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RESEARCH MEMORANDUM

A "WATCH DIAL" SOURCE OF ILLUMINATION FOR NIGHT OPERATIONS

S. T. Cohen

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PREFACE

This Memorandum derives from RAND's interest in methods of improving U.S. air and ground operations in Vietnam. Many such operations would benefit from better use of night illumination. The deficiencies of current illumination methods and schemes point up the desirability of an illumination source free of the drawbacks associated with flares and electric lighting. Furthermore, levels of illumination are desired that would expose but not assist enemy operations.

This report suggests a proposed illumination source that takes its energy from radioactive decay. The study examines the general characteristics of such a system -- the type of radioisotope to be used, the modes of use, the problem of radiological safety, and the approximate costs to produce required levels of illumination.

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SUMMARY

This RAND Memorandum describes a night illumination scheme that uses a light source similar to that of a radium watch dial. By mixing a radioisotope (available in sufficient amounts from Atomic Energy Commission production) with a fluorescent material and encasing the mixture with a small thickness of transparent material, a highly versatile source of light can be achieved. A plastic casing can be shaped in any desired form, thus allowing the light to be distributed both according to need and to minimize the effectiveness of countermeasures. Furthermore, by selecting a radioisotope that emits only beta rays no serious safety problem would exist.

Such an illumination scheme could be used to assist defensive operations in a number of situations found in the Vietnam war, including hamlet defense, outpost defense, and surveillance of extensive barriers designed to inhibit enemy infiltration. The light sources can be easily emplaced -- underground, on the surface, or in trees -- to provide steady, and essentially permanent illumination where it is needed. Once emplaced, there is no problem of operation or maintenance. If the light source is covered or removed it can be uncovered or replaced easily. No radiological hazard will exist -- to friend or foe.

The cost, in radioactive material, to produce quarter-moon and full-moon light intensities will be in the range of $1,000-$10,000 per square mile and $10,000-$100,000 per square mile, respectively. Barring darkening or corrosion of the plastic, these costs hold for an essentially indefinite period. The costs of inert components of the system need not add substantially to those numbers, because of the basic simplicity of the design.

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I. INTRODUCTION

Considering the very large propensity and ability of Viet Cong and North Vietnamese forces to move and conduct operations at night, the question arises whether a source of illumination to expose and deter night movements can fit practically into the nature of the conflict, and significantly assist U.S. and South Vietnamese operations. To best fill such needs the source of illumination would have to be simple, easily applicable, of long life, and difficult to counter. These requirements suggest the use of a light source arising from the interaction of some fluorescent material with nuclear radiation emitted by an appropriate radioisotope -- that is, a mechanism based upon the same principle as a radium watch dial.

If a radioisotope -- having a half-life commensurate with the required task, a production cost commensurate with the military value of the application, and posing no significant radiological hazard -- could be used to provide the needed energy, then an area to be placed under surveillance could be illuminated to the desired level over a considerable period of time. In effect such a scheme would resemble a fluorescent lighting system, without batteries or electrical generators, which would operate continually and be unaffected by power fluctuations. And, in contrast to problems arising from the use of flares for the illumination of critical areas, this scheme could be employed in a fashion where such factors as interference, movement, weather, and natural growth would not have an adverse effect.

Since such a source of light can be designed and emplaced in a way that would make it highly difficult or impractical to "turn off," the illumination would be more resistant to countermeasures than are conventional sources of illumination. Radioactive decay being an inexorable process (outside a nuclear laboratory), the only way to interfere with the light source would be to destroy it physically or, if possible, cover it. Because such an illumination scheme, with its basic simplicity, permits hardening or dispersal to be readily

accomplished, countering by the enemy can be a formidable job. It can be a difficult and time-consuming operation.

Regarding the intensity of illumination to be achieved, two levels can be considered: (1) a light field that can be exploited effectively by the human eye, something on the order of, say, a full-moon; and (2) a field that can be exploited by scotopic devices, both simple (low gain) and sophisticated (high gain), depending upon whether the [redacted] devices are to be used by Vietnamese or more technically proficient American forces. Inasmuch as this kind of illumination system can be placed where the enemy is apt to be, or directed at his location, it can be employed in a manner that produces a visual asymmetry in favor of friendly forces. This is to say that the light field can illuminate the enemy to a degree that can be exploited by friendly forces, but not vice versa.

THE NEED FOR ILLUMINATION

The Viet Cong and North Vietnamese are engaged, of course, in a spectrum of nocturnal activities. They can be on the move -- for the sake of moving, to transport supplies, to head toward a planned military operation, or to infiltrate a barrier. They can be in a given area -- attacking a hamlet, an outpost, or a Special Forces camp. They can also be in an area where they are on the defense instead of on the offense.

