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Center for Night Vision and Electro-Optics

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NIGHT VISION GOGGLES (AN/PVS-7) — PERFORMANCE ISSUES AND ANSWERS

by

Walter B. Morrow, Jr.

March 1989

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During 1987, pursuant to a tasking by the Undersecretary of the Army through the Institute for Defense Analysis, the US Army CECOM Center for Night Vision and Electro-Optics (C^2NVEO) carried out a comprehensive series of studies to characterize the spectral content of night sky irradiance across the spectral sensitivity bands of second and third generation AN/PVS-7 Night Vision Goggles. This effort was then logically extended to the development of a detailed comparative performance analysis of night vision goggles within the true spectral characterization of the night sky environment. Several related issues were also of concern to the Undersecretary, including the effect of using various bandpass and notch spectral filters with goggles, and finally the operational life and reliability of night vision goggles.

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SECTION I. BACKGROUND

During 1986, the Undersecretary of the Army became increasingly concerned about the relative cost and performance of the new non-development item (NDI) AN/PVS-7, *Night Vision Goggles,* being procured by the US Army to supplement and ultimately replace the AN/PVS-5 Night Vision Goggles. Replacing the AN/PVS-5 with the AN/PVS-7 has the advantage of giving the Army night vision goggles which use one image intensifier tube instead of two, thus improving supportability and reducing tube replacement costs. At the same time, third generation image intensifier tubes were becoming available and promised a significant improvement in low light level performance—a difference quickly taken advantage of by the Army in the development of the third generation AN/AVS-6 High Performance Aviation Goggles. The advantages of using third generation in the general purpose night vision goggles was perceived to be offset by the apparent higher cost associated with the third generation image tube. This perception has arisen because second generation technology tubes had been produced by the tens of thousands and represented a well-established technology and cost baseline, while third generation tubes were only beginning to be produced and to experience the normal learning curve quantity cost reduction process associated with production demand.

The Undersecretary had stated concerns about the trade-offs which had been and might be made in these programs, as well as the ultimate real value to the Army of developing third generation image intensifier tubes. The major issue to be resolved was the determination of the optimum mix and allocation of second and third generation night vision goggles. At that time, testing programs had been inconclusive primarily due to failure to account correctly for the spectral content of the night sky and the effect of artificial light contamination. An educated determination of the optimum mix and allocation of third and second generation tubes could not be made until this test oversight was corrected.

On 20 October 1986, the Undersecretary met with representatives of the Institute for Defense Analysis (IDA) to initiate a program to resolve these issues. During November and December 1986, IDA initiated a series of meetings with senior personnel representing Army Materiel Command (AMC); Army Training and Doctrine Command (TRADOC); Army Communications-Electronics Command (CECOM) Center for Night Vision and Electro-Optics (C^2NVEO); and other Army agencies. Their efforts culminated in formal messages from HQ, AMC to HQ, TRADOC, and subsequently messages from TRADOC to C^2NVEO, requesting a series of formal studies. This was initiated on 6 February 1987. The Director, C^2NVEO, felt that the Undersecretary should be provided with a comprehensive analysis and report on the subject. In order to fully comply with the overall AMC tasking, the TRADOC requests, and additional guidance by the Director, C^2NVEO, an intensive program was designed and executed by C^2NVEO using two continental US (CONUS) and three outside CONUS (OCONUS) test sites to accomplish the following objectives:

1 Design, fabricate, and deploy ten sets of Night Sky Irradiance Measurement Systems (five imaging systems and five non-imaging systems) to measure the integrated spectral content of the night sky in the second and third generation spectral sensitivity bands and correlate with concurrently produced night sky illuminance (photometric) data. Select and train seven-member test teams to conduct these measurements at locations in West Germany; Panama; South Korea; Fort Irwin, CA, and Fort A.P. Hill, VA. Conduct tests nightly over a period of one lunar cycle, approximately 30-45 days, depending upon weather conditions at the sites. Maintain a comprehensive meteorological record during all tests. These tests were designed to determine the relative amount of night sky irradiance in the second generation, third generation, and photopic bands as well as the level and range of artificial light contamination at the test sites. This data was critical and necessary to properly interpret comparative field tests of second and third generation night vision systems.

2 Concurrently with the measurements taken in the above effort, measure and correlate the integrated spectral reflectance of selected targets and backgrounds with the irradiance data, which is to be used as the data base for performance modeling employing the Night Vision Static Performance Model for Image Intensifier Systems. This data, like that cited in No. 1 above, was critical to determining and interpreting the relative field performance of the second and third generation systems.

3 Conduct a series of field range-detection tests using the night vision goggles to develop a real performance base with which to correlate and compare to the modeling results obtained from the irradiance, illuminance, and contrast data. Second and third generation and photopic night sky irradiance would be monitored and recorded throughout these tests. These test would utilize and integrate the results of No. 1 and No. 2 above.

