# Surveillance by Satellite (U)

ELLIS E. LAPIN

*The Aerospace Corporation, Los Angeles, Calif.*

(Received Aug. 11, 1975)

(U) The mechanisms and limitations of the use of infrared radiation detection as a means of conducting surveillance for the purpose of giving warning of the launch of ballistic missiles is discussed. The threat, the observables, and the detector are briefly treated as an introduction to a description of the Defense Support Program. The capabilities and experiences with that system are described. Some possible directions for further development are indicated. Figures illustrative of the threat, the phenomenology, sensor construction, and system capability are included.

## INTRODUCTION

(U) The U.S. Air Force has in operation a space satellite system to conduct surveillance of very nearly the entire globe to get early warning of attacks by enemy ballistic missiles. Surveillance entails close and continuous observation, and the continuous aspect differentiates this activity from reconnaissance.

(U) Space satellites constitute desirable platforms for the conduct of observation, because a large fraction of the enemy's territory can be surveyed at all instants. The observable in the case of attack by ballistic missiles is the hot plume from the rocket, which radiates in the visible and infrared portions of the electromagnetic spectrum. An appropriate sensor/detector is necessary; for example, a telescope with cells, responsive to infrared light, stationed at the focal plane.

(U) At the outset, it should be recognized that genuine information may be corrupted by real signals from nonmissiles and that the information may be suppressed or distorted by several phenomenological effects.

(U) The object here is to discuss the mechanisms, limitations, and potential for systems of this nature.

[redacted]

## THE THREAT

([redacted]) For the near future, the objects of interest are the intercontinental and submarine-launched ballistic missiles in the Soviet and Chinese inventories. The number and kinds of rockets, the distribution of launch complex, the typical silo distribution within a complex, and the oceanic areas from which attacks may be mounted are illustrated in Fig. 1. These constitute the threat: 1,500 or more ICBM's; 600 or more SLBM's; somewhat more than 20 complexes, with 40 or so missiles each, distributed across much of the Soviet land mass; and an oceanic region for submarine launch operations comprising one-fourth the area of the globe. The implication of this distribution is that suitable surveillance systems must have at least hemispheric—and preferably a global—coverage capability.

## THE OBSERVABLES

(U) The rocket plume intensity, the apparent position of the plume, and time are the observables. A more or less typical "apparent" intensity history is illustrated in Fig. 2 with scales that are typical of the intensities of the various burn stages of rockets. The intensity signature is characterized by a peak resulting from the com-

[redacted]

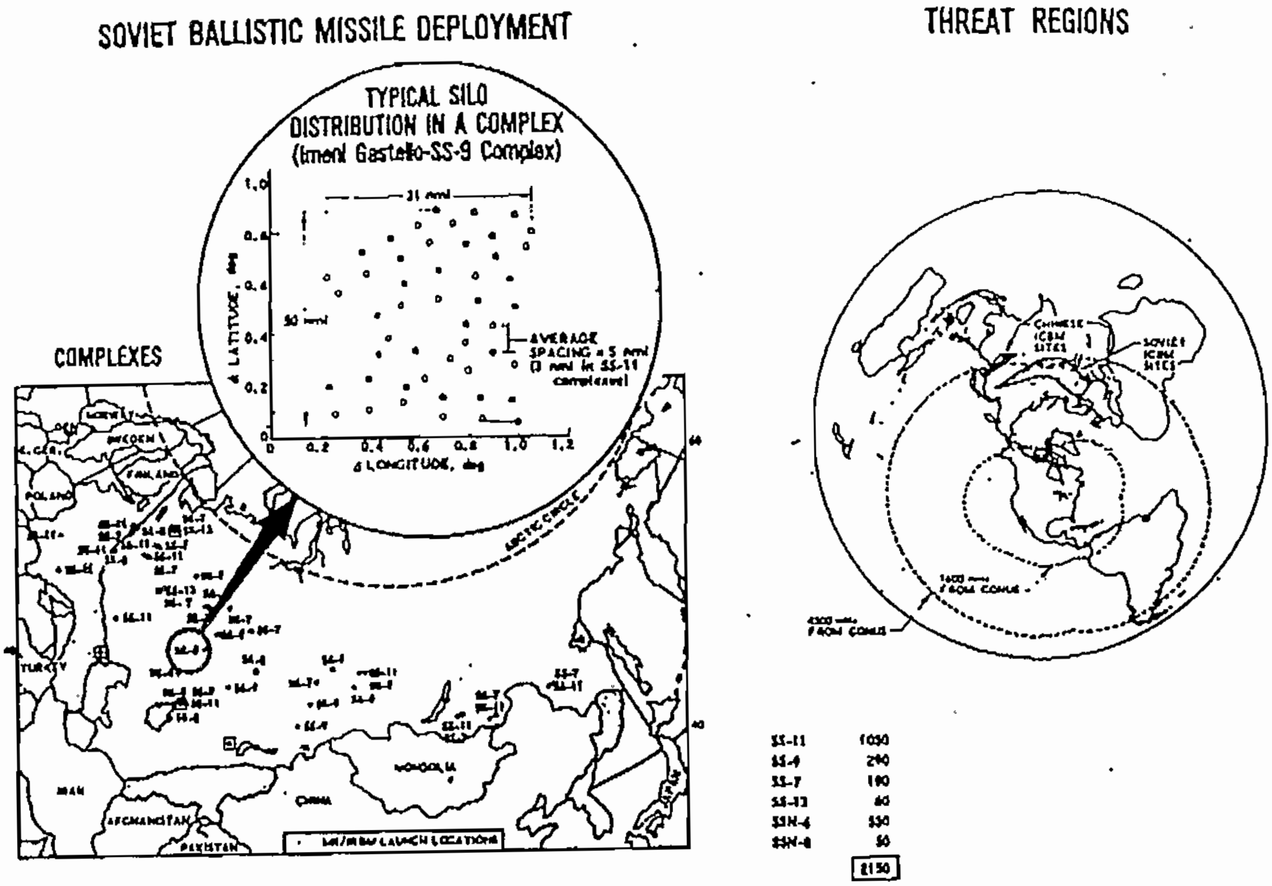


Figure 1. The ballistic missile threat. (Figure classified [redacted])

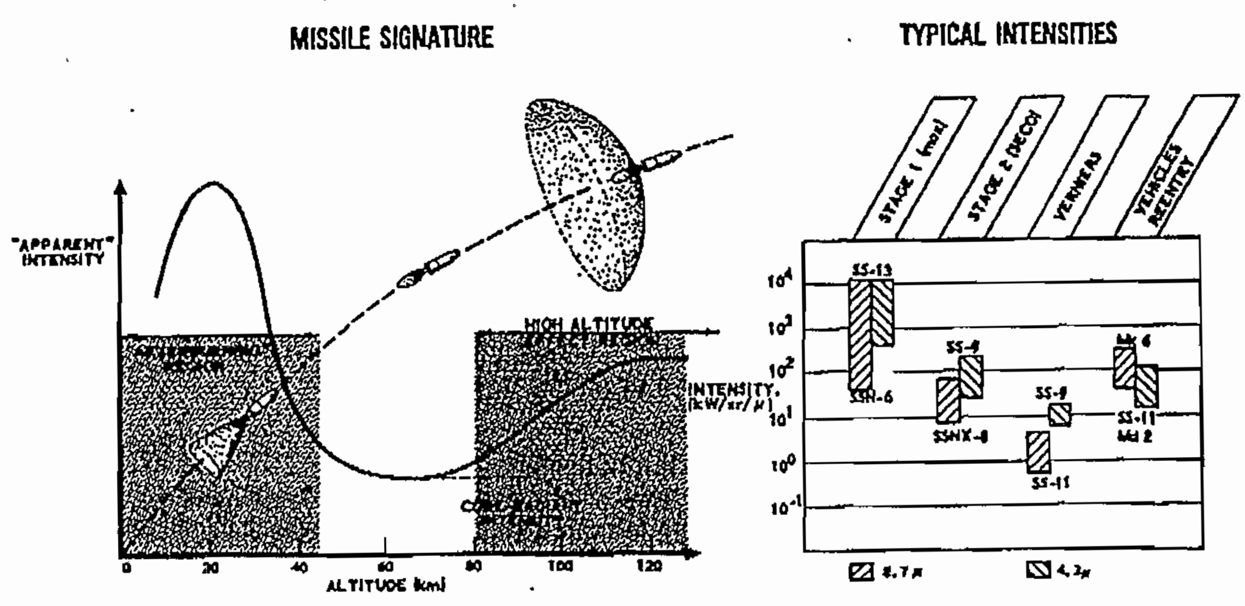


Figure 2. The infrared observable—intensity. (Figure classified ~~Secret.~~)



[redacted]

peting effects of reduction in atmospheric attenuation and diminished concentration of atmospheric oxygen (to burn the excess of fuel over oxidizer in the free plume) as the missile rises. The trough corresponds roughly to the radiation from the hot core of the plume in an atmosphere so rarified that afterburning is negligible, and the rise to a second maximum is attributed to a radiation that is enhanced by fluid dynamical effects at very high speeds. For warning alone, it is sufficient that the detection instrument be responsive to signals varying over two to three decades. For other purposes, it would be desirable that the range of response encompass four or more decades.

(U) Figure 3 illustrates the family of ballistic trajectories attainable by a rocket. The region in which observations may be conducted by detecting hot plumes is confined to that small area to the left of the termination of burning line (cutoff). The plume is visible only over a small fraction of its flight path.

(S) Some further characteristics of plumes are indicated by the collection in Fig. 4, where it is seen that the plume itself is of enormous extent, with linear dimensions of the order of a half-mile. The radiance is greatest near the rocket nozzle, fading-off with distances along the plume. At observation distances of the order of six or so earth radii, the synchronous-altitude satellites station, all of the radiance can impinge on a single detector cell with an intensity that is perceptible and sensible. The intensity of the signal correlates with thrust and with fuel type, providing signatures that differ somewhat among types of rockets (with respect to peak intensity, signal duration and signature shape).

