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Accidental Nuclear War: A Risk Assessment

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Recent developments in strategic weaponry have led to increasing fears that the danger of war by accident or inadvertence is growing. In particular, the deployments of 'fast-attack' systems with short flight times, combined with the growing complexity and automation of strategic warning and command and control systems, has given rise to the belief that during a major international crisis there would be insufficient time to distinguish false alarms from an actual warning of an enemy attack. An examination of a mathematical model of the warning and launch sequence that would follow from a strategic alarm suggests strongly that there would be almost no time to make such a decision unless a 'launch-on-warning' strategic posture were adopted. There is evidence to suggest that in fact both superpowers believe they would be forced to adopt such a policy in the event of a serious crisis. Given a 'launch-on-warning' posture, an examination of available data on false alarms provided by NORAD leads to the conclusion that a false alarm sufficiently severe to trigger a strategic attack would occur about 50% of the time during a lengthy crisis. This finding highlights the urgent need for the superpowers to undertake co-operative measures to reduce the risk of war by accident, including the dismantling of short flight time systems and undertaking major improvements in their ability to communicate and to co-ordinate their actions in time of crisis.

1. *Introduction*

For over a generation, scholars in world politics have asserted that arms races greatly increase the likelihood of war (Richardson 1960; Singer 1958). In recent years, this belief has been buttressed by a considerable body of research findings suggesting that serious crises between and among great powers are very likely to escalate to all-out war if their participants are involved in an arms race or have high levels of military spending (Wallace 1979; Maoz 1982; Cusack & Eberwein 1982). And whether we define an arms race in terms of military expenditures (Wallace 1982), or as a function of the increasing capabilities of the strategic hardware acquired by each side (Squires 1982; Wallace 1985), there can be little doubt that the two superpowers are currently engaged in one. Thus systematic research would seem to confirm the intuitive belief held by growing numbers of the attentive public that a major crisis between the superpowers would, in current circumstances, very likely result in global nuclear holocaust.

However, some scholars have made a strong counterargument to the effect that the historic arms race — war link has been rendered obsolete by nuclear weapons (Weede 1980; Altfeld 1983). According to this view, the terrifying consequences of nuclear attack, combined with the enormous strategic and tactical uncertainties about the course of a nuclear conflict once initiated, lead to an unprecedented inhibition on escalation during crises. This inhibition has even been powerful enough to promote the development of unilateral, bilateral, and multilateral conventions, agreements, and institutional mechanisms designed to ward off or de-escalate potentially serious crises. The data lend some indirect support to this view, as none of the major crises preceded by arms races *after* 1945 have escalated to war, even though the great majority before that date did so.

But what if this unquestioned inhibitory mechanism were counterbalanced by a mechanism which could lead to a sharp *increase* in the probability of escalation? Some believe that such a mechanism is inherent in the very complexity of the command and warning systems which control the nuclear weapons arsenals of both superpowers. They believe that under crisis conditions there is a very real danger that a hardware failure or software error in these complex systems, to say nothing of human error, could touch off a war by accident or inadvertence. This possibility that nuclear weapons systems could be activated in response to a malfunction rather than an actual attack has inspired considerable attention from government experts and defense professionals (Goldwater & Hart 1980; Frei 1982; Bracken 1983). With few exceptions, however, there has been little hard evidence put forward which would allow us to assess the risk with any degree of precision. Still rarer have been convincing solutions or even palliatives to this often-perceived problem. The task of this paper will be to shed some light on both of these vexing questions.

2. *Accidental war: Defining the danger*

Few issues in the current nuclear strategic debate generate as much confusion and disagreement as the question of war by accident. In the public mind (bolstered by media portrayals), war by accident implies a breakdown of nuclear command and control systems so crippling that a launch occurs 'out of the blue' in the absence of war or even crisis. Military professionals dismiss such scenarios with scorn, arguing that the very complexity of contemporary C^3I systems, replete with multiply-redundant checks and counterchecks, make it extraordinarily unlikely that an accidental or inadvertent use of nuclear weapons would occur from a single or even multiple failures in command or warning systems.[1]

In the past few years, however, concern over the danger of accidental war has been re-kindled, not amongst the uninformed, but by a growing number of scientists and technical professionals (Bereanu 1981, 1982, 1983; Babst et al. 1984; Borning 1984; Crissey & Sennott 1984; Steinbrunner 1984). They are concerned precisely with what was alluded to in the introduction, namely that with the growing level of tension and confrontation between the superpowers — not to mention the ever-present prospect of a full-blown crisis — the institutional checks and restraints against premature launch will fail to function as effectively as in calmer times. Worse, they note that both sides have put in place or are contemplating strategic decisions which would have the effect of subverting these checks in time of crisis, either by the 'early release' of tactical nuclear weapons to battlefield commanders, or by the adoption of a 'launch-on-warning' policy (Allen 1980; Aleksandrov 1982). Thus, in this more sophisticated and knowledgeable conception, an accidental war would not arise as the result of a 'bolt from the blue', but rather from institutional and psychological pressures leading to uncontrollable crisis escalation.

3. *Growing strategic vulnerability*

The mise-en-scène for the pessimists' scenario is the growing perception by some strategists on both sides that their strategic retaliatory forces are vulnerable to pre-emptive destruction or neutralization. This ever-increasing fear is the result of nearly a generation of evolution in strategic weapons and the doctrines governing their use, and of the increasingly intractable command and control problems which result therefrom.

The central problem of nuclear command and control is, of course, to avoid any possibility of a nuclear attack resulting from unauthorized orders, incorrect or misinterpreted information, or human or machine error in the transmission of orders and information, while at the same time preserving the ability to respond rapidly and successfully to enemy actions. Therefore, a crucial requirement for a successful nuclear C^3I system is that the timescale of its various operations (sensing, verifying, encrypting, decoding, etc.) be small by comparison with the time scale of a strategic attack. Until about 25 years ago, this was not too difficult to achieve. The only strategic delivery vehicle of importance was the manned bomber, and as these took several hours to reach their targets from time of detection, it was a relative straightforward matter to devise systems which met the competing requirements of reliability, security, and responsiveness.

In the late 1950s and early 1960s, the advent of the ICBM, capable of reaching its targets in 25–35 minutes, altered the ratio of timescales dramatically. In response, C^3I sensitivity and redundancy was improved in a number of ways. Infrared-sensing satellites were stationed in geosynchronous orbits to allow instant detection of an enemy missile launch. Airborne radar pickets were put in place to permit more rapid detection and confirmation of enemy strategic actions. (The Soviets achieved the same goal by developing a system of over-the-horizon radar.) And a system of multiple command centers (including an airborne command center) was put in place to ensure that a surprise attack could not wipe out the chain of command.

But changes to the C^3I system itself were not the only response. The hardening of missile silos and simultaneous promulgation of the doctrine of 'Mutual Assured Destruction' in the early 1960s allowed strategic planners to adopt the strategy of 'launch-under-attack', under which they assumed that they could afford to 'ride out' a nuclear strike and still retain the ability to retaliate effectively. As long as 'launch-under-attack' was regarded as a viable strategic option, the fact that the timescale of a strategic attack was moving dangerously close to the operating timescale of existing C^3I systems was not perceived as a crippling problem.

