7. DISCUSSION PAPER (Rajaraman)

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NUCLEAR WEAPONS IN SOUTH ASIA
RISKS AND THEIR REDUCTION

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THE SOUTH ASIAN SCIENTIFIC COMMUNITY AND THE BOMB

(A PREFACE)

With India and Pakistan having officially turned nuclear in 1998, the size and scope if their community of nuclear analysts, particularly outside the government, also has to change qualitatively. Considerable expertise on nuclear weapons and arms control has already existed for decades in both countries. But the bulk of this expertise resides within government agencies --- in India for instance in its defence and foreign services and its departments of atomic energy and space. Without questioning either the competence or the integrity of governmental experts, it is nevertheless vital that decision making on an important area like nuclear armament should involve the same process of checks and balances as , say economic or political issues. There should be constant and ongoing dialogue between experts within and outside the government, the latter providing the counterweight in ensuring an informed public debate.

With this in mind, if you consider how much nuclear expertise we have, for instance in India, among people who are not now and were not in the past government functionaries, only a small (albeit very distinguished) set of people is available. Some of those are present right here today. Even amongst them, the expertise has mainly been on the international politics of nuclear armament, the history of the cold war and the strategic nuances of the various test ban and arms control treaties. The main functional role of this expertise has been in the area of diplomacy, in recommending the posture our country should adopt with respect to different arms control negotiations and treaties . In comparison there have been very few active scientists, particularly from the academia who have taken the time to educate themselves and contribute to the national debate on the nuclear weapon issues. The fact the almost all of basic research in the country is supported by the government has also led to a tacit stifling of independent opinions.

This is to be contrasted with the situation in Europe and America. For instance consider the US where it all started. Most of the leading scientists in the Manhattan project went back to the academia after the war. While remaining on call as consultants to the government defence services, they also provided a major source of counter-balancing opinion, first on the H bomb, then on Star Wars and most recently on the missile defence system.

Even in India, the non-involvement of academic scientists in arms control might have been fine as long as we were “outsiders” studying and responding to the goings-on between nuclear weapon nations. But having officially become nuclear powers ourselves, with our own nuclear weapons to produce , maintain and deploy safely, there is need for a major scientific and technical component to the public debate. Whether you are a pro-nuclear hawk or an anti-bomb activist you have to be familiar with the intricacies and hazards of production, maintenance and deployment of indigenous nuclear weapons. Issues of command and control, strategies of deterrence, postures of alertness, possible civil defense measures all have major technological components to them.

It is imperative that a we in South Asia also build up a credible set of independent arms control analysts with sufficient technical expertise to be able to hold their own on the substantial technical aspects of nuclear weapon policy. Any hope of being able to restrict the growth of nuclear arsenals, let alone reverse the process and eventually eliminate them will require arguments that are not just politically acceptable and strategically sound but also technically viable. Whether we are scientists and non-scientists our ultimate interest is the same, *viz* , the reversal of the nuclearisation of South Asia and of the world, and in the interim, keeping the nuclear arsenals as small and safe as possible. But we scientists have the particular responsibility to study and bring out the technical underpinnings of these issues, communicate them to the public in some simplified form and raise the level of debate.

Personally that was my motivation, after the 1998 tests, for resolving to take out a fraction of my time from physics research and devote it to learning and writing about the nuclear build up threatening South Asia. In recent years I have, mostly in collaboration with M.V.Ramana and Zia Mian, analyzed such issues as

- The risks posed by accidental explosions and fires near nuclear weapons
- The danger of unwanted launch through false alarms and instrumental errors
- Transit times for missiles in the South Asian theatre
- Early warning systems, radars, satellite surveillance
- Possible risk reduction measures that early warning could facilitate.

Enclosed as Annexure are two examples of such work . Annexure I describes some risks attendant with the possession and deployment of nuclear weapons in South Asia, and possible ways to reduce these risks. Annexure II represents a draft summary of more recent work on Early warning Systems in South Asia, missile flight times, radars, and the utility of such early warning systems. The full manuscript of this second work is under completion.

ANNEXURE I (for the Geneva Pugwash meeting , November 2002)

NUCLEAR WEAPON RISKS IN SOUTH ASIA

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With their governments having chosen to go nuclear the people of India and Pakistan must become fully aware of the risks that go with possessing nuclear weapons. Thanks to the worldwide notoriety that the ghastly attacks on Hiroshima and Nagasaki have received over the decades, there is some public awareness of the holocaust that results when nuclear bombs are dropped on civilian populations. But the death and destruction caused by nuclear weapons need not be confined only to situations when they are used in war as part of a calculated military decision. There are other substantial dangers that go with possessing nuclear weapons in addition to the consequences of their deliberate and premeditated use in war.

Any assessment of the extent of these hazards in the Asian subcontinent has to be based on the size and scope of the nuclear arsenals that India and Pakistan are expected to possess within a few years.. While we will never really be told, on grounds of national security , the details of our nuclear capabilities a rough estimate can be made from the aims spelt out in the draft Indian Nuclear Doctrine[1]. Pakistan has not has brought out a similar document. But it is reasonable to guess that demands of parity will induce them to broadly match the Indian nuclear force and be susceptible to the same type of risks.

The Indian Nuclear Doctrine demands a capability, in the event of an enemy attack, for "punitive retaliation" to "inflict damage unacceptable to the aggressor", " even in case of a "significant degradation by hostile strikes". For this purpose the Doctrine calls for a well spread out nuclear capability based on a "triad of aircraft, mobile land-based missiles and sea-based assets", with the survivability of the arsenal to be enhanced by " multiple redundant systems, mobility , dispersion and deception". In order to inflict this retaliation promptly, the level of readiness of the weapons will be such that one can "shift from peacetime deployment to fully employable forces in the shortest possible time".

Taken together these statements seem to call, even conservatively, for well over a hundred nuclear bombs widely dispersed over land and sea, with an associated fleet of missiles and jet bombers fuelled by extremely volatile liquid fuels, all in some state of near readiness, day after day, for a possible retaliatory attack. There is every possibility that the subcontinent may, over the years, get itself into a hair-trigger situation wherein each country has a battery of nuclear tipped missiles, all set to go from launching pad to target within a matter of minutes. India has declared a No First Use policy and stated that its nuclear arsenal is intended only to be a deterrent. Nevertheless, a deterrence policy employing such a large and widespread arsenal brings with it a host of other dangers. We will first describe some of this danger and ***then suggest some measures that may reduce the risk.***

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[1] Draft Nuclear Doctrine http://www.indiagov.org/govt/indnucld.htm#nucl

THE RISKS

The risks that go with possessing nuclear weapon may be grouped into three major categories :

1.A hasty or panic driven decision to launch a nuclear weapon based on misjudgement or misinformation about an impending enemy attack . There is also the risk of unplanned launching of a weapon through failure of command, control and deployment procedures or by terrorists.

2. Accidents, fires and fuel explosions in the vicinity of nuclear weapons. These weapons are intrinsically very hazardous objects, containing not only several kilograms of plutonium or weapons grade uranium, but also massive amounts of very powerful chemical explosives.

3.Rumours of an imminent nuclear attack from the other side and the resultant panic and stampede in crowded urban areas. This by itself can lead, especially during wartime crises, to massive loss of life and property without a single nuclear bomb having to be actually dropped.

Let us describe these dangers in some detail and then suggest some ways to minimise the risks involved.

1. Launch by error or misjudgement.

Nuclear bombing of civilian populations is a terrible human disaster, even when it is employed as a deliberate, fully considered wartime response. What would be even more tragic is if such bombing were to take place as a result of a hasty, panic driven miscalculation of the "enemy's " actions and intentions, or worse still, was an unauthorised launch caused by some communication error, computer malfunction or terrorist hijack..

