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Nuclear Early Warning in South Asia

Problems and Issues

India's 1999 Draft Nuclear Doctrine proposed the setting up of 'effective intelligence and early warning capabilities', to provide 'early warning, communications, damage/detonation assessment'. Pursuing this policy, India has started acquiring key components of such an early warning network, including the Green Pine radar from Israel. Pakistan too has hinted at matching Indian plans for putting in place early warning systems. Against this background this study examines the different ingredients that go into the setting up of early warning systems and assesses their effectiveness. Using the insights gained from the study it also draws policy inferences about the viability and advisability of early warning systems in south Asia.

M V Ramana, R Rajaraman, Zia Mian

Even as they talk about improving relations, after having lurched from crisis to crisis since their nuclear tests five years ago, the governments of India and Pakistan continue to enlarge and develop their nuclear arsenals.[1] Following the example set by the US and Soviet Union during the Cold War, they continue to produce fissile material for more nuclear weapons, develop and test ballistic missiles, and establish command and control systems of these arsenals.[2] With arsenals growing steadily, significant steps are now being taken, particularly by India, towards building an early warning system that can detect incoming nuclear-armed missiles and, it is hoped, inform decision-makers that nuclear war has begun before the warheads themselves explode.[3] It is the next round in the quest for advantage.

The search for some form of early warning capability in south Asia could have been anticipated from statements and actions by both countries. India's 1999 Draft Nuclear Doctrine proposed setting up "effective intelligence and early warning capabilities", that would use "space based and other assets" to provide "early warning, communications, damage/detonation assessment".[4] Pursuing this policy, India has started acquiring key components of such an early warning network, including the Green Pine radar from Israel.[5] The Green Pine is also part of the Israeli Arrow anti-ballistic missile system that India has expressed an interest

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in and a sign of things to come.[6] India's capacity to launch geo-synchronous satellites could serve as the basis for a satellite based early warning system as well (as is done by the US' Defence Support Programme early warning satellites). In late 2001, India also launched a Technology Experiment Satellite (TES) with a high resolution imaging camera reportedly capable of "sensitive defence surveillance applications".[7] India has also purchased from Israel a Phalcon airborne early warning system.[8]

While Pakistan has not made public a formal nuclear doctrine, three former senior officials warned of the "dangers of pre-emption and interception" and recommended that a "high state of alert will become more necessary as India proceeds with deployment of nuclear weapons".[9] Pakistan's minister for science technology hinted at matching Indian plans for early warning when he announced that the government was preparing to launch a geo-stationary satellite "to meet its strategic and communication needs".[10]

These developments motivated us to do a technical study of the prospects for nuclear early warning in south Asia, published recently.[11] In that study, we examined the different ingredients that go into setting up early warning systems and assessed their effectiveness. A crucial ingredient is the missile flight time between different locations in India and Pakistan. Although it is self evident and generally appreciated that south Asian missile flights will be much shorter than, say, missiles flying between the US and Russia, it is important to estimate what the flight times actually are rather than simply presume that there will be sufficient time to permit verification of a missile launch, consultation and thoughtful decision-making. We showed how such estimates could be made starting from first principles of physics in a transparent manner. Then we went on to examine the relevant missile detection and tracking systems likely to be used in south Asia, including the Green Pine radar and satellites, to determine the available missile warning time. Lastly, we analysed what could be done in this available time, using as models the threat assessment and response procedures that have been followed by the US and the USSR (now Russia) for decades.

In this article we present the main results of that study, suppressing the technical details and derivations. Using the insights gained from the study we also draw, in the concluding section of this paper, policy inferences about the viability and advisability of early warning systems in south Asia.

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Condolences

A Ballistic Missile Primer

The flight of a ballistic missile may be broadly divided into three phases. The first is the 'boost phase' when the rocket is powered by its burning fuel. Once all the fuel is exhausted, the missile jettisons the propellant tanks. This ‘burnout’ altitude is about 30 km for single stage missiles like the Prithvi or the Scud, and about 100 km for two-stage missiles like the Agni. Beyond the burnout point the missile nosecone or re-entry vehicle containing the warhead moves in free fall, i e, under the influence of only the earth’s gravitational force. This is the ‘ballistic phase’. Finally, as the payload falls back towards the earth it re-enters the atmosphere. Motion in this last ‘re-entry phase’, as well as in the launch phase, is complicated by air resistance.