As the 1980s began, however, both sides planned the deployment of strategic weapons systems which gravely upset these calculations. The increased accuracy, but even more significantly, the short flight times of these weapons could permit 'decapitating' strikes on command centers in time of crisis, destroying or disrupting C^3I systems to the extent that retaliation might prove impossible. This danger has unquestionably fueled much of the vehemence of the Soviet reaction to the deployment of Pershing II missiles in Europe, since these could be targeted on the major command posts in the Western USSR, and would reach their destinations in less than 8 minutes. The Soviets have admitted that they would be unable to respond in this period of time (Aleksandrov 1982). No less threatening are the Soviet Yankee-class SSBNs routinely patrolling the North American coast, now deployed in greater numbers as part of the Soviet promise to put the US in 'equivalent peril'. Using depressed-trajectory launches, Soviet SLBMs could attack American command centers in 4 to 15 minutes even from their normal patrol range (which, presumably, would be shortened in time of crisis). Even more ominously, if they were targeted to explode at a height of 500 km., they would produce extraordinarily powerful electromagnetic disruptions (the 'EMP') which would very likely result in 'massive failures of communications systems, power supplies, and electronic equipment' (Steinbrunner 1983). Such an effect could be produced within 7 minutes of launch, leading many analysts to conclude that 'launch-under-attack' is obsolete, and should be replaced by some variety of 'launch-on-warning' strategy. This advocacy represents an admission that the reduction of the timescale of a strategic attack to something approaching the timescale of C^3I operations poses a dilemma for which there is no immediate technical solution, and for which, as we shall see, no satisfactory solution *of any type* may exist.

4. *The strategic dilemma during crises*

The hypothetical vulnerability of the land-based missile forces of both sides to strategic pre-emption by a 'decapitating' attack is obviously an ongoing feature of the strategic balance, and as such both sides have accommodated themselves to it, at least in the absence of crisis. They can do so without much noticeable effect on their perceptions and behaviour because they take it for granted that the probability of the other side launching an unprovoked and unheralded surprise attack is infinitesimal. But during a crisis this would almost certainly change radically. As many studies have shown (Herman et al. 1974; Holsti 1970) perceptions of enemy intentions and interpretations of enemy behavior are radically altered when levels of conflict and tension increase. Events perceived as harmless, co-incidental, or accidental during peacetime become hostile and malevolent during a crisis, while at the same time hostile countermoves are perceived as acceptable, or even necessary. Moreover, the time available for a response is perceived to shorten, and the repertoire of responses available is perceived to narrow during a crisis.

Even when flight times were measured in hours rather than minutes, these perceptual changes could combine with the massive and complex electronic warning system to promote the belief that an enemy attack was under way when in fact none existed. Bracken (1983) cites an incident that took place during the Suez crisis as an example:

> In early November at the same time as the British and French attack on Suez, the Hungarian uprising was taking place. TASS, the Soviet press agency, was drumming up fears of worldwide nuclear war. Moscow issued a communiqué to London and Paris strongly hinting that rocket attacks against these cities were being considered, and, in a separate communiqué to Washington, Moscow suggested that joint US-Soviet military action should be taken in Suez. This last message was received in the White House in the late afternoon of November 5.
>
> Against this context, on the same night, the following fourfold coincidence took place. The headquarters of the US military command in Europe received a flash message that unidentified aircraft were flying over Turkey and that the Turkish airforce had gone on alert in response. There were additional reports of 100 Soviet MIG-15's over Syria and further reports that a British Canberra bomber had been shot down also over Syria. (In the mid-1950s only the Soviet MIGs had the ability to shoot down the high-flying Canberras.) Finally, there were reports that a Russian fleet was moving through the Dardanelles. This has long been considered an indicator of hostilities, because of the Soviet need to get its fleet out of the Black Sea, where it was bottled up in both world wars. The White House reaction to these events is not fully known, but reportedly General Andrew Goodpaster was afraid that the events 'might trigger off all the NATO operations plan'. At this time, the NATO operations plan called for all-out nuclear strikes on the Soviet Union.
>
> So it turned out, the 'jets' over Turkey were actually a flock of swans picked up on radar and incorrectly identified, and the 100 Soviet MIGs over Syria were really a much smaller routine escort returning the president of Syria from a state visit to Moscow. The British Canberra bomber was downed by mechanical difficulties, and the Soviet fleet was engaging in long-scheduled exercises. The detection and misinterpretation of these events, against the context of world tensions from Hungary and Suez, was the first major example of how the size and complexity of worldwide electronic warning systems could, at certain critical times, create a crisis momentum of its own.[2]

Such mistakes, misperceptions, and misinterpretations presumably would be multiplied in a contemporary crisis, given the extraordinary increase in the size and complexity of warning systems that has occurred in the nearly 30 years since Suez. Superimposed upon the vulnerability of each side's command centers to instant decapitation, the danger is palpable. In a crisis, each side's leaders are predisposed to believe the worst; they are bombarded with a plethora of information, much of it ambiguous and some of it misleading or erroneous; and, unlike the Suez case, the time available to check, confirm, or re-interpret this information before the 'use-them-or-lose-them' point is reached would be only a few minutes. It requires little imagination to realize that in those minutes of confusion and panic, the danger of war by accident or inadvertence is very real.

Moreover, the system need not reach the actual threshold of missile launch before it begins to run out of control. Just as in the crisis prior to World War I, the processes of alert and mobilization on each side during a crisis are synergistic:

> Tight coupling of forces increases, information begins to inundate headquarters, and human, preprogrammed-computer, and organizational responses are invoked. Each response, whether it arises from a human operator or a computer, is intended to meet some narrow precautionary objective, but the over-

> all effect of both Soviet and American actions might be to aggravate the crisis, forcing alert levels higher. Although each side might believe it was taking necessary precautionary moves, the other side might see a precaution as a threat. This would in turn click the alert level upward another notch.
>
> Beyond a certain level not only is a mutually reinforcing alert possible, but there would be major political consequences as well. The alert itself would undoubtedly contribute to the political tension because, fundamentally, decision makers would know how impossible it is to separate military moves, however precautionary, from political ones. During the crisis it would not be clear that a certain enemy action was indeed precautionary, and this very incomprehensibility would drive the mutual stimulation. In particular, if the Soviet Union, which inactively operates its nuclear forces, actually seemed to be going on alert, this would be a shock that would trigger hundreds of preprogrammed American responses.[3]

Thus, it would seem that on theoretical grounds alone there is little reason to assume the deterrent effect of nuclear weapons necessarily reduces the probability of escalation in a crisis; indeed, as we have seen, the nature of the warning and control processes governing these weapons may actually *increase* the escalatory risk[4] by comparison with the pre-nuclear age. It is crucial as well to note that this risk does *not* depend upon the formal adoption of a 'launch-on-warning' strategy; we are arguing that the very atmosphere and dynamics of a severe crisis will produce a *de facto* launch-on-warning decision rule, setting the stage for catastrophe.

