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DETECTION OF HIGH ALTITUDE EXPLOSIONS BY OBSERVATION OF AIR FLUORESCENCE

BY

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Detection of High Altitude Explosions By Observation of Air Fluorescence

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I. INTRODUCTION

When a nuclear explosion occurs at very high altitude or in space some 70% of the energy radiated from the fireball is in the form of x rays. This is a consequence of the high surface temperature of the fireball which immediately after the explosion is several tens of millions of degrees Kelvin. Detection systems based on observing these x rays or effects produced by them have an obvious advantage over other methods. In the case of an explosion which occurs well above 100 km having a 1 Kev surface temperature (typical of a device which has been purposely shielded) the x rays reaching the earth will be absorbed in the upper atmosphere. Directly below the explosion most of the energy is deposited in a 30 km wide layer centered about 80 km. From the properties of the upper atmosphere presented in Table 1 it can be seen that ionization and excitation of molecular nitrogen will be the principal channel of energy loss. The x rays ionize nitrogen producing energetic photo-electrons, and leaving many of the N_2^+ ions in excited states. In turn electrons as they slow down produce other excited N_2^+ and N_2 molecules until they are thermalized. The slowing down time is of the order of 10^{-6} seconds. (The detection schemes to be discussed in this paper are based on observing the fluorescence radiation of the excited N_2 or N_2^+ either from the ground or from satellites. Of the radiation produced one of the strongest features is the (0-0) band of the N_2^+ first negative band system. A large part of the energy radiated in this band is concentrated in the P and R branches within 20Å of 3914Å. The N_2 and N_2^+ energy level schemes are presented in Figs. 1 and 2. More fluorescent energy than that radiated in the first negative system is probably found in the first positive system of N_2 located in the near infra-red.

The concept of using the air fluorescence pulse as a method of bomb detection was developed at the Los Alamos Scientific Laboratory by Herman Hoerlin, Donald Westervelt and others. This group is also responsible for the development of practical field detectors based on observing the λ3914 radiation from the (0-0) 1st negative band of N_2^+. These detectors utilize a wide angle lens imaging all of the sky through an interference filter on the cathode of a photomultiplier tube. Another system, operating on the red and infra-red radiation of the N_2 first positive system, is being developed by a group at the Atomic Weapons Research Establishment under Mr. Ronald Wilson. This system uses a wide open, filterless, array of photo conductive cells.

The flourescence from any small part of the sky, or even from the entire sky visible from the ground lasts for a very short time. Thus if the X ray flux is large enough there is the possibility of recognizing this pulse even against the background of intense sky light in the daytime.

Let the nuclear explosion take place at a distance R above the top of the layer in which the X rays are to be absorbed and at a zenith angle ζ for an observed located on the surface of the earth at P (Fig. 3). The X rays arrive first at the point Q at the top of the layer along the line from O to P. The total photon travel time from O to Q and then Q to P is the same as that from O to M and then M to P were M is at the bottom of the layer. This is true even though the photon is an X ray on the first leg of the trajectory and on the second leg it is a low energy quantum. Thus the duration of the fluorescent pulse in the direction of OP is determined by the electron stopping time and is consequently about 10^{-6} seconds. The total travel time along any other path, say ONP from O to P is longer than that along OQMP and the fluorescence will begin later in directions other than along the line of sight from P to O. In particular there will be a cone of directions enclosing OP for which the shortest photon travel time is just 10^{-6} seconds longer than that along OP. In such directions fluorescence will just seem to begin as it is dying along OP and as the fluorescence observed from P decays within this central zone it will appear to spread out in an expanding more or less elliptically shaped band until it finally disappears over the horizon. For the case of $\zeta = 0$, O at infinity and the altitude of fluorescence 80 km the half angle θ' of the cone of initial fluorescence is given approximately by

$$8 \times 10^{6} (\sec \theta' - 1) = c \times 10^{-6} \text{ cm} \qquad (1)$$

where c is the velocity of light. θ' is thus about 5.5° and the solid angle Ω_1 subtended by this zone from P is $\pi \theta'^2$ or about 2.5×10^{-2} sterad. The fluorescing circular band at any subsequent time will subtend approximately the same solid angle and persist for approximately the same time. Thus some 300 μsec will be required for the ring to sweep across the entire sky. A great deal of work relating to the absorption of X rays and the production of the fluorescence pattern has been done by E. Bennett at Los Alamos. More recently Tomlinson of USAEL has been active also in developing a simplified but very flexible treatment of this problem.

To estimate the range R at which a photo-electric detector situated at P could detect an explosion at 0 by observing this fluorescence signal it is necessary to compute the number of photo-electrons produced at the detector during the time τ for which it integrates the coherent signal received from the expanding fluorescent ring. These signal photo-electrons must be compared with the incoherent stochastically distributed photo-electrons produced by the background sky light in the spectral band to which the detector is sensitive during the same time interval.