4 Concurrent and coincident with the above series of tests, evaluate the effect of using a series of spectral bandpass and notch filters, create a detailed and comprehensive spectral reflectivity data base to augment the night vision performance model. The use of such filters affects second and third generation systems performance differently and variably with differing field conditions.

5 Evaluate the current status of operational life and reliability of second and third generation image intensifier tubes and that of the AN/PVS-7 systems in which they are used. Also evaluate the relative variation of performance over the effective life of each tube type. The first part was particularly important since operational life and reliability have historically been the dominant cost drivers, not acquisition cost. The second part was important because performance levels are not necessarily fixed at some level over the life of an image intensifier tube but in fact change predictably but differently for second and third generations.

6 In association with the Army Materiel Systems Analysis Agency (AMSAA), conduct a comprehensive Life Cycle Cost Analysis (LCCA) of the systems under evaluation. While operational life and reliability issues were briefed to the Undersecretary, this specific life cycle cost analysis derived from those RAM considerations was not briefed. The C^2NVEO report was provided to AMSAA in compliance with the HQ, AMC tasking, incorporated into the AMSAA's report and distributed by AMSSA. AMSSA was represented in the briefing to the Undersecretary. The report reflected the operational life and reliability data which was briefed to the Undersecretary.

The worldwide field tests of No. 1 above were conducted between 1 May and 28 June 1987. The remaining five objectives, along with a substantial amount of data analysis and modeling, were accomplished between 1 July and 1 November 1987. While technical reports were being prepared to document these efforts in detail, the basic results and conclusions were available and summarized in November 1987. On 3 December 1987 IDA representatives were briefed at C^2NVEO on the results. Also attending that briefing were representatives of DA and TRADOC, and the Program Manager (PM)-NVD. In preparation for briefing the Undersecretary, a second briefing was held on 17 December 1987 at C^2NVEO for IDA representatives which addressed the issues of image tube life and reliability in greater detail than the first briefing. On 7 January 1988, C^2NVEO briefed US Army Infantry School (USAIS) personnel at Fort Benning, GA. During the week of 11 January 1988, the Assistant Secretary of the Army for RD&A and the TRADOC Deputy Commanding General (CG) for Combat Developments were briefed. Finally, under the direction and leadership of the PEO-IEW, the CG, AMC and staff were briefed on the morning of 19 January 1988, and the Undersecretary of the Army was briefed in the afternoon. In these briefings, the specific details of No. 1 and No. 2 were not explicitly covered but were implicit in and a foundation for the interpretation of the comparative field performance test results of the second and third generation goggles.

At the close of the briefing, the Undersecretary directed the PM-NVD and C^2NVEO to remain in contact with IDA regarding the issues studied in this effort and maintain a proper record to preserve the corporate knowledge gained by this effort. Thus, C^2NVEO planned a series of technical reports which are in various stages of completion, and some still in the planning stages, to fully document this effort. The Undersecretary further charged the PM-NVD and C^2NVEO to perform the following tasks:

- lay out a proper foundation for future program direction,
- assure that programs are really needed and worth the cost, and
- consider how to equip the Army in quantity as soon as possible.

In keeping with this direction, C^2NVEO has developed a test and analysis plan to deal with the complex issues of night vision imagery under dynamic performance conditions, as opposed to static; and to continue developing the Night Sky Irradiance and Spectral Reflectivity Data Bases for use in modeling and analysis. The underlying issue that motivated this effort is determining an optimum mix of second and third generation night vision goggles, which was not specifically accomplished nor was it a direct objective of the specific tests carried out. A solid foundation was established, however which, with the successful conclusion of planned testing and analysis by C^2NVEO, can support the modeling and analysis as well as wargaming development efforts necessary to determine an optimal mix if such a mix exists.

The following items are among the specific accomplishments of the effort which was briefed to the Undersecretary:

1. Initial establishment of correlation for five key geographic sites over approximately 45 days of the photopic, and second and third generations light levels with the attendant ability to explain more concisely the performance similarities and differences between second and third generation systems. Again, the specific details of this effort and of accomplishment No. 2 below were not briefed explicitly to the Undersecretary, but were and are the critical underpinning for interpretation of the direct field range/detection tests of the second and third generation goggles.

2. Initial establishment of the levels and impact of artificial illumination sources in second and third generation performance, as well as the ratios of artificial illumination to natural starlight, skyglow, etc., at each site. This was important because second generation systems are more sensitive to artificial illumination than third generation; conversely, third generation uses natural starlight and skyglow much more efficiently than second generation.