5. *The launch sequence model*

So far we have examined the question of accidental war during crisis with reference to evidence that is almost entirely anecdotal and inferential, rather than systematic and direct. As is typical in discussions dealing with nuclear weapons, many crucial steps remain beyond direct testing; any experiment involving nuclear war can only be run once. But this does not mean that all aspects of the issue are beyond systematic, quantitative analysis. In particular, one vital parameter — the amount of time available to respond to a warning of enemy attack — can be estimated under a wide variety of conditions with reasonable precision, given our knowledge of how warning systems react to perceived threats. Data on a second crucial parameter — the rate at which false alarms are generated within the warning systems — are also available. With estimates of these two parameters in hand, and with the aid of some fairly simple mathematics, it is possible to calculate the magnitude of the danger of accidental war with some precision.

To begin with, then, we can calculate the decision time available in crisis from an examination of the superpower strategic warning systems. What follows is a simplified model of the operation of the American early warning system as far as it is known from unclassified sources.[5] We assume (lacking any specific knowledge to the contrary) that the Soviet system is structurally similar, but utilizes older, slower computer technology.

Let us imagine that a Soviet ICBM has been launched towards the US; we shall call this the *Launch Point*, defined as time zero in the model. Within 1 or 2 minutes (the interval being referred to as *Detect-Time*), the Satellite Early Warning System (SEWS) has detected the infrared trail of the booster. This point is called *First Detection*. The information obtained is then transmitted by SEWS to the four principle command posts; the North American Aerospace Defense Command (NORAD), the Strategic Air Command (SAC), the National Military Command Center (NMCC), and the Alternate National Military Command Center (ANMCC). NORAD analyses and retransmits the data to the other three posts.

The information is then processed for 30 seconds or longer, and is labelled either a potential threat or a non-threat. This is called the *Evaluation Point*. This processing (*EvalTime*) can take as long as two minutes in the worst case of multiple, confusing signals.

When information concerning a potential threat is received at the command posts, a *Missile Display Conference* is called to evaluate and assess the analysis. Ground stations may be called to confirm the data. This point, referred to as *MDC Called,* occurs within 30 seconds of the *Evaluation Point*. A MDC lasts from 1 to 2 minutes (*MDCLen*).

The current stated posture of American strategic forces is known as *Launch Under Attack*. It requires that confirming evidence from a physically distinct family of sensors be obtained before a potential threat is considered serious, the so-called doctrine of *Dual Phenomenology*. If a missile is coming, a ground-based radar installation will confirm the data within 3 to 7 minutes (*DualTime*) of *First Detection,* depending upon which sensors have picked up the launch and which trajectory the missile is following. The point of confirmation will be called the *Second Detection*.

If the Commander in Chief (CINC) of NORAD decides that the confirming data are in hand, or that the event in some other way warrants treatment as a threat, he convenes a *Threat Assessment Conference* (TAC.) This point is referred to as *TAC Called*. Senior personnel are called in, including the Chairman of the Joint Chiefs of Staff, and preliminary steps are taken to ensure force survivability. The TAC assigns a high or low probability to the potential threat, depending upon whether or not confirming data was received. A TAC is called within 30 seconds of *Second Detection*, or at the completion of the MDC, whichever is sooner, and lasts from 1 to 2 minutes *(TacLen)*. The assessment process begins at *Second Detection* and lasts from 30 seconds to 2 minutes *(AssessTime)*. The point at which the assessment is completed is called the *Assessment Point*.

If the TAC assessment has a high confidence, a *Missile Attack Conference* (MAC) is called (*MAC Called)*. In principle a MAC includes all the senior personnel and the President, and is called within 30 seconds of the *Assessment Point,* or at the completion of the TAC, whichever is sooner. It is optimistically assumed that the President can be incorporated into the discussion within 1 to 2 minutes, and that a counterattack can be ordered immediately upon completion of the MAC, which time point then represents the *Earliest Attack Point*. This remains in the realm of speculation, however, because, fortunately, a MAC has never been convened.

If one assumes the threat is real and comes from an impending first strike aimed at ground-based missiles, then it will be necessary to fire those missiles before they are hit. This point in time is called the *Use Them or Lose Them Point,* calculated by subtracting from the *Impact Point* an interval *Launch Time,* representing the time from the issuing of a launch order to the successful launch of the retaliatory missiles. *Launch Time* will be between 3 and 6 minutes. *Impact Point* is the time of the initial enemy launch plus the *Flight Time*, which is between 25 and 30 minutes for an ICBM. If one assumes (as outlined above) that the enemy's initial strike will attempt to disrupt your C^3I by generating an Electromagnetic Pulse, an *EMP Point* may be defined which occurs one minute before *Impact Point.*[6]

From this model of the warning system, several measures of available decision time may be calculated. The simplest measure is independent of the launching policy: it is simply the time difference between the *Use Them or Lose Them Point* and the *Earliest Attack Point,* which is referred to as *Slack Decision Time*. This is a measure of the actual time available to fire the threatened missiles and does not reflect the status of information and communications.

If *Launch Under Attack* is the operating policy, then four meaningful measures of decision time may be calculated. *Decision Time* is the raw window of time between the *Second Detection* and the *Use Them or Lose Them Point. Informed Decision Time* is the time from the receipt of the TAC Assessment until the *Use Them or Lose Them Point. Clean Decision Time* is the interval that begins with the *Second Detection* and ends with the *Use Them or Lose Them Point* or the *EMP Point,* whichever is earlier. Finally, the *Clean and Informed Decision Time* is the interval that begins with the receipt of the TAC assessment and ends with the *Use Them or Lose Them Point* or the *EMP Point,* whichever is earlier. It is this last measure that is critical, as it represents the prime decision time within which the highest level personnel must confer, analyze, and act before either the communications systems are disrupted or the threatened missiles are destroyed. A launch policy that results in insufficient *Clean and Informed Decision Time* would undermine the deterrent effect of the strategic weapons systems in question, and would therefore likely be discarded during a crisis period in favor of policies that allowed more decision time.

If *Launch On Warning* (LOW) is the operating policy then the decision windows must be calculated differently. While *Launch Under Attack* requires confirming evidence from two physically different families of sensors, no such requirement exists for *Launch On Warning*. Thus, the latter policy trades confidence in the warning information for greater decision time. Under LOW, *Decision Time* is the interval from *First Detection* until the *Use Them or Lose Them Point. Informed Decision Time* becomes the time from the *Evaluation Point* until the *Use Them or Lose Them Point.* The *Clean Decision Time* is the interval between the *First Detection* and the *EMP Point.* Lastly, the *Clean and Informed Decision Time* is calculated as the interval from the *Evaluation Point* to either the *Use Them or Lose Them Point* or the *EMP Point*, whichever is earlier. Let us now insert parameter values[7] in the model, and see what decision times are derived.