If one needs to know the trajectories of missiles to great precision, this can only be done through numerical calculations involving elaborate computer programmes that include the boost and re-entry phases and the effects of air resistance. But by employing judicious approximations, one can derive relatively simple formulae to make back-of the envelope estimates of flight times, missile velocities and so on. The ballistic phase consumes the longest duration in the missile’s flight and is also the easiest to calculate since it is free of the complications caused by engine thrust and air resistance. After calculating accurately the time taken in the ballistic phase we added one minute each for the boost and re-entry phases to arrive at our estimates for the total missile flight time. Our estimates are accurate to the nearest minute – which is quite adequate for making strategic and policy judgments.

We estimated the missile flight times for typical pairs of possible launch sites and targets in south Asia, taking as launch points different military bases (e g, airbases) and as targets command centres, big cities or national capitals. Examples are a launch from a base near Karachi towards Thiruvananthapuram – a likely site for India’s strategic nuclear command centre[12] – or from Agra to Karachi, or Sargodha to New Delhi.

Normally, missiles are flown on ‘optimal’ trajectories, where the goal is to maximise the range (flight distance). But it is also possible to fire a powerful, long-range, missile at a near-by target, along a trajectory designed to minimise the time it would take to cover this distance. For example, Pakistan’s Ghauri and India’s Agni missiles, which have ranges in excess of 1,000 km, could be used to attack targets only 500-600 km away. Such a ‘depressed trajectory’ flight of a long range missile can significantly reduce the flight time compared to that of a short-range missile flown over the same distance and would pose the more significant challenge to an early warning system. Table 1 give some typical examples of flight times for both optimal flights and a depressed trajectory flight. The normal (optimal) flight times are around 10-13 minutes for distances between 1,000-2,000 km, and about 8 minutes for a missile flying the approximately 600 km path from Agra to Lahore, or Sargodha to Delhi. But the estimated depressed trajectory flight time is much shorter; the missile covers a distance of

600 km in only about five minutes. For comparison, US and Soviet land-based intercontinental ballistic missiles, capable of striking the major cities in the other's country, had flight times of over 30 minutes.

The estimated total flight times given in **Table 1** were checked by more detailed computer calculations of missile trajectories and the results agree to the nearest minute. For example, both our simple estimates and our more detailed calculations predict that it would take about 10 minutes for a flight of 1,100 km, the distance between Agra and Karachi. We have also verified that corrections due to other effects, such as the rotation of the earth, alter our estimated flight times by only a few per cent.

Table 1: Estimated Duration of Some Plausible South Asian Missile Flights

Launch Point	Target	Distance (km)	Estimated Total Flight Time (minutes)
Airbase near Karachi	Thiruvananthapuram	2000	13
Sargodha Airbase	Mumbai	1470	11
Agra Airbase	Karachi	1128	10
Agra Airbase	Lahore	608	8
Sargodha Airbase	New Delhi	581	8
Depressed trajectory flight		600	5

There are a number of radar systems around the world that are used for early warning or as part of anti-ballistic missile systems. Two examples are the Pave Paws system, used as part of the US early warning of ICBM launches from Russia, and the Patriot that was used extensively in the 1991 Gulf war to detect and track incoming Iraqi Scud missiles. Before coming to specific radar systems that are likely to be used in south Asia for early warning, it may be helpful to give some basic information about radars for the benefit of non-experts.

A radar in its essence consists of an antenna that emits electromagnetic wave pulses, some of which impinge on the potential target. Some fraction of this signal is reflected back by the target towards the radar. Based on this reflected signal, one can calculate the location and speed of the target. The intensity of the radiation reflected from a target decreases rapidly with increasing distance to the target. Thus, beyond a certain distance, depending on the characteristics of the target (its size, geometry, materials used, etc), the reflected signal as received by the radar will become indistinguishable from the background 'noise' that radars inevitably pick up. When the target is at this distance or greater, the radar cannot unambiguously detect the target.

In fact, to be reliable, the received radar signal should be many times larger than the background noise. The optimal ratio of signal to noise is set by balancing two competing requirements. To detect all potential targets, the minimum acceptable signal should be as small as possible. At the same time, noise should not be mistaken as a signal from a target. Once a ratio of signal to noise has been decided upon, the characteristics of the radar determine the distance to which a particular target in a given orientation can be detected. This distance is termed the radar range. But, to reiterate, this range is dependent on the target being detected and the target's orientation with respect to the radar beam.