The danger of false alarms and miscalculations is very real. The history of the cold war between the US and the USSR abounds with examples.[2] The US for instance had built an elaborate "early warning system" which would warn them about impending missile attacks. The idea was to have the opportunity, within the 25 minutes it takes for ICBM missiles to travel from the USSR to the US, to evaluate the warning, confirm an attack and make a decision going all the way to the President whether or not to launch your own bombs before the incoming missiles destroyed them[3]. It was a very sophisticated system using the latest state of the art technology involving a worldwide network of satellites and radars, and packed with filters to remove false signals. Yet, between 1977 and 1984 the early warning systems gave 20,000 false alarms of incoming missiles attacks.[4] Of these about 1,000 were considered serious enough for bombers and missiles to be placed on full alert waiting only for the final Presidential order to retaliate. The situation for the erstwhile Soviet Union was tighter still. Submarine based US missiles from the North Atlantic or Pacific Oceans could reach targets in Russia within 10 minutes[5] ! While detailed information about the Russian experience is less plentifully available, there have been many false alarms there too. In 1995 for instance , a Norwegian rocket launched purely for scientific purposes was treated as a possible enemy attack by the Russian detection machinery and the matter went all the way up the defense ministry chain to President Yeltsin.

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[2] A detailed and expert study of the dangers of accidental nuclear launches in the U.S.– U.S.S.R. (Russian) context is given by Bruce G. Blair in "*The Logic of Accidental Nuclear War*", Brookings Institution , Washington D. C. (1993)

[3] See for instance Harold A. Fieveson and Bruce G. Blair, "How to Lengthen the Nuclear Fuse ", *IEEE Spectrum*, March 2000, pp 40-43

[4] Zia Mian and A.H. Nayyar, "No Time to Think", *Himal Magazine*, Kathmandu, July 1998

[5] Harold A. Feiveson and Bruce G. Blair, "How to Lengthen the Nuclear Fuse ", *op cit,* (2000)

Fortunately in each of these cases the mistake was discovered in time to forestall the ultimate counter attack decision. Nevertheless, the shocking fact is that on many of these occasions, the world was just minutes away from a nuclear holocaust through error !.

The point is not that our own early warning systems in India will also be prone to false alarms. In fact we will probably not have the luxury of even such a fallible early warning system. This is not just because of the costs involved but also because of geography. The missile travel time between Pakistan and India is only about 5 minutes --- far too short a time to provide any meaningful warning. (Bombs delivered by planes will take longer, but that is offset by the difficulty in spotting the bombers carrying nuclear weapons from the dozens of other similar planes in action during wartime.) One would therefore have to settle for indirect indicators that give a little more time to react --- things like signs of unusual activity at missile launch sites , airfields and nuclear ammunition depots of the enemy, intelligence reports of their military plans and political intentions and so on. These can yield at best secondary evidence of an impending attack, much less concrete and more amenable to misinterpretation. A very plausible scenario is one where, at a time of wartime crisis, such indirect evidence suddenly peaks to a crescendo and points towards an imminent nuclear attack. Such evidence may be very strongly indicative, but it is unlikely to be one hundred percent certain. One can imagine the extraordinary dilemma that the country's political leadership would then face. They may find themselves under immense pressure from the more hawkish elements among them and the military to launch a preventive attack within a matter of hours if not minutes. Notwithstanding any declarations of No First Use, and no matter how responsible the leadership is or how conscious they are of the gravity of a wrong decision it is still hard to imagine them just sitting on their hands and waiting for the bombs from the other side to land before retaliating. Herein lies the serious risk of circumstances forcing a hasty panic-driven nuclear attack in response to a perceived threat that may eventually turn out to have been false.

The pressure to launch a preventive attack would be all the more intense if missiles and bombers loaded with nuclear weapons were already fully deployed and ready to take off in minutes. When such fire-power is kept primed day after day, ready to be used any moment , it is itching to be fired. The mere availability of such capability generates a momentum of its own to the decision making process. There is very little doubt that the decision to drop the bombs over Hiroshima and Nagasaki was in part influenced by the fact that the bombs, only recently fabricated after a massive military and scientific effort, were sitting there, waiting to be tested over a "real target".

Finally, the fact that the antagonist also carries a similar nuclear arsenal with very similar risks, increases the danger many-fold. What may be viewed as a purely deterrent weapon by one side cannot, if kept in a state of ready-to-fire alert, be distinguished by the other side from a capability mounted to make a surprise first attack. Each side, in evaluating the threat from the other, will not only have to consider the likelihood of a deliberate attack, but also factor in the possibility of inadvertent, unauthorised or hasty crisis driven attacks. Such increased perceptions of threat can bounce back and forth between the strategic calculations of the two countries, getting magnified in the process.

In addition to the danger of human errors of judgement by the leadership there is also the risk of inadvertent launch by failure of technology. Nuclear weapons and missiles will utilise, both during the storage phase and the launch phase a vast array of very sensitive high tech components . So will satellite-based detection systems and the command and control chain . The latter requires a communication network linking the apex decision maker "with his finger on the nuclear button" to the military personnel actually responsible for firing the weapons, the field commanders and the intelligence sources. At a time of nuclear crisis, each of these systems has to work with total precision. A failure could lead to misinterpretation or miscalculation resulting in an inadvertent launch. System failures are well within the realm of possibilities. The false alarms in the U.S. early warning systems, mentioned earlier, included many examples of such systems failure. In one case someone forgot to switch off a computer program which was simulating attacks. In another a tiny computer chip failed. While we in India may not set up an early warning system the US experience teaches us the valuable lesson that even a system using the most sophisticated technology in the world, made with the best available components and manned by a highly trained elite corps of the US military can fail time and again due to factors as mundane as human error and computer chip malfunction.

Turning to India no one familiar with the way infra-structural facilities function in our country can fail to be concerned about our ability to maintain and run, day after day, such a vast and complex array of communication systems at a zero-error level. True, the high-tech wings of our government do function far more efficiently than our state electricity boards . We have successfully completed many complex technological missions, including space launches and the Pokhran tests themselves. However, there are important differences between something like a space launch and, say, the maintenance of nuclear command and control communications. A failure in some component of a satellite launch system may lead to re-starting the countdown , or at worst the loss of the rocket and satellite. Those are certainly very serious and expensive consequences, but nowhere nearly as catastrophic as the failure of some crucial communication link or some weapon safety mechanism during a nuclear crisis. In dealing with possible nuclear attacks, there are no second chances. Another difference is that a space launch or a nuclear test is an individual time-bound project climaxing in a particular event. Our technologists have shown that we do have the discipline to tighten our normally relaxed "Chalta Hai" approach for the duration of such special projects. However, the nuclear communications and weapon launching systems are different in nature . They are not going to be used on some pre-specified date, or periodically, from time to time. Hopefully they will remain unused for years together. Yet, in the event of a nuclear crisis the system will be called upon, within a matter of minutes, to function from end to end with full efficiency. Therefore, it will have to be maintained in perfect working order day after day at a zero margin of error in anticipation of a sudden crisis. Periodic checks and practice drills on individual links of the system are no substitutes for the real thing, when the entire system has to function amidst the chaos and tension of an impending nuclear attack. In the past, our proven record with the long term maintenance of important but mostly dormant systems has not been so glorious. There is a tendency to start with great alertness and efficiency and then, as nothing untoward happens for a while, to let the vigilance slip. Examples of such slippage abound, starting from the failure of fire alarm systems in public buildings to large-scale tragedies as happened in the Union Carbide factory in Bhopal. Another example was the inability to speedily round up, during the Indian Airlines hijack , our crack teams of hijack experts presumably trained and maintained at great cost precisely to be on instant readiness .

2. Fires and fuel-explosions near a nuclear weapon

Apart from the devastation they cause when deliberately exploded, nuclear weapons as physical objects are intrinsically dangerous even when "at rest". They carry hazards just sitting in storage or in transit on the backs of trucks and planes or being loaded on to missiles

In essence, a nuclear weapon consists of a shell of powerful chemical high explosive (HE) surrounding a core of either plutonium or highly enriched uranium. (In fusion weapons, there is a second stage that is in turn ignited by the fission weapon described here.) The role of the HE is that when it detonates, it crushes the fissile material core into a critical mass and triggers a chain reaction, leading to the nuclear explosion. This HE is itself a major source of risk. Although tucked away inside the external metal shell of the bomb it is still vulnerable to getting ignited by external fires and explosions in the vicinity of the bomb. Once the HE catches fire that can lead, as we shall describe, to many serious consequences.