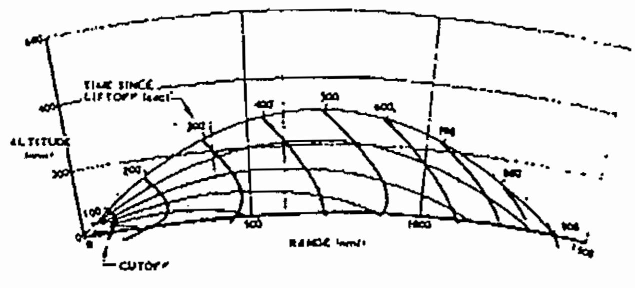


Figure 3. The infrared observable—time. (Figure unclassified.)

(U) The attenuating effect of any atmosphere intervening between the rocket plume and the observing station is shown in Fig. 5. While the atmosphere is generally transparent, it is more or

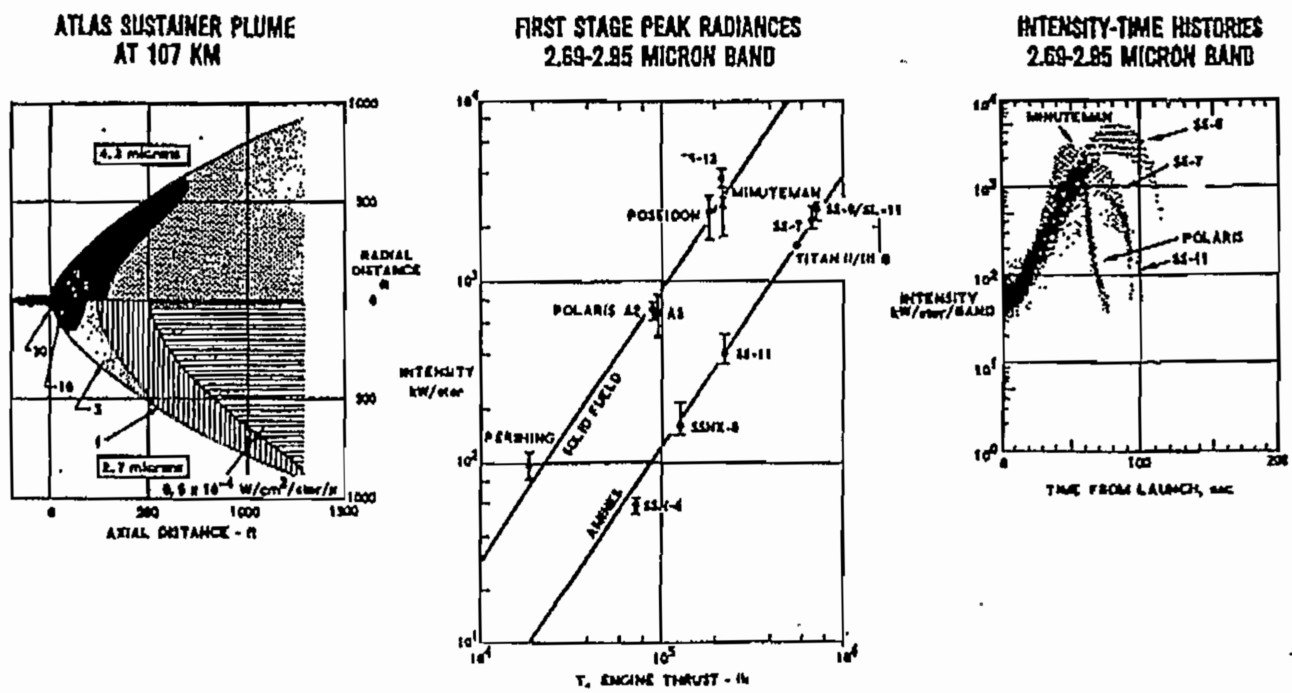


Figure 4. Target intensity. (Figure classified [redacted].)

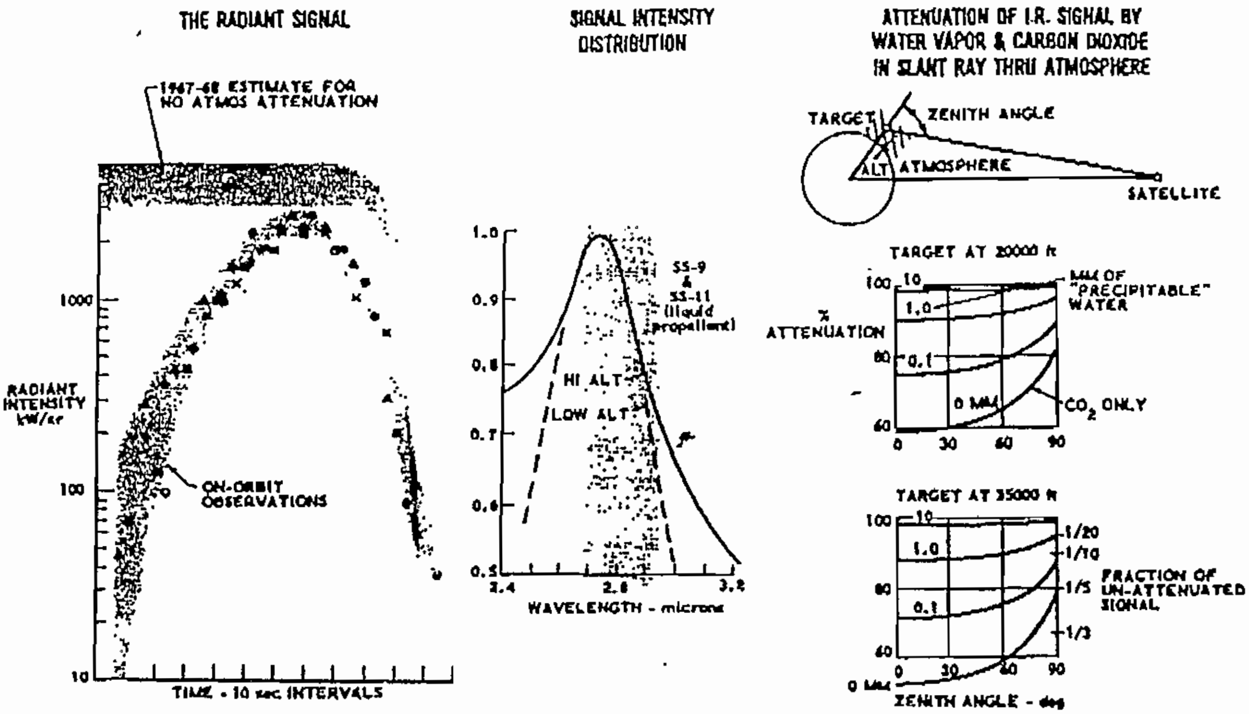


Figure 5. Signal attenuation. (Figure classified [redacted].)

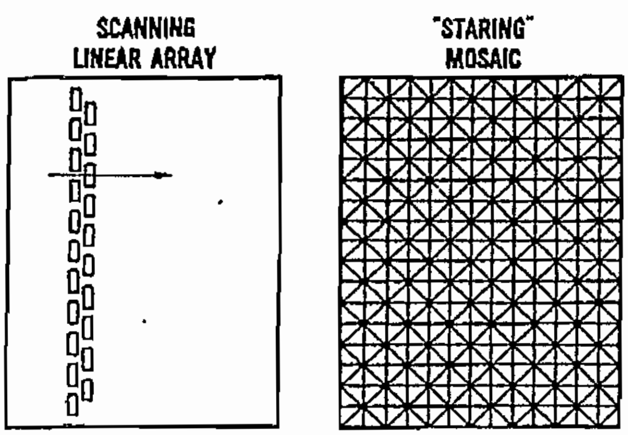


Figure 6. Detector cell arrays. (Figure unclassified.)

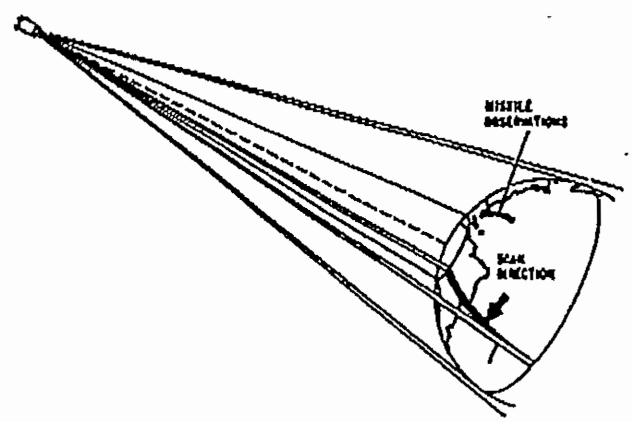


Figure 7. Generation of coverage in the defense support program. (Figure classified [redacted].)

less opaque to radiation in the infrared in the vicinity of the 2.7-, 4.3-, and 6.3-micron-wavelength regions, where strong absorption bands of $CO_2$ and $H_2O$ exist. While the products of combustion are these kinds of molecules, they are strong enough radiators to be seen despite the attenuation, the degree of which is strongly dependent upon the length of path through the atmosphere and the water content in this path. Precise determination of the attenuation requires an intimate knowledge of the intensity–wavelength characteristics of the *radiating* signal, as well as the atmospheric composition. The right-hand portion of Fig. 5 portrays the approximate state of affairs attributable to the predominating atmospheric and geometric parameters.

## THE DETECTOR

(S) Many substances exhibit a peculiar response to exposure to infrared light, the characteristic measure of performance of which, $D^*$, has the significance of signal to noise-per-unit-frequency ratio when one watt is incident on one square centimeter of detecting substance. The parameter $D^*$ is intimately related to the knee of the curve of output versus radiant input; and $D^*$ values of the order $2 \times 10^{11}$ cm-hertz$^{1/2}$-watt (in lead sulfide) are achievable for the 2.7-micron band at temperatures attainable in space by passive temperature control schemes. Other characteristics of importance are the speed of response, the responsivity, and a measure of the inherent noise generating characteristic.