Detection of missiles by radars is not a straightforward or fully reliable process. There are many sources of false, unwanted and unpredictable signals that any radar system must contend with. A flock of birds, for example, can produce significant radar clutter. Radar signals also bounce off regions of the atmosphere where no apparent reflecting sources exist, for example, atmospheric and meteorological inhomogeneities that have discontinuities of refractive index. Such signals have been dubbed 'angels' or 'ghosts'.[13] Rain and clouds may also affect performance, depending on the radar wavelength. In the 2003 US war against Iraq, the advanced version of the Patriot system reportedly generated many false radar signals.[14]

In order to estimate the amount of early warning possible in south Asia, we need to know the kind of radar likely be used. In June 2002, defence secretary Yogendra Narain confirmed that India "had acquired a Green Pine radar" from Israel.[15] Since this is a fairly advanced system, we will assume that it would form part of the Indian early warning system. The technical specifications of this Green Pine radar are not fully available in the public domain but parameters of other radar systems like the Pave Paws and the Patriots are available. From these one can make reasonably educated guesses for the Green Pine parameters.

Given a radar system with some specific parameters, the range at which it can observe a missile depends on the cross section the latter presents to the incident radar beam, which in turn depends on the stage of the flight and the tilt angle of the missile. If the missile is in the early boost phase, then the radar signal may be reflected by almost the entire missile's full body (side-on) possibly including its fins as well. Altogether this would offer a cross section of about 100 m2. In this situation, we estimate that the Green Pine type of radar may detect the missile as far away as 2,000 km. As the missile rises and tilts towards the horizontal, it offers a smaller cross section. Once the rocket engines have been jettisoned after burn out, this range may reduce to about 700 km. By the time the warhead has separated and is approaching the radar nose-on (which offers a far smaller cross section of about 0.01 m2) the detection range would decrease even further to about 200 km.

There is one other important factor to keep in mind – the curvature of the earth. A radar cannot see objects located below its horizon, so a ground based radar cannot see the ground based launch of a missile hundreds of miles away. It has to wait for the missile to rise above the horizon. Further, to reduce ground clutter (reflections from objects on the ground and so on) the radar does not scan angles below a certain minimum angle. The Pave Paws radar beam, for example, goes only as low as an angle of 3 degrees to the horizon.[16] Thus, if the radar is at a distance of 300 km from the missile, then it can only see missiles that are at an altitude of about 20 km or greater.

Keeping all these factors in mind, we examined the hypothetical case of a missile launched from Pakistan's Sargodha air force base towards New Delhi to determine when the missile launched along a depressed trajectory may be detected by a radar kept at India's Ambala air force base. Our calculations show that the earliest that detection can take place is around 87 seconds after launch, i e, when the missile has travelled for almost one third of the total time it will take to reach its target.

Detection of what may be a missile soon after launch is itself insufficient to serve as useful early warning of a missile attack; for example, countries with missiles frequently conduct flight tests. One needs to track it over a period of time to establish if the missile is in fact heading towards a target within one's own country and to determine the trajectory accurately. We estimate that this could be of the order of about 20 seconds.

All this would imply that a radar system similar to Green Pine could provide a relatively unambiguous detection, and warning, at best only about 110 seconds after a missile's launch. Given that the total time of flight along a depressed trajectory over 600 km is about 300 seconds, this would leave less than 200 seconds for all subsequent assessments and responses.

Warning from Satellites

India has expressed an interest in setting up satellite-based early warning, and Pakistan has talked more vaguely of a strategic role for satellites. Although India already has considerable expertise in launching satellites, any plan of setting up viable early warning satellites can only be considered preliminary. But satellites have been an important component of early warning systems used by the US and Russia to provide the first detection of missile launches. France is in the initial stages of building an early warning satellite system.[17] Before we discuss the prospects of satellite warning systems in south Asia, it will be useful to review the experience of these countries.