6. *Decision time available*

The first case we shall examine using the above model is a hypothetical Soviet ICBM attack on the U.S. Each of the parameters is assigned low, high, and mean values, representing the possible range of estimates along with the 'best guess'. These three parameter values yield three hypothetical outcomes: pessimistic, optimistic, and best guess. Table I displays these values for a Soviet ICBM attack.

We can see immediately that even under the most pessimistic assumptions, the *Launch Under Attack* policy retains at least 8.5 minutes of *Slack Decision Time* and at least 8 minutes of *Clean and Informed Decision Time,* and the 'best guess' estimate is over 15 minutes. There would therefore seem to be no need to adopt a LOW policy, even during a severe crisis; at such times, political and military leaders would of course hold themselves in close contact with the military communications system, and would have sufficient time to weigh the evidence carefully. There would be no need to begin a counterattack until the evidence of an enemy strike was overwhelming.

The situation is not so favorable, however, when we consider a Soviet SLBM attack. The much shorter flight times of the SLBMs (9–12 minutes) reduce the time to the *EMP Point* to little more than a quarter of the value it has in the case of an ICBM attack.

As we can see from Table II, this results in a 'best guess' estimate of *Clean and Informed Decision Time* of *zero.* Even with optimistic parameter settings, there remain only 2.5 minutes. Changing to a LOW policy provides 3.25 minutes of extra time, but of course at considerable sacrifice of data confidence. But even if LOW were *not* formally adopted as policy, there would be extraordinary pressure on decision-makers to initiate a counterattack before the *EMP Point* if the TAC seemed to show an enemy SLBM launch, given that such a launch could be the C^3I-disabling 'opening salvo' of an all-out strategic attack. As can be seen from the table, the effect of this is to negate the accident protection built into the 'Dual Phenomenology' principle. Thus, the deployment of Soviet fast-attack systems has gone a long way to subvert the system of checks and redundancies built into the US early warning system.

Table I. Soviet ICBM Attack on the US

ATTACKER:	Soviet Union	MISSILE:	ICBM		
Assumptions					
FlightTimeLo	25	FlightTimeMe	27.5	FlightTimeHi	30
DetectTimeLo	1	DetectTimeMe	1.5	DetectTimeHi	2
EvalTimeLo	0.5	EvalTimeMe	1.25	EvalTimeHi	2
DualTimeLo	3	DualTimeMe	5	DualTimeHi	7
AssessTimeLo	0.5	AssessTimeMe	1.25	AssessTimeHi	2
LaunchTimeLo	3	LaunchTimeMe	4.5	LaunchTimeHi	6
MDCLenLo	1	MDCLenMe	1.5	MDCLenHi	2
TACLenLo	1	TACLenMe	1.5	TACLenHi	2
MACLenLo	1	MACLenMe	1.5	MACLenHi	2
CASE:	Pessimistic	Best Guess	Optimistic		
Launch Point	0	0	0		
First Detection	2	1.5	1		
Evaluation Point	4	2.75	1.5		
MDC called	4.5	3.25	2		
Second Detection	9	6.5	4		
TAC called	6.5	4.75	3		
Assessment Point	11	7.75	4.5		
MAC called	8.5	6.25	4		
Earliest Attack Point	10.5	7.75	5		
Use Them or Lose Them Point	19	23	27		
EMP point	24	26.5	29		
Impact point	25	27.5	30		
Slack Decision Time	8.5	15.25	22		
Launch under attack policy					
Decision Time	10	16.5	23		
Informed Decision Time	8	15.25	22.5		
Clean Decision Time	10	16.5	23		
Clean & Informed Decision Time	8	15.25	22.5		
Launch on warning policy					
Decision Time	17	21.5	26		
Informed Decision Time	15	20.25	25.5		
Clean Decision Time	22	25	28		
Clean & Informed Decision Time	15	20.25	25.5		

Turning the problem around, and putting ourselves in the place of Soviet decision-makers seeking to detect and respond to an American ICBM attack, leads us to the conclusion that their situation in a crisis would be even more desperate than the one facing the American leadership. Table III displays the corresponding model values for an American attack on the USSR.

Parameter values in the launch sequence reflect the older, more primitive computer systems used by the Soviets and the greater reliance on human action. In addition, Soviet missiles take somewhat longer to prepare for launch. Even so, except in the most pessimistic case, there is at least 11 minutes of *Clean and Informed Decision Time* available to the Soviet leadership if it should adopt a *Launch Under Attack* policy. Assuming that, as with the Americans, the leadership would be tightly bound into the military communications system in a deep crisis, there would seem to be enough time for them to delay a response until the evi-

Table II. Soviet SLBM Attack against the US

ATTACKER:	Soviet Union	MISSILE:	SLBM		
Assumptions					
FlightTimeLo	9	FlightTimeMe	10.5	FlightTimeHi	12
DetectTimeLo	1	DetectTimeMe	1.5	DetectTimeHi	2
EvalTimeLo	0.5	EvalTimeMe	1.25	EvalTimeHi	2
DualTimeLo	3	DualTimeMe	5	DualTimeHi	7
AssessTimeLo	0.5	AssessTimeMe	1.25	AssessTimeHi	2
LaunchTimeLo	3	LaunchTimeMe	4.5	LaunchTimeHi	6
MDCLenLo	1	MDCLenMe	1.5	MDCLenHi	2
TACLenLo	1	TACLenMe	1.5	TACLenHi	2
MACLenLo	1	MACLenMe	1.5	MACLenHi	2
CASE:	Pessimistic	Best Guess	Optimistic		
Launch Point	0	0	0		
First Detection	2	1.5	1		
Evaluation Point	4	2.75	1.5		
MDC called	4.5	3.25	2		
Second Detection	9	6.5	4		
TAC called	6.5	4.75	3		
Assessment Point	11	7.75	4.5		
MAC called	8.5	6.25	4		
Earliest Attack Point	10.5	7.75	5		
Use Them or Lose Them Point	3	6	9		
EMP point	7	7	7		
Impact point	9	10.5	12		
Slack Decision Time	0	0	4		
Launch under attack policy					
Decision Time	0	0	5		
Informed Decision Time	0	0	4.5		
Clean Decision Time	0	0	3		
Clean & Informed Decision Time	0	0	2.5		
Launch on warning policy					
Decision Time	1	4.5	8		
Informed Decision Time	0	3.25	7.5		
Clean Decision Time	5	5.5	6		
Clean & Informed Decision Time	0	3.25	5.5		

dence for the existence of attack is overwhelming.

If we posit an American SLBM attack on the Soviet Union, however, the situation is totally different. Flight times for such an attack drop to between 9 and 12 minutes, which result in the *Use Them or Lose Them Points preceding* the *Earliest Attack Points,* thus yielding zero *Slack Decision Time,* i.e. no time to fire back. As we see from Table IV, the decision times, being a function of the *Use Them or Lose Them Point,* are all zero for a *Launch Under Attack* policy. Even LOW provides only some meaningless *Clean Decision Time,* the interval between *First Detection* and the *EMP Point* at the 7 minute mark. A very similar result is produced by a hypothetical American attack using Pershing II missiles based in Western Europe, with flight times in the range of 6 to 8 minutes. Again, no prime decision time is available to the Soviet leadership, as we see from Table V.