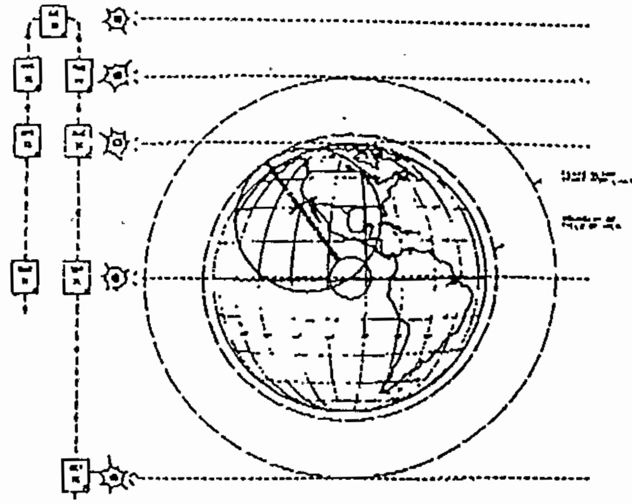

Figure 8. Telescope field of view. (Figure classified Secret.)

(S) The detector cells can be variously arrayed, with the field of view being scanned either by the cells themselves, through the motion of an oscillating mirror, or by continuously staring at the scene with a very large number of cells. The Defense Support Program (DSP) sensor uses a line scanner that surveys the scene, virtually a hemisphere, through a continuous, slow rotation (6 rpm) of the entire satellite. Figure 6 illustrates general scanning methods. Figures 7 and 8 illustrate the DSP method. The general arrangement for the DSP sensor is shown in Fig. 9, that sensor using a 24-in aperture, $f$/1.5 Schmidt optical system having somewhat more than 2,000 detectors in an array situated at the focal plane.

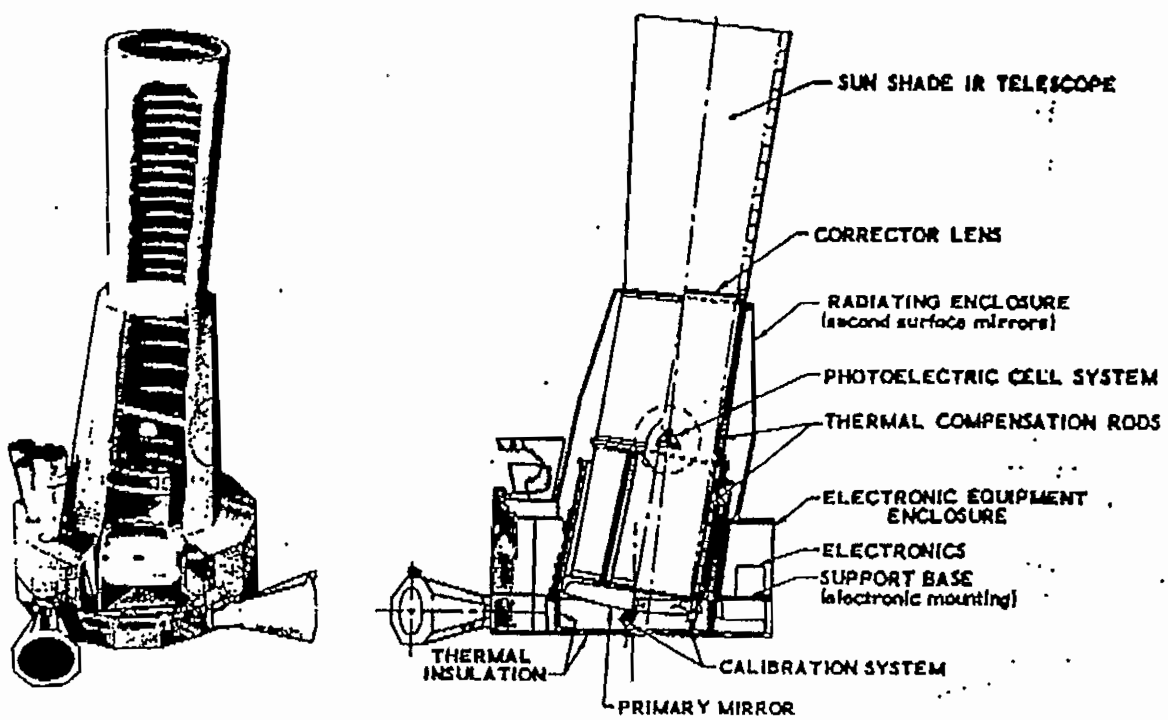


Figure 9. Defense support program infrared telescope. (Figure classified Secret.)

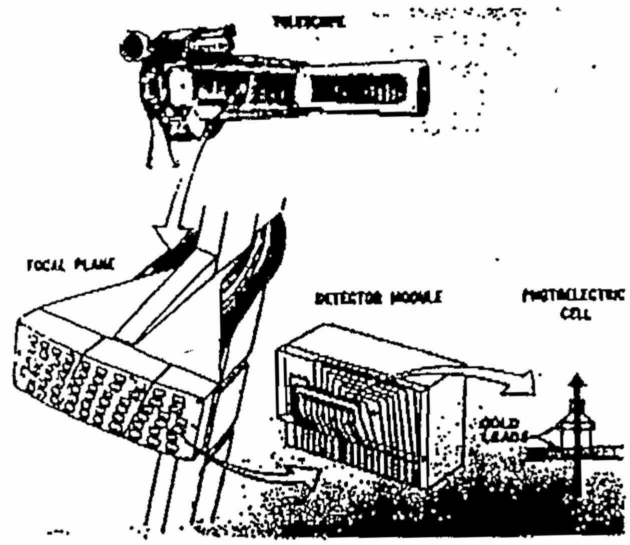


Figure 10. Defense Support Program focal plane array. (Figure classified Secret.)

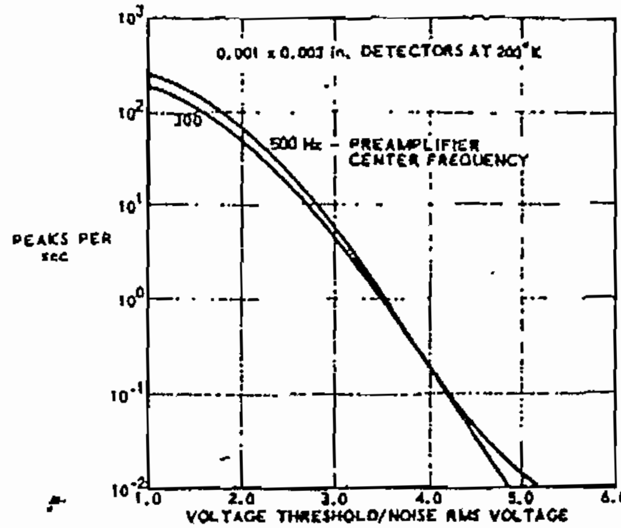


Figure 11. Electrical noise from detector/preamplifiers. (Figure classified Secret.)

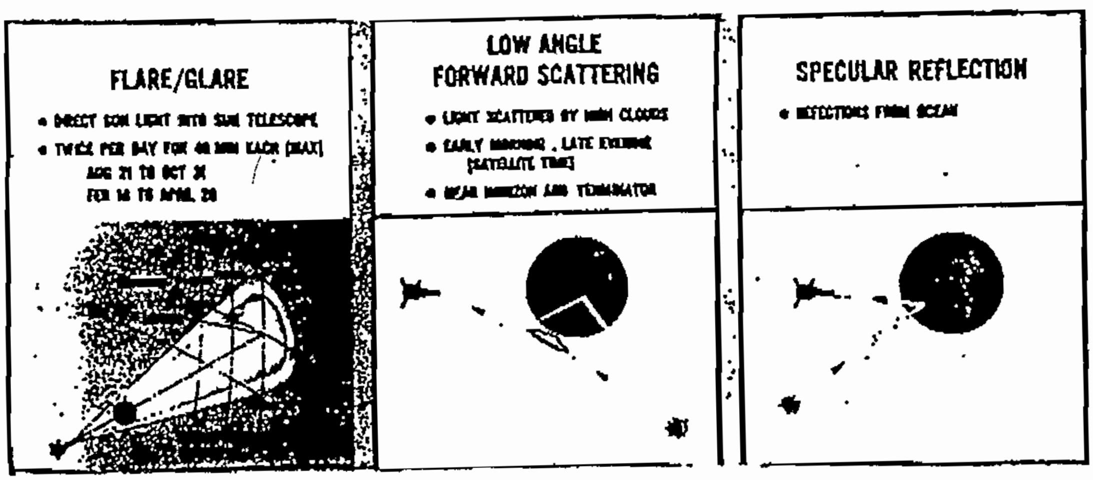


Figure 12. Sun interference. (Figure classified Secret.)

The array, shown in Fig. 10, comprises 128 modules bearing 16 detectors each, the individual detector dimensions being about 0.001 × 0.003 in. (The large open rectangles in the portion of the figure labeled "Focal Plane" are apertures for the *wire leads*, the detector modules being the small, solid black rectangles.) The sensor has an ability to detect a lighted match at 100 to 200 miles, which attests partly to the state of the telescope and detector art and partly to the magnitude of the energy released in combustion.

(U) The signals generated by the passage of infrared light (optical filters confine the passband

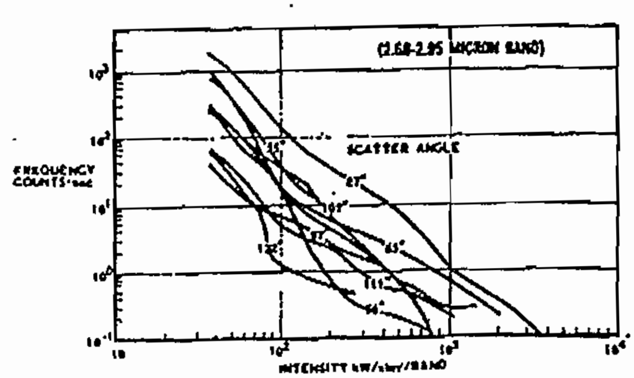


Figure 13. Background-produced returns. (Figure classified Secret.)

