attack. In the "mobile" scenario, Topol-M and Topol missiles are also used to attack Minuteman silos. The number of warheads that Russia would still have after attacking missile silos is 268 and 251, respectively. This would allow it to attack leadership and command and control targets and destroy all submarines in ports and all strategic bombers.

As we can see from Table A6, strategic submarines provide the United States with the best protection of its ability to retaliate, because they cannot be destroyed even in a surprise attack. But the U.S. land-based ICBM force would

Table A6: Estimated outcomes of a Russian first strike against U.S. forces.

	2005 baseline		500-warheads silo		500-warhead mobile	
	Total missiles	Expected to survive	Total missiles	Expected to survive	Total missiles	Expected to survive
ICBMs						
Minuteman III	500	115.9	116	6.3	116	28.3
SLBMs						
Trident II	288	192	288	192	288	192

also provide quite substantial deterrent capability, because the capability of the Russian missiles to attack hardened targets is quite limited.

NOTES AND REFERENCES FOR APPENDIX A

1. MX/Peacekeeper missiles are being withdrawn from service.

2. Robert S. Norris, Hans Kristensen, “U.S. Nuclear Forces, 2005.” *The Bulletin of the Atomic Scientists*, 61 (1) (January/February 2005): 73–75.

3. Robert S. Norris and Hans Kristensen, “U.S. Nuclear Forces, 2005.” *The Bulletin of the Atomic Scientists*, 61 (1) (January/February 2005): 73–75; *Nuclear Weapon Database: United States Arsenal*, Center for Defense Information, http://www.cdi.org/issues/nukef&f/database/usnukes.html, accessed on July 1, 2005.

4. Robert S. Norris and Hans Kristensen, “U.S. Nuclear Forces, 2006.” *The Bulletin of the Atomic Scientists*, 62 (1) (January/February 2006): 68–71.

5. According to the Navy, OPTEMPO for Trident SSBNs is more than 70%—ADM Richard W. Mies. “The SSBN in National Security.” *Undersea Warfare* (Fall 1999), http://www.globalsecurity.org/military/library/report/1999/ntlsecurity.htm, accessed on June 17, 2005. Another Navy source gives the following information: “Currently, the SSBN force operates on a 112-day cycle that consists of a 77-day strategic deterrent patrol, followed by a 35-day refit period.” CAPT Butch Hansen, “A New SSBN Operating Cycle for Kings Bay.” *Undersea Warfare*, Fall 1999, http://www.globalsecurity.org/military/library/report/1999/newssbn.htm, accessed on June 17, 2005.

6. In addition to this, it would be difficult for the United States to implement a 500-warhead force structure if submarines in transit are counted as part of the active force. It would require measures that are harder to implement than reducing the number of warheads per missile from six to four. A similar approach toward counting submarines in transit was adopted, for example, in Sidney D. Drell and James E. Goodby, *What Are Nuclear Weapons For? Recommendations for Restructuring U.S. Strategic Nuclear Forces*, An Arms Control Association Report, April 2005, p. 16. See also John Deutch, “A Nuclear Posture for Today.” *Foreign Affairs* (January/February 2005).

7. The upgrade would change the fuse, so the warhead can be used in a ground burst mode. George N. Lewis and Theodore A. Postol, “The Capabilities of Trident against Russian Silo-Based Missiles: Implications for START III and Beyond.” Cambridge, MA, February 2–6, 1998.

8. “The Capabilities of Trident against Russian Silo-Based Missiles.”

9. Robert S. Norris and Hans Kristensen, “U.S. Nuclear Forces, 2005.” *The Bulletin of the Atomic Scientists*, 61 (1) (January/February 2005): 73–75.

10. *Ibid.*

11. Data on the number of deployed missiles is taken from the Russian Strategic Nuclear Forces site, http://russianforces.org/current/, accessed on December 6, 2005.

12. Russian Strategic Nuclear Forces site, http://russianforces.org/current/, accessed on December 6, 2005.

13. Hans Kristensen, “Russian Nuclear Submarine Patrols.” The Nuclear Information Project, http://www.nukestrat.com/russia/subpatrols.htm, accessed on January 23, 2006.

14. Russian Strategic Nuclear Forces site, http://russianforces.org/current/, accessed on December 6, 2005.

15. For a description of procedures involved in warhead removal see Alexei Arbatov, Vladimir Dvorkin, *Revising Nuclear Deterrence*, CISSM Report, October 2005, 71.