At any moment let an element of fluorescing surface (Fig. 4) of area Σ be at a distance r from a horizontal detector whose aperture has an area A. Let the surface brightness by B_s in photons per cm^2 per second per unit solid angle. Then

$$B_s \, \Sigma\mu_1 \frac{A\mu_2}{r^2} \qquad (2)$$

signal photons pass through the aperture per second. Here μ_1 and μ_2 are the cosines of the angles between the surface normals to Σ and A and the line joining P and Σ. Expression (2) may be written as

$$B_s \; A \; \Omega_1 \, \mu_2 \qquad (3)$$

where Ω_1 is the solid angle subtended by Σ. If the instrumental solid angle Ω in which the optical system will pass photons includes Ω_1, T is the transmissivity of the photometer and $\mathcal{E}$ is the photon efficiency of the detector then, neglecting μ_2,

$$S = B_s \; \Omega_1 \, A \, T \, \epsilon \tau \qquad (4)$$

will represent the number of photo electrons produced during a time τ. In this approximate treatment mean values are being used. For simplicity we suppose that some surface subtending a solid angle Ω_1 within the field of view has an average brightness B_s during the entire time τ.

On the other hand, if the background sky brightness is $B_{\lambda b}$ in photons/cm^2 sec ster Å at the sensitive wavelength of the photometer and the photometer has an optical bandpass of W Å, then

$$N^2 = B_{\lambda b} \; W [\Omega A T] \, \tau \epsilon \qquad (5)$$

is the number of noise photo-electrons produced during the time τ. Here Ω is the entire solid angle of the photometer. Since these photo-electrons are stochastic the ratio of signal to noise is proportional to

$$\frac{S}{N} = B_s \frac{\Omega_1}{\sqrt{\Omega}} \sqrt{\frac{AT\tau\varepsilon}{B_{\lambda b} W}} \qquad (6)$$

Or if

$$\Omega_1 = f\Omega \qquad (7)$$

$$\frac{S}{N} = B_s \; f \sqrt{\frac{AT\tau\varepsilon}{B_{\lambda b} W}} \qquad (8)$$

If some criterion such as S/N = 5 is required for detectability then the minimum detectable signal will be

$$B_{so} = \frac{S}{N} \frac{1}{f} \sqrt{\frac{B_{\lambda b} W}{[\Omega AT] \tau\varepsilon}} \qquad (9)$$

In any optical system the product ΩA must remain invariant throughout the apparatus. Where interference filters are used to delimit a narrow optical band pass W the solid angle of the rays passing through the filter cannot exceed

$$\Omega' = \frac{2\pi\mu^2 W}{\lambda} \qquad (10)$$

where μ is the index of refraction of the filter. Hence if the usable surface area of the filter is A then

$$\Omega A = \Omega' A' \qquad (11)$$

For a 20 Å band filter at 3914Å of 20 cm^2 area ΩA is only 1.2 cm^2 ster. An obvious advantage accrues to a system which need not use interference filters to avoid collecting too much of the background sky spectrum.

II. GROUND BASED SYSTEMS UTILIZING N_2^+ BLUE FLUORESCENCE

A system based on detecting the (0, 0) band of the 1st Negative band system of N_2^+ may be considered as an example. The background skylight for the sun near the zenith has a brightness of 4×10^7 Rayleighs/Å, or $10^{13}/\pi$ photons/cm^2 sec ster Å.* If W is taken as 20Å and T as 0.5 the product $[\Omega AT]$ is 0.6. For a 120° field of view f will be 1/40 1/4

*In this paper the unit of surface brightness to be used is the Rayleigh (R). It is defined as $4\pi \times 10^{-6}$ times the surface brightness in photons/cm^2 sec ster. It is thus an apparent emission rate of 10^6 per second per cm^2 column. For photons in the 1st negative (0-0) band hv is 5×10^{-12} ergs so

$$1\ R \cong 4 \times 10^{-7}\ ergs/cm^2\ sec\ ster$$
$$= 4 \times 10^{-14}\ watts/cm^2\ ster.$$

If the integrating time is taken at 100 μsec and ϵ as 0.1 then for S/N = 5 the minimum detectable fluorescence brightness will be

$$B_{so} = 2 \times 10^{12} \text{ photons/cm}^2 \text{ sec ster}$$
$$= 25 \times 10^6 \text{ Rayleighs}$$
$$= 10^{-6} \text{ watts/cm}^2 \text{ ster}$$