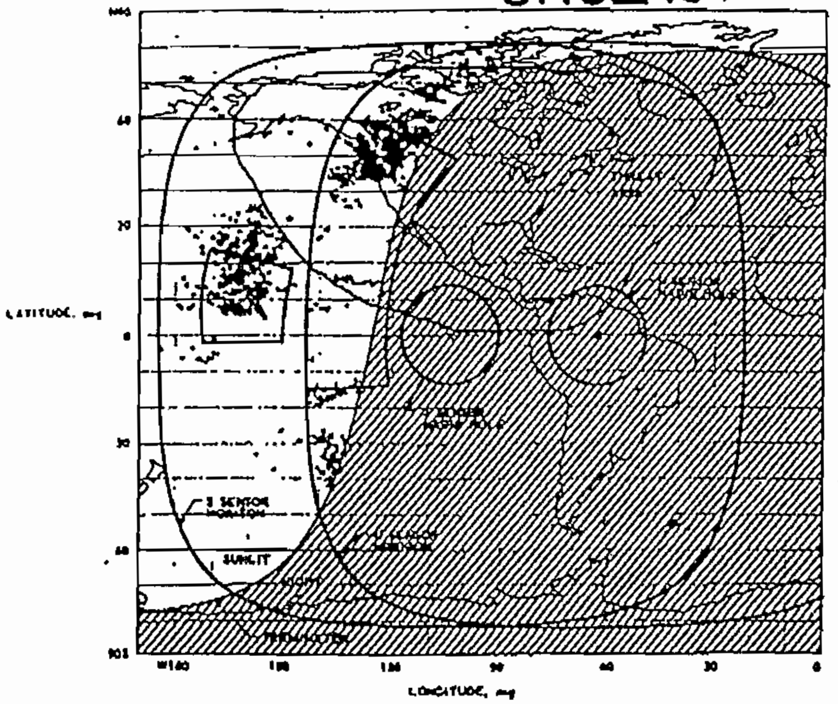


Figure 16. Background blanking boxes. (Figure classified ~~Secret~~.)

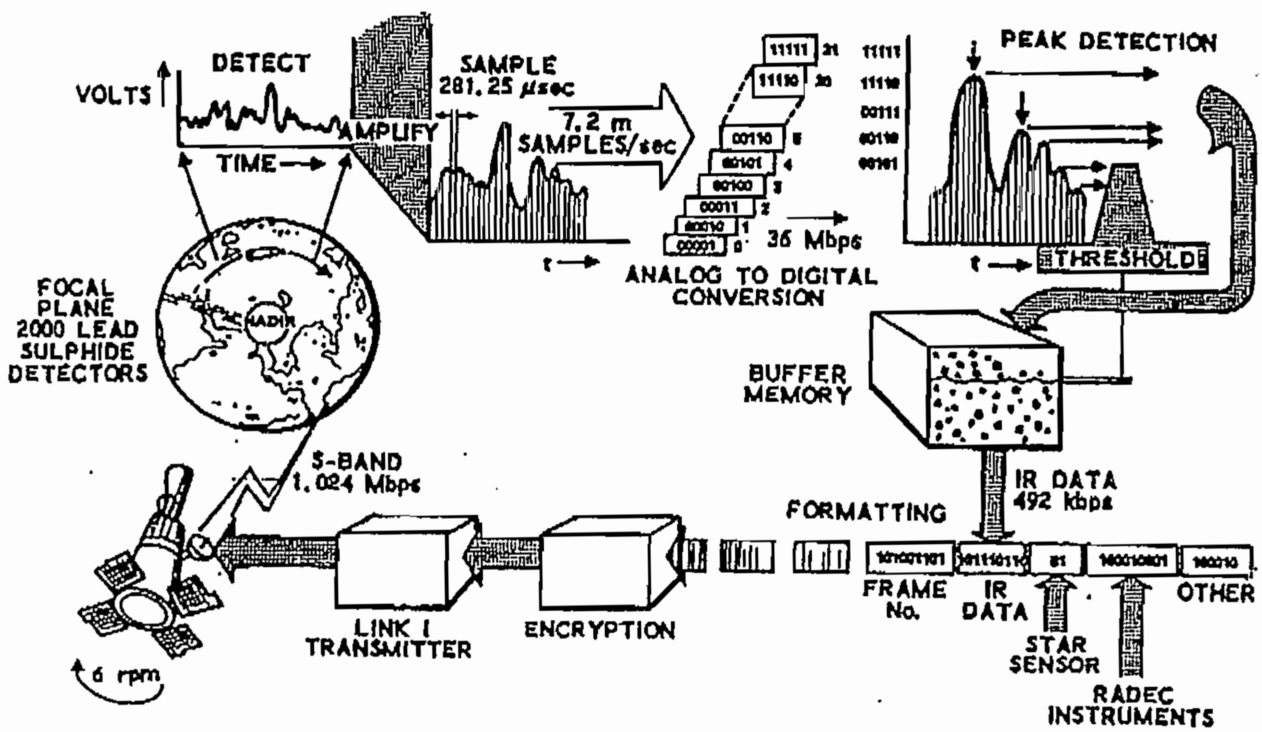


Figure 17. Sensor data processing. (Figure classified ~~Secret~~.)

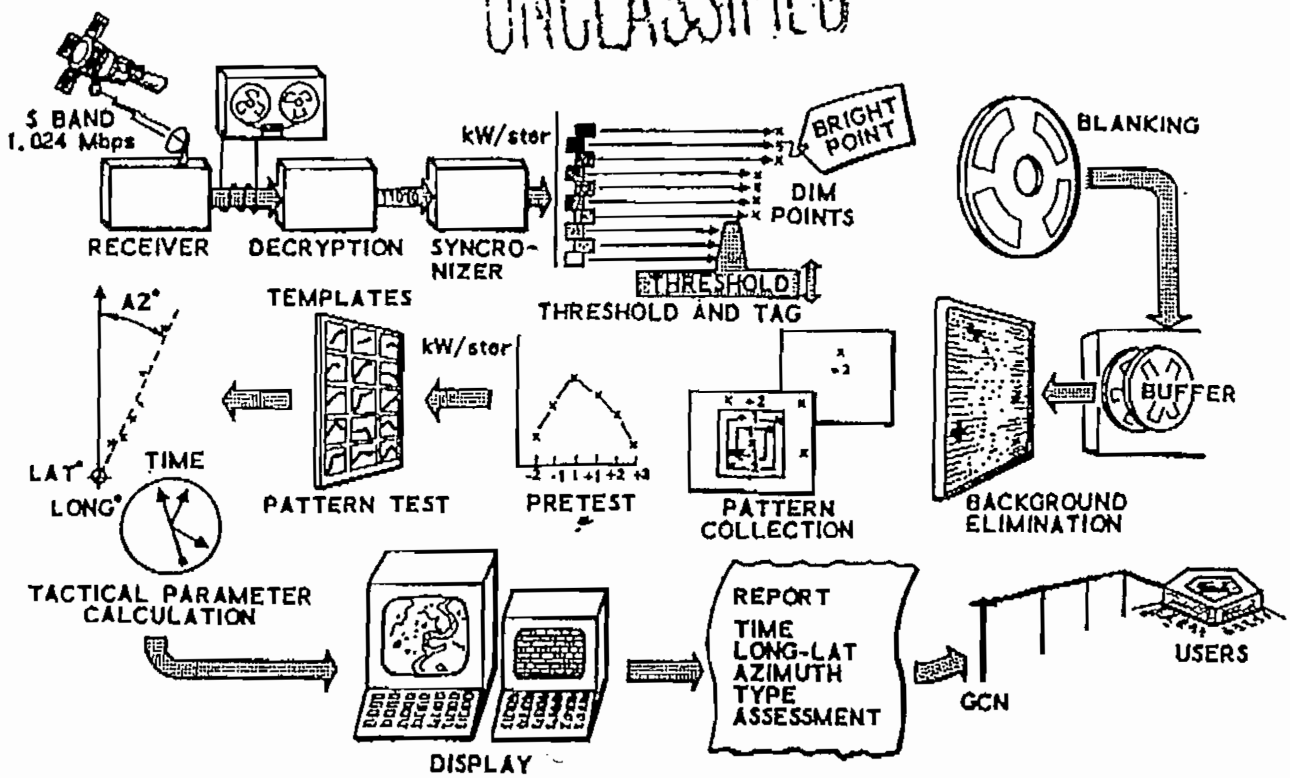


Figure 18. Ground data processing. (Figure classified [redacted])

rise to an "apparent" track, a typical one of which is shown in Fig. 14. Such tracks are characterized by nearly constant intensity and a stationarity that persists for time intervals that are large compared to the durations of real missile-stage burns (missile tracks are characterized by an intensity-variation history and, generally, a perceptible and recognizable motion). The appearance of interference in the scene depends upon the time of day, as illustrated by Fig. 15, and the season. In the DSP system, particularly intense interference can generate such huge quantities of data as to swamp the computational facilities, making it necessary to discard the information received from certain portions of the scene at certain times by "blanking." Typical blanks are indicated in Fig. 16. Blanking, it should be noted, occurs in the data processing, not in the acquisition of the information by the sensor. It is possible to produce automatic data handling procedures in which the blanking is self-adaptive to the local momentary scene. Such logic, of course, must also *not* institute a blank on the signals occasioned by a large set of nearly simultaneous rocket launches—a conceivable attack scenario.

(S) The passage of infrared light—for example, radiation from a rocket or from interference—over the detector cell produces a continuous signal. The transmission of *all* the information contained in such "analog" signals is ponderous, but it turns out to be adequate to report only the signal peak and the time and place of its occurrence. (More than this information is of course desirable.) The scheme followed by DSP for this reduction in the total quantity of data is indicated by Fig. 17. The data link is sized to accommodate $0.5\times10^6$ bits/sec from the infrared focal plane, even though the total quantity of real signals from a massive attack by 1,000 missiles in a 1-min interval amounts, roughly, to about $0.2\times10^6$ bits.