The US Defence Support Programme (DSP) satellites work by detecting the heat of a missile plume against the background radiation emitted by the earth and clouds.[18] These satellites are in geosynchronous orbit, at an altitude of about 36,000 km, and so seem to stay above one point on the earth. From that location, the DSP satellites are made to rotate about their own axis six times a minute, sweeping the sensor's field of view around the earth so that it covers almost an entire hemisphere. Any strong source is thus picked up every ten seconds. Multiple observations serve to confirm that it is a missile in flight and to estimate its trajectory, and its impact area. The DSP satellites also carry optical, florescence and X-ray detectors to locate nuclear explosions on the earth's surface, in the atmosphere and in space. India's declared aim to acquire a space based capability for early warning and damage and detonation assessment would seem to indicate a goal of a DSP-type of system.

The area viewed by a DSP satellite is about 200 million square km, roughly 40 per cent of earth's surface area. For example, a US DSP satellite launched in May 1971 into orbit was able to cover much of Europe, almost all of Africa, west Asia, Russia, central Asia, south and south-east Asia.[19] This coverage is very similar to what India might seek if the aim were to monitor missile launches and nuclear detonations involving Pakistan and China and the Indian Ocean.

There are a number of technical limits on satellite based missile detection. The infrared radiation from the missile plume is largely absorbed by water vapour and carbon dioxide in the lower atmosphere.[20] The radiation is also scattered by rain, heavy dust and does not penetrate clouds.[21] Thus, a missile can be plausibly detected only when it emerges above the cloud layer. The cloud-top at latitudes of 20-40 N (i e, covering Pakistan and northern India) is typically at altitudes of 3-4 km, but can be as high as 10 km.[22] Reaching this altitude would require about 30 seconds to one minute after launch Once the missile has risen above the clouds, the signal from the plume is still not easily distinguished from the normal background heat radiated from the earth and solar radiation reflected from the cloud tops. The experience of US DSP satellites suggests a number of operational problems. A Congressional study of failures of the US early warning system noted that "there are many indications of [missile launch] detections that have to be evaluated but prove not to be associated with a threatening missile launch."[23] A significant problem has been solar reflection from cloud-tops and the ocean surface, along with ice and snow, including from high mountainous areas, which blinds the DSP satellites.[24] The satellites are reported to be "frequently put out of commission for several hours by the effects of sun glare".[25] The blind spots and false alarms induced by solar reflections required the US to arrange a constellation of DSP satellites where coverage 'extensively overlapped' and the satellites were sufficiently far apart that the blind spots normally did not coincide; nevertheless, false alarms reportedly "continued to plague surveillance."[26]

Geostationary early warning satellites for the detection of possible missile launches are clearly a very demanding technology. The Soviet Union sought a look-down capability equivalent to the US DSP satellites starting in 1979 and the first Soviet satellite with this capability was launched in 1991 with limited success; as late as 2002, it was still described as "an essentially experimental programme".[27] Instead, the Soviet Union relied throughout the 1980s on a system of satellites in very elliptical orbits that did not look directly at the earth but waited for the missile plume to become visible against the background of space. This system has had its own set of problems.[28]

India's Geosynchronous Satellite Launch Vehicle (GSLV) programme offers it the capability to launch a satellite comparable in size and weight to a US DSP satellite.[29] The first developmental flight, GSLV-D1, was launched in April 2001. India tested the GSLV again in May 2003.[30] Pakistan does not have an equivalent launch capability.[31] In any event, neither country has a demonstrated capability to make the infrared sensors needed to image missile launches against the background of reflected sunlight. It is likely that the pursuit of this kind of capability will be difficult and costly and regardless will give warning of a possible missile launch at best only 30 to 60 seconds before a ground based radar system.

There are also satellites that look in the visible part of the spectrum. An example is India's Technology Experiment Satellite (TES) launched in October 2001.[32] TES is reported to carry a one-metre resolution camera.[33] It is claimed TES images could provide a military surveillance capability to the Indian Air Force.[34] At 1m resolution many details of military significance can be obtained, including general detection of nuclear weapons systems, and precise identification of aircraft, command and control headquarters, etc. These are summarised in **Table 2**.