An American attack with cruise missiles

Table III. American ICBM Attack on the Soviet Union

ATTACKER:	United States	MISSILE:	ICBM		
Assumptions					
FlightTimeLo	25	FlightTimeMe	27.5	FlightTimeHi	30
DetectTimeLo	2	DetectTimeMe	2.5	DetectTimeHi	3
EvalTimeLo	1	EvalTimeMe	2	EvalTimeHi	3
DualTimeLo	3	DualTimeMe	5	DualTimeHi	7
AssessTimeLo	1	AssessTimeMe	2	AssessTimeHi	3
LaunchTimeLo	4	LaunchTimeMe	7	LaunchTimeHi	10
MDCLenLo	1.5	MDCLenMe	2.25	MDCLenHi	3
TACLenLo	1.5	TACLenMe	2.25	TACLenHi	3
MACLenLo	1.5	MACLenMe	2.25	MACLenHi	3
CASE:	Pessimistic	Best Guess	Optimistic		
Launch Point	0	0	0		
First Detection	3	2.5	2		
Evaluation Point	6	4.5	3		
MDC called	6.5	5	3.5		
Second Detection	10	7.5	5		
TAC called	9.5	7.25	5		
Assessment Point	13	9.5	6		
MAC called	12.5	9.5	6.5		
Earliest Attack Point	15.5	11.75	8		
Use Them or Lose Them Point	15	20.5	26		
EMP point	24	26.5	29		
Impact point	25	27.5	30		
Slack Decision Time	0	8.75	18		
Launch under attack policy					
Decision Time	5	13	21		
Informed Decision Time	2	11	20		
Clean Decision Time	5	13	21		
Clean & Informed Decision Time	2	11	20		
Launch on warning policy					
Decision Time	12	18	24		
Informed Decision Time	9	16	23		
Clean Decision Time	21	24	27		
Clean & Informed Decision Time	9	16	23		

would introduce a greater degree of uncertainty with regard to the available decision time, but the result is crucially dependent on the ability of Soviet air defenses to provide early warning of an attack.[8] In the pessimistic and best guess cases, the *Use Them or Lose Them Point* precedes the *Earliest Attack Point,* again leading to no *Slack Decision Time.* Only in the optimistic case of very early detection is there ample prime decision time.

Thus, the traditional policy of *Launch Under Attack* appears to be a feasible doctrine for the operation of the superpower C^3I systems faced with a threat of ICBM attack alone. The 25 to 35 minute flight times of ICBMs are a sufficiently large multiple of the warning system response time that some decision time — rather little, in fact, when compared to the normal timescale of human collective decision-making, but at least some — is available to the superpower leaderships. But in the case of an SLBM or Pershing II missile attack *even the adoption of a*

Table IV. American SLBM Attack on the Soviet Union

ATTACKER:	United States	MISSILE:	SLBM		
Assumptions					
FlightTimeLo	9	FlightTimeMe	10.5	FlightTimeHi	12
DetectTimeLo	2	DetectTimeMe	2.5	DetectTimeHi	3
EvalTimeLo	1	EvalTimeMe	2	EvalTimeHi	3
DualTimeLo	3	DualTimeMe	5	DualTimeHi	7
AssessTimeLo	1	AssessTimeMe	2	AssessTimeHi	3
LaunchTimeLo	4	LaunchTimeMe	7	LaunchTimeHi	10
MDCLenLo	1.5	MDCLenMe	2.25	MDCLenHi	3
TACLenLo	1.5	TACLenMe	2.25	TACLenHi	3
MACLenLo	1.5	MACLenMe	2.25	MACLenHi	3
CASE:	Pessimistic	Best Guess	Optimistic		
Launch Point	0	0	0		
First Detection	3	2.5	2		
Evaluation Point	6	4.5	3		
MDC called	6.5	5	3.5		
Second Detection	10	7.5	5		
TAC called	9.5	7.25	5		
Assessment Point	13	9.5	6		
MAC called	12.5	9.5	6.5		
Earliest Attack Point	15.5	11.75	8		
Use Them or Lose Them Point	0	3.5	8		
EMP point	7	7	7		
Impact point	9	10.5	12		
Slack Decision Time	0	0	0		
Launch under attack policy					
Decision Time	0	0	3		
Informed Decision Time	0	0	2		
Clean Decision Time	0	0	2		
Clean & Informed Decision Time	0	0	1		
Launch on warning policy					
Decision Time	0	0	2		
Informed Decision Time	0	0	1		
Clean Decision Time	3	4.5	6		
Clean & Informed Decision Time	0	0	1		

Launch on Warning policy would not guarantee either nation that a counterattack could be launched before a crippling blow is received. We may therefore presume that during a deep crisis there will be enormous pressure on the leadership of both superpowers to order a launch at the first indication that an enemy attack is under way.[9]

For this reason, a major false alarm occurring during such a crisis would create a serious risk that a strategic nuclear strike might be launched by mistake. To assess the likelihood that such a catastrophe might take place, we need to know the rate at which serious false alarms occur under ordinary circumstances, and the speed with which they can be resolved.

7. *False alarms: Calculating the probabilities*

The importance of the false alarm rate and resolution times cannot be overemphasized. If false alarms are relatively rare events, it would be unlikely that one would occur dur-

2*

Table V. American Pershing II Attack on the Soviet Union

ATTACKER:	United States	MISSILE:	Pershing II		
Assumptions					
FlightTimeLo	6	FlightTimeMe	7	FlightTimeHi	8
DetectTimeLo	2	DetectTimeMe	2.5	DetectTimeHi	3
EvalTimeLo	1	EvalTimeMe	2	EvalTimeHi	3
DualTimeLo	3	DualTimeMe	5	DualTimeHi	7
AssessTimeLo	1	AssessTimeMe	2	AssessTimeHi	3
LaunchTimeLo	4	LaunchTimeMe	7	LaunchTimeHi	10
MDCLenLo	1.5	MDCLenMe	2.25	MDCLenHi	3
TACLenLo	1.5	TACLenMe	2.25	TACLenHi	3
MACLenLo	1.5	MACLenMe	2.25	MACLenHi	3
CASE:	Pessimistic	Best Guess	Optimistic		
Launch Point	0	0	0		
First Detection	3	2.5	2		
Evaluation Point	6	4.5	3		
MDC called	6.5	5	3.5		
Second Detection	10	7.5	5		
TAC called	9.5	7.25	5		
Assessment Point	13	9.5	6		
MAC called	12.5	9.5	6.5		
Earliest Attack Point	15.5	11.75	8		
Use Them or Lose Them Point	0	0	4		
EMP point	6	7	8		
Impact point	6	7	8		
Slack Decision Time	0	0	0		
Launch under attack policy					
Decision Time	0	0	0		
Informed Decision Time	0	0	0		
Clean Decision Time	0	0	0		
Clean & Informed Decision Time	0	0	0		
Launch on warning policy					
Decision Time	0	0	2		
Informed Decision Time	0	0	1		
Clean Decision Time	3	4.5	6		
Clean & Informed Decision Time	0	0	1		

ing a crisis, and the risk of war by accident would be low. Similarly, if almost all alarms can be resolved rapidly, the risk is small. But if false alarms occur with sufficient frequency that there is a substantial probability of one occurring during a crisis, and if their resolution times begin to approach the *Use Them or Lose Them Point*, then the risk is substantial.