16. *The U.S. Nuclear War Plan. A Time from Change*, Natural Resources Defense Council, June 2001. Available at http://www.nrdc.org/nuclear/warplan/index.asp, accessed on January 22, 2006.

17. *The U.S. Nuclear War Plan*, 70–74. More warheads would be required to destroy various supporting facilities, but these would not be targets for a first disarming strike.

18. *The U.S. Nuclear War Plan*, 82–84.

19. *The U.S. Nuclear War Plan*, 106. Not all of the targets on this list, however, would have to be destroyed in a first disarming attack.

20. Evolution of strategic nuclear forces during the cold war has led to development of detailed damage-assessment models that take into account the complex nature of nuclear explosions and take advantage of the rich experimental data collected during nuclear tests. For example, *Handbook of Nuclear Weapon Effects*, 1st Edition, Defense Special Weapons Agency, September 1996, or V. M. Loborev (ed.), *Fizika yadernogo vzryva, Vol. 1 & 2* (Nauka, Moscow, 1997). Although these models might offer better accuracy in predicting the result of a nuclear strike, this improvement in accuracy cannot change the overall assessment of a possibility of a disarming strike. A strike of this kind can be a practical option only if its predicted outcome is not overly sensitive to the details of the damage-assessment model.

21. See, for example, *The U.S. Nuclear War Plan*, 43.

22. For example, Volkov and Norenko give 10 MPa as the hardness of most advanced Soviet missile silos and note that hardness has never been increased beyond that level. E. B. Volkov, A. Yu. Norenko, *Raketnoye protivistoyaniye* (Moscow, SIP RIA, 2002), 42.

23. This hardness of a Minuteman silo is in general agreement with the estimate of “about 2000 psi.” provided by U.S. sources. See, for example, Thomas B. Cochran, William M. Arkin, Milton M. Hoenig, *Nuclear Weapons Databook, Volume I, U.S. Nuclear Forces and Capabilities* (Ballinger: Cambridge, MA, 1984), p. 117.

24. For warhead yields, see Norris and Kristensen, “U.S. Nuclear Forces, 2005” and *Russian Strategic Nuclear Forces*. Calculations are based on Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons*, 3rd ed., 1977 and the model presented in *The U.S. Nuclear War Plan, Appendix D.*

25. Alternatively spelled out as Circular Error Probable or Circle of Equal Probability. The probability of a warhead landing inside a circle with this radius is equal to that of a warhead landing outside of it. Russian sources usually give the value of “maximum deviation.” which is 2.7 times larger than the standard deviation of the normal distribution and about 2.3 times larger than CEP.

26. Data on missile accuracy are estimates based on an analysis of a range of public sources. For U.S. missiles the primary source was Cochran *et al.*, *Nuclear Weapons*

Databook. Data for Russian missiles are based on Pavel Podvig (ed.), *Russian Strategic Nuclear Forces* (Cambridge: MIT Press, 2001) and *Raketnoye protivistoyaniye*, 60.

27. Volkov and Norenko give 0.03 MPa for soft targets (*Raketnoye protivistoyaniye*, 62), which is roughly 4.5 psi.

28. Estimates of the kill radius assume an air burst, which at low overpressures allows to maximize the area exposed to a certain level of overpressure. Calculations are based on the model described in *The U.S. Nuclear War Plan, Appendix D.*

29. START Treaty, Article VI(9)

30. START Treaty, Article VI(9). See also *The U.S. Nuclear War Plan*, 52.

31. START Treaty, Article XIV; START Treaty, Seventh Agreed Statement. Article XIII also allows dispersal of missiles beyond the deployment area during exercises, subject to notification.

32. Steven Zaloga, “Strategic Forces of the SNG.” *Jane’s Intelligence Review*, Feb. 1, 1992, 79, quoted in NRDC targeting, 52.

33. Russianforces.org site, Accessed on January 27, 2006.

34. *The U.S. Nuclear War Plan*, 56–57.

35. START Treaty, Article XIV.

36. In particular, although these results show vulnerability of the Russian strategic forces, they should not be interpreted as demonstrating possibility a successful disarming strike, as it has been done by some authors (Keir A. Lieber and Daryl G. Press, “The End of MAD? The Nuclear Dimension of U.S. Primacy.” *International Security*, 30(4) (Spring 2006), 7–44.

37. We also do not consider possible contribution of conventional high-precision weapons, even though some Russian experts argue that this contribution may be significant. Eugene Miasnikov, *Precision Guided Weapons and Strategic Balance*, Center for Arms Control Studies, MIPT, Dolgoprudny, November 2000, http://www.armscontrol.ru/start/publications/vto1100.htm, accessed on Feb. 12, 2006.