Certainly it would be desirable to have them illuminated under these different conditions. However, for some situations their unknown location and course of movement make it impossible to determine a point or area to apply a light source. For other situations, when their whereabouts are known or can be predicted, it may be infeasible or impractical to use the illumination scheme suggested herein, because of the difficulty of application and the ease of countermeasures. For example, if an area to be lit up is in enemy territory, the illumination could be risky to emplace and might have the drawback of being very easily countermeasured, such as being covered or removed.

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For these reasons the applications having the most attractive potential would seem to be those in areas normally controlled by friendly forces that may come under enemy attack or be infiltrated by the enemy. This suggests such applications as aiding hamlet, outpost, or Special Forces camp defense, or the illumination of a physical barrier -- where the emplacement or dispersement of the light sources can be made most effectively, most safely, and in a manner that minimizes the possibility of successful countermeasures.

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II. REQUIREMENTS AND CHARACTERISTICS OF THE SCHEME

SELECTION OF A RADIOISOTOPE

The choice of an appropriate radioisotope for this illumination application is, in principle, a function of three factors: (1) a half-life that relates practically to the time involved in the production and delivery of the emitter, and to the probable period of use; (2) a degree of radiological safety to both friend and foe, in view of handling during delivery, dissemination of the luminous material in the field, and the probable periods of exposure, after dissemination; and (3) the production cost of the radioisotope.

An examination of possible applicants, considering these three factors, yields several possibilities. They are isotopes that emit alpha or beta particles. (Gamma emitters would pose undue safety problems.)

It is difficult to say what choice may be deemed optimum. Considering the intangible nature of such a choice, the term "optimum" becomes hazy indeed and would depend upon the probable length of application. But this would, in turn, depend upon the uncertainties of the war itself. Who can predict how long a given defended area will remain in friendly hands or be removed from the possibilities of enemy attack? For that matter, the broad complexion and duration of the war itself also can relate importantly to the selection.

In view of this vagueness, let us select a specific radioisotope, Strontium-90, a plentiful fission product, as an example. This selection is made somewhat arbitrarily, but it is also based on a rough appraisal of production cost and availability.

Strontium-90 has a half-life of about 25 years. (It decays to Yttrium-90, which has a half-life of 65 hours. The yttrium decays to Zirconium-90 which is stable.) Therefore we can dispense with the problem of the requirements on length of application. Both Strontium-90 and Yttrium-90 emit beta rays, but no gamma rays. This makes for a readily available solution to the shielding problem, with respect to radiological safety.

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AEC estimates place the cost of Strontium-90 at $15 to $20 per thermal watt. A production rate of more than 100 kilowatts per year is expected by 1970.

LIGHT INTENSITY REQUIREMENTS

Present sources of illumination used in Vietnam suffer from a number of deficiencies. Flares may point out the enemy's location but they also can provide the enemy with a better lit target area. They are frequently difficult to place; they drift with the wind; their smoke can obscure the target; they burn for limited periods of time; they may swing and produce wavering light patterns at the surface; and their light emission may interfere with an airborne observer's vision of the ground. If an airborne source is used, there will be some unavoidable delay in getting it to the scene of action. In some cases the delay might be long enough to allow the action to end before the illumination can be brought to bear.

For applications where it is not practical or desirable to keep operating personnel in attendance but where illumination would be a valuable asset, a limitation might be imposed on the period over which the system could be used, if it was restricted to a chemical energy source. There may also be reliability and maintenance problems that affect the system, and if periodic replacement is necessary some difficulties and hazards might exist. Finally, for an unattended system, the difficulty associated with enemy countermeasures may become reduced to a degree where the system can easily be put out of action.

Where the operation of the system is to be carried out by indigenous personnel (the South Vietnamese), the question of power supply and maintenance takes on a different complexion. Electrical generators may pose maintenance problems. If chemical batteries provide the power source there is the possibility that the supply may be stolen or sabotaged. And, of course, there is the replacement problem, which may entail logistical difficulties and some element of danger as well.

If a light source could be employed that was largely devoid of these kinds of drawbacks, was simple to apply, required no maintenance or replacement, and could be highly dispersed and hardened to minimize countermeasure effectiveness -- some significant advantages would accrue. Such properties can be achieved through the use of a [redacted] radioactive-powered fluorescent light source.

Unlike conventional light sources, a fluorescent source of this nature could readily be shaped in almost any number of geometrical arrangements. It could function as a unit light bulb or it could be shaped in the form of luminescent tubing or tape and emplaced in a fashion that might make it difficult for the enemy to get at easily.

Two levels of illumination have been suggested for application: full-moon intensity, which could be utilized by the unaided eye; and quarter-moon intensity, which can be exploited by scotopic assistance.