3. Established the foundation for development of year-round day/night light level data base, including photopic, and second and third generations; and including shadow and canopy factors. The data base is useful in the performance analysis of image intensified systems, daylight optical systems and directed energy systems. The initial data base contains approximately 30 nights of data at the selected sights and some beginning hypothesis about correlating photopic, and second and third generations equivalent night sky irradiance. Additional work in this area expanded to a 24-hour/day basis in being set up.

4. Developed a new data base of spectral reflectivities over the range 400 to 2,000 nanometers, including various targets and terrain features; and exhibits a collection of foreign and Warsaw Pact uniforms. Spectral reflectivity conducted with night sky irradiance is the basis for determining target/background contrast. The value of contrast (all other parameters being equal) determines whether or not a target can be seen; i.e., detected or recognized.

5. Developed an enhanced data base for static range detection performance of second and third generation night vision goggles specifically correlated to true night spectral irradiance in the system spectral performance bands. This was the natural and direct result of the previous accomplishments.

6. Evaluated the comparative performance impact of a variety of coated optical components (COCs) on second and third generation systems providing a sound basis for Army decisions on the use of COCs. This was not one of the original objectives but has some valuable implications for applications of image intensified night vision devices. COCs generally degrade night vision performance but circumstances have been observed in which target/background contrast may be improved by use of selected COCs.

7. Documented and established the relative operational life and reliability of second and third generation image tubes through evaluation of lab and field test data, maintenance data, replacement parts data, as well as direct interaction with users in field units both CONUS and OCONUS. This was important because of misinterpretation of the system MTBF of the goggle system and the essentially independent MTTF (mean life) of the image intensifier tube used in the goggles. The latter (tube MTTF) and not the former (system MTBF) is the true cost driver (or cost saver) in the goggle system.

While C^2NVEO believes that these accomplishments are noteworthy, it is equally clear that much is still be done if the Army is to obtain the best use and advantage from its current and planned NVEO technology and capability and achieve a high degree of true night operational capability. Several areas of concern and areas for continued study have surfaced in the pursuit of this analysis and are summarized briefly here:

1. Second and third generation performance envelopes for dynamic application, i.e., driving vehicles and aircraft pilotage, need to be developed. Static range detection alone is not a proven predictor of performance for the dynamic case.

2. Completion of year-round light levels radiametrically and/or in the photopic, and second and third generation bands. Actually, such data taken on a 24-hour/day year-round basis is necessary to support NVEO device operational use and many applications of directed energy devices.

3. During the course of the worldwide study, C^2NVEO's teams and management met and worked with a broad spectrum of NVEO users, trainers, doctrinal proponents, maintainers, etc., and believe that there is a need for introspection and reflection on how well we understand and are using the NVEO assets that the Army has and will have in the near future. The issues run from technical performance, as addressed in this work, to logistics—one facet of which is life and reliability, also addressed herein. There seems to be generic issues beyond this, however, which ask how well we translate intrinsic NVEO device performance into the solid knowledge that allows individual soldiers and battlefield commanders to derive full benefit from the technology they have been given. This knowledge possesses several dimensions: (1) the understanding of the information content of images viewed through these devices and their logical interpretation, (2) the technical and practical limits of performance to the user, (3) the realization of what can be or was accomplished with NVEO devices which would not or could not have been accomplished without them, and finally (4) the knowledge associated with repair, supply, and support. All of this is, of course, largely a matter of communication.

The briefing as provided to the Undersecretary on 19 January 1988 is presented in the ensuing sections.

SECTION II. MEMORANDUM TO FILE, 5 February 1988

DEPARTMENT OF THE ARMY
OFFICE OF THE
PROGRAM EXECUTIVE OFFICER
INTELLIGENCE AND ELECTRONIC WARFARE
VINT HILL FARMS STATION
WARRENTON, VIRGINIA 22186-5115

REPLY TO
ATTENTION OF

AMSEL-RD-NV-TS

5 Feb 88

MEMORANDUM FOR RECORD

SUBJECT: 19 Jan 88 Meeting with Mr. Ambrose Concerning Night Vision Devices Program

1. Subject meeting was held in Room 25715B at 1200 hours. The following persons were in attendance:

Mr. Ambrose	OUSA
COL (P) Campbell	PEO-IEW
Mr. Gresham ✓	PM-NVD
LTC Boudreau	OUSA
COL Norman	SARD
Mr. Stohlman	SARD
LTC Moss	DCSOPS
CPT Powers	TRADOC
COL King	TRADOC
Dr. Oskar	AMC
Mr. Waggoner	AMSAA
Mr. Travesky	CNVEO
Mr. Morrow	CNVEO

2. Summary of Presentation.

a. PEO-IEW opened the meeting by explaining that a two-part briefing would be presented to: (1) put the 2nd and 3rd generation image intensifier night vision goggle acquisition program in perspective and (2) respond to specific questions that Mr. Ambrose had raised on these devices.