APPENDIX B: EARLY-WARNING SYSTEMS AND THEIR CAPABILITIES

The early-warning systems deployed by the United States and the Soviet Union share the same general principles—they include satellites that are designed to detect missiles shortly after their launch and radars that detect warheads as they approach their targets. It is believed that having two types of sensors that use different physical principles is important for the system to provide reliable warning and minimize the probability of an error.

Even though the basic principles were the same, specific configurations of the U.S. and Russian early-warning systems are quite different, mainly due to differences in geographical positions of the two countries, their approaches to launch-on-warning and technological capabilities.

U.S. Early-Warning Satellites

The U.S. space-based early-warning system includes satellites of the DSP (Defense Support Program) type, which are deployed on geosynchronous orbits.

The DSP satellites have been in service since the early 1970s and during this period went through at least five major design changes.[1] The satellites launched since 1989 are known as satellites of the DSP I class.

The primary sensor deployed on the satellites of the DSP I class is a linear short-wave PbS infrared detector with 6,000 elements. In addition to it, these satellites carry mid-wave HgCdTe auxiliary sensor.[2] The field of view covers the entire Earth disk visible from the satellite and the area above the Earth limb, allowing the satellite to detect launches from polar regions. The satellite scans the field of view by rotating its body around a vertical axis every 10.24 seconds.[3] In addition to the sensors that detect missile launches, these satellites carry sensors that are designed to detect nuclear explosions.[4]

The U.S. Space Command does not publish orbital data for DSP satellites (as well as for most U.S. military satellites). However, satellite positions can be determined from the data published by the Los Alamos National Laboratory, which runs the Geosynchronous Energetic Particle Data project. The DSP satellites launched in 1976–1997 carry sensors designed for this project and the data on positions of these sensors (and therefore of the satellites) are publicly available.[5] This information, combined with data from independent observers, allows to determine positions of the all DSP satellites that are in operation today.[6] These data are presented in Table A7.

The DSP satellite deployment history indicates that until late 1980s–early 1990s the satellites were deployed mainly in three positions. A satellite positioned at 65E or 69E provided coverage of most of the Soviet Union (as well as the surrounding regions), a satellite at 134W, 152W, or 105W covered the Pacific, and a satellite at 65W, 70W, 80W, or 85W covered the Atlantic.[7]

Beginning in the early 1990s the pattern of deployment changed. By 2002 the number of active satellites in the constellation was increased to seven, which allows certain areas to be monitored by more than one satellite, increasing reliability of detection. The coverage provided by the current constellation of satellites is shown on Figure A1. As we can see, most of the landmass is simultaneously covered by at least three DSP satellites.[8]

Table A7: U.S. early-warning satellites.

	NORAD number	Launch date	End of operation	Type, system	Orbital position
USA 39	20066	06/14/1989	Active	F-14, DSP I Blk 14	145W
USA 65	20929	11/13/1990	Active	F-15, DSP I Blk 14	38W
USA 75	21805	11/24/1991	12/2004?	F-16, DSP I Blk 14	165W
USA 107	23435	12/22/1994	Active	F-17, DSP I Blk 14	165W
USA 130	24737	02/23/1997	Active	F-18, DSP I Blk 18	145E
USA 142	25669	04/09/1999	04/1999	F-19, DSP I Blk 18	
USA 149	26356	05/08/2000	Active	F-20, DSP I Blk 18	8.5E
USA 159	26880	08/06/2001	Active	F-21, DSP I Blk 18	70E
USA 176	28158	02/14/2004	Active	F-22, DSP I Blk 18	103E