## THE DATA REDUCTION

(S) The observations acquired by the sensors aboard the satellite (in DSP the infrared telescope is but one of several sensing instruments) must be rendered intelligible by some form of data reduction. The process must include decryption and decommutation (aboard the satellite information from parallel data streams is serialized). The data

[redacted]



304-444 - O - 74 - 4

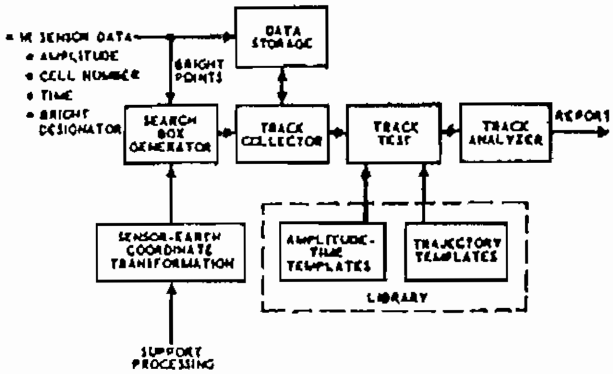


Figure 19. Data flow in the processing for detectors and reporting. (Figure classified ~~Confidential~~.)

must be corrected for calibrations and must be acted upon by algorithms that conform to a logic structure capable, first, of differentiating rocket signals from noise and, then, of ordering the information for determination of rocket launch time, launch point, heading, and rocket type (probable point of impact and arrival time are important, but are beyond determination from data with quantization intervals in the present DSP). The rocket observations and information relative to the condition of the instruments and satellite must also be organized for display, control, and distribution of messages to the ultimate users. Additional ancillary computation is neces-

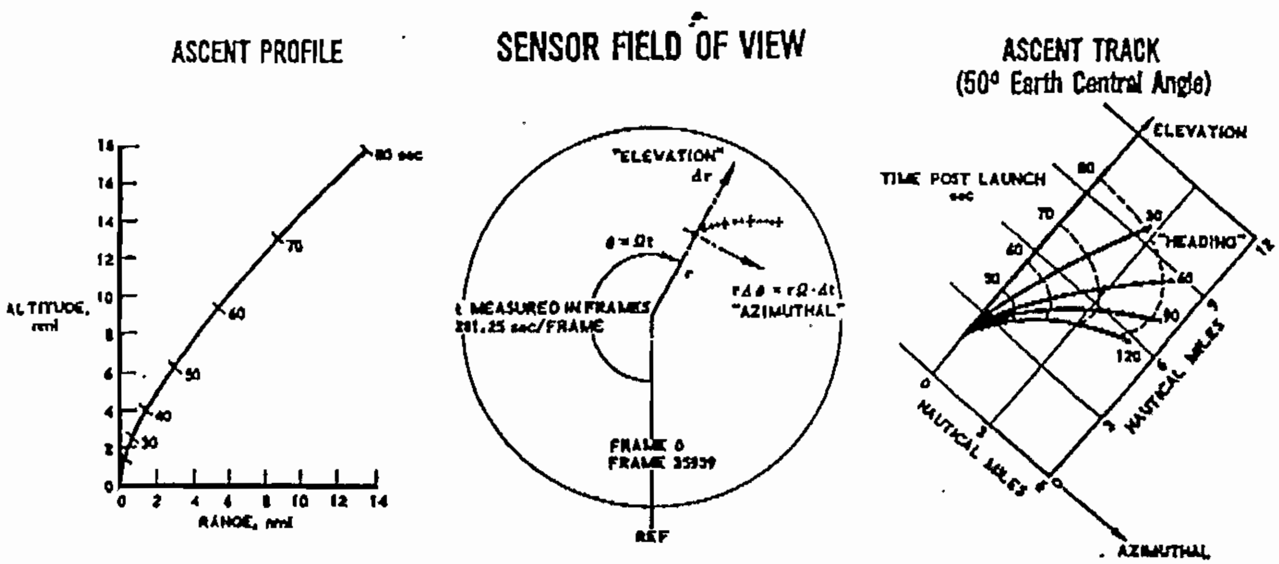


Figure 20. Target motion. (Figure classified ~~Secret~~.)

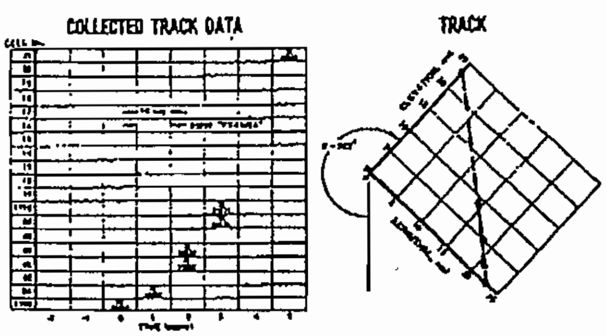


Figure 21. Formation of a track. (Figure classified ~~Secret~~.)

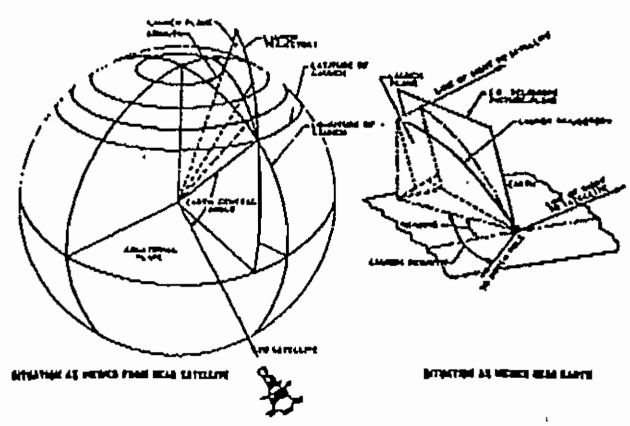

Figure 22. Estimation of launch azimuth. (Figure classified ~~Secret~~.)

sary for the maintenance of star catalogs (to determine quite precisely where the sensor is pointed), and information is needed for maintenance of the sensor and spacecraft systems. There must be a capability for computation of commands on the basis of the kind and qualities of the sensor information received, and there also must be a capability for the recording of data. There must be provision for communication between the data-reduction computer and the computers serving the recipients of the message. At appropriate points in this network, there must be provision for human monitoring and intervention.

([redacted]) The general flow of information in the DSP computing scheme is indicated in Fig. 18,* and the principal elements of the computation are shown in Figure 19. The computer itself has a capability for execution of a million instructions per second, and it is assisted by a "preprocessor," also a large computer, which performs the largely repetitive operations associated with organizing the incoming information. Logical operations are conducted within the main computer. The process is one of discrimination between noise and "real" signals; of search for further subsequent (in time) real signals in the geographical vicinity of that signal initiating the process; of assembly of collections of observations into tentative tracks; of testing of these tracks against analytical and pragmatic criteria; and, upon establishment of validity, of determination of the launch coordinates, direction, time, and type of missile. For the last, comparisons are made with stored catalogs of the characteristics of a number of rockets. The computations also involve comparisons between star sightings and predictions of star sightings, information which is used for computating the instantaneous attitude of the satellite. (The DSP satellite attitude is *controlled* rather coarsely—to one or two tenths of a degree with an oscillation period of about 20 min; but the instantaneous attitude is *determined* quite precisely to within about 3 or 4 sec of arc). Boresighting corrections, to account for the distortions due to the diurnally varying solar heating, are also made. A complete track involves as few as three independent observation points and as many as ten, so the time for the accumulation of information is 20 to 90 sec. The data processing is rapid, and it complies with a specification that calls for issuance of a message 120 sec after launch of an ICBM and 65 sec after launch of an SLBM. The Defense Support Program software has demonstrated a capability for accomplishing this processing in simulations of situations typified by more than 250 simultaneous launch events.

(U) Missile motion is an important characteristic vis a vis data reduction. Figure 20 shows a typical rocket ascent trajectory and the appearance that successive observations of such trajectories would make in telescope coordinates. The shapes of the curves connecting the successive observations, cubics approximately, are dependent upon their location in the telescope field of view, that is, the earth central angle. Once the processing has winnowed the true rocket observations from the noise—the major data processing task—the collected information would appear as shown in Fig. 21, in which the tabulation indicates the intensity and time (frame number) of observation. The construction of a track and the associated launch point and launch time then follow. The estimation of azimuth requires more information than is acquired by observations made from a single satellite. The geometrical situation is illustrated in Fig. 22, from which it can be seen that launch ascents having different headings, but identical projections on the IR telescope picture plane, are indistinguishable. There are several ways in which sufficient information can be obtained to produce azimuth: binocular viewing; monocular viewing with an instrument capable of measuring range to the observed point; and the use of information from other sources to supply the data that are missing in ordinary monocular observation. The last is used by DSP, the needed information being taken from the stored catalogs of standard ascent trajectories in the form of rocket altitude versus time.

([redacted]) The wartime situation may be characterized by the more or less simultaneous launch of a large number of ballistic missiles. Even in peace time there are occasional multiple launchings, and Fig. 23 indicates the appearance of the final collected tabular information within the computer, the geometric appearance of the tracks, and the

*Furnished by the Aerojet Electro-Systems Corp.