Full-moon intensity calls for a flux of 10^{-2} foot-candles. This corresponds to approximately 10^{-5} watts per square yard, or 40 watts per square mile. Since the efficiency of conversion of electron (beta ray) energy into light is about 5 percent, this would entail radioisotope requirements of 2×10^{-4} watts per square yard, or approximately 1 KW (thermal) per square mile. Assuming a production cost of $20 per watt for Strontium-90, this requirement would entail an illumination cost of $\$4 \times 10^{-3}$ per square yard, or on the order of $10,000 per square mile -- assuming that all the light is utilized. Practically, we might say that $10,000-$100,000 per square mile is representative of the cost range.

Quarter-moon intensity corresponds to 10^{-3} foot-candles. Thus this illumination level calls for an investment of $\$4 \times 10^{-4}$ per square yard, or on the order of $1,000-$10,000 per square mile.

RADIOLOGICAL SAFETY

The radioactive concentrations dictated by the two illustration requirements set forth here involve on the order of one and ten curies per square yard. Unless shielded, the beta ray flux from such

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concentrations would pose a distinctly possible radiological hazard (depending upon how long the enemy exposed himself). However, since the decay of Strontium-90 involves no gamma ray emission, the safety problem can be simply dealt with, for the beta rays can be easily stopped and the secondary gamma radiation (bremsstrahlung) will not be of sufficient intensity to present a significant radiological hazard.

The average beta ray energy from the Strontium-90 decay scheme is approximately 1 MEV. If the mixture of radioisotope and fluorescent material was encased within some transparent plastic material, for example, polyethylene, only a few millimeters of such material would suffice to stop the beta rays. The resulting gamma radiation, from the stopping of the beta rays, would be emitted at a very low efficiency, on the order of 0.1 percent. This is to say that only about 1/1000 of the beta ray energy will manifest itself as gamma rays.

As a result of this low bremsstrahlung efficiency, the dosage rate in an area so illuminated will be in the vicinity of a few-hundredths to a few-tenths roentgens per day. This is like a hundred to a thousand times natural background. On the other hand, these illuminated areas will be occupied by the enemy for but a very limited time -- minutes to, at most, hours. Furthermore, attacks are not made daily, but far less frequently. Therefore, the probable average dosage rate will be considerably closer to background.

If desired, the radioactive source can be shielded against quite conveniently, without seriously interfering with the light source, by simply placing the source underground. This measure could readily bring the radiation field far below background.

For the reasons brought out here, the ease of shielding should permit safe handling and dispensing of the fluorescent material.

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III. APPLICATIONS

Because of the number of possible applications and the large variation in the size of the area to be illuminated, there is no "typical" example that can be used to indicate the needed amounts and costs of radioactivity. In this sense, areas and geometries will be considered purely in an illustrative vein.

For hamlet defense, illumination might be applied in two fashions: First, assuming that the hamlet is surrounded to some extent by a clearing, a band in this clearing can be illuminated by placing a large number of light sources or a continuous strip (appropriately mirrored) at the inner edge of the band. This disposition would then permit the defenders to observe any infiltration across the clearing. Second, where the clearing ends and the brush or jungle begins -- and where the Viet Cong may be concealed -- strips of luminescent tubing may be wound into the upper branches. This, then, in "Christmas Tree" fashion, would illuminate some small width of jungle to the required degree.

For the first application (illuminating a band in a clearing) the following installation is suggested. The light source could be a plastic or glass ball set at the focal point of a parabolic mirror, which would be fastened to the base of a metallic pipe. At the other end of the pipe would be another reflector designed to spread the light sent up the pipe by the parabolic mirror over an area to be illuminated. The pipe would be put into the ground so that the light source was, say, several feet below the surface. This would effectively reduce the bremsstrahlung radiation escaping to the surface to an insignificant level. It would also provide a high assurance that even if the area were mortared no radioactivity would be dispersed over the area.

The reflector at the top might be simply a small mass of metal, perhaps an inch across but very thick. This small size and physical toughness would work to reduce its vulnerability to enemy fire, in case they attempted to shoot out the light. (Also, to keep dirt and

dust out of the system, it would be advisable to surround the pipe opening and the upper reflector with a plastic window. In addition, to ensure that nothing gets into the pipe in case the window is broken, a transparent plug can be inserted in the pipe.) On the other hand, if the vulnerability was dictated by resistance to small arms fire, the top reflector might purposefully be large and thin, so that a bullet would pass through it readily but impair only a small fraction of the reflecting surface.

Suppose, to hypothesize a situation, a band surrounding a hamlet is to be illuminated to full-moon intensity. Assume that this band is 1,000 yards in circumference and 50 yards wide yielding an area of 50,000 square yards. Under ideal conditions this would dictate a radioactive source strength corresponding to 10 watts of Strontium-90. This would entail a cost of $200. However, if we take such factors into account as imperfect reflection, light absorption in the source and in the windows, and so on, we might round off the requirement to something on the order of 50 watts and a cost of $1,000. This could be divided into, say, one hundred units costing perhaps $10 each. (The essential simplicity of this scheme would make it appear that the costs of pipe, reflectors, plastic, and so forth, would not significantly change this value.)