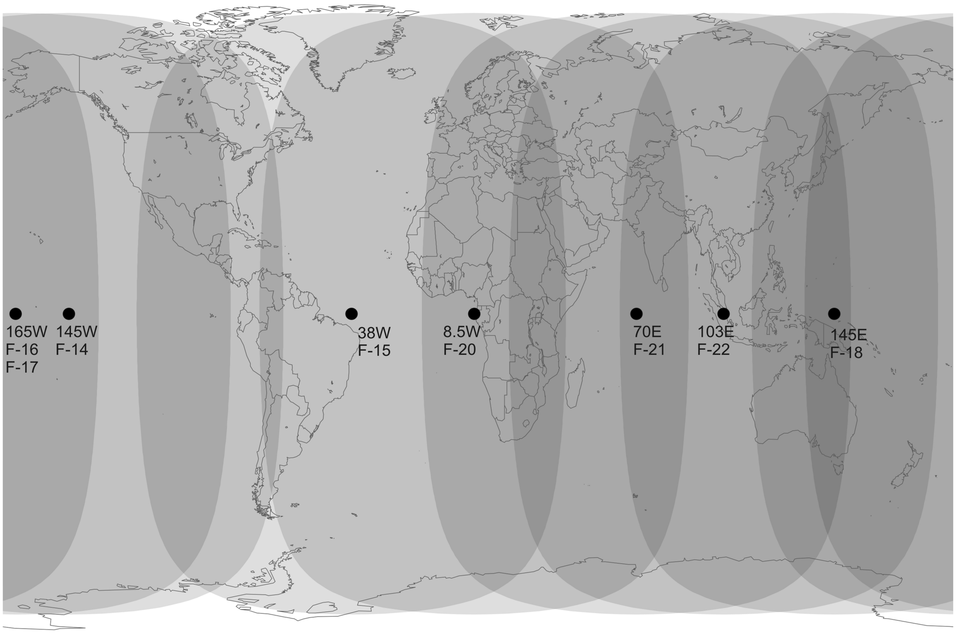

Figure A1: U.S. early-warning satellites and their coverage areas.

The DSP early-warning satellites are supposed to be replaced by new SBIRS satellites—the DSP F-23, which is scheduled to be launched soon, is the last DSP satellite that have been manufactured.[9] However, it is not clear when the replacement will take place, because the SBIRS program is several years behind the schedule.[10]

U.S. Early-Warning Radars

The network of early-warning radars deployed by the United States consists of large phased-array radars deployed at eight bases, two of which are outside of the U.S. territory.

Table A8 shows the locations of the radars and some of their characteristics. Figure A2 shows locations of the radars and orientation of their fans on a map.

All early-warning radars are operated by units of the 21st Space Wing, which is headquartered at Peterson Air Force Base in Colorado.[11]

The oldest of the currently operational radars is the PARC radar, which was built as part of the Safeguard missile defense system in the 1970s. It is operated by the 10th Space Warning Squadron (SWS) at Cavalier Air Force Station (AFS) in North Dakota.[12]

The radars at the Cape Cod AFS in Massachusetts and at the Beale Air Force Base (AFB), California are known as sea-launch ballistic missile (SLBM) warning radars. They are operated by the 6th SWS, and the 7th SWS respectively.[13] Orientation of these radars makes them particularly suitable for

Table A8: U.S. early-warning radars.

Location and radar	Coordinates	Azimuth of radar faces	Comment
Cape Cod AFS			
PAVE PAWS	41.7525N 70.5383W	45°, 165°	
Beale AFB			
PAVE PAWS	39.1360N 121.3508W	185°, 305°	
Clear AFS			
BMEWS	64.2904N 149.1879W	340°	Non-operational. Being dismantled
	64.2888N 149.1925W	300°	
	64.2865N 149.1937W	260°	
SSPARS	64.3000N 149.1897W	4°, 244°	Previously deployed at Eldorado AFS
Eldorado AFS			
PAVE PAWS	30.9787N 100.5530W	130°, 250°	Dismantled. Moved to Clear AFS
RAF Fylingdales			
SSPARS	54.3615N 0.6697W	7°, 127°, 247°	
Robins AFB			
PAVE PAWS	32.5806N 83.5691W	80°, 200°	Non-operational
Thule, Greenland			
BMEWS	76.5676N 68.3205W	320°	Dismantled
	76.5688N 68.3073W	0°	
	76.5679N 68.2919W	40°	
	76.5654N 68.2840W	80°	
SSPARS?	76.5697N 68.2964W	0°, 120°	
Cavalier AFS			
PARC	48.7244N 97.8994W	5°	

detection of incoming sea-launched ballistic missiles. The radars deployed at these sites are PAVE PAWS large phased-array radars.[14]

To provide maximum warning time against Soviet intercontinental ballistic missiles, the United States deployed radars of the BMEWS (ballistic missile early-warning system) closer to the Soviet (now Russian) territory—at the Fylingdales base in the United Kingdom, in Thule on Greenland, and at Clear AFB in Alaska. The BMEWS radars that were initially deployed there used mechanical steering and by now all of them have been replaced by phased-array PAVE PAWS-class radars known as SSPARS (for Solid-State Phased-Array Radar System). The SSPARS radar at Clear AFS is the PAVE PAWS radar moved to Alaska from Eldorado AFS in Texas.[15]

The radar in Thule is operated by the 12th SWS, the radar at Clear AFS—by the 13th SWS. The 21st Space Wing has a detachment at RAF Fylingdales, U.K., which coordinates missile warning and space surveillance with the Royal Air Force.[16]

The two PAVE PAWS radars that were supposed to detect ballistic missiles coming from the south—at Eldorado AFS in Texas and at Robins AFB in Florida, have been deactivated. As mentioned earlier, the radar at Eldorado AFB has been moved to Clear AFS.