[redacted]

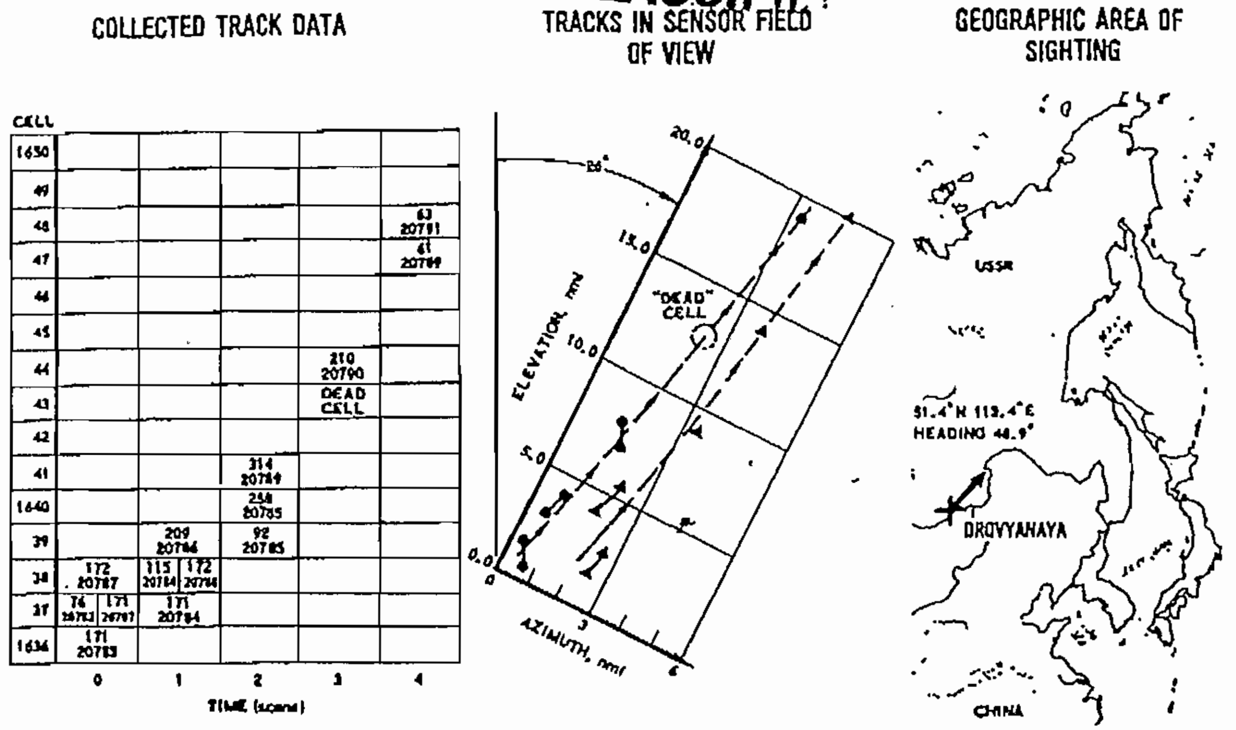


Figure 23. Simultaneous launch of two rockets. (Figure classified Secret.)

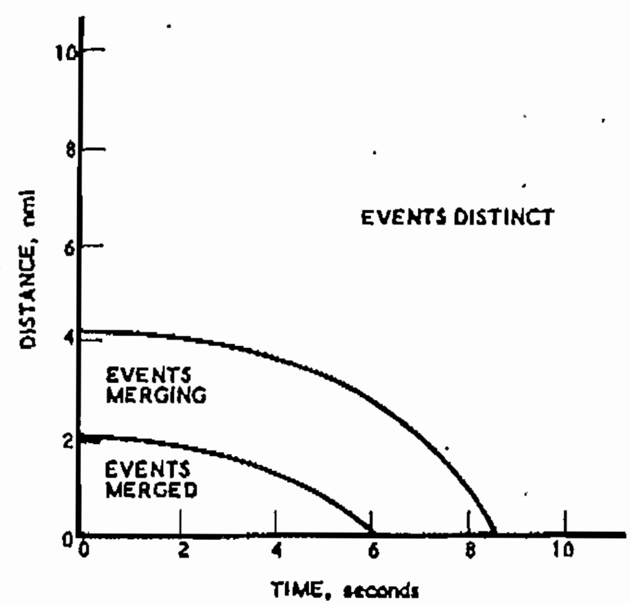


Figure 24. Event resolution. (Figure classified Secret)

geography. There is a limit, imposed by the granularity of the observations and the formulation of the logic, to how well the individual events may be resolved. The present status of DSP in this regard is shown in Fig. 24.

([redacted]) For good estimates of the probable point of impact of a missile, it is necessary to determine quite accurately the missile velocity and flight-path angle at some point along the trajectory either at, or subsequent to, the termination of all thrusting. The present DSP cannot do this. But it can, and does, supply an estimate of the width of the trajectory corridor. The values of this width depend upon the launch location relative to the observing satellite, the direction of launch, and the type of missile, as illustrated by Fig. 25.

## THE DEFENSE SUPPORT PROGRAM SYSTEM

([redacted]) The preceding sketch of the salient properties of infrared and the limitations of technological means establishes a position from which one may appreciate the Defense Support Program. The principal elements of the system are indicated



[redacted]

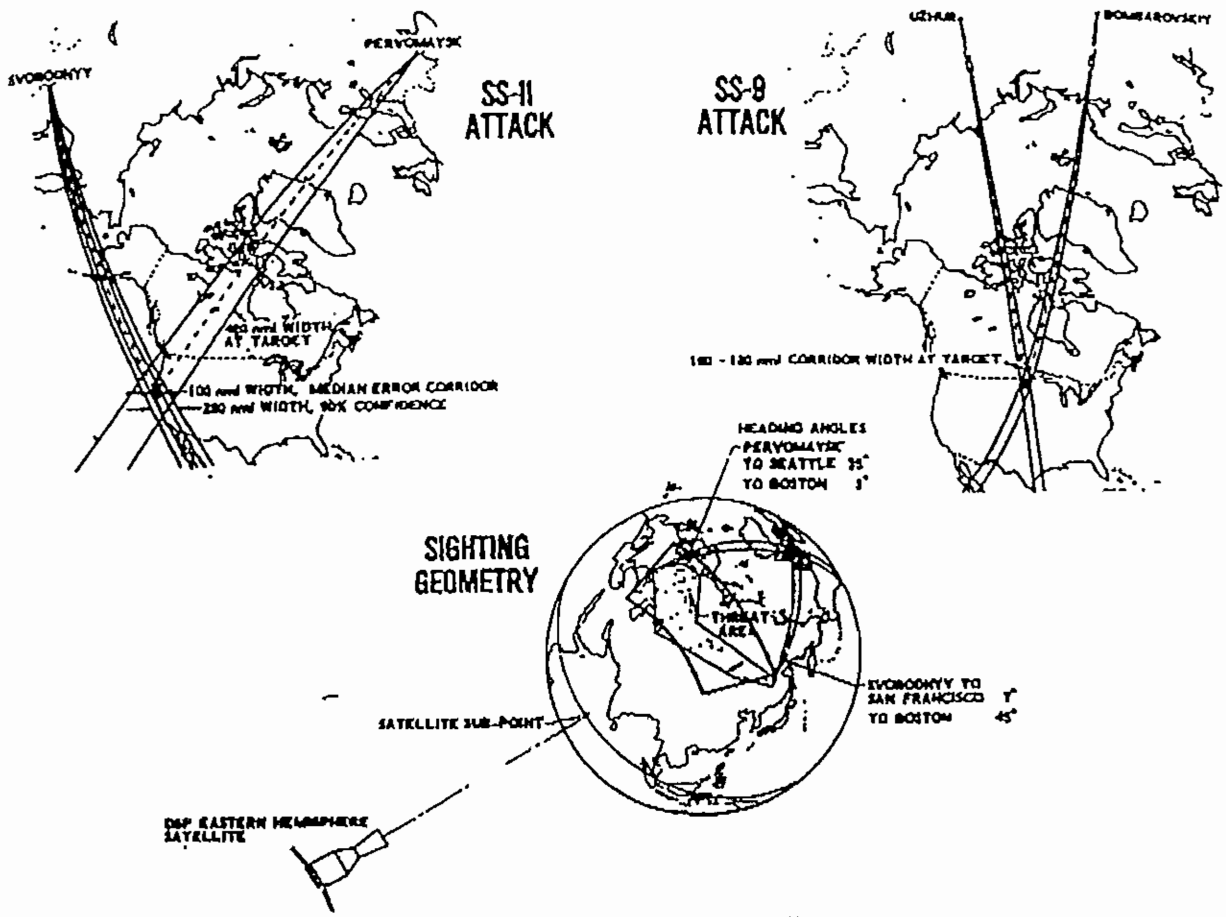


Figure 25. Attack corridor widths. (Figure classified [redacted])

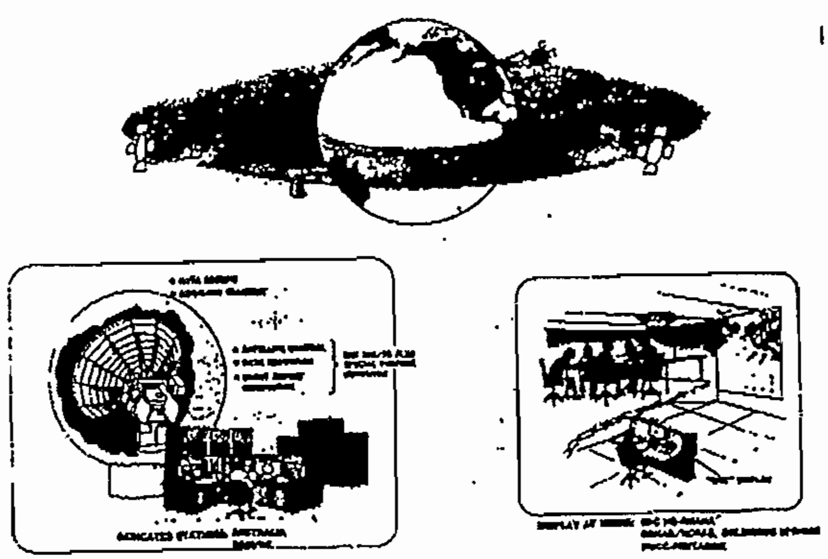

Figure 26. Elements of the defense support program. (Figure classified [redacted])

[redacted]

TABLE 1. *System characteristics. (Table classified [redacted].)*

| | |
|---|---|
| • I.R. SENSOR SYSTEM | |
| • COVERAGE | HEMISPHERIC |
| • FRAME TIME | 10 sec |
| • ACCURACY OF DETERMINATION OF LINE-OF-SIGHT | 7 arc-sec |
| • MINIMUM DETECTABLE TARGET INTENSITY | 15 kW/ster/band |
| • INTENSITY DYNAMIC RANGE | 200:1 |
| • GROUND-LINK DATA RATE CAPABILITY | 1 Mbit/sec |
| • OPERATING LIFE | >3 yr |
| • GROUND DATA REDUCTION SYSTEM | |
| • SIMULTANEOUS TARGET HANDLING | 150 |
| • INSTRUCTIONS EXECUTED/sec | $10^6$ |
| • MESSAGE CONSTRUCTION TIME | 65–150 sec |
| • ACCURACY OF REPORT PARAMETERS | |
| LAUNCH POINT | 2-10 mi |
| LAUNCH HEADING | 5-25 deg |
| LAUNCH TIME | 3 sec |
| • FALSE REPORTS (single events) | 1/week |
| • AVAILABILITY (at least one "string") | 98% |