The possibility of accidents and fires in the vicinity of nuclear weapons is very real, particularly when the weapons are kept on high alert, deployed on their missiles and bombers carrying highly combustible fuels .There have been any number of examples. An official summary released by the U.S. Department of Defense in 1981 lists 32 accidents involving U.S. nuclear weapons between 1950 and 1980[6]. These

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[6] U.S. Department of Defense in coordination with Department of Energy, *Narrative Summaries of Accidents Involving U.S. Nuclear Weapons, 1950-1980 (Interim)*, 1981.

accidents are typically caused by mishaps of delivery vehicles, either aircraft or missiles. Notable among missile accidents is the 1960 case of a U.S. BOMARC missile at the McGuire Air Force base in New Jersey which suffered an explosion and a fire in the missile's fuel tanks[7]. There have also been accidents involving aircraft, the most famous being near Palomares, Spain, and Thule, Greenland. In both cases, aircraft carrying nuclear weapons crashed and the high explosive surrounding the nuclear core detonated[8]. Information about accidents in the erstwhile Soviet Union is harder to obtain, but there are reports of at least 25 serious nuclear weapon accidents there[9]. These included a 1977 accident in which, reportedly, fuel leaked from a nuclear missile in its silo and subsequently exploded. Even as recently as June 16, 2000 a ballistic missile that was being unloaded near Vladivostok from a transport ship caught on the pier railing[10]. This led to a leak of approximately 3 tons of the oxidizing agent, which in turn exploded. A number of people were injured and villages had to be evacuated. Fortunately in that incident the missile did not carry a nuclear bomb.

There have been no reports so far of nuclear weapon accidents in South Asia , but there have been many instances of major fires in large ammunition depots. A recent example is the huge fire in an ammunition depot near Bharatpur two years ago, where reportedly several hundred tons of ordinance were destroyed and rockets and missiles shot up and exploded.[11] There were other similar fires at Birdhwal Head and at Bikaner. If a couple of nuclear weapons mounted on delivery vehicles happened to be in a depot during one such fire, the type of accidents we discuss below can easily happen. Of particular concern in South Asia are the liquid fuelled missiles, India's Prithvi and Pakistan's Ghauri, which may have significant risks during launch preparations . According to reports most of India's Prithvi missiles are believed to be fuelled by a liquid propellant consisting of an oxidizer of inhibited red fuming nitric acid (IRFNA) and a 50:50 mixture of xylidine and triethylamine.[12],[13] This combination is hypergolic, i.e., self-igniting and highly volatile and has to be loaded just prior to launch.

Once the HE inside a nuclear weapon catches fire due to some external accident or fire it could result in one of three possibilities, listed below in increasing order of seriousness:

(i) The High Explosive burns *but does not detonate*. This will lead to the melting of the weapon and could release a limited amount of plutonium into the environment. But this will be localized in the immediate vicinity of the accident and limit the severity of its effect on the environment and public health. So we will not elaborate on this possibility further.

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[7] Jaya Tiwari and Cleve J. Gray, U.S. Nuclear Weapons Accidents, available on the internet at: http://www.cdi.org/Issues/NukeAccidents/accidents.htm

[8] Sidney Drell and Bob Peurifoy, Technical Issues of a Nuclear Test Ban, *Annual Reviews of Nuclear and particle Science, vol. 44, 1994, pp. 285-327* (based on U.S. DOD Narrative History)

[9] Shaun Gregory, *The Hidden Cost of Deterrence: Nuclear Weapons Accidents* (London: Brassey's, 1990) pp. 184-190.

[10] British Broadcasting Corporation, "Toxic cloud moves along Russian Far Eastern coast after missile fuel leak," June 16, 2000

[11] Prakash Bhandari, (Times News Network), Times of India, January 14th, 2002.

[12] See, for example, Hormuz Mama, "Improved Prithvi Missile Launched," *International Defense Review*, August 1, 1992, p. 784. However, it has also been suggested that Ghauri may use RP1 (Kerosene) as fuel; S. Chandrashekar, "The Origins and Antecedents of the Ghauri Missile – An Assessment," *Current Science*, Vol. 76, No. 3, February 10, 1999, pp. 280-285

[13] Some Prithvi subsystems are reportedly now using solid fuels – from the point of view of safety against fire accidents this is a welcome move.

(ii) *Detonation* of the HE leading to vaporisation of the plutonium and its dispersal into the atmosphere;

(iii) Detonation of the HE triggering an uncontrolled fission reaction and *nuclear explosion.*

The last possibility is the overwhelmingly the worst. It is the least likely but cannot be ruled out. True, so far there has been no incident of a nuclear weapon going off by accident. But that may be in part because of safety measures built into the design of weapons by major nuclear powers. For instance, modern nuclear weapons in the U.S. arsenal are "one-point safe", i.e., their design ensures that the accidental explosion of just one of the HE packages will not trigger a nuclear explosion. (To be precise, a one-point safe weapon carries a probability of less than one in a million of producing a nuclear yield of even 4 pounds of TNT equivalent in the event of detonation at any one place in the HE system.[14] This is to be compared with the fact that even a kiloton tactical nuclear weapon has an explosive yield equivalent to 1000 tons of TNT.) However, considerable testing has to be done before installing such safety measures into weapon design. Concern about nuclear weapons safety was responsible in large part for the 130 safety related tests carried out by the United States.[15] The USSR reportedly conducted about 25 safety tests involving 42 weapons, between 1949 and 1990.[16] It is not clear whether Indian and Pakistani nuclear programmes, still in early stages of development without too many tests under their belt, carry such design-level safety.

Should such an accidental nuclear explosion take place, the result would be the same as that of a nuclear weapon used deliberately in war. An accidental nuclear explosion with a yield of 15 kilotons (similar to the Hiroshima bomb) would destroy everything within 5 square kilometres through the combined effects of blast and fire. An area of over 25 square kilometres would be subject to radioactive fallout at levels such that half the adult, healthy population living there would die from radiation sickness. If this were to happen in the vicinity of a large South Asian city, several lakhs of people would die.[17]

In the chaos and confusion that would inevitably follow in the immediate aftermath of such an unprecedented accident, it will be take time to determine its cause . There is therefore the additional danger that such an accidental nuclear explosion may be misinterpreted as an attack from the enemy. That in turn can trigger retaliatory attacks and a full scale nuclear war, particularly if some of our nuclear weapons are on ready alert.

Next let us turn to the second scenario listed above. Even if the detonation of the HE does not result in a full scale nuclear explosion it will still blow the contents of the bomb into smithereens. While less devastating than a nuclear explosion, this will still inflict massive damage by any ordinary standards. Let us describe this possibility in some detail.[18] [19] [We will focus on such accidents involving plutonium. India has used plutonium in its nuclear weapons while Pakistan has so far relied on uranium; but with production of

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[14] US Arms Control and Disarmament Agency, *Fiscal Year 1979 Arms Control Impact Statements*, p. 92.

[15] Thomas B. Cochran and Christopher E. Paine, “Hydronuclear Testing and The Comprehensive Test Ban: Memorandum to Participants JASON 1994 Summer Study,” Natural Resources Defense Council, Washington D.C., 1994, p.11.

[16] Robert S. Norris and William Arkin, Soviet Nuclear Testing, August 29, 1949 – October 24, 1990, *The Bulletin of the Atomic Scientists*, May/June 1998.

[17] M.V.Ramana, *Bombing Bombay: Effects of Nuclear Weapons and a Case Study of a Hypothetical Explosion* (Cambridge: International Physicians for the Prevention of Nuclear War, 1999), p. 31.

[18] This class of accidents and its health hazards were discussed in the pioneering work of Steve Fetter and Frank von Hippel, in “The Hazard from Plutonium Dispersal by Nuclear-warhead Accidents,” *Science and Global Security*, Vol. 2, pp. 21-42, (1990).