Table 2 : Image Resolution (metres) Required for Detecting Significant Military Capabilities

	Resolution	Resolution Required

Target	Required for Detection (m)	for Precise Identification (m)
Surfaced submarines	7.5-30	1.5
Surface ships	7.5 -15	0.6
Bridges	6	1.5
Troop units	6	1.2
Airfield facilities	6	3
Radar	3	0.3
Aircraft	4.5	1
Command and control		
headquarters	3	1
Supply dumps	1.5 -3	0.3
Missile sites	3	0.6
Rockets and artillery	1	0.15
Nuclear weapons components	2.5	0.3

Source: Jeffrey T Richelson, 'Implications for Nations without Space-Based Intelligence Collection Capabilities', in Michel Krepon, Peter Zimmerman, Leonard Spector and Mary Umberger, (eds), *Commercial Observation Satellites and International Security*, St Martin's Press, New York, 1990.

This kind of information may be used to locate possible military targets and to monitor the development of infrastructure and deployment of forces over a period of several weeks. The movement of military equipment (jets, tanks, ships, etc) from their bases, or between bases in a crisis could be used to assess preparations for a possible attack. It is however of little use as a real-time early warning system. Rather, it may offer what is described as 'strategic warning.'

Optical imaging satellites have some drawbacks, Working in the visible range, they can only take pictures during daytime, and where there is no cloud cover. Moreover, imaging satellites are susceptible to simple counter-measures. Since satellite orbits are regular and predictable, and their capabilities reasonably well understood, it is feasible to use camouflage, deception, windows of opportunities, etc. to avoid giving away at least some information.[35] It is worth recalling that India was successful in concealing preparations for its May 1998 nuclear tests from US spy satellites.

In summary, a missile launch may be reliably detected by a geo-synchronous infrared early warning satellite only after it rises above the cloud cover. This means detection of the missile about half a minute to a minute after launch. But, as we have seen in the previous section, a radar like the Green Pine can detect the missile about 90 seconds after launch (for the Sargodha-Delhi case). Thus, a geosynchronous infrared satellite could typically provide only half a minute to one minute of additional warning in south Asia. This is to be contrasted with the US-Soviet case where, given the longer flight times, early warning satellites that can detect a missile in the launch phase will provide several minutes of additional warning time. Imaging satellites on the other hand offer only long-term information, and can be fooled by simple counter-measures.

Time to Worry?

An early warning system is more than the set of detectors and platforms for monitoring missile launches. It includes the procedures for evaluating the information produced by such detectors and assessing the reliability and significance of such data and interpreting it as 'warning'. In the preceeding sections, we arrived at estimates of the maximum time that would be available for this threat assessment and decision-making. To understand the steps needed to translate the initial signal into a meaningful warning and response, we outline the procedures adopted by the US and the Soviet Union (now Russia) to assess missile warnings. The flight times between the missile fields and targets of those two states are about 30 minutes.[36] We then look at whether analogous procedures could be practical in south Asia given the much shorter warning times.

In the US, the task of detecting and assessing ballistic missile launches is managed by North American Aerospace Defence Command (NORAD). Though most of the details about its operation are secret, independent analysts have managed to construct a broadly consistent picture of the general procedures that are followed.[37] These are simplified and presented here as sequence of events with their allotted duration:

1 Observation of missile launch by satellites in geosynchronous orbit and relay of signal to ground stations for processing (half a minute after launch).
2 Decision by the ground station staff whether to forward this information to NORAD and other command centers assessing missile warnings (about 15 seconds).
3 Convening of Missile Event Conference at NORAD. Command director would assess the reliability of satellite data, based on telephone communications with ground station operators, who would re-verify the initial detection and confirm that it was not due to equipment malfunction. Strategic warning analysts, who look at intelligence estimates of the international political and military situation, and force deployments are also consulted. The command director would then forward the level of confidence in the warning to the war rooms at the Pentagon and Strategic Command (3 minutes).
4 About four minutes after a possible missile launch, if the

NORAD officer judged there was medium or high confidence in a warning, the information would go up the chain of command, that included the Joint Chiefs of Staff Chairman and Defence Secretary, ultimately leading up to the President and a Missile Attack Conference would be initiated. By this time, there may or may not have been separate warning from ground-based radars (4-6 minutes).
5 There would now be less than 20 minutes remaining from the initial 30 minute flight time (assuming a Soviet ICBM). This would leave about 10 minutes for discussion, before a decision would have to be made whether US missiles were to be launched.
6 If the decision was made to fire US missiles, it would take 2 minutes to send launch orders, 3 minutes to fire the Minuteman ICBMs, and several more minutes for the missiles to travel to a safe distance from their bases.