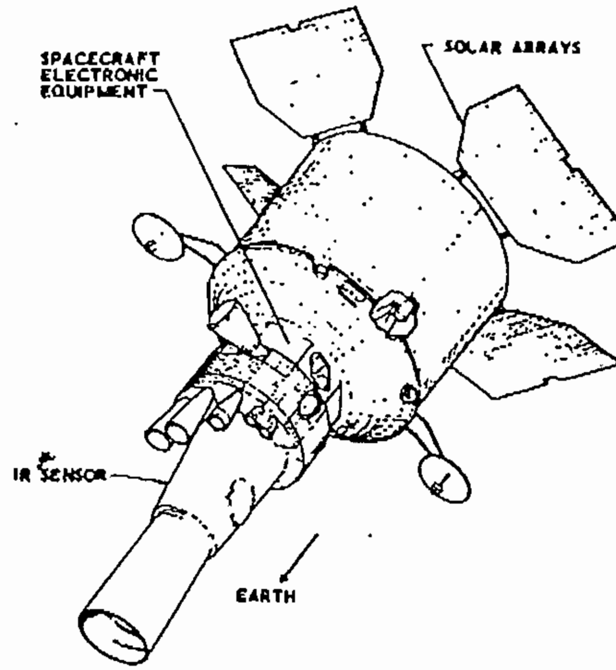


Figure 27. Defense Support Program satellite. (Figure classified [redacted].)

in Fig. 26, and general characteristics are given in Table 1. The satellite used, Fig. 27, weighs about 2,400 lb and is 22 ft long and 9 ft in diameter before deployment of the solar array paddles. Its present operational coverage is approximately as shown in Fig. 28. The satellites are deployed in synchronous orbit: one views the Chinese and Soviet land mass, and two others are deployed to cover the axis from which submarine-launched ballistic missiles might threaten.* At present, the operation of the satellites and reduction of the data pertaining to operation and to the mission take place at two ground stations, one in the Eastern Hemisphere (Australia) and one in the United States (Denver). Messages relating to the warning mission are transmitted over an extensive ground communications network as text teletype and as digital messages directly to the computers of several users.

(S) The satellites also carry a complement of instruments to detect, characterize, and supply information relevant to the diagnostic study of nuclear events (Table 2).

([redacted]) The first satellite was launched in November 1970, and in four years of operation the system has observed more than 1,500 ballistic missile launchings and 22 nuclear detonations. It has also observed many other events, ranging from refinery gas fires in Arabia to midair collisions, to military engagements. During the October 1973

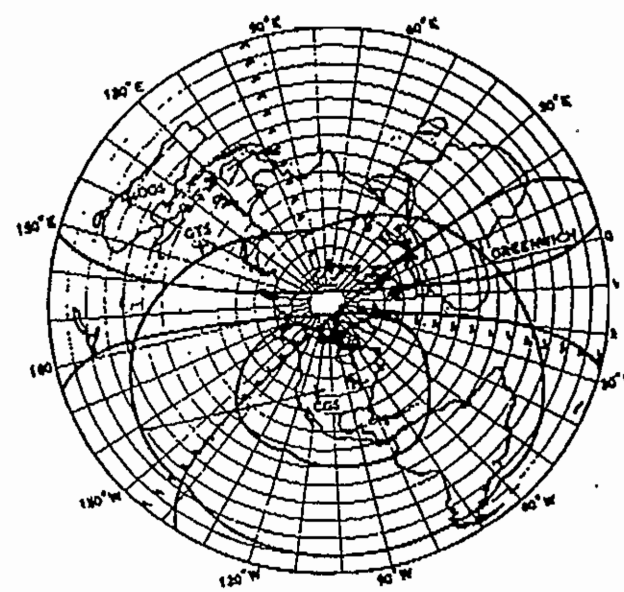


Figure 28. Geographical coverage by the DSP 1974 deployment of three satellites. (Figure classified [redacted].)

*The satellites can be repositioned at will by ground command.



UNCLASSIFIED

[redacted]

war in the Middle East, daily summaries of the IR observations were assembled. Large fires were identified, and there were numerous observations indicative of SAM activity.

([redacted]) The establishment of the system represents an expenditure in excess of a billion dollars and the efforts of roughly 2,000 people, both civilian and military. Four principal industrial contractors were engaged in this undertaking for three years prior to the first satellite launch, and to varying degrees they are still so engaged. Four satellites have been launched, and eight are in various stages of assembly. Two ground stations were built and are dedicated to the operation of the system. A ground and MILCOMSAT communications network was established, and special displays were installed at the three principal using commands. The system includes a facility for training people for operations and maintenance and a laboratory for data processing and analysis.

([redacted]) The demonstrated capability is the continuous surveillance of all regions (except for points north of latitude 81° N) from which missile attacks against the United States can be launched, giving ICBM/FOB's warning information within 2 min after launch and reports of submarine-launched ballistic missile launchings within 65 sec after launch, if these occur closer than 1,700 nmi off the Continental United States. Reports of nuclear detonation, giving time, place, and estimated yield are made within minutes of the event. The probability of launch detection is in excess of 96 percent, and the system is available more than 98 percent of the time; the false report rate for ICBM/FOB's is virtually nil, and the false report rate of SLBM's is of the order of several per week under unfavorable solar conditions (Northern Hemisphere summer).

## SOME NOTES

(U) The quantity of IR signature information acquired is very large, even though restricted to the passband interval 2.69 to 2.95 microns. The principal threat missiles have been seen repeatedly, from several sites, under conditions similar to those that might prevail at the onset of hostilities. Some technical questions still remain, some unexplained phenomena have been encountered, and some information of a scientific nature has been obtained.

TABLE 2. *Nuclear detonation detection and monitoring sensors. (Table classified [redacted]ct.)*

| | |
|---|---|
| GEOGRAPHICAL LOCATION | • ATMOSPHERIC BURST LOCATOR [illegible]<br>• INFRA-RED TELESCOPE<br>• X-RAY LOCATOR<br>• FLUORESCENCE ALTIMETER } [illegible] |
| TIME OF BURST | • ATMOSPHERIC BURST LOCATOR<br>• PHOTODIODES<br>• CODED RETICLE X-RAY LOCATOR<br>• X-RAY SPECTROMETERS [illegible] |
| YIELD | • ATMOSPHERIC BURST LOCATOR<br>• PHOTODIODES [illegible]<br>• X-RAY SPECTROMETERS<br>• NEUTRON SENSOR [illegible]<br>• PROMPT GAMMA DETECTOR |
| DIAGNOSTIC | |
| YIELD TO MASS RATIO | • DELAYED GAMMA DETECTOR<br>• NEUTRON SENSOR |
| STAGING | • PROMPT GAMMA DETECTOR<br>• PROMPT GAMMA-FLUORESCENCE DETECTOR |
| OPTICAL TIME-HISTORY | • PHOTODIODES |
| ENVIRONMENT MONITOR | • ENERGETIC PARTICLE DETECTOR [illegible] |

(U) Close examination of the many time–intensity histories (see Figs. 4 and 5) reveals that the variation in the peak intensity, due presumably to all causes (missile-to-missile variation in propellant, propellant utilization system operation, flight profile, and variation in atmospheric attenuation), occurs to the extent of a factor of about two. The variation when the rocket is still deep in the atmosphere is much greater—perhaps by a factor of ten. The atmospheric attenuation computation itself still leaves much to be desired. Similarly, the intensity variation with viewing aspect (side view, or nose-on or tail-on viewing of the plume) is not altogether resolved. A number of factors confound this latter effect; fuel type—which helps to establish whether the plume is optically "thick" or "thin"—rocket speed, and rocket altitude. A reduction in apparent intensity accompanies nose-on viewing for most first stages, and an increase in intensity accompanies such viewing for some second stages at high altitudes and high speeds. The analog signal accompanying the traverse of the plume by the DSP detectors really is still unknown, for only the peak intensity is reported: the rest must be inferred.

([redacted]) Despite considerable measurement and study, the explanation for a curious phenomenon has not been found; and the effects are of some importance for prolonged use of the sensor system. The detector cells are cooled by a special radiator, a device consisting of second-surface mirrors that generally radiate to deep space, but are intermittently exposed to the sun. Careful, long-term

[redacted]

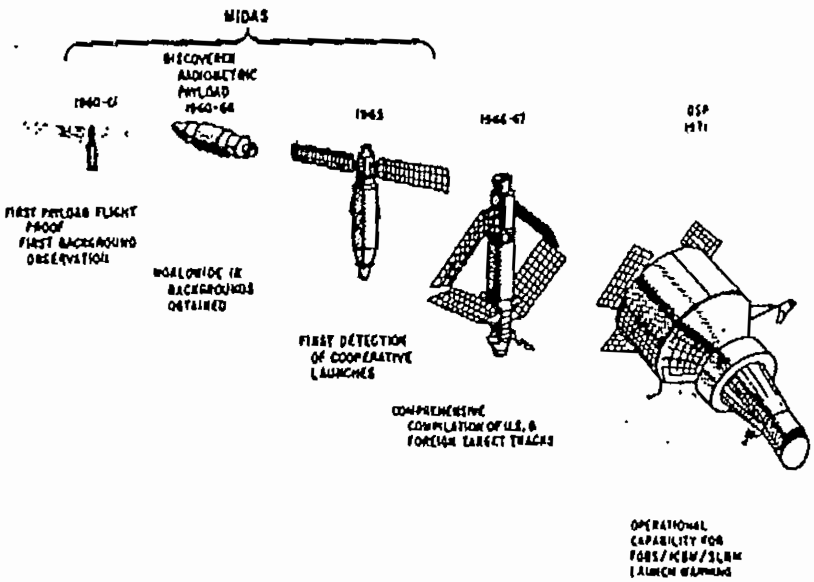


Figure 29. Milestones in the development of surveillance satellites. (Figure classified [redacted].)

measurements on four satellites have established that there is a slow, long-term increase in the absorptivity of these mirrors. The best hypothesis, in support of which there is some evidence, is a contamination from outgassing which reacts to exposure to the solar ultraviolet. The long-term effect is appreciable—a 25° K warming of the focal plane over a period somewhat longer than three years.