Unfortunately, false alarms sufficiently severe that they result in Emergency Action Conferences seem to be by no means rare occurrences. Using the Freedom of Information Act, the Center for Defense Information in Washington was able to obtain data on the frequency of conferences produced by false alarms from the North American Aerospace Defense Command (NORAD).[10] According to NORAD, between January, 1978, and May, 1983 false alarms were responsible for six Threat Assessment Conferences and no less than 956 Missile Display Conferences.

7.1 *Threat Assessment Conferences*

As noted earlier, Threat Assessment Conferences are extremely serious events, leading to significant changes in alert status and involving the highest levels of military command. They are called only if there appear to be multiple and persistent indications that a strategic attack is under way. Yet in at least two of the six cases reported by NORAD, a single human or mechanical failure caused the multiple false indications.[11] We may therefore treat such major false alarms as true random events, whose occurrence is as likely during a crisis as at any other time. What are the chances that such a major failure would in fact occur during a serious crisis?

If TACs are true random events, and if we assume their occurrence rate is constant over time, then their occurrence can be modeled as a Poisson arrival process. If we know the 'arrival rate' x (defined as the average number of TACs per day), and we posit a crisis t days in length, then the probability p[A] of a TAC during the crisis is given by:

$$p[A] = 1 - e^{-xt}$$

As it turns out, if we posit our hypothetical crisis as equal in length to the Cuban Missile Crisis (30 days),[12] and assume that TACs continue to occur at the rate reported by NORAD from 1978 to 1983, the probability that one would occur sometime during the crisis is .1, or 10%.

Now of course this calculation is based solely on the probability of a catastrophic failure in the *American* system; it does not take account of any failures on the Soviet side. We have no data whatsoever on these, but since Soviet remote sensing and computer systems are widely acknowledged to be inferior to their American counterparts we can hardly suppose that their failure rate is *less* than the American one. If we assume that the frequency of catastrophic failures on the Soviet side is equal to the American failure rate,[13] the combined probability of a breakdown p[B] in *either* system is given by

$$p[B] = 1 - e^{-2xt}$$

which yields a value of approximately .2, or 20%. Given the risks associated which such an event during a crisis, this is an unacceptably high value.

7.2 *Missile Display Conferences*

Thus far we have concentrated solely on the most severe form of false alarm event, those that cause TACs even in peacetime conditions. But there are as well numerous lesser events.

Table VI. Emergency Action Conferences by Year. Missile Display Conferences and Threat Assessment Conferences

Year	Routine	MDCs	TACs
1977	1567	43	0
1978	1009	70	2
1979	1544	78	2
1980	3815	149	2
1981	2851	186	0
1982	3716	218	0
1983	1479	255	0

Table VI displays the annual number of events that resulted in the lowest level of Emergency Action Conference, the so-called Missile Display Conferences. It is apparent from the table that such events are quite frequent, and becoming more so all the time. By 1983, they were occurring at the rate of 20 per month, representing a steady annual increase of over 20% since 1978.

Now there is no question but that many of these false alarms do not represent particularly serious events, and many are in fact resolved in less than a minute. In these cases, the MDCs are called as double-checks rather than in the expectation that something is truly amiss. Nonetheless, there will always be a few whose resolution will be delayed owing to some unforeseen combination of factors. Under normal conditions, leaders will merely wait until the anomalous indications have been resolved. But if there is a severe crisis, and if the delay extends until the *Use Them or Lose Them Point,* leaders may be prone to interpret the anomaly as the first indication of an enemy attack, and take some pre-emptive action. The chance that any particular anomaly will provoke a strategic response may be small, but in light of our earlier discussion, the probability is clearly not zero.

If we assume that false alarms result from a large number of independently distributed random variables,[14] their resolution times may be assumed to be exponentially distributed.[15] Thus the probability that any single false alarm will require more than the available time to resolve is simply the antilog — that is to say, an exponential function — of the ratio between the time available to resolve the false alarm (in this case, the time difference between *MDC Called* and the *Use Them or Lose Them Point*) and the mean resolution time for all false alarms. Where w is the decision time available, and y is the mean resolution time, then the probability p[NR] that a given false alarm cannot be resolved in time is

$$p[NR] = e^{-w/y}$$

As we see from Table VII, this means that the probability of an unsuccessful resolution increases dramatically as the decision time shortens.

Table VII. Probability of Unsuccessful Resolution

Ratio of 'Strategic Window' to Resolution Time	Percentage of Alarms Unresolved
12 : 1	.0006
10 : 1	.0045
8 : 1	.034
6 : 1	.25
4 : 1	1.83
2 : 1	13.5
1 : 1	36.8

If the available decision time is 10 times the length of the mean resolution time — the situation until the introduction of fast-attack systems — then only 45 out of every *million* alarms will be unresolved. But if the decision time/resolution time ratio drops to 6 to 1, the number of unsuccessful resolutions climbs dramatically to 2500 per million, and if the decision time is only twice as long as the mean resolution time, fully *thirteen and a half percent* will be unresolved.

It can be shown that the probability p[NRC] of such an unresolved alarm occurring on either side during a crisis of length t days is given by