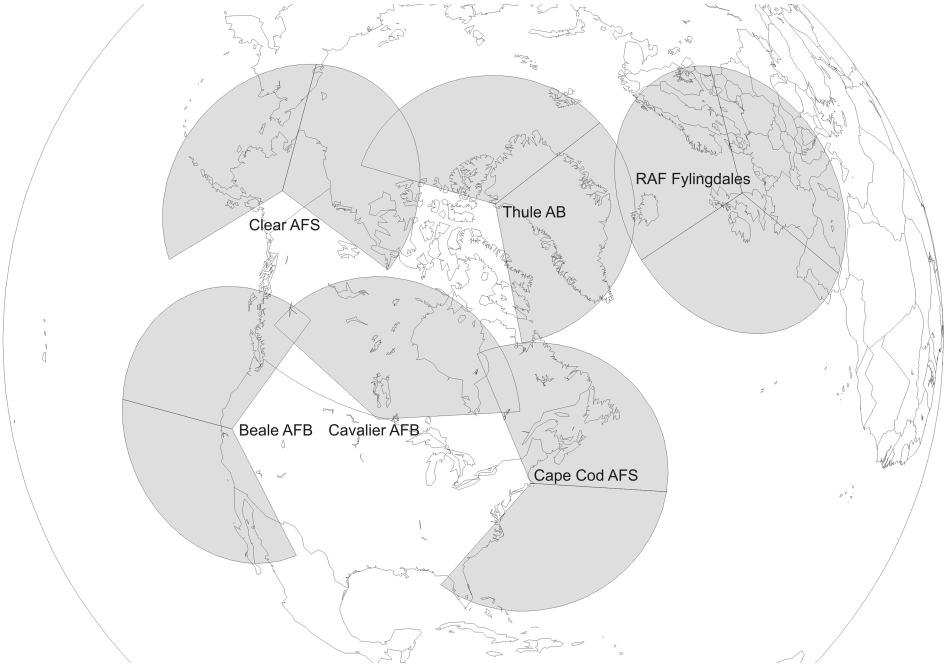

Figure A2: Radars of the U.S. early-warning network. Size of radar fans may not correspond to radar detection range.

Some of the early-warning radars are undergoing an upgrade that is aimed at integrating them with the missile defense system that is being developed by the United States.[17]

Russian Early-Warning Satellites

The space-based early-warning system developed by the Soviet Union initially was limited to detecting intercontinental ballistic missile (ICBM) launches from the U.S. territory.[18] The first-generation system, known as US-KS or Oko, includes satellites deployed on highly-elliptical orbits (HEO) and a geostationary satellite. The first-generation satellites were known as 73D6 when they were launched into highly elliptical orbits, and 74Kh6 when launched into the geosynchronous orbit.[19] Table A9 lists all early warning satellites that Russia launched since 1997.

A full US-KS system would include nine HEO satellites and one geostationary satellite. In this configuration the system can provide uninterrupted coverage of the U.S. ICBM bases. The approximate area of coverage is shown by the ellipse on Figure A3. The US-KS system cannot detect launches from areas outside of the U.S. territory because sensors installed on the first-generation satellites do not have the capability to detect missile plumes against the background of Earth.

Table A9: Recently launched Russian early-warning satellites.

	NORAD number	Launch date	End of operation	Type, system	Orbit, position
Cosmos-2340	24761	04/09/1997	05/2001	73D6, US-KS	HEO
Cosmos-2345	24894	08/14/1997	02/1999	74Kh6, US-KS	GEO, 24W
Cosmos-2350	25315	04/29/1998	06/1998	71Kh6, US-KMO	GEO, 80E
Cosmos-2351	25327	05/07/1998	05/2001	73D6, US-KS	HEO
Cosmos-2368	26042	12/27/1999	12/2002	73D6, US-KS	HEO
Cosmos-2379	26892	08/24/2001	Active	71Kh6, US-KMO	GEO, 24W
Cosmos-2388	27409	04/02/2002	Active	73D6, US-KS	HEO
Cosmos-2393	27613	12/24/2002	Active	73D6, US-KS	HEO
Cosmos-2397	27775	04/24/2003	05/2003	71Kh6, US-KMO	GEO
Cosmos-2422	29260	07/21/2006	Active	73D6, US-KS	HEO

The US-KS system is operating at a fraction of its full capacity. As of August 2006, there were only three operational satellites on highly elliptical orbits—Cosmos-2388, Cosmos-2393, and Cosmos-2422. Figure A3 shows ground tracks and positions of these satellites. The time that each of these satellites spends in a position that allows it to detect launches from the U.S. territory is about six hours a day.