(U) The IR telescope does occasionally see infrared radiating stars. Advantage is taken of these sightings to "boresight" the telescope and to calibrate the variation of the boresight angle with the diurnal variation of spacecraft temperature. The sightings of the IR stars has increased the known catalog of such stars—about one-fifth of the celestial sphere is swept over the course of a year—and, uncovered a cyclical variation in the infrared intensities of some of these stars. The variation in infrared intensity is not in phase with variation in the visible spectrum.

## SOME DISCUSSION

([redacted]) The *why* for surveillance for early warning seems clear. The survivability of the bomber force is strongly dependent upon a warning that precedes missile impact by about 7 min. Warning, plus perhaps more detailed information regarding the size and constitution of the attack, can assist in the determination of the appropriate response from our *Minuteman* and *Poseidon* forces. These are military considerations. There is also a civil consideration, neglected for almost two decades: shelter. The civil defense effort of the 1950's, greeted with indifference by the general population, might be revived on a sounder basis. In the earlier era, a credible warning system did not exist.

([redacted]) The success of the system is attributable to a lengthy period of detailed phenomenological and technological research and to conservatism in design. The beginnings of infrared go back over nearly two centuries; but the technical evolution of the surveillance satellite took place in a period of slightly more than a decade, and some milestones in this evolution are shown in Fig. 29. From this work there emerged a design intended for further research and development, and direction specifying an intent to employ the design operationally came early in that development. The conservatism that characterized this development is reflected in the performance. The device, intended for operation against rockets radiating at intensities of the order of 1 MW/sterad in the operating bandwidth, is used operationally (and has been demonstrated to be successful) against rockets radiating at intensities of less than 100 kw/sterad, and the specification for useful lifetime on orbit, 15 months, has been exceeded by a factor approaching three. This attests to the design conservatism, redundancy, and reiterated thorough ground check-out testing.

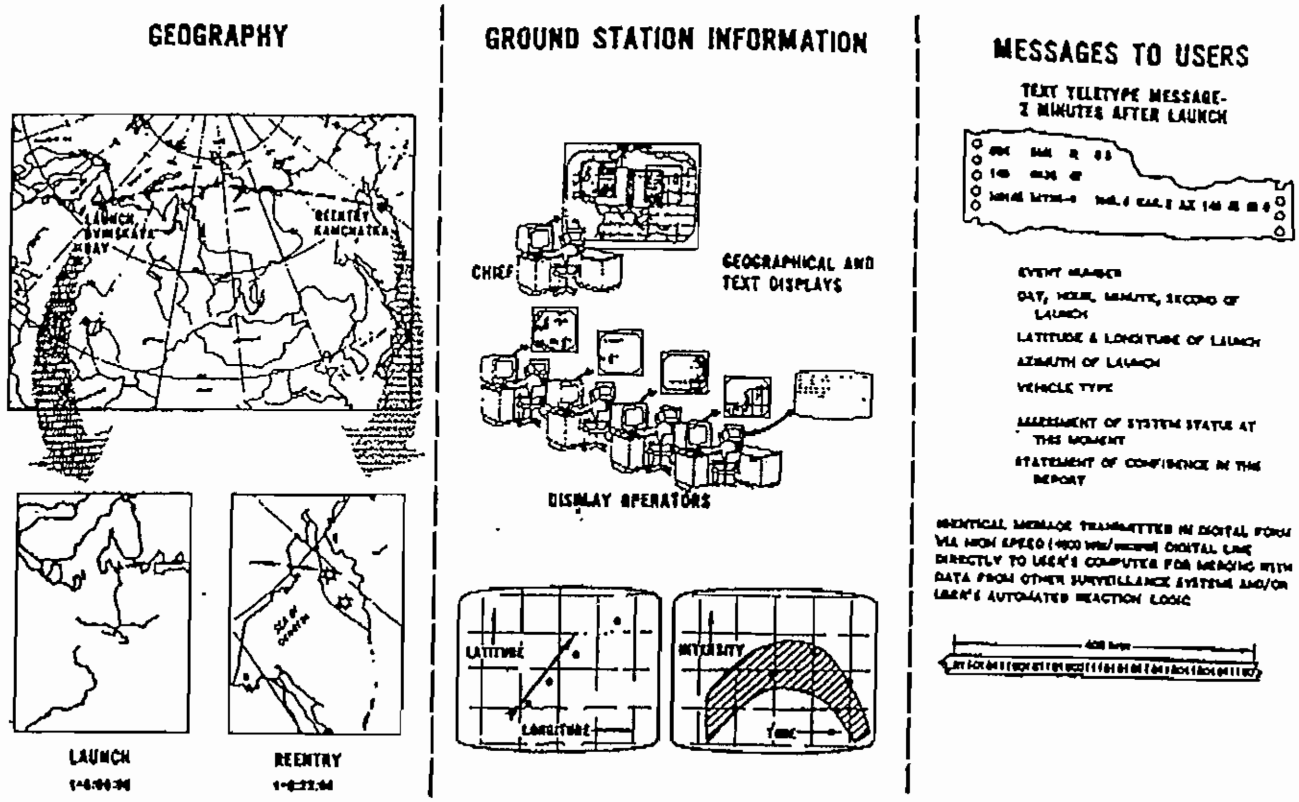


Figure 30. System information, data displays, and messages. (Figure classified [redacted])

([redacted]) The system has limitations. It seems that solar interference cannot be obviated entirely by software, and in synchronous equatorial deployment, a region near the poles is not covered. Also, the overall system performance under conditions simulating massive raids is scenario dependent.

([redacted]) Some exploratory research indicates that the 4.3-micron wavelength region may be a desirable future consideration, since the solar-reflection problem is much diminished and the plumes from some, although not all, rocket fuels are bright in this band. The staring mosaic has been offered as another possibility to defeat solar interference. The detection principle here is response to a change in the scene; but to get rejection of the background simultaneously with response to a massive raid may necessitate a very large number of detectors, perhaps two to three orders of magnitude more than in the existing design. The geographical-coverage limitation in the existing design can be overcome by deploying the satellites in an inclined elliptic orbit so that they would simultaneously view the Chinese and Soviet land masses and the Continental United States. (A number of the current DSP design satellites have been constructed to incorporate a capability for inclined elliptic, as well as synchronous equatorial, deployment.) At least two satellites, then, are needed to continuously view the Chinese and Soviet areas. A virtue of the synchronous equatorial deployment is that while its areal coverage is not much different from that in inclined elliptic, the particular geographic area that is covered is always the same. Another possibility—and an experiment is now ready to verify the feasibility of this—is to observe polar launches by expanding the field of view to look above the horizon.

([redacted]) The *whither* for surveillance by satellite, at least for the early warning mission, also seems clear. Outage-free coverage, now achieved by multiple-satellite deployment, is a recognizable goal for individual satellites. True global coverage by the entire system is another. A reduction in the quantity of information that must be processed and then later rejected as noise is a third. Future systems also should be harder in the nuclear sense.

(●) Not so clear is the case for seeing ever dimmer targets. About a decade ago there was apprehension that by using additives, or by other means, the intensity of plumes might be so reduced as to preclude detection. A considerable experimental effort in this connection was planned, but it was abandoned because of the contention that the necessary modifications to the rockets would considerably reduce the throw weight and/or range. Such penalties in throw weight and range (and retrofit expense) may be tolerable to the Soviets, who seem to have an excess of both. However, there seems to be a theoretical limit to the reduction in intensity that can be achieved, and this may not be too far below the capability of the present sensor design. Nevertheless, reconsideration of the possibilities is indicated.

(U) Figure 30 illustrates the status of surveillance by satellite as currently perceived. The improvement in the state of the art since the time the DSP design was laid down is thought to be one to two orders of magnitude, which would admit advancing from a 10-sec-scan-time, 20-kw/sterad threshold device to a ½-sec-scan-time, 2-kw/sterad threshold device. The kinds of events that would become visible to such a device are depicted in the figure.

(●) The military necessity for observing such events, in the face of the costs that the development of such systems would entail, is not clear. It may be that the strategic requirements for the control or disposition of forces may necessitate the acquisition of more detailed information than that needed only for warning. Perhaps coupling of a surveillance system with a weapon, now forbidden by SALT, will drive a need for a quantum jump in surveillance by satellite.

(●) No discussion of surveillance can be complete without at least some reference to radars, which still constitute part of the national overall surveillance system. For attacks at very long range, some facts of geometry and ballistics become awkward for radars: the earth is round, but electromagnetic waves propagate linearly, and so detection along the ballistic path becomes either very difficult at very long range or too late when resumed at short range. Ballistically, it is also possible to force the radar to detection only at short range by employing "depressed" (that is, nonoptimum for range) trajectories. Depressed trajectories are not in use, and a limit to depression may be imposed by aerodynamic heating, range, and reentry considerations. Nevertheless, it is an interesting tactic, with considerable significance for surveillance by radar. It does not affect surveillance by satellite. The possible use of both systems simultaneously has been justified by the argument that coverage by dual phenomenology offers confirmation and wards off defeat of both systems either by a new countermeasure or the occurrence of some unanticipated phenomenon. But this is true only if both systems do indeed cover in such a way that the warning message is timely.

(●) The existence of surveillance-by-satellite systems poses some global military–political questions. Are they stabilizing (that is, almost as deterrent as the existence of the Triad)? Would it be desirable that the opponents have their system, too? What are the consequences of a presumptive decision on their part not to field a system? An even more diligent search for the Achilles' heel in our defensive posture? Overt espousal of retaliation only, but with a covert intent to attack first?