$$p[NRC] = 1 - e^{-2xt\ p[NR]}$$

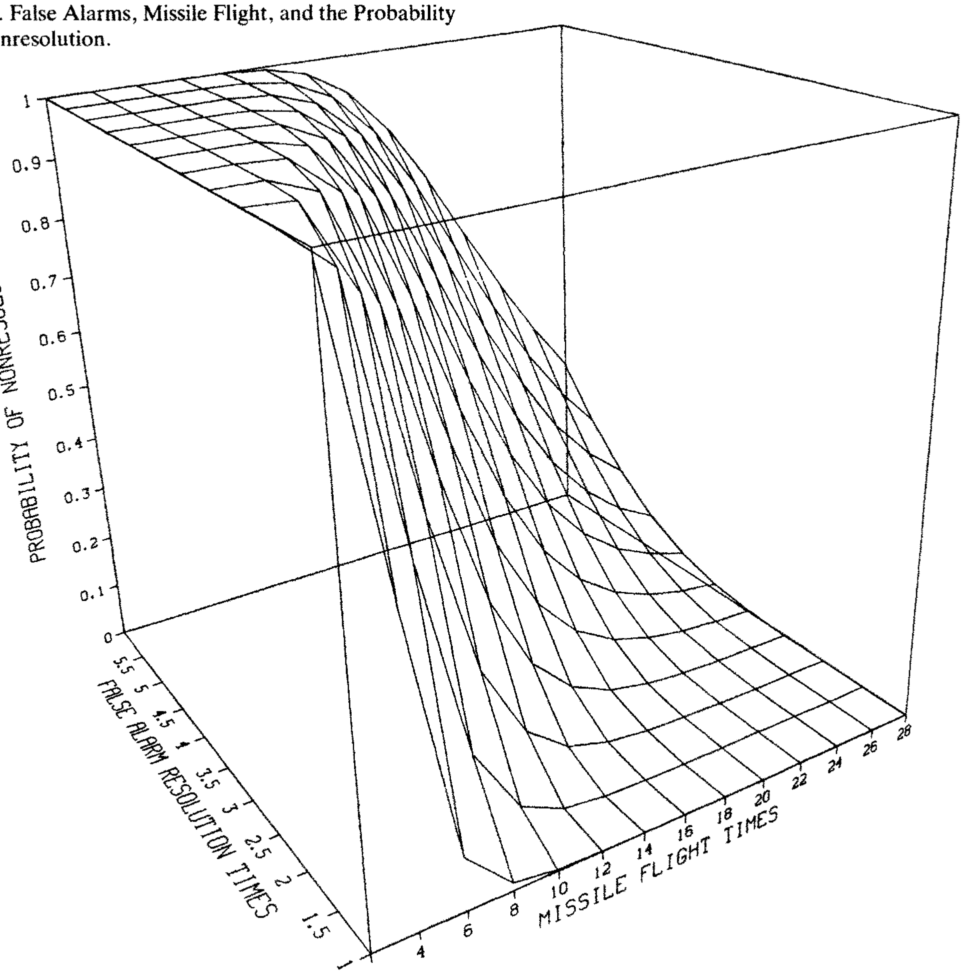
where x is the average number of false alarms of some type per day. This equation 'thins' the original Poisson process by only considering those false alarms that fail to be resolved within the available decision time.

If we now assume that MDCs occur at the rate observed empirically as of May, 1983, and hypothesize as before a crisis 30 days in length, we can calculate the probability that an unresolvable false alarm will occur before the crisis terminates. Fig. 1 displays the values of this probability corresponding to decision times from 2 to 28 minutes, and mean resolution times from 1 to 6 minutes.

It shows dramatically how shorter decision times increase the chance of an unresolved alarm. For example, assuming a decision time of 15 minutes and a resolution time of 2 minutes (the approximate situation for an ICBM attack), there are less than 2 chances in a thousand that an unresolvable false alarm will occur during a crisis of 30 days' duration. But if the decision time is reduced to 6 minutes, chance of an unresolved alarm rises to over 50%, and if there are only 4 minutes of decision time available (the situation in the case of an SLBM or Euromissile attack), the calculated probability increases to .93, even if the resolution time decreases to 1.5 minutes.[16]

Fortunately, as mentioned earlier, not all

Fig. 1. False Alarms, Missile Flight, and the Probability of Nonresolution.



events resulting in MDCs are of such seriousness that they would lead to strategic action, even if unresolved. For example, an anomalous radar trace suggesting a single Soviet missile fired at the US would scarcely be expected to provoke an immediate all-out US strike, even during crisis. Marsh (1985) suggests that about 4% of all MDCs are 'serious', or about 10 events a year. But even if we consider only this smaller number of serious events, the chance that an unresolved serious event would occur during a thirty day crisis is still far from negligible. If there are only 3.25 minutes of decision time (the calculated value of *Clean and Informed Decision Time* for a co-ordinated Soviet attack including SLBMs), and if the mean resolution time of such serious alarms is 3.5 minutes, the probability that one would occur during a crisis is .48. Even if we make the extremely optimistic assumption that the mean resolution time of such alarms is 2.5 minutes (only one minute longer than the practical minimum resolution time for any alarm), this probability is still .36. Combining this probability[17] with that of a TAC-generating event during the same crisis, *we arrive at the conclusion that there is almost a 50% chance of a war-threatening false alarm of some type occurring during severe, lengthy crisis.*

7.3 *Some additional considerations*

It is important to emphasize that some very optimistic assumptions have been made throughout the above calculations. First, as touched on above, we have implicitly assumed that the performance of the Soviet C^3I system is essentially equivalent to that of the American one, not only with respect to the occurrence of false alarms, but also in terms of the resolution times of these alarms. The chillingly inept performance of the Soviet command during the KAL incident strongly implies that this may be unrealistic; the cumbersome and overcentralized nature of Soviet military decision-making suggests a range of resolution times many times longer, with a corresponding sharp increase in the probability of an unresolved alarm.

Second, we have assumed that the rate of false alarms remains constant during a crisis, and does not increase. But as Bracken (1983) points out, this is highly unlikely, since during crises more sensors are monitored, while others routinely used for intelligence gathering are switched over to early warning, thus increasing the load on data processing hardware and software. It is worth pointing out here that the failure rate of computing machinery increases with load at a rate far greater than linear; thus, the rate of false alarms would probably increase severalfold during a crisis, further augmenting the risk of war.

Finally, we have assumed that the danger of *human* error does not increase during crisis; however, psychological studies are virtually unanimous in demonstrating a sharp decline in task performance under stress. The effects of the prospect of imminent national destruction on command performance can only be guessed at, but they are virtually certain to be unfavorable. Combined with the additional stress caused by increased sensor input and overloaded equipment, the likelihood of simple mistakes in perception and action — to say nothing of errors in interpretation or judgement — will obviously increase.

8. *Conclusions and further directions*

Of course there are more uncertainties than verified facts in this exercise, and the questions greatly outnumber the answers. Our lack of useful Soviet data, limited knowledge of resolution times, inability to predict the length of a crisis, and — above all — uncertainty as to a decision-maker's actual response to an unresolved false alarm in unique circumstances all prohibit us from making any precise statements about the actual probability of war during crisis.

But to focus on the inevitable imprecision of such calculations is to miss the point. The issue is that the chance of war by accident is *not negligible;* certainly it would be foolish to dismiss the danger as remote. Given the awesome consequences, this alone should be more than enough reason for concern. This concern can, in turn, be channelled in two complementary directions: 1) Additional research into the dangers of war by accident, and 2) the development of proposals to counteract the risk. Under the first heading, there needs to be a great deal of further research into the performance of early warning sensors, the data processing systems that manage the flow of information, and how the performance of the system and its components is likely to be altered in crisis situations.

Now of course research of this type is no doubt continuously underway within various national defense establishments and their associated agencies. But historical experience suggests that classified, in-house research *cannot* substitute for free and open scientific enquiry on any matter where a wide range of expertise and experience is required. It seems important, therefore, that an *international* effort be mounted by the global scientific community to begin research on this issue, drawing on the specialized professional and technical communities for expertise where required. It should not be too difficult to mobilize institutional and financial support for this effort, since by definition everyone is opposed to war by accident.