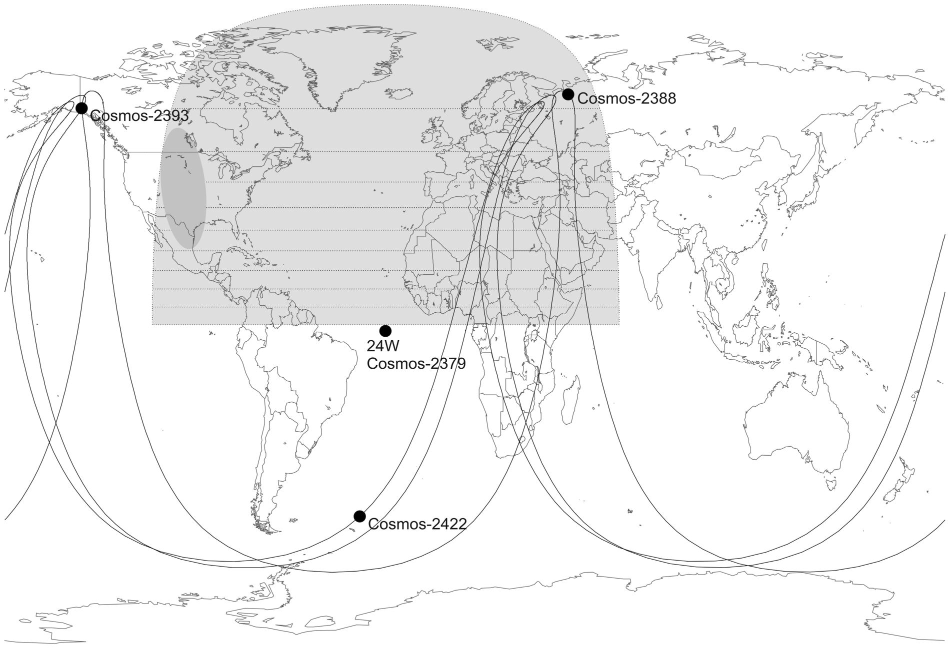

Figure A3: Ground tracks of the Russian early-warning satellites and the coverage they can provide. The small shaded area on the U.S. territory shows an approximate location of the area covered by the US-KS satellites on highly elliptical orbits. The larger shaded area shows potential coverage of the Cosmos-2379 satellite of the US-KMO system. The actual coverage provided by that satellite is unknown.

The incomplete status of the US-KS system is mitigated by the presence of the geostationary early-warning satellite, Cosmos-2379. Deployed over the point with longitude of 24W, this satellite can provide continuous coverage of the U.S. territory, providing backup for the HEO satellites. Normally, this would be a mission of a first-generation 74Kh6 satellite deployed in this point.

Cosmos-2379, however, is believed to be a second-generation 71Kh6 satellite of the US-KMO system.[20] This means that its sensors have the capability to detect missiles against the background of Earth. Figure A3 shows the approximate area that Cosmos-2379 can cover in this case. The strips indicate possible direction of the field of view scanning as well as size of the sensor.[21] As shown on the figure, it is believed that the field of view does not cover areas below the equator.

Together, three early-warning satellites provide continuous coverage of the U.S. ICBM bases and, most likely, of the U.S. submarine patrol areas in the North Atlantic. Unlike the satellites of the U.S. system, Russian satellites provide very little redundancy—most of the time there is only one satellite that monitors any specific point within the coverage area. This negatively affects reliability of detection, for satellite sensors can be blinded by reflections off the clouds or the Earth surface, but does not create any gaps in coverage that would be detectable to an attacker.

The long-term plan for development of the space-based segment of the Russian early-warning system calls for deployment of up to seven geostationary satellites of the US-KMO system. If this plan materializes, Russia will be able to detect launches from most of the regions. However, as Table A9 illustrates, the deployment has been set back by problems with spacecraft. At this point it is not clear if the deployment of the US-KMO system will be ever completed.