This timeline adds up to about 30 minutes, which is comparable to an ICBM flight time from Russia, and would enable the retaliatory missiles to take off and be at safe distance before their silos are destroyed. However, all of this assumes that every procedural and technological element in the early warning system works perfectly.

There is less information about Soviet (and now Russian) early warning systems.[38] One description suggests the following expected sequence of events following detection by satellites or ground-based radars of a possible missile launch:3[9]

1 Positive attack identification from satellites (about one minute after launch) or radar would lead to warning report by the Centre for the Analysis of Missile and Space Situation, the Russian counterpart of NORAD, to Defence headquarters, general staff, and strategic rocket forces.
2 This centre would send a signal to president, defence minister and chief of general staff (through the nuclear suitcase).40
3 Within 4-6 minutes after a missile launch, political and military leadership along with chief of early warning center would confer on warning.
4 If the early warning system provides dual sensor (i e, radar and satellite) warning of attack, then general staff would send a preliminary command activating the communications system to nuclear forces. This communication link is normally kept disconnected.[41]
5 According to Russian procedures, the national command authority (president and defence minister) is allotted three minutes to discuss and authorise (or withhold) permission to launch Russian missiles.
6 To institute and transmit the launch order, with the unlock codes, takes about 2-3 minutes. A total of 12-13 minutes would have elapsed since incoming missile lift-off.
7 Once the order has been received it takes as long as 8 minutes for the Russian missiles to emerge from their silos. A total of about 20 minutes would have elapsed between the

time of launch of the enemy attack and the launch of the Russian missiles.

Russian procedures are thus designed to beat the expected arrival time of ICBMs from the continental US by a margin of 10 minutes. But Russia had serious concerns that these procedures may not work as planned. This led them to install in addition a “dead hand” that would automatically transmit launch orders.4[2]

Technology and operating procedures are both fallible and can combine at times to create false alerts of early warning systems. We have described these in a previous article.[43] Eliminating false signals within about 10 minutes obviously calls for a battery of electronic devices and super fast computers checking and cross checking the signal. Any technical malfunction or human error in this large and complex network of systems which gives rise to a false signal needs to evade detection only for 10 minutes before it can lead to the calamity of a nuclear attack based on a false warning. Considering that typically every year there were about 2,500 false alarms from US early warning systems, due to causes varying from swarms of geese to the rising moon, one can see how many close brushes we have had to a nuclear war through detection errors.

We have given above a sketch of the procedures instituted by the US and the Russia to evaluate and respond to an early warning signal. We saw that the US procedure took about half an hour, while the Soviet procedures were a bit faster. Both sides built in time for efforts to verify the data from their early warning systems But it must be stressed that decision-making was forced to fit into the available time before the missiles descended on the decision-makers. It should not be assumed that the 20 to 30 minutes available for assessment and decision-making was even remotely adequate for making monumental judgements about the possible start of a nuclear war and launch of nuclear weapons.

In south Asia, as we have seen, the available warning time could be of the order of 200 seconds or less. The opportunities available to decision-makers to properly assess the data from their early warning systems are effectively non-existent. Thus, the risk posed by false alarms is greater here than was the case in the Cold War conflict. It is in the light of this that the usefulness of early warning systems has to be assessed.

Conclusion

Our analysis suggests that in south Asia, with existing missiles, the estimated total missile flight times range from 8-13 minutes for ranges of 600 km-2,000 km respectively for missile flown to their full ranges. These missile flight times encompass paths from plausible missile launch points in both countries to targets such as the national capitals and major military facilities, including possible locations of the nuclear arsenals or their command posts, in the other country. The time could be significantly less if the long range missiles both states have are flown on a depressed trajectory, in which case the missile flight time could be as low as 300 seconds, that is 5 minutes, for a 600 km missile flight. That would clearly offer the greatest challenge to the early warning system, and for this reason it may well be adopted.

The earliest that a missile on a depressed trajectory could be detected might be about half a minute to a minute after launch, provided India or Pakistan had the appropriate infrared sensors on early warning satellites in geo-synchronous orbit. Neither country has this capability at present; given the experience of Russia/Soviet Union, one would expect that the development of the necessary IR sensors would be a significant challenge. Imaging satellites can at best offer long-range strategic intelligence about movements on the ground rather than real time tactical warning about an incoming missile.