[19] A more recent analysis, with particular reference to South Asia was done by Zia Mian, M.V.Ramana and R.Rajaraman, in *Risks and Consequences of Nuclear Weapon Accidents in South Asia*, Center for Energy and Environment (Princeton University) report PU/CEES 326 (September 2000). An extract from this work has been published in *Current Science* , Vol 80, no.10, 2001, p.1275-1284.

plutonium from the Khushab reactor starting, Pakistan may follow India in developing plutonium based weapons.]

If the HE detonates, effectively all of the plutonium will be transformed into a fine aerosol. This aerosol will rise with the hot gases created by the explosion, mix with the air and spread. Any prevailing wind would transport it to considerable distances, typically up to tens of kilometres. People and animals in this region would inhale this plutonium laden atmosphere. The biological damage caused by plutonium exposure is a complicated matter, but it has been studied extensively. The two primary routes of damage by plutonium contamination are ingestion and inhalation. Ingestion is a less significant risk since almost all of the plutonium will be excreted within a few days. The more serious risk comes from inhalation of very small plutonium particles, which can stay imbedded deep in the lungs typically for periods of the order of a year.

The primary effect of plutonium inhalation is an increased chance of lung, liver and bone cancers. In assessing this cancer hazard , it is important to note that detailed studies by the US National Academy of Sciences and other groups support a "linear no-threshold model" of such radiation damage.[20] This means that there is no "threshold", i.e. no minimum radiation level below which there is zero risk of cancer. Any dosage of radiation received, however small, will carry a correspondingly small but non-zero probability of causing cancer. This has the following serious implication. As the radiation cloud spreads into a larger and larger area and contaminates more and more people it admittedly thins out, but however thin, it still continues to carry some small cancer hazard for each of the persons in the large population touched by the cloud. Consequently there is a substantial cumulative contribution to cancer fatalities even from areas far away from the site of the accident.

Imagine a nuclear weapons accident of this type at an air force base or nuclear weapons depot which happens to be at the edge of a major city in our subcontinent. If the city happens to be downwind at the time of the explosion then calculations show that there could be approximately 5,000 - 20,000 cancer deaths caused by plutonium inhalation .[21] While less devastating than a full scale nuclear explosion, this is still a huge tragedy. Even the lower estimate of this casualty count is larger than the total number of fatalities in the recent attack on New York's World Trade Center and the Pentagon which has shaken the world. Cancers caused by plutonium inhalation take years to incubate and develop; so this tragedy will not appear as dramatic as the WTC attack but the deaths, slow and less conspicuous, will be just as many. The risk of such an accident is not that far-fetched. There *are* bases and cantonments at the edges of large cities and there is no publicly available information that assures us that a nuclear weapon will not be stored in one of these or transit though them. Even if such an accident did not take place at the edge of a major metropolis but happened, say, 50 kilometres upwind of a middle-sized town the resulting toll would still be considerable. Estimates show that it would lead to approximately 200 - 900 fatalities from the town and the surrounding countryside. In all these cases, in addition to the fatalities there will be the medical costs of treating the fatal and non-fatal cancers resulting from inhalation of plutonium. There is also the massive financial cost of de-contamination. Detailed estimates of such costs have been made in the U.S. Even if these costs are scaled down to Indian context, cleaning out the radio-active debris from just the immediate neighbourhood of the accident will already cost hundreds of crores of rupees.

Are the types of nuclear accidents described here very likely ? A reliable quantitative estimate of the probability of their occurrence is hard to calculate. This probability may not be large, but it is certainly not zero. It is worth recalling that India and Pakistan have each officially claimed only about half a dozen

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[20] *Health Risks of Radon and Other Internally Deposited Alpha-Emitters (BEIR IV)* (Washington, D.C.: National Academy Press, 1988) p. 177. The International Committee on Radiological Protection (ICRP) also asserts that "there are no adequate grounds for assuming a real threshold" and uses a simple proportional relationship at low doses. See the *1990 Recommendations of the International Committee on Radiological Protection* , ICRP Publication 60, (New York: Pergamon Press, 1991) p. 18.

[21] See Zia Mian, Ramana and Rajaraman, *op cit*

nuclear tests with no suggestion that any of them were intended purely to test safety with respect to either the inadvertent detonation of the HE or the consequent full scale detonation of the nuclear bomb itself.

3. Rumors and Panic

An aspect of living under the nuclear shadow that does not seem to have received much attention is the danger of panic-born (if not deliberately malafide) rumors that "a bomb is on its way". One reason for its relative neglect may be that it is a civil rather than military problem, calling for expertise not so much in defense and foreign affairs as in municipal crisis management and mass psychology. But it nevertheless has the potential to suddenly explode into a very serious problem particularly in the densely populated rumor-susceptible countries of the sub-continent.

Imagine a future Kargil or an even larger conflict in which one of the countries has just suffered a major defeat with thousands of casualties. In that situation, how many residents of, say Delhi, Mumbai or Lahore will be immune to a sudden, possibly well orchestrated rumor that humiliated extremists on the other side have just captured and pushed the nuclear button as an act of irrational revenge? It could spark off a mad stampede of people, carts and cars, killing or injuring tens of thousands of people without an actual bomb ever having dropped there.

Fears of such panicky stampedes may sound exaggerated during peacetime. Larger than life nuclear disasters of low probability are always hard to comprehend and are consigned to distant corners of people's psyche even in potentially "targeted" cities. But a nuclear attack will cease to appear to be an unreal unlikely event once a military crisis develops. Those who were living in the U.S. during the Kennedy era will remember the sudden peaking of fear and tension during the Cuban missile crisis. A similar crisis here in the future, with hundreds of nuclear weapons ready to fire on both sides can provide a fertile ground for panic. This also opens up the prospect of yet another form of terrorism, namely, (dis)information terrorism.

SOME RISK REDUCTION MEASURES

It should be stated categorically that the only sure way to bring these nuclear risks down to zero is to abolish all nuclear weapons. This should continue to be the ultimate goal of all rational and peace loving people. But as of now, nuclear weapons **are** here. Even as we strive to eliminate them altogether, it would in the meantime be prudent to press for whatever risk reduction measures we can in the face of the security perceptions of the concerned countries. It may be particularly fruitful to do this in the Asian subcontinent where nuclear arsenals are just beginning to be built and nuclear strategies still not firmly in place. There may still be time to influence policy makers into incorporating some of the following risk reduction measures.

A Posture of De-Alert

The term De-Alert stands for deliberately stepping back from the precipice of nuclear war by standing down one's own nuclear arsenal from a state of instant readiness by introducing built-in delays. This is not a particularly new or radical suggestion. Arms control analysts have discussed at length various de-alerting scenarios for the U.S. and Russia to adopt.[22] Some de-alerting (though far from full) had actually been done by the U.S. around 1991 when Minuteman missiles (slated for later elimination under the START 1 agreement) were ordered to stand down. At an operational level, there are a variety of steps that can lead to de-alerting. The most basic de-alert measure would be to keep the weapons de-mated from their delivery vehicles. This can be strengthened further by deliberately building in further delays in loading the weapons by burying ground based weapons underground, jamming nuclear weapons and so on. Other de-alert measures suggested have included removal of guidance systems from the missiles and storing them

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[22] See for instance Harold A. Feiveson and Bruce G. Blair,(2000), *op cit* and B.G.Blair, H.A. Feiveson and F.von Hippel, The Washington Post , November 12th, 1997

separately, and redirecting US nuclear submarines to patrol deep in the southern hemisphere out of immediate range of their targets in Russia . A safety measure widely used in the U.S. against accidental or unauthorized launch of nuclear weapons is the installation of the so called Permissive Action Link (PAL).[23] This is an electromechanical device installed on nuclear weapons which locks them against use. The weapon will not explode unless this PAL is unlocked which can be achieved only by employing a highly unbreakable code. By the end of the 'seventies, almost all land and air based nuclear weapons in the U.S. had PALs installed in them. Similar locking devices known as coded switch systems can also be installed on bomb delivery systems, which would bar bomb racks from releasing the weapons or prevent the completion of the countdown to the missile launch. Codes for unlocking these devices were not to be distributed to the weapon commanders by higher authority until the decision to employ the weapons had been made. The Russian nuclear forces also had such locking codes which carried the additional safely feature that if unlocked during a state of high alert they automatically locked themselves again if the weapons had not been launched within the planned period.