Russian Early-Warning Radars

Russian early-warning radar network consists of radars of several types deployed at sites spread across the former Soviet Union. The locations of the radars and some of their characteristics are listed in Table A10.[22] As we can see from the table, about half of the sites are located outside of the Russian territory. Operations of these radars are covered by bilateral agreements that Russia concluded with host countries.

Four of the currently operational radars can be classified as large phased-array radars, comparable in capability to their U.S. counterparts. These are two Daryal radars deployed in Pechora and Gabala, Azerbaijan, the Volga radar in Baranovichi, Belarus, and the Don-2N radar in Pushkino, which was built as part of the Moscow A-135 missile defense system.[23] The Dnepr-M/Dnestr radars are modification of the old Dnepr design known as Hen House. Because of their linear design, radars of this class cannot provide accurate elevation data.

Table A10: Russian early-warning and missile defense radars.

Location and radar	Coordinates	Azimuths of radar faces	Comment
Olenegorsk			
Dnestr-M/Dnepr	68.1135N 33.9105E	325°, 295°	
Daugava	68.1166N 33.9205E	310°	
Balkhash (Kazakhstan)			
Dnestr-M/Dnepr	46.6027N 74.5310E	120°, 184°	
Dnestr-M/Dnepr	46.6316N 74.5130E 46.6252N 74.5180E	62° 62°	
Daryal-U	46.6007N 74.4979E 46.5883N 74.4670E	120 120	Non-operational
Mishelevka			
Dnestr-M/Dnepr	52.8776N 103.2731E	70°, 200°	
Dnestr-M/Dnepr	52.8746N 103.2610E 52.8814N 103.2661E	130°	
Daryal-U	52.8617N 103.2395E 52.8553N 103.2323E	122°	Non-operational
Sevastopol (Ukraine)			
Dnepr	44.5787N 33.3866E	228°, 173°	
Mukachevo (Ukraine)			
Dnepr	48.3771N 22.7074E	194°, 258°	
Daryal-UM	48.3853N 22.8006E 48.3882N 22.7940N	215°	Non-operational
Pechora			
Daryal	65.2106N 57.2956E 65.2106N 57.2763E	0°	
Gabala (Azerbaijan)			
Daryal	40.8712N 47.8096E 40.8678N 47.7964E	160°	
Baranovichi (Belarus)			
Volga	52.8620N 26.4677E 52.8351N 26.4753E	263°	
Pushkino			
Don-2N	56.1732N 37.7701E	60°, 150°, 240°, 330°	ABM radar
Lekhtusi			
Voronezh-DM	60.3N 30.6E		Under construction
Armavir			
Voronezh-DM	45.0N 41.1E		Planned

Figure A4 shows locations of the radars and the sectors that they cover. It is usually believed that there is a gap in the radar coverage in the East, between the radars in Pechora and Michelevka. In the early 1980s, the Soviet Union attempted to build an early-warning radar in Krasnoyarsk, but it was dismantled after objections from the United Stated. Our estimates, however, demonstrate that even if the gap exists it is very small. Only an attack from a narrow range of positions against a limited set of targets would have a chance of avoiding detection by the radars in Pechora and Mishelevka. Practical importance of this gap is minimal.

A somewhat more serious gap had opened on the West, after the Dnepr radar at Skrunda, Latvia was taken out of service and dismantled in 1998. The Volga radar in Baranovichi, Belarus, that began operations in 2002 closes this

Figure A4: Russian early-warning and missile defense radars. Size of radar fans may not correspond to radar detection range.

gap only partially. This gap, however, is to some extent closed by the radar of the Moscow ABM system in Pushkino. Even though it is located deeper inside the Russian territory, the difference between warning time provided by this radar and the one that would have been provided by the dismantled radar in Skrunda is relatively small.

Overall, the existing radar network is capable of providing warning against most of the missile threats. It does, however, require modernization. Most of the Dnepr-M and Dnestr radars are more than 30 years old and are probably getting close to the end of their operational lives. Russia has initiated some projects in this area, but it is unlikely that it will deploy any new radars that would be comparable in their capabilities to the large phased-array radars built by the Soviet Union.[24] In 2005 Russia began deployment of a new modular radar, known as Voronezh-DM, at Lekhtusi, near Sankt-Peterburg. One more radar of this type will be deployed at Armavir after 2007. This project is still at early stages and it remains to be seen if the new radars will have the potential that would allow using them for missile early-warning missions.