Turning to early warning radars, our calculations have shown that systems such as the Green Pine would take about 110 seconds to detect and track an incoming missile. That would only be half a minute to a minute after what a geo-synchronous satellite with adequate infrared sensors, if available, would take. This is markedly different from the case of the US and USSR/Russia, where satellites provided several additional minutes of warning. In light of the above arguments, it appears that early warning satellites in south Asia will serve little useful purpose.

But despite these considerations and the technical challenges to be overcome in setting up viable geo-synchronous satellites with the necessary infrared detectors, it may be argued that such a system is worth developing since satellites could provide an independent way of observing missile launches, and thereby reduce the risk of false alarms. However, this is a simplistic argument. It ignores the many complexities and problems that are generated by having complex inter-dependent systems that combine together multiple technologies, institutions and people. For instance, if there are two early warning systems the warnings from each of them would have to be evaluated and there are possibilities of conflicts between them. This raises the question of which one to trust. There is also the possibility of a common mode failure.[44] Extra components also add to the complexity of the system making it more opaque and harder to foresee ways by which the system may not perform as designed.[45] Redundancies also produce a false sense of security that may prompt decision-makers to trust the system more than warranted.

Regardless, whether missile launch is detected by a satellite or a radar, or both, any assessment procedures in India and Pakistan would require that information be processed and evaluated, decision-makers informed, and action taken within at most 4-7 minutes (if early warning satellites do the detection) – for an attack targeted at the respective capital cities. This is an unprecedented constraint on procedures for evaluation and verification of any warning and for decision-making about retaliatory use of nuclear weapons. In the case of a depressed trajectory missile launched towards a capital city there would be barely enough time for the warning to be communicated to decision-makers. There would be no time whatsoever to consult or deliberate after receiving this warning.

In the absence of time for deliberation and decision-making, any action would have to rely entirely on prior planning. In theory there seem to be three classes of available responses. One is to feed the warning signals directly into a missile defence system and hope that the interceptor (another missile) will be able to locate and destroy the incoming nuclear warhead. This has been described as trying to hit a bullet with a bullet. While India has been trying to acquire the Arrow missile defense system from Israel,[46] and is seeking the Patriot system from the US, a demonstrated missile defence system does not exist in south Asia and may well not be technically possible. Any kind of missile defence system, if acquired, will almost certainly trigger a race involving ever increasing production and deployment of missiles and their interceptors, and increase pressure for the use of depressed trajectories and for other ways to reduce missile flight times, as well as possible use of countermeasures to complicate detection of the warhead.

A second possible option would be to wait and see if the attack was real, and to establish its size and scope and significance and make time to evaluate a response accordingly. This means deciding to ride-out a possible attack and then, possibly in consultation with the international community, considering what the proper response ought to be. It leaves open the possibility of deciding that nuclear mass murder will not be compounded with more of the same. If a state chooses to ride out the attack, (a policy that fits in logically with a posture of no-first-use of nuclear weapons) there is no point in investing in an early warning system.

The third possible response would be to retaliate immediately upon receipt of a warning, i.e. a launch on warning posture. There are a number of reasons why organisational biases would predispose decision-makers to use the acquisition of an early warning system for adopting a launch on warning posture.[47] This in turn requires keeping weapons on high-alert. With alerted weapons, and a launch on warning posture, the risks of nuclear weapons accidents and accidental nuclear war become even more grave.[48]

There seems to be little wisdom in developing or otherwise acquiring early warning systems in south Asia. Under no circumstance can they offer more than a few minutes of warning. This is insufficient for decision making in any meaningful sense of the term. Early warning systems may also be potentially dangerous because of the ever-present danger their presence poses of precipitous decisions caused by false alarms.

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Notes

1 The belligerence, crises and arms race unleashed by the May 1998 nuclear tests are described in M V Ramana and Zia Mian, 'The Nuclear Confrontation in South Asia', *SIPRI Yearbook 2003: Armaments, Disarmament and International Security* Oxford University Press, (New York: 2003.

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25 Bruce G Blair, *The Logic of Accidental Nuclear War* Brookings Institution, Washington DC, 1993, p 193.
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28 Pavel Podvig, 'History and the Current Status of the Russian Early Warning System', *Science and Global Security,* Vol 10, No 1 (2002), pp 21-60.
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