In the Indian context the first step would be to ensure that the weapons and their delivery vehicles are stored far away from each other instead of being mated with one another, ready to go. This by itself can introduce a minimal delay of anywhere from few hours to a day before a launch can be executed after orders are given. Such an in-built time-gap between the decision to fire and its execution will reduce many of the risks listed earlier. By precluding instantaneous deployment it will greatly diminish the probability of hasty, emotionally driven or accidental use of nuclear arms. Decision makers, even after ordering a nuclear attack will perforce have some additional grace time to reverse that decision. Such a reversal may be warranted (and may well prevent an avoidable nuclear holocaust) if the original decision had been based on information or intelligence reports subsequently were found to be incorrect or less serious. Or, if the decision were forced by the pressures and passions of a wartime crisis and saner counsel prevailed after the decision was taken. Keeping the weapons well separated from the missiles will also reduce the possibilities of an accidental launch as well as of confiscation of the combined package of weapon and delivery system by terrorists or extremists.

It is generally believed that in India , as of now , nuclear weapons are indeed not mated with their delivery vehicles and are stored separately. There are also reports that the weapons themselves may be in a disassembled form with the radioactive core stored separately from the firing assemblies.[24] All this certainly enhances safety. But it must be ensured that this situation is not just a feature of the early stages of nuclear armament and will remain so as a matter of policy even when the full arsenal and its command and control systems are firmly established.

Safety measures against nuclear weapon accidents

Another benefit of storing the weapons separately from the missiles and bombers is that the chances of nuclear weapon accidents described earlier would be greatly reduced. The most serious source of fire near weapons comes from the highly inflammable fuels used in rockets and planes. Even a distance of a few hundred meters between the weapons and their delivery vehicles will greatly lower the chances of a fire in the latter igniting the High Explosive in the former. One can lower these risks further by installing the best available safety measures into the weapons. One such is the use of the so-called "Insensitive high explosives" (IHE ; this a special type of explosive of comparable potency but one that cannot be set off so easily). Another is the installation of Fire Resistant Pits. Some of these devices would add to the weight of the weapon . With both India and Pakistan seeking to develop small, light nuclear warheads that can more easily be fitted on ballistic missiles, it is possible that these safety features may not have been implemented. In that case they should be. Further measures, such as keeping the weapons partly

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[23] A detailed description of PAL devices is given in Bruce G. Blair, "*The Logic of Accidental Nuclear War*", Brookings Institution , Washington D. C. (1993)

[24] Manoj Joshi in the *Times of India*, Delhi Edition, 4th November 2001

dismantled or burying them deep underground can also be considered . These would not only reduce the danger of accidents but also increase the built-in delay period.

Feasibility of De-alert and Compatibility with Deterrence

Introducing some form of de-alert does some difficult problems to be solved on all fronts --- the political, military and technical. However, these problems are not insurmountable. Given the immense importance of nuclear risk reduction it is worth trying to find ways of overcoming them. To get a flavour of these problems consider first a unilateral declaration of some de-alert neither measures by India, without requiring them to be necessarily verifiable by our neighbours nor reciprocated by them. Setting this up is comparatively less complicated since it does not require bilateral agreements or any exposure of one's nuclear assets to other countries. The single largest problem with instituting such measures unilaterally from our side would come from making them acceptable from our own military and strategic point of view. Any suggestion for de-alert measures and built-in delays will be immediately countered with concerns about its negative impact on our deterrence capability. Inasmuch as India has declared a No First Use policy, the only rationale for its nuclear arsenal – the one stated in the Indian Nuclear Doctrine -- is its deterrence effect against an attack from the other side. It would be unrealistic to expect the government , within its overall policy of having to decided to go nuclear, to consider de-alert measures which seriously compromise the deterrence value of the arsenal.

These concerns must therefore be addressed. Admittedly any of the de-alert measure we have suggested -- even the minimal step of storing the weapons de-mated and far away from the missiles -- will handicap our retaliatory capability to some extent. But this is no reason to *a priori* abandon considering postures of paused deployment. Rather, the loss of deterrence value that a particular set of inbuilt delays carries with it has to be estimated in quantitative detail and weighed against the grave risks of an accidental or hasty nuclear attack that go with a fully alert hair trigger posture .

The mere fact of a delay, even by as much as a day, between the decision to retaliate after having been attacked and its actual execution does not, *in of itself*, reduce the deterrence value. This is true even if the built-in delay is a part of a publicly declared policy, known to other countries. The prospect of a retaliatory nuclear strike on cities is no less scary merely because it comes after a day's delay. There is very little that the enemy can do in the way of protective action in that short a time. Most of the talk of "civic measures" to protect the population in the event of a nuclear attack is totally unrealistic. In the United States, there was an initial burst of enthusiasm in the early days of the Cold War among some individual homeowners and communities for reinforced underground shelters stocked with canned food and medicines. This petered out soon thereafter as it became clear that such shelters were inadequate in the face of a full scale attack by megaton weapons and could in any case cover only a small fraction of the population. The prospects of such specialised protective shelters are negligible in our South Asia where even basic housing is unavailable for millions. Nor can any country empty all its major cities (any one of which could be a target of the retaliation) within 24 hours ! There is nowhere to run from an incoming nuclear bomb. So a counter attack, *as long as it certain to come* , is just as lethal even if it comes after a full day's warning.
The real concern from the deterrence point of view stems not so much from the delay in retaliation, but from possible loss of retaliatory capability because of the delay. These could happen for two reasons: (a) The destruction of one's arsenal by the other side during the period of re-arming and launching, lengthened because of the in-built delays, and (b) pressures building up during this period, particularly from international sources to not retaliate despite having been attacked first.

In discussing the survivability of our retaliatory capability, it should be pointed out that it is not really necessary that hundreds or even dozens of independent missiles and bombs survive in order to inflict "unacceptable damage". All that you need to be able to do is drop one or two modest 20 kiloton bombs on a couple of major cities. At today's population densities, this will already kill several hundreds of thousands of people within minutes and injure many more. Surely no sane national leadership can consider that as an acceptable price for any amount of military or strategic gain. Indeed any rulers of a country who seriously find "acceptable" a near-million civilian casualty would be so pathological that they cannot be relied upon to be deterred even by the prospect of a hundred bombs being dropped on them. Usual psychological norms of rational response cannot be applied in such a case. Therefore it makes no rational sense to demand survivability of more than the minimal capability of being able to hit just a couple of cities. To ensure this, one may need to have some redundancy and the required force may have to be further strengthened if there are two potential nuclear adversaries instead of one. But all this still does not require a retaliatory capability of thousands of weapons that the U.S. and Russia maintain, nor even the hundreds that lesser nuclear powers keep. A surviving strike force of a half a dozen weapons with delivery vehicles may well suffice. Our de-alert strategy needs to ensure only that much. The questionable increase in deterrence value by having available a strike force a dozen or a hundred times larger is offset by the grave risks of maintaining such large arsenals. [Incidentally, this argument should not be misconstrued as an endorsement of nuclear weapons as long as they are only a handful. Rather it is an argument against building arsenals in the hundreds in the name of deterrence. In India where from most reports there are already well over two dozen weapons, this is an argument for reduction.]

Of course, keeping even a half dozen weapons and launchers safe during the critical day's grace period built into a de-alert posture is a very difficult and complicated matter. Elaborate secret strategies and technological innovations will have to be evolved by scientific, military and intelligence experts using some combination of underground storages, land based mobile carriers as well as submarines in the future. This is not the place to discuss these options in detail. Suffice it to say that complex though these problems may be they are in principle tractable and solvable by the expertise we have available.