NOTES AND REFERENCES FOR APPENDIX B

1. "Defense Support Program." Fact Sheet, U.S. Air Force, May 2000, http://www.losangeles.af.mil/SMC/PA/Fact_Sheets/dsp_fs.htm, accessed on January 24, 2006.

2. V. Agapov, “DSP—idet rassledovaniye prichin avarii.” *Novosti kosmonavtiki*, No. 6 (1999): 52.

3. LANL Geosynchronous Energetic Particle Data, General Information, http://leadbelly.lanl.gov/lanl_ep_data/information/general.shtml, accessed on July 14, 2005.

4. These sensors are known as Advanced RADEC I and Advanced RADEC II (Advanced RAdiation Detection Capability). V. Agapov, “DSP—idet rassledovaniye prichin avarii.” *Novosti kosmonavtiki*, (1999): 53.

5. Summary plot of satellite positions during 1979–1994 can be found at “Defense Support Program.” Globalsecurity.org, http://www.globalsecurity.org/space/systems/dsp.htm, accessed on July 14, 2005. Data for 1995–2004 are published in Vladimir Agapov, “Orlinyi glaz.” *Novosti kosmonavtiki*, 14 (4)(255) (April 2004) 21–24. Information on most of the current satellites is available from the Satellite Situation Center, the Goddard Space Flight Center, http://sscweb.gsfc.nasa.gov/cgi-bin/sscweb/Locator_graphics.cgi, accessed on July 14, 2005.

6. Vladimir Agapov, “Orlinyi glaz.” *Novosti kosmonavtiki*, 14 (4)(255) (April 2004): 21–24.

7. In addition to this, some satellites were parked at the point 75E after being withdrawn from the constellation. Vladimir Agapov, “Gde zhe oni pryachutsya?” *Novosti kosmonavtiki*, No. 5 (196) (1999) 34.

8. It is interesting to note that North Korea and the Middle East are under constant observation by four satellites.

9. Northrop Grumman Ships 23rd DSP Satellite to Cape Canaveral for Launch Preparation, SatNews Daily, http://www.satnews.com/stories2005/688.htm, accessed on July 14, 2005.

10. The first launch was supposed to happen in 2002–2003. See, for example, Space Based Infrared System, U.S. Air Force Fact Sheet, http://www.losangeles.af.mil/SMC/PA/Fact_Sheets/sbirs_fs.htm, accessed on July 14, 2005.

11. “The 21st Wing Info.” Fact Sheet, http://www.peterson.af.mil/21sw/wing/main_info/main_info.htm, accessed on July 8, 2005.

12. “The 21st Wing Info.”

13. *Ibid.*

14. “Pave Paws Radar System.” U.S. Air Force Fact Sheet, May 2004, http://www.af.mil/factsheets/factsheet.asp?fsID=168, accessed on July 8, 2005.

15. “Clear Radar Upgrade.” http://www.globalsecurity.org/space/systems/sspars.htm, accessed on July 8, 2005.

16. “The 21st Wing Info.”

17. Radar Upgrades Progressing, MissileThreat.com, http://www.missilethreat.com/news/200504120833.html, accessed on July 8, 2005.

18. For a more detailed description of the Russian early warning system see Pavel Podvig, “History and the Current Status of the Russian Early-Warning System.” *Science and Global Security*, 10 (2002): 21–60. For updates on the status of the system see RussianForces.org site, http://russianforces.org/sprn/.

19. Before geostationary satellite was added to the system, it was known as US-K.

20. In Podvig, “History and the Current Status of the Russian Early-Warning System” Cosmos-2379 is incorrectly listed as a first-generation satellite. One reason it is classified

as a satellite of the US-KMO system is that it was deployed at the 80E point first and only after some time moved to its current position at 24W. Satellites of the US-KS system have never performed maneuvers of this kind.

21. This estimate is based on the picture published in *Tsentralny nauchno-issledovatelski institut Kometa, 30 let* (Moscow: Oruzhiye i tekhnologii, 2003), 86.

22. This table is based on the data provided in Podvig, "History and the Current Status of the Russian Early-Warning System." Coordinates of the radars and their orientations were updated based on the satellite imagery provided by Google Earth, http://earth.google.com.

23. The Daugava radar deployed in Olenegorsk is a pilot Daryal transmitter that works in conjunction with the Dnepr radar located at the site.

24. It should be noted that construction of the Volga radar in Belarus began before the breakup of the Soviet Union, so it cannot be considered a new radar.