To determine what bomb yield and range will combine to produce such a minimum brightness it is necessary to know the efficiency η with which X ray energy for a given bomb temperature is converted to fluorescent energy in the selected band or band system. It is also necessary to know the yield in X ray energy of 1 kt of bomb yield. Since 1 kt is 4×10^{19} ergs the bomb yield in ergs of X rays

$$E_x = 4 \times 10^{19} \; Y_x \qquad (12)$$

Where Y_x is the yield in kt of X rays is about 0.7 of the total bomb yield Y in kt. At a distance R from the explosion the energy flux in X rays per unit area is

$$F_x = \frac{E_x}{4\pi R^2} = \frac{10^9}{\pi} \frac{Y_x}{R^2} \; \frac{\text{ergs}}{\text{cm}^2} \qquad (13)$$

where Y_x is in kt and R is in km. Thus

$$R = \sqrt{\frac{10^9}{\pi F_x}} \sqrt{Y_x} \qquad (14)$$

If F_x is the flux which produces B_{so} then R is the range of detection per kt. It varies as the square root of Y_x. Since the radiative lifetime of the $B^2\Sigma u^+$ state of N_2^+ is short F_x is transformed in 10^{-6} seconds with an efficiency η

into fluorescent energy isotropically radiated. Thus

$$B_s = \frac{\eta F_x}{4\pi\, 10^{-6}} \times 10^{-7} \frac{\text{watts}}{\text{cm}^2 \text{ ster}} \qquad (15)$$

Taking η as 10^{-2}

$$F_{xo} \cong 10^4 B_{so} \cong 10^{-2} \text{ ergs/cm}^2 \qquad (16)$$

Thus

$$R \cong 1.5 \times 10^5 \sqrt{Y_x} \text{ km} \qquad (17)$$

A 1 kiloton explosion could be detected at 150,000 km, a 10 megaton explosion at 15 million km.

The range as it is inversely proportional to $F_{xo}^{1/2}$ is also inversely proportional to $B_{so}^{1/2}$. Thus, according to (9) it varies only as the fourth root of all the instrumental factors and environmental factors which determine the minimum detectable signal except the ratio of the instrumental solid angle to the solid angle instantaneously subtended by the fluorescent ring. Given prior information about the direction of the explosion and a clear sky it would be foolish to make f less than unity. However, such a maximizing of f must perforce be accompanied by a reduction in τ since the pulse length varies almost as f^{-1}. $[\Omega AT]$ may be kept constant by an increase in A.

Hence, the range is in reality proportional approximately to the fourth root of all variables. Even such an advantage in reducing the field is to be gained only by a multi-channel system designed so that one channel is sure to be directed toward the explosion because in fact B_s decreases sharply for other directions. The possibility of using narrow field systems has been the subject of much discussion. It is, however, apparent that in practice there is little to be gained in range from application of such a technique. The principal arguments for the multichannel detector will concern pattern recognition for the purpose of discriminating against false alarms and determining the direction of the explosion. However, as false alarms from lightning are most apt to occur with overcast skys when the fluorescent ring pattern will be unrecognizable, the use of this technique for discrimination is of dubious value.*

As for the other factors which determine B_{so} decreasing the optical bandpass W for the ideal case being treated here does not cause a reduction in the threshold brightness. This is because B_{so} depends on the ratio $W/\Omega A$ and ΩA is directly proportional to W. In practice the signal photons are also distributed over a spectrum of frequencies and S really depends on the integral

$$B_s = \int_W B_{s\lambda} \quad W_\lambda \quad d\lambda \qquad (18)$$

where W_λ is the spectral transmissivity of the filter. Thus decreasing W below the range of wavelengths in which there is an important contribution to $B_{s\lambda}$ means that to achieve a given B_{so} larger peak values of $B_{s\lambda}$ are necessary.

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*Overcast has the effect of somewhat reducing the overall brightness and smearing the fluorescent signal in time. These effects have been studied in detail by H. Stewart. They do not reduce seriously the efficiency of an all sky system designed with an electrical bandpass matched to the all sky signal.

III. GROUND BASED BROAD BAND RED SYSTEMS

The limitations imposed on ΩA by the size of practical interference filters have led to various suggestions for and, indeed, to the development of detecting systems based on spectral features in the nitrogen fluorescence radiation other than the first negative system. For example, if the first positive system in the near infrared is to be detected no filter at all need be used since the energy in this system is spread over a broad spectrum. The detector can be an array of solid state, phot-conductive cells with an area as large as 10^4 cm^2. With T=1 and Ω about 3, the value of $[\Omega AT]$ is 3×10^4 cm^2 sterad. $\mathcal{E}$ for such cells is about 0.6 so that in $\mathcal{E}[\Omega AT]$ there is an advantage of 1.5×10^5 with this device. However, W is perhaps 2000Å and $B_{\lambda b}$ is 1.5×10^6 R/Å so that $B_{\lambda b}$ W is about four times as large as in the 3914 Å system. Thus B_{so} will be reduced by a factor of $\sqrt{4 \times 10^4}$ or 200. The result would be an increase in range by a factor of about 15 to about $2 \times 10^6 \sqrt{Y_x}$ km, if the efficiency for exciting this band system is taken to be the same as that for exciting the 3914Å (0-0) band by 1 kev X rays.