The other problem that proponents of a delayed response have to address from the deterrence point of view is the prospect of international pressures building up during the delay period against using one's retaliatory capability. That is simply a matter of national will, or rather, the perception by others of our national will. When the World Trade Center was attacked, the U.S. immediately announced its goal of hitting back at the attackers. Although they took several weeks to set up the military and diplomatic preparations before embarking on the actual attack, no amount of world opinion could dissuade them from going ahead with it. In fact "international opinion" is so fickle that as the attack on Afghanistan showed signs of success, most of it melted down anyway. Why should it then be feared that in the event of a much more serious nuclear attack on , say, India it would not be able to retain its independent options on how to respond ? Again, the point here is not to recommend any form of nuclear attack, whether as a first strike or in response to one, but only to point out that risk reducing de-alert measures need not be abandoned on the grounds that the associated delay will imperil deterrence .
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Verifiability, transparency and bilateral de-alert agreements

We have argued that India can, without necessarily crippling its deterrence capabilities, unilaterally adopt some of the risk reduction measures mentioned above. It would be in its own enlightened self interest to do so. What would be even more desirable would be bilateral treaties between India and its nuclear neighbours Pakistan and/or China adopting a common posture of de-alert in some transparent and mutually verifiable manner . Such bilateral arrangements would be immensely more difficult to set up than unilateral risk reduction steps, not only for political reasons but also because they would require resolution of more complex technological and strategic details . It is well beyond the scope of this article to analyse the possibility of such bilateral de-alert agreements comprehensively. Nevertheless we would like to venture some *preliminary* remarks about bilateral risk reduction treaties --- on the advantages they offer and on some of the practical problems which may make them a difficult goal.

There are undeniably immense benefits that such bilateral agreements would bring, particularly between India and Pakistan where tensions have been high and there is a genuine concern about a nuclear war. Firstly, all the benefits described above in support of unilateral de-alert measures would now accrue to both signatories of such a treaty. There would be several hours if not a full day of grace time for either side to retract nuclear launch decisions, thus greatly reducing the risk of either country executing a hasty or emotionally driven nuclear attack. More importantly, if the de-alert measures taken by the each country could be verified by the other periodically, through physical inspection, electronic signals or satellite images, it would go a long way to diminish the fear of sudden and unexpected attacks. This in turn will substantially reduce the possibility of false alarms triggering a nuclear war -- one of the worst nightmares of the Cold War. If there were to be any intelligence reports indicating reversal of de-alert moves by one side there will be ample time to communicate with the other side and confront them with this information or to have it can be confirmed by other means. The availability of this grace period will be particularly invaluable during times of war and border crises.

Installation of these mutually verifiable de-alert measures could carry other secondary but still important benefits. The process of setting them up will necessarily require considerable interaction between the two countries. It will call for cooperation not only between politicians and beaurocrats of the two countries but also between defense and technical personnel who will have to collaborate closely at all stages -- in agreeing to a mutually acceptable set of de-alert measures, in installing them and in devising ways of ensuring their verifiability. All this will provide important opportunities for establishing the much talked about “confidence building” between the two countries. Lastly, the mutual verifiability and transparency of these safety measures would allow each country to publicly assure its citizenry of their existence. People could be told with some confidence by their governments that there is no possibility of a sudden nuclear attack from the other side either by accident or through a hasty irreversible decision. That would go a long way towards reducing the risk of false rumours of impending attacks with the associated danger of panic and mass stampede.

While such risk reduction treaties would undeniably be beneficial, they are still a distant goal. Obviously many problems on the strategic, technical and political fronts would have to be overcome before they could become a reality. At the technical and strategic level there are the complex de-alert measures to be designed in detail. These would on the one hand have to be acceptable to each side in terms of its own security and nuclear deterrence concerns , while on the other they would have to be sufficiently transparent and verifiable for the other side to remain satisfied that the measures are indeed being respected. Even more difficult is obtaining political acceptance of such an agreement. What one would be asking for is that countries that have felt so threatened by one another as to install a battery of nuclear weapons now agree to stand down those very weapons from full alert, lower some of the secrecy surrounding their arsenals and expose them for mutual verification of de-alert measures.

Finding solutions to these problems would be less difficult if, for purposes of argument , we first limit ourselves to just the Indo-Pakistan pair, leaving out China (more on that later). Then the technical problems of designing verifiable de-alert measures would be more tractable, particularly if we invoke the argument made earlier that a small surviving arsenal is sufficient for the mutual deterrence requirements of these sub-continental neighbors. Right now, given the tensions prevailing between India and Pakistan after the terrorist attack on December 13th followed by the troops build up on both sides of the border, it is difficult to imagine them agreeing to measures that will require significantly exposing their nuclear armoury and technology for mutual inspection . But it would be equally naïve to imagine that such things can never happen. For one thing, relationships between large nations take place on many tracks. Even in the midst of the fiercest of battles field commanders from both sides keep in touch and cooperate on selected matters. The hotline between the U.S. and the U.S.S.R. was installed and operated during the height of the cold war. Also, unlike the Sino-Indian relationship, which is based on comparatively dry geo-political, trade and strategic concerns, the Indo-Pakistani relationship has a large emotional component stemming form the deep cultural ties of two peoples who are basically the same. While this emotional component brings with it all the baggage of past recriminations, it can also lead, when the mood is right, to a rapid groundswell of popular opinion in favour of friendship and cooperation. If General Musharraf’s speech on January 12th does translate itself into a renewed focus in Pakistan on economic development and social welfare, the natural bonds of kinship that have always existed between the peoples of the two countries could re-emerge leading to more mutual confidence building activities on several fronts.. These in turn would pave the way to nuclear risk reducing agreements too.

However our discussion of risk reduction agreements with neighboring nuclear powers in the preceding paragraphs has been grossly incomplete. Any such analysis will have to take into account not only

Pakistan but also China. Our nuclear capability has been developed in response to security concerns involving both our nuclear neighbors. It is obviously not possible to demarcate our entire arsenal into one part directed towards Pakistan and another towards China in order that we may enter into a treaty with Pakistan to de-alert the former portion alone ! [While Prithvi missiles their shorter range may not threaten China, the different varieties of Agni could be viewed as a threat by both countries and the bombs themselves could be employed on either front.] Negotiating any form of a de-alert agreement with China is a much more complicated matter even on the intellectual plane, let alone the practical. This is not only because China has (and will continue to have for a long time) a much stronger nuclear force than India, but also because its arsenal in turn is addressed not just to India but much more so to other larger nuclear powers. By going nuclear we have willy-nilly linked our national security problems to not just our immediate neighbors but to the whole chain of nuclear powers.

It should however be emphasized that these problems associated with having multiple adversaries does not seriously affect the more modest goal of introducing some risk reduction measures ourselves, unilaterally. As we have argued it is in our own interests of safety to do this. If they are not part of bilateral or multi-lateral agreements, with the added constraints of external inspection and verifiability that go with them, then it should be possible to install an appropriate set of de-alert measures that reduce nuclear risk substantially without seriously compromising core deterrence capability. Those could be the first steps towards the ultimate goal of total disarmament.

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ANNEXURE II (for the Geneva Pugwash meeting, November 2002)

EARLY WARNING SYSTEMS IN SOUTH ASIA

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Introduction

As was to be expected , after formally establishing themselves as nuclear powers with the 1998 tests both India and Pakistan have continued to build up their nuclear arsenals, their armada of ballistic missiles as well as the technology and infrastructure needed for command and control. In doing this they are broadly following the blueprint set by the US and the USSR in the early days of the cold war, which eventually lead to those two nations confronting one another with tens of thousands of nuclear weapons on instant readiness to attack.