A variation of this scheme might be to stretch out the light source, say in the form of a continuous strip. This would work toward reducing vulnerability to enemy fire since a continuum of targets, rather than a discrete number, would exist. The fluorescent source would then be in linear form (laid beneath the surface) and the upper reflector would be a metallic strip.

The second application (stringing luminescent tubing into upper branches) could, to some extent, be accomplished by turning the band illumination lights into "searchlights" directed at the jungle. On the other hand the "Christmas Tree" approach would present the enemy with a different and probably considerably more difficult countermeasures problem. By winding luminescent strips into the upper

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branches the task of tree climbing and unraveling could become so time-consuming and difficult as to be more trouble than the task is worth.

For the illumination of a physical barrier, which is not manned but which can be put under armed airborne surveillance, it would appear that the most effective use of the light source material would be to incorporate it directly into the barrier components. This would be at points where infiltration is slowest and where countermeasures are most difficult. As such, one may envisage passing a luminescent tape through concertinas of barbed wire. It would be necessary, however, for the top side of the tape to be opaque (it would be a reflector) so that no interference with the vision of those aloft would result.

Studies of Viet Cong operational patterns indicate a significant measure of consistency in their preference for certain routes. In fact this knowledge is used by us in considerable efforts to illuminate (with flares) a number of key cross-points used by the Viet Cong. If the "watch dial" illumination scheme were used instead, not only could the area be illuminated far more cheaply, but a realization by the Viet Cong that continuous illumination existed might deter them from this route and force them to take less preferable approaches. As for the barrier surveillance case, care would be required to ensure that no significant amount of light went upward.

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APPENDIX

For situations where the source of illumination is several feet underground there will be no radiological problem to consider. If, however, the material is strung into tree branches or through barbed wire then a possibly relevant gamma ray (bremsstrahlung) dosage rate may exist.

The bremsstrahlung efficiency for beta rays, of energy E-MEV, slowing down in a material of atomic number Z, is approximately EZ/1000. E is about 1 MEV for the Strontium-90 decay scheme and Z is about 2 for plastics. Thus the efficiency is about 2/1000.

The average energy of the bremsstrahlung radiation is approximately 1/10 the initial beta ray energy. Thus the external radiation hazard stems from a source of 0.1 MEV gamma rays.

A rough idea of the radiation hazard can be obtained by assuming that the luminous source material is uniformly distributed in some plane above the surface. Based on this assumption, the dosage rate at some distance beneath the plane is given by

$$D = \frac{N}{2} \times F\ (\mu h) \times k$$

where

D is the dosage rate in roentgens/sec;

N is the amount of gamma ray energy emitted per cm^2 by the plane;

F is the air attenuation factor. For an absorption coefficient μcm^{-1} and a receiver h cm from the emitting plane, $F = -Ei\ (-\mu h)$;*

k is the number of roentgens per MEV of gamma rays received per cm^2.

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*The exponential integral function.

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As an example, suppose that a full-moon intensity at the surface is achieved by stringing fluorescent sources in trees, near a hamlet, at a height of 20 feet. Taking a light intensity degradation factor of five, from the ideal case, the radioactive source intensity requirement would be about 10^{-3} watts per square yard. This is equivalent to 8×10^5 MEV/cm^2/sec.

For a bremsstrahlung efficiency of 2×10^{-3}, the gamma ray emissivity is then $8 \times 10^5 \times 2 \times 10^{-3} = 1.6 \times 10^3$ MEV/cm^2/sec.

For 0.1 MEV gamma rays, μ is 2×10^{-4} cm^{-1}; and μh, for h = 20 ft, is $2 \times 10^{-4} \times 20 \times 30.5 = 0.1$. F is therefore $-Ei\ (-0.1) = 2$.

For 0.1 MEV gamma rays, k is 5×10^{-10} roentgens/MEV/cm^2.

Thus

$$D = \frac{1.6 \times 10^3}{2} \times 2 \times 5 \times 10^{-10}$$

$$\cong 10^{-6} \text{ roentgens/sec.}$$

This dosage rate is some two or three orders of magnitude greater than natural background radiation. However, considering that any occupation of the illuminated area (the jungle) is going to average at most on the order of, say, several hours per month, and probably much less, the dosage accrued by the enemy in attacking hamlets, may not be appreciably different from his yearly accrual from natural sources. Needless to say, the dosage that might result from this source is far below permissible levels for industrial and laboratory personnel who work in a radiation environment.

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