These range figures are valid only under the assumption that the limitation in signal recognition is set by the shot noise produced in the detector by incoherent background radiation. In practice, there exists for either of the systems discussed a family of spurious external sources of coherent photon pulses which can be confused with bomb produced fluorescent pulses. Unless a method is developed either to eliminate such pulses or recognize them as spurious, they obviously constitute a limitation on the reliability of the system. Furthermore, the effective range may be determined by the signal to noise characteristics of the discrimination channel which under false alarm conditions must be at least as high as that of the true signal channel when the signal in the signal channel is B_{so} if this limitation is not to prevail. This point will be examined again in connection with the discrimination problem.

The ranges estimated here assume that the bomb temperature is 1 kev (typical for a device which has been purposely shielded). If the temperature is considerably lower, the result perhaps of additional shielding, the x rays are absorbed higher in the atmosphere. For example, from a bomb effectively at 0.1 kev the absorption peak rises from 80 km to 110 km for a zenith burst. When the burst is on the horizon it shifts from 100 km for a radiating temperature of 1 kev to 150 km for a temperature of 0.1 kev. According to calculations by Rees these altitudes go to 175 km and 300 km if the temperature is 10^5 °K (12 eV).

As far as the 1st negative band at 3914Å is concerned the reduction in fluorescent brightness which results is only by a factor of about two for a zenith burst when the temperature is reduced to 100 eV. This reduces the range only by about $\sqrt{2}$. But going to as little as 10^5 °K will cause a full order of magnitude decrease in B_s compared to 10^7 °K for a loss of a factor of 3 in range.

When the x ray absorption takes place at high altitude atomic oxygen will play an important role in the energy transformation. Some states of O and O^+ will even be excited at a much higher rate than the N_2^+ B $^2\Sigma_u^+$ state. However, the interesting transitions in O and O^+ are all from metastable levels. The fluorescence energy is released so slowly that the instantaneous brightness is low, the integrating time long. No scheme based on observing such lines appears to have an advantage over those built around the N_2^+ and N_2 bands. This same defect afflicts schemes to utilize the low backgrounds in twilight for detecting shots over the horizon.

IV. SATELLITE BASED FLUORESCENCE DETECTORS

The fluorescence observed from a satellite orbiting far above the emitting layer has several important characteristics which differ from the fluorescence observed on the ground.

1. If the burst and the detector are both above the fluorescing layer there is a time delay of some 200 microseconds between the arrival of photons at the detector from the bottom of the layer with respect to the arrival of photons from the top of the layer for the simplest case. Thus if stopping times and radiating life-times are short the peak brightness is reduced by a factor of about 1/200. However the pulse lasts for a longer time and the area of the radiating zones is larger.

2. Although the solid angle subtended at the detector by an individual volume element is related to that subtended on the ground by the inverse ratio of the square of the distances to the fluorescing layer the total contributing volume of fluorescence per unit solid angle is larger for the satellite detector if it is more than 80 km above the layer.

3. The attenuation by absorption and scattering, particularly in the ultra-violet is much less between the layer and the satellite. This opens up the possibility of observing the Lyman-Birge-Hopfield system of N_2 lying between 1200Å and 2200Å.

4. The background is very different. In the visible it is higher but in the ultraviolet, particularly below 2100Å it is much smaller than the day sky background.

Thus, although the fluorescent signal must be collected over a longer time from a satellite than from the ground thereby increasing the number of noise photons received this disadvantage is countered by several other factors. The fluorescing area is much larger per unit solid angle, the solid angle needed to encompass the entire visible fluorescing layer is much smaller, particularly for a distant satellite and in the ultraviolet the background brightness of the albedo is very low. In (9) this amounts to an increase in f and τ and a decrease in $B_{\lambda b}$ against a decrease in Ω. Thus, the threshold B_{so} will generally be considerably smaller for a satellite detector even if the light grasp G or $\{A \Omega T\}$ and the photoelectric efficiency ε are the same. This is sufficient to overcome the reduction in brightness B_s for specified values of R and Y_x for the Lyman-Birge-Hofield (LBH) system as compared to 3914 observed from the ground. Fortunately the lifetime of the a $^1\Pi g$ state is some 1.7×10^{-4} seconds, slightly shorter than the travel time delay. Hence the reduction in brightness and increase in τ because of this factor is not great.

Furthermore, since half the LBH energy escaping upward after attenuation is emitted between 1750 and 2050Å a larger optical bandwidth W may be employed. This means that $A \Omega$ can be very large. ε is also high for photomultipliers in this spectral region. Therefore, LBH fluorescent detectors in a satellite system at several earth radii can apparently attain a range an order of magnitude above the ground based 3914 all sky system. Since only two or three such satellites would monitor all of space without holes and since most importantly the lightning discrimination problem and weather limitations disappear this method seems to merit very serious study.

However, it would seem strange to use a satellite system designed to detect indirect effects of bomb X rays where direct detection of the X rays is possible. If fluorescence systems cannot compete with satellite based direct X ray detection for range the argument for use of fluorescence detectors must be based on the advantages accruing from the comparative convenience, reliability, and flexibility of a ground based system.