That India would go about consolidating its nuclear infrastructure was already anticipated in the Nuclear Doctrine Document it put out in 1999.[25] The document envisaged an "assured capability to shift from peacetime deployment to fully employable forces in the shortest possible time"[26]. The doctrine also proposed setting up "effective intelligence and early warning capabilities" and proclaimed that "Space based and other assets shall be created to provide early warning, communications, damage/detonation assessment ".[27]

Pakistan did not put out a formal nuclear doctrine. But it is likely, if one goes by statements of their governmental and military leadership that they will, in their own way, embark on a similar nuclear build-up. For instance, in a newspaper article three leading Pakistani statesmen, Agha Shahi, Zulfiqar Ali Khan and Abdul Sattar recommend that "In the absence of an agreement on mutual restraints, the size of Pakistan's arsenal and its deployment pattern have to be adjusted to ward off dangers of pre-emption and interception." They also suggest that "A high state of alert will become more necessary as India proceeds with deployment of nuclear weapons"[28]. Specifically Pakistan too has suggested that it will turn to the use of satellites – with its Minister for Science Technology announcing that "the government is preparing to launch its own geo-stationary satellite by the end of the year to meet its strategic and communication needs"[29]

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[25]Draft Report of National Security Advisory Board on Indian Nuclear Doctrine, August 1999

[26] *ibid*, item 3.2
[27] *ibid*, item 5.6
[28] Agha Shahi, Zulfiqar Ali Khan and Abdul Sattar, "Securing Nuclear Peace", The News, 5th October, 1999
[29] "Geo-stationary satellite by year-end: Ata", Dawn, 23 January 2002, http://www.dawn.com/2002/01/23/nat1.htm

As part of such build up India is installing key components of an Early Warning System. A major step in this direction has been the acquisition of the Greenpine radar from Israel. India has also launched a Technology Experiment Satellite (TES) with an imaging camera on October 22, 2001 as part of the "space based assets" promised in the doctrine.[30] .

But there are serious reasons to be concerned that the different early warning technologies proposed to be used may not really serve the purpose, particularly in the South Asian context. On the contrary, since early warning systems are generally used in conjunction with launch ready weapons, there is also a possibility that they may contribute toward bringing the subcontinent closer to the brink of war.

These concerns motivate us to study the different aspects of Early Warning systems in some quantitative detail. Since whatever early warning that is available has to be used before the missiles hit their target, an important input in the analysis is a reliable estimate for the travel time of missiles from their launch to the target. So we begin the next section by presenting calculations of missile trajectories and the corresponding flight times, particularly in the context of the South Asian theatre. We do this first analytically starting *ab initio* from first principles within some reasonable and clearly stated approximations. This culminates in a Table giving missile flight times for typical South Asian missiles, launch points and targets . We then follow this up with more precise numerical calculations, particularly for orbits with depressed trajectories, which may be considered strategically optimal in some circumstances in the context of South Asian distance scales.

This is followed by a study of detection and tracking systems. We begin that section with a general introduction to radar theory , deriving the famous radar equation with particular reference to scan and track modes. The general discussion is then applied to the Greenpine radar to estimate its range given the typical orbit parameters of South Asian missile flights. In the same section follows a discussion on satellite detection systems. Along with a general outline of imaging satellites at different orbit heights, available characteristics of India's TES satellite are presented and compared with other imaging satellites like Quickbird and IKONOS.

Some of the discussion in sections 2 and 3 on the science and engineering of missile orbits, radars and satellites is not new. It is well known to experts in the field including, no doubt, those in the defense and space establishments in India and Pakistan. However the extent of such expertise outside government circles in South Asia is not sufficient to support meaningful public debates on the proposed early warning systems. That is our motivation behind presenting a simple and pedagogical introduction to missile orbits and radar theory. We have also offered reliable approximations which can enable non experts to make quick back-of-the-envelope estimates for missile trajectories, flight times and radar ranges.

Radars and satellites form the hardware component of early warning systems that detect and send signals of possible incoming objects . On receipt of this signal vital "human software" comes into play calling for a well codified sequence of steps to determine

(i) whether the signal is genuinely that of an incoming missile or a false alarm , and,
(ii) if it is a genuine signal, then the course of action to be taken in response.

> All this has to be done within the incredibly short time of the few minutes available between the warning and the missile impact on the target.

In section 4 we discuss these threat assessment and response procedures. Such procedures have been in effect in both the US and the USSR (now Russia) for decades . We describe them and consider which of these steps can be meaningfully taken within the truncated decision making time available for South Asian missile flights.

[30] http://www.isro.org/Oct22_2001.html

Having analysed the different components that go into the Early Warning system, in the final section we put all this technical material together to reach conclusions about the viability and advisability of such systems in South Asia. A typical Soviet ICBM would take about 30 minutes to travel to the continental United States. By comparison, our analysis shows that the corresponding flight time can be as little as 6 minutes for a depressed trajectory flight from Lahore to New Delhi. For "optimal trajectories" and longer distances of about 2000 km, this time would be larger, but is still at most 13 minutes. Depending on how quickly the missile is detected after launching , this interval between first detection and final decision making would be even smaller.

Given this time constraint which is particularly acute in South Asia, one has to ask whether there really are any substantial threat assessment and decision making advantages that accrue from setting up an elaborate early warning system . What meaningful steps can you take within those minutes of warning time? This is in turn related to the size of the respective nuclear arsenals, their deployment postures and survivability quotients. These issues are discussed in the concluding section. Apart from whether the benefits of setting up such systems are worth the considerable financial cost of doing so, we also consider a graver aspect of this issue. Generally early warning systems are accompanied by a set of launch ready weapons on full alert, as is being done in both the US and Russia till today. From the limited viewpoint of maximally using early warning systems such a posture would make sense. But , as we conclude , using early warning systems as part of a package that includes fully alerted nuclear weapons would be the sure road to disaster in South Asia.

Subsequent Sections :

The remaining sections of the manuscript under preparation discuss in detail, respectively, the flight dynamics of missiles, basic Radar physics with special application to Greenpine , an introduction to detection satelites , and finally the sequence of decision making steps taken , for instance in the US, after a signal is received from the early warning hardware.
In this brief summary we will not present these substantive sections in full, and leave out all the mathematical derivations. But a few of the key arguments and results, along with the final conclusions are sketched below.

Missile Flight Dynamics

The flight of a ballistic missile may be broadly didvided into three phases. The first is the "launch phase" when the rocket is being powered by its burning fuel ejected backwards. After the fuel burnout is complete comes the "Keplerian phase" when the residual payload of the missile is in free fall, i.e. under the influence of just earth's gravitational force. 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 the air resistance of the atmosphere of varying density.

For long range ICBM missiles travelling between Russia and the US mainland the Keplarian phase is by far the longest of the three. The launch phases of these missiles last anywhere from about one minute for Minuteman II to almost three minutes in the case of the Titan II.[31] The final re-entry phase is also about a minute long. The remaining flight time of nearly 40 minutes is spent in the Keplerian phase.

Information about South Asian missiles is not available in great detail. But the SLV-3 rocket which is reportedly similar to Agni-I has a burn time of about 50 seconds[32]. So does the first stage of the two stage Agni-II , whose second stage motor burns out a minute later.[33] The re-entry phases of these

[31] How does one quote Fetter's A Ballistic Missile Primer ?
[32] Gopal Raj ?
[33] JPEG image

missiles should again be of the same order of a minute. Since the total flight time of missiles in the South Asian theatre will be much shorter than between Russia and the U.S., the Keplarian phase may not be as dominant in comparison. But even a short range missile flight from , say, Sargodha airbase in Pakistan to New Delhi will (see below) take about 8 minutes, most of it still coming form the Keplerian phase. This will more so for the longer flights from Sargodha to Thiruvananthapuram or from Agra to Karachi.

Ordinarily trajectories of missles and satellites are calculated numerically using elaborate computer programmes. This is unavoidable for those entrusted with launching missiles, since they need to know their trajectory with great precision. However, for security analysts making overall judgements about the usefulness of early warning systems it is important to have available simple and transparent recipes for making “back of the envelope” estimates of flight times and other features of different trajectories. Fortunately, this can be done by exploiting the fact that the Keplerian phase is not just the longest portion of a missile’s flight, but also the simplest to analyse mathematically. To a very good approximation this phase can be treated as the motion of a body under the influence of just the gravitational force of a perfectly spherical earth. This motivates us to begin this section with such an *ab initio* analysis of the Keplerian phase starting from first principles. We derive simple analytical approximations appropriate to the South asian context for estimating the flight time as a function of the range and rocket velocity. This is then followed by more accurate numerical calculations for the full trajectory including the launch and re-entry phases.