8.1 *Policy proposals*

The routine academic plea for further research is not a satisfactory stopping place in times such as these. There are several concrete measures that could be undertaken immediately to reduce that risk of accident in times of crisis. The most obvious and least original of these is the control or prohibition of those weapons systems which, owing to their short flight times, threaten each side's command centers. This would involve, on the American side, the removal of Pershing II missiles from Europe, and some restrictions on the deployment US, French and British ballistic missile-firing submarines. The Soviet quid pro quo would be a drastic curtailment of SSBN operations off the North American coast, and a major pull-back of SS-20 missiles from the European theater. Most knowledgeable authorities state that the degree of stability obtained by such a move would be 'almost incalculable' (Bracken 1983). In fact, as we saw above, we *can* calculate that removing the short flight time systems would reduce the risk by several orders of magnitude. It would emphatically *not* eliminate all danger of war in time of crisis, but it would remove one very significant source of danger.

A second measure which might go a long way to reduce the danger of accident is the adoption of a 'no-first-use' policy. Of course, verbal declarations are by themselves not much use, but if they are coupled with the adoption of strategic policies, weapons deployments, and force configurations which in fact do not rely on the early use of nuclear weapons (Gottfried et al. 1984) each side would have reason to believe, in time of crisis, that the other side intended to practice nuclear restraint rather than pre-emption. In particular, a change in the current NATO doctrine which calls for the early unlocking of the Permissive Action Link controls (PALs) over tactical nuclear weapons in time of crisis would seem to be a matter of high priority. Once each side has given authority for nuclear use to a widely-dispersed group of low-level commanders under conditions of great tension the probability of accidental or inadvertent use is multiplied enormously, and of course a tactical loss of control would very likely heighten the pressures for strategic pre-emption. A 'no-first-use' policy would thus add an element of stability in time of crisis.

Another important series of steps would aim at building a degree of independent redundancy into the detection systems. The superpower surveillance and monitoring systems, and their associated data processing systems, are, as we have seen, led by their very sensitivity to be prone to false alarms. Thus the availability of real-time redundant information from independent sources could speed up the process of resolving false alarms and therefore mitigate the danger of accident. Two proposals here are noteworthy. The first is that made by Senator Nunn for dual crisis centers in Washington and Moscow jointly staffed by Soviet and American personnel. In time of crisis, this would enormously increase the speed and 'bandwidth' of the information flow from the very limited capabilities of the current hotline. The second proposal, first put forward by the French delegation to UNSSOD I, calls for the establishment of an International Satellite Monitoring Agency (ISMA) staffed and equipped independent of superpower control. Although originally viewed primarily as having an arms control verification function, it would perhaps be of more immediate use in an early-warning role. If these proposals were adopted, each side would benefit from two additional sources of independent information to assist in resolving false alarms.

But perhaps the most effective check on nuclear accidents may come from the growing realization, based on recent scientific evidence, that the entire notion of 'successful strategic pre-emption' is a contradiction in terms. Most atmospheric scientists now believe (Sagan 1983) that even if one side were able to deal a strategically successful pre-emptive blow, knocking out enough forces and command centers on the other side to avoid direct nuclear retaliation altogether, the aggressor would be unable to escape devastation as an indirect result of his own attack. Massive clouds of smoke and dust resulting from the explosions and resulting fires would cause major climactic disruptions, perhaps as severe as those associated with the Cretaceous-Tertiary boundary extinctions 63 million years ago. The impact of the near-total destruction of crops and livestock, freezing temperatures in summer, concentration of pyrotoxins and radioactive pollutants, and hurricane-force snowstorms near the coasts would scarcely be less severe than the nuclear attack itself.

If the scientists are right, then Mutual Assured Destruction has been resurrected, willy-nilly, and in this perhaps lies our best hope. If once again decision-makers can be convinced that no conceivable advantage can be achieved from a nuclear launch regardless of what the other side does (see Fig. 2), then a measure of stability will once again have been achieved in superpower relations.

Fig. 2. Game Matrix for Launch Decision Given 'Nuclear Winter'

	Enemy Attack	No Attack
Launch	$-\infty, -\infty$	$-\infty, -\infty$
Don't Launch	$-\infty, -\infty$	0 , 0

In such a climate, perhaps the ultimate issue of the futility of attempting to use thermonuclear energy to attain political goals can, at last, be seriously addressed.

NOTES

1. Bracken (1983) argues that the inhibitory mechanisms against nuclear launch are so powerful in peacetime situations that as a practical matter, the US would have great difficulty responding to a genuine surprise attack. As the peacetime readiness level of Soviet strategic forces appears to be even lower, he concludes with Nye (1984) that a war resulting from a 'pure accident' is highly unlikely.
2. Bracken, op. cit., pp. 65–66.
3. Bracken, loc. cit.
4. It has been suggested that the new generation of communications sensing satellites (such as the one launched recently by the space shuttle) may procide a more reliable early warning of a major attack. But in fact such satellites provide only warning of *preparations* for an attack; they cannot determine whether these preparations are precautionary or presage an actual attack (see the *New York Times* January 26, 1985). Thus, in the 'worst case' atmosphere of a crisis, this additional information might tend to exacerbate rather than calm the spiraling tensions just described.
5. This model is based on that presented by Marsh (1985), who has collated and summarized the available unclassified information on the American early warning system.
6. If cruise missiles only are used in the attack, the *EMP Point* coincides with the *Impact Point*.
7. These are largely based on those in Marsh (1985).
8. It is generally believed that the Soviets lack the sophisticated airborne radar picket planes (such as the American AWACS) necessary to detect small, low-flying targets like cruise missiles (deSobrino et al. 1983).
9. Indeed, there is some evidence to suggest that both superpowers plan to launch an attack during crisis *before* an actual enemy launch if there is merely a strong indication from intelligence sources that an attack is planned and is immanent. This is certainly the assessment of the Defence Intelligence Agency; see also Ford (1985).
10. These data were contained in a letter dated June 30, 1983, from D. W. Kindschi, Chief, Media Relations Division, Directorate of Public Affairs, NORAD HQ, Peterson AFB, Colorado.
11. In one case, the failure of a 57-cent microchip in a relay computer caused a false display suggesting a Soviet missile attack from several directions at once. In another, a computer operator placed a tape containing a simulated all-out Soviet attack on the on-line computer. Both of these events were the subject of considerable congressional scrutiny. See *United States General Accounting Office*, Report to the Chairman, Committee on Government Operations, House of Representatives of the United States, 'NORAD's Missile Warning System: What Went Wrong?' GA1.13: MASAD-81-30. (May 15, 1981).
12. The strategic forces of both superpowers were on full alert from October 23 to November 21, 1962. See Larson (1963).
13. Most expert opinion asserts that the detection and data processing systems of the superpowers are similar, with a slight technological advantage going to the American side. An assumption of approxi-

mately equal failure rates therefore seems reasonable. See Arkin & Fieldhouse (1984).

14. If this were *not* the case, their elimination from the system would be an easy task!
15. Bereanu (1983) shows that under some conditions this can be proven.
16. As noted above, it is very unlikely that resolution times can be reduced below 1.5 minutes, not only because it takes at least that time to process a signal (Steinbrunner 1983), but also because by the time an event triggers an MDC, its resolution requires a command decision involving more than one individual.
17. Since the probabilities of these events are independent, the probability that *at least one* will occur is calculated in the usual manner as one minus the product of the probabilities of their non-occurrence.

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