V. DISCRIMINATION AGAINST FALSE ALARMS

There are two outstanding discrimination problems confronting ground based fluorescence detector systems which use the 1st negative and 1st positive systems of nitrogen . One is common to both the blue and the red photometers. Lightning excites radiation at the wavelength of both band systems strongly and some pulse shapes from lightning closely resemble bomb fluorescence pulses. This causes two sorts of problems. For one during severe lightning storms the triggering rate for the detectors becomes so high that a forbiddingly large quantity of records would be accumulated for off-line analysis. Secondly, even after such analysis an inadmissably large number of ambiguous signals would remain. One discrimination technique which can be used, in principle, on line to reduce the triggering rate and off line for analysis also is spectral. In X ray excited spectra the ratio of 3914Å band intensity to 4140Å intensity is 15 and the ratio of 3914Å to 6563Å intensity is 30. Evidence so far available shows that these ratios are much smaller in lightning spectra. At the present time a criterion for triggering in the blue system is that the ratio of 3914Å to 4140Å be larger than some predetermined ratio - less than 15/1. Evidence concerning the prevalence of strong H_α emission in lightning spectra as a result of water vapor dissociation has focussed attention on 6563Å as a potential discrimination channel. However, the data available on lightning spectra is very skimpy indeed. It seems clear that if spectral discrimination is to be employed and is not to limit the range of the bomb detection system it must be demonstrated that whenever threshold brightness B_{so} is obtained in the signal channel for a lightning stroke the probability is higher than some predetermined value that the signal to noise in the discrimination channel also be above the threshold level. This is a criterion which concerns not only the apparent signal brightness of the sky at the discrimination channel wave length relative to the signal channel wavelength but background sky brightness and all of the other factors which go to determining signal to noise ratios in a detector system. To arrive at an acceptable level of safety for the application of this criterion an extended study is needed of lightning spectra and frequency and pulse shapes over a large range of geographical and seasonal conditions particularly as to the effect they would produce in any proposed discrimination photometer. Failing satisfactory results from such a study discrimination by other means, electromagnetic, space-time patterns (fluorescent ring) or coincidence requirements between spatially separated stations would be necessary.

For the red system, based on the first positive N_2 fluorescence the problem of lightning discrimination is perhaps more severe from a spectral viewpoint. If the spectral band width is very wide there appears to be no hope of finding two bands in the infra-red 1000Å or more wide such that their relative responses to bomb fluorescence and lightning fluorescence are noticeably different. On the basis of meagre information regarding lightning spectra in particular the most hopeful possibility appears to be to use 200Å band widths, one centered at 8850Å for bomb fluorescence, the other centered at 8200Å for lightning. This suggestion needs the same rigorous verification for validity discussed already. Indeed it may be preferable to use the electromagnetic signal from lightning rather than any optical signal as a discrimination device.

The possible use of fluorescent detectors which effectively split the sky into several fields of view has alrady been mentioned. As devices which can uniquely recognize the characteristic expanding ring signature of bomb fluorescence these detectors have a value as discriminators. However, since this unique property is no longer theirs during cloudy weather and since lightning is most apt to occur then their merit as discrimination tools is chimerical. A split field detector appear to have the following advantages

a) adequate range either in its principal mode or as an allsky device during overcast periods;

b) location of the burst direction when the sky is clear;

c) lightning discrimination for clear skys or with localized cloud cover, particularly on the horizon.

However, a split field system sensitive in the red will have the difficulties of all red wide band systems with lightning discrimination during periods when it cannot respond to the expanding ring pattern.

Another source of spurious signals which is serious for detectors with a large aperture is called twinkle. It arises from a large scale fluctuation in the illumination with large amplitude frequency components in the band pass of the detector. The source of these fluctuations is a turbulent variation in the index of refraction of the atmosphere and perhaps absrptivity variations at cloud levels which rapidly modulates the scattered sunlight. Among existing detectors twinkle is troublesome only for the red large area solar cell system. Extensive studies are underway to determine the source and spatial coherence characteristics of twinkle. It appears that the use of a sunshade can reduce triggering from twinkle to the level of a minor problem if not eliminate it completely.

By use of an adequately large number of stations in a network with delayed coincidence links between stations discrimination against false alarms (whether from lightning or twinkle) and diagnostic information on the location of a nuclear burst can be obtained. To monitor very distant tests - those that occur beyond the magnetosphere at 50,000 km or more some 10 stations would be needed to insure that at least two stations can observe fluorescence over the entire sky. The same network would imply that at least one station could observe fluorescence at the zenith for any test above 1000 km. Thus holes would develop below 1000 km and discrimination would be possible only for ranges greater than 5×10^4 km. 435 stations would be needed to provide at least two station discrimination capability for all shots as low as 600 km. In view of the possibility of utilizing various other techniques for detection in the case of bursts within the magnetosphere the use of such extensive networks would not seem to be necessary. Care should be taken to see to it that the low altitude regions above the poles where trapping of particles will not occur is adequately covered by a fluorescent network. But, unless a great expenditure of money, effort and off-line data handling is acceptable it does not appear to be reasonable to ask the fluorescence system to cover the region below 50,000 km so thoroughly that the signals from at least two stations can be compared for purposes of diagnosis and discrimination.