In this abstract summary we will not present the detailed mathematical derivation of the missile trajectroies and flight time. They will be given in the full manuscript under preparation.

We will mention here only two important aspects of the final results:

1. We have shown that the exact expressions for the flight time can be approximated in the context of South asian distance scales by the very simple relation

$$T = \left(\frac{2R}{V_{esc}}\right) \sqrt{\theta_T} \qquad (15)$$

where V_{esc} is athe escape velocity form earth’s gravity (afixed number of about 11 km/sec), R stands for the radius of the earth (6370 km), and θ_T is the angullar range of the flight related to the usual linear range *d* by $\theta_T = d/R$.

One major feature of this formula is that the flight time is proportional, not to the range but its square root. Suppose we try to estimate missile flight times in South Asia by comparing it with a typical ICBM flight from the USSR to mainland USA (traversing 6000 km and taking roughly 30 minutes) . Then the flight time for one tenth the distance (600km) in South Asia would be shorter, not by a factor of one-tenth (3 minutes) as is sometimes glibly quoted, but by a factor closer to the sq.root of 10, giving about 8 minutes.

2. By substituting the range for any given missile path, the flight time can be easily estimated from this simple formula to an accuracy that is good enough general policy analysis of early warning systems. Examples of flight times thus calculated for typical launch-site and target pairs is given in the Table below :

2. Some hypothetical South Asian launch point–target combinations

From	To	Distance (km)	Range θ_T (rad)	Minimum Launch Velocity (km/sec)	Keplerian Flight Time * (sec)	Estimated Total Flight Time ** Minutes
Sargodha Airbase (Pakistan)	**New Delhi**	**581**	**0.091**	**2.37**	**347**	**8**
Agra	**Lahore**	**608**	**0.095**	**2.42**	**354**	**8**
Agra	**Karachi**	**1128**	**0.177**	**3.30**	**484**	**10**
Sargodha Airbase (Pakistan)	**Mumbai**	**1470**	**0.231**	**3.77**	**553**	**11**
Airbase near Karachi	**Tiruvananthapuram (India)**	**2000**	**0.314**	**4.40**	**645**	**13**

* The Keplerian flight times are obtained at the optimal tilt angle for the post burnout velocity and by using the small range approximations.
** This estimate, rounded off to the nearest minute adds an extra minute each for the boost and re-entry phases

Radars:

The Radar range equation is:

$$R_d = \left(\frac{t_s P_{ave} \sigma A}{4\pi \Omega_s k T_s L \left(\frac{S}{N} \right)} \right)^{\frac{1}{4}}$$

Into this equation one should enter the actual parameters of the radar system, say, the Greenpine. Since we did not have access to all the parameters of the Greenpine system, we have used typical parameters from similar radar systems for which data was available in the open literature.

Radar Parameters

	Pave Paws	Patriot	Our assumed parameters
Average Power (kW)	150	10	200
Antenna Area (m^2)	767	4.5	12 x 4.8 (m^2)
Wavelength (m)	0.7	0.05-0.08	0.21-0.25
Bandwidth	100 kHz	100 kHz (?)	100 kHz
Scan Time (s)	NA	7.5	4
Search Angle (azimuth)	120˚ + 120˚	90˚	120˚
Search Angle (elevation)	3˚- 80˚	20˚ - 70˚	3˚ - 20˚

Radar Range depends strongly on cross section. Assuming L = 10, S/N = 20 and Noise temperature = 600 K, we have for different target cross sections,

Cross section	Range
"Nose-on" 0.01 m^2	229 km
Re-entry vehicle "Side-on" 1.0 m^2	725 km
Missile body 10 m^2	1289 km

If we give the benefit of doubt to the radar system placed on the border may be able to detect the re-entry vehicle side on or even at launch, you may get almost the full flight time as warning. But that is typically only 8-10 minutes and less than 6 minutes in case of a Depressed trajectory from Lahore to Delhi.

Note :During boost phase, the c.s. increases due to ionization in exhaust. Presence of fins could increase cross section significantly. If all factors are favorable, the range may even be 2000 km.. That would mean that India and Pakistan will probably be able to see other's launches with powerful radars (like Green Pine)
Radar horizon => missile has to rise about 10 km above ground (20 seconds)
Another ten (??) seconds to detect missile, determine trajectory and decide if missile is headed towards one's own country

Satellites

- Technology Experiment Satellite (TES) – low earth orbit (568 km)
- Like IKONOS (681 km orbit)
- Visible thickness of ground swath along direction of motion is only 11 km

- Cannot have complete coverage all the time
- More useful for military data gathering and strategic warning
- Geosynchronous satellites – India has the capability to launch
- Can it make IR detectors that can observe launches against background due to cloudshine etc?
- Even if it could, that would provide approximately same kind of warning time as radar

Threat Assessment and Response Procedures

Expected sequence in the US (Bruce Blair)

STAGES	TIME ELAPSED
1. Observation of missile launch by geosynchronous satellites	**(30 sec)**
2. If signal passes scrutiny by ground staff it is forwarded to missile warning centers at NORAD, Strategic Command, and Pentagon, and alternate command post.	**(1 min)**
3. Missile Event Conference called at NORAD, to assess reliability of satellite data as warning of a missile attack (re-verify initial detection, rule equipment malfunction, consultation with strategic warning analysts intelligence inputs,) and forward judgment to the Pentagon and Strategic Command.	**(4 min)**
In one concrete case in 1980, because of conflicting information flows from early earning satellites , radars, ground stations, and strategic warning analysts , NORAD took 8 minutes as against the allotted 3 minutes to determine that there was no confidence in the warning !	
4. Threat Assessment Conference (TAC). By this time, there may or may not have been separate warning from ground-based radars	**(6 min)**
5. If warning assessed as indicating "with high confidence" impending attack, Missile Attack Conference (MAC) is called , including the President, defense secretary, JCS chairman nuclear commanders in chief, to examine the warning, and determine possible options.	**(10 min)**
6. Next 10 minutes for discussion and decision whether to ride out an attack/false warning or launch retaliatory missiles.	**(20 min)**
7. Sending launch orders (2 min), 3 minutes to fire the Minutemen	**(25 min)**
8. Several more minutes to be travel to a safe distance from their bases.	

Given that South Asian flight times are 8-10 minutes , (at most 13mts for the long flight to Trivandrum), even if you assume immediate detection, the flight time will be more or less consumed even before step 6 (the analogue of the Missile Attack Conference) where for the first time the apex political leadership is brought into the loop . Therefore all decisions will have to be pre-made. That is very dangerous, particularly if the plans involve ready to launch weapons. Any false alarm would lead to an unnecessary nuclear war by error !

Conclusions

- **Early warning is not very early in India or Pakistan**
- **Danger of false alarms**

From 1977 through 1984, U.S. early warning systems gave an average of 2,598 warnings each year of potential incoming missiles attacks. 5% required further evaluation. In 1995. Norwegian scientific rocket launch was interpreted by the Russian early warning system as a possible attack and the matter went all the way up the command chain to President Yeltsin . Cases in the US where the warning was discovered to be the result of an error only *after eight minutes had elapsed* since detection

- **Missile deployment combined with the installation of an early warning system would generate pressures to adopt a launch on warning posture**
  Such a posture could well result in accidental nuclear war

- **It is therefore vital that even if early warning systems are set up, both countries stay in a state of de-alert with sufficient delay built–in before weapons can be launched.**

- **Assuming that sanity prevails , and no policy of pre-planned instant retaliation is put in place, what are the other possible uses of early warning ?**

1. Give time for the leadership to go into bunkers .
   If the incoming missile is heading for their location, shelter after warning would be possible only if the leadership is already in the same building as the shelters. There would be not time to drive or fly in helicopters.

2. Give time to issue orders and requisite codes for delayed retaliation before the leadership is hit. This is to ensure deterrence.

3. Issue some form of warning to the civilian population in the targeted city.