To summarize, extensive studies are needed to determine whether or not spectral discrimination can eliminate false alarms for single stations from lightning. This is the case for all ground based systems. If such discrimination is possible then it will be required for single channel all sky systems and also for those systems that can provide space-time patterns in clear weather. This is so because the space-time method of discrimination will fail if skies are overcast. The primary argument for the multichannel system is thus psychological. It relates to the degree of conviction and certainty which the record from such a system would carry if it should succeed in observing actual bomb fluorescence under clear skies. If spectral discrimination should prove to be incapable of providing an adequate degree of reliability for a single station then recourse must be had to correlation between stations in a network. If both types of discrimination are built into the overall system the single station capability will be particularly valuable for shots so low that they cannot be observed in fluorescence from more than one station. (It might be well to point out here that the signature of the pulse observed either from the ground or a satellite will be altered significantly if the nuclear burst occurs near or below the 80 km region.) Finally, the whole problem of lightning discrimination would disappear for a satellite borne fluorescence detector designed to receive the ultra-violet LBH band system.

VI. SHIELDED EXPLOSIONS IN SPACE

There have been suggestions that it is possible to reduce considerably the X ray flux incident on earth from an explosion in space as well as the effective temperature as seen from earth by interposing a lead shield between the burst and the earth. Such a shield could conceivably be deployed in the form of a hemisphere sufficiently far from the burst point that by the time the fireball reaches the shield its temperature is fairly low. The physics of this system is very complex and poorly enough understood that it is not yet clear what the quantitative relationship is between the thickness and geometry of the shield and the reduction in effective temperature and yield. The problem of shielding remains an inadequately explored one at the present time.

ACKNOWLEDGEMENT

This paper is essentially a summary of the findings of a summer study on the detection of nuclear explosions by airfluorescence conducted by the University of Pittsburgh for the Advanced Research Products Agency under contract with the Office of Naval Research during 1964.

Z	T	$n(N_2)$	$n(O_2)$	$n(O)$		$n(O)$		$n(O_3)$	
km	°K	cm^{-3}	cm^{-3}	cm^{-3}		cm^{-3}		cm^{-3}	
				Day		Night		Summer	
				Winter	Summer	Winter	Summer	Day	Night
50	274	1.84(16)	5.1(15)					1 (12)	1.5(12)
80	165	3.5 (14)	1.0(14)	1 (9)	7(10)	5 (6)	1.3(10)	1.1(8)	3 (9)
100	210	2.8 (12)	8.5(11)	1.6(11)	3(11)	1.6(11)	2.5(11)	6 (6)	2 (8)
120	275	3 (11)	4. (10)	4 (10)					
140	420	4 (10)	3.9 (9)	1.1(10)					
160	600	1.0 (10)	7 (8)	4.5 (9)					
220	1000	6.1 (8)	3.3	7.5 (8)					

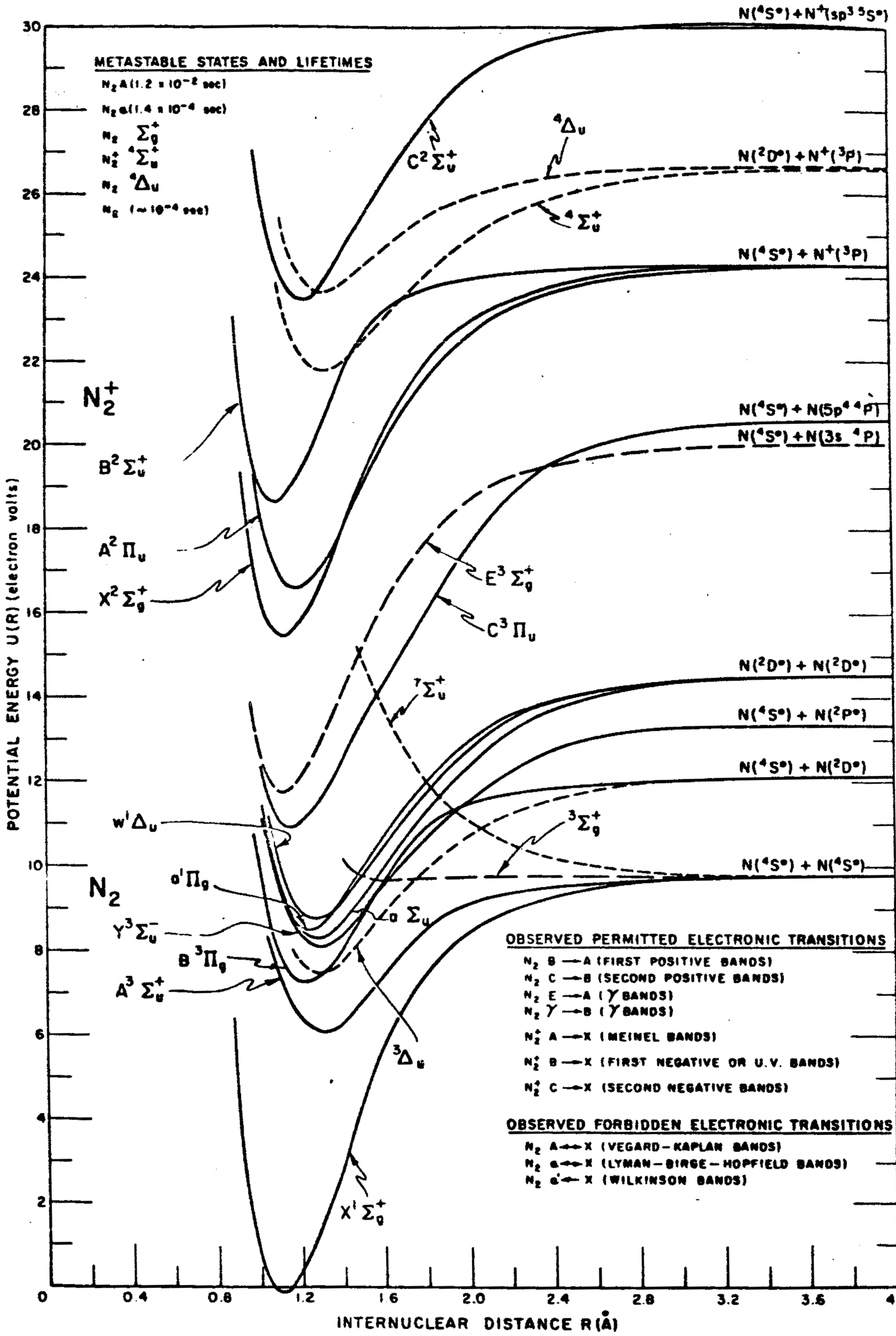
FIGURE CAPTIONS

Fig. 1 Potential Energy Curves for N_2 and N_2^+.

Fig. 2 Energy Level Diagram for N_2 and N_2^+.

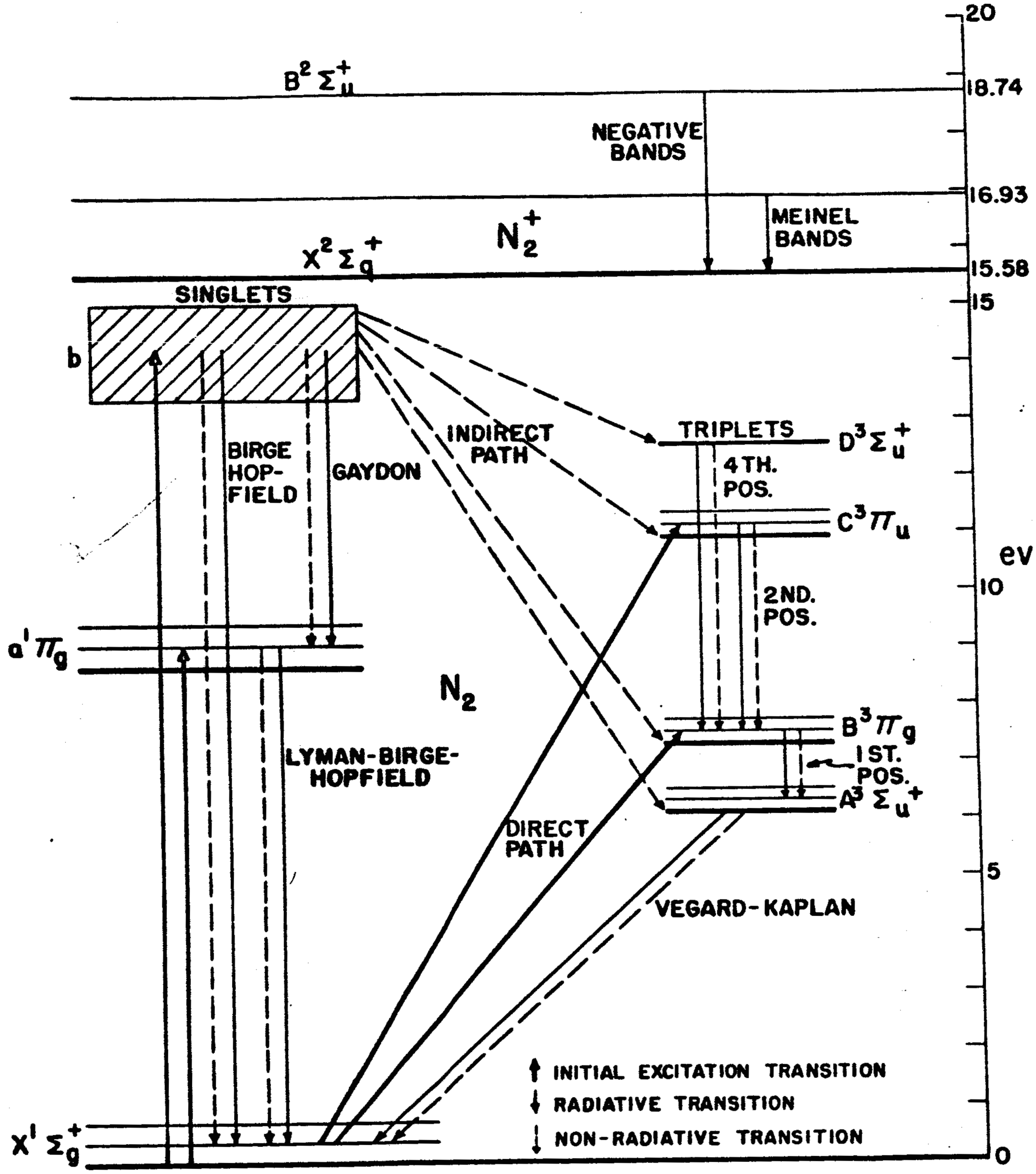
Fig. 3 Geometry of the X ray produced fluorescence pattern.

Fig. 4 Measurement of the Brightness of a Piece of Fluorescing Surface (Σ) by a Detector (A).



— POTENTIAL ENERGY CURVES FOR N_2 AND N_2^+ (Dashed curves may be in error by 0.2 ev; dotted curves by 1 ev.)

Figure 1



ENERGY LEVEL DIAGRAM OF MOLECULAR NITROGEN, N_2 & N_2^+

Figure 2

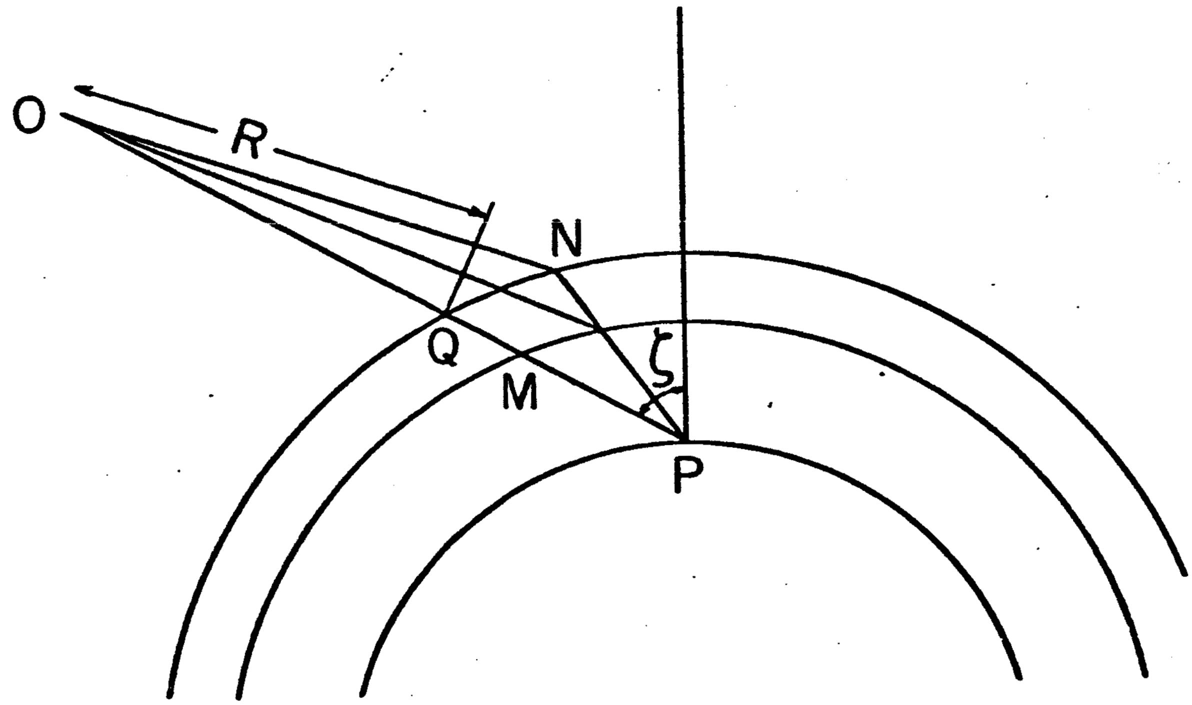


Fig 3

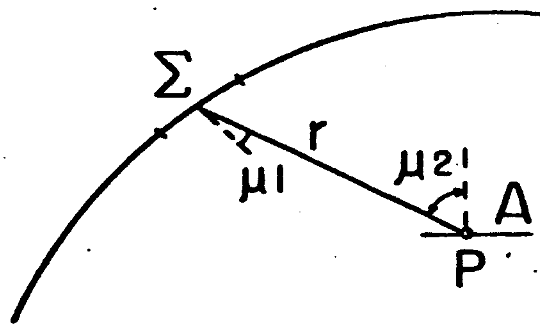


Fig 4