b. Mr. Gresham presented the PM-NVD concept for a post FY90 acquisition of night vision devices. He described the competitive acquisition strategy for all known night vision requirements. Mr. Ambrose agreed with the FY90 buy concept as means of continuing the trend toward program stability; however, he indicated that the solicitation schedule should be moved up for a 1 Oct 89 contract award.

c. Mr. Walter Morrow briefed on the technical aspects of the 2nd and 3rd generation goggles. The technical briefing covered operational requirements, system performance parameters, and image tube operational life as summarized below:

(1) Operational Requirements. The AN/PVS-7 ROC (10 Feb 1982) identifies the need for the user to detect a man target

at 150 meters under starlight conditions and/or perform such tasks as driving, map reading, and tire changing. At a given light level and contrast detection of a man target can be accurately translated into a contract specification. However, no contract level is specified in the ROC. Moreover, other tasks such as changing tires and driving would not be easily translated even if contract levels were specified. Mr. Ambrose asked TRADOC to look at specifying more precisely performance requirements and asked CNVEO to examine ways to translate this performance to systems specifications. Mr. Ambrose expressed the view that we should have learned enought about electro-optical devices over the past several years to enable this transfer. Mr. Ambrose also indicated he would like to fire a rifle with goggles at CNVEO or an Army base where they are available.

(2) System Performance Parameters. Basic tube systems performance parameters such as signal/noise ratio, photocathode sensitivity and related parameters were presented as background for various performance tests conducted during the past year. The results of the Fort Benning FOE, CNVEO's range detection tests, and comparative contrast analysis of Eastern Bloc uniforms were reviewed. These tests showed that contrast and light level are critical performance parameters and the 2nd generation will perform better under some conditions while 3rd generation will perform better under others. In general, 3rd generation out performs 2nd generation by 20-30% in range detection performance. Since all tests were static, CNVEO is unable to state how 2nd and 3rd generations would compare under dynamic conditions. With regard to laser filters, significant performance degradation is expected but limited field tests conducted failed to show a clear impact of the three filter approaches considered. However, it's apparent that the "one-lambda" filter would have limited adverse effects on either 2nd or 3rd generation, while the "three-lambda" filters would have a more severe impact on 2nd generation than on 3rd generation. The impact of filters under dynamic conditions (e.g., driving or flying) is not known.

(3) Image Tube Operational Life. The 2nd generation tubes are achieving 2000 hours MTTF in life and reliability testing with a variance of 1000 hours to 4500 hours. Indicators from several sources suggest that field operational life is also approaching this 2000 hours. Data from 1984-1986 indicates field usage approximates 200 hours per year on average per goggles. More recent data indicates increased usage for some units, particularly the 2nd ID in Korea. Attrition rates for tubes were estimated from field data to be a nominal 2 to 3 percent. The decay characteristic over operational life was

discussed indicating that the signal to noise ratio of a 2nd generation tube decays from about 12.0 down to 9.0 at end of effective life. The tube is not dead at this point, but it might not be safely used below ½ moonlight level and in a dynamic mode. For example, driving might not be safe when S/N is less than 9.0. The operational life of 2nd generation tubes can be increased by either raising specifications at a sacrifice in yield or by applying an ion barrier film at a sacrifice in yield and performance. CNVEO showed that for a sample of eleven tubes tested to end of life, 3rd generation tubes achieved an average life of 7376 hours with a variance of 6000 hours to 12,500 hours. No field data is available yet to assess how well these tubes hold up under operational conditions.

3. Guidance received from Mr. Ambrose during the discussions follows:

a. The plan for the FY90 consolidated buy is acceptable providing the schedule is tightened up to take full advantage of the night vision industries' intensive capitalization and present industrial ramp-up. Additional technical, life cycle, learning curve, and requirements evaluations will be required in the near term to ascertain the appropriate future mix of 2nd Gen/3rd Gen I^2 and thermal goggles. We were tasked to take advantage of our night vision experience and apply all we have learned about night vision technologies to our current operational and equipment requirements. We were directed to work toward eliminating disconnects between equipment specifications and requirements documents. Cost, schedule, performance, operations, needs and technical factors are to be considered and balanced at some point short of giving the best available to all users. We are to avoid over specifying, favor high volume production proposals, look toward lower cost throw-away items, equipping the whole force as required, and maintaining the technological and operational edge over potential adversaries.

b. The PM and CNVEO are to keep in touch with Dr. Biberman regarding these issues and keep a "memory book" to assume that corporate knowledge will outlast any one person's involvement in the long term program. PM-NVD will maintain this record for programmatic issues with CNVEO maintaining the technical record.

AMSEL-RD-NV-TS FEB 5 1988

SUBJECT: 19 Jan 88 Meeting with Mr. Ambrose Concerning Night Vision Devices Program

c. The group was charged to lay out a proper foundation for future program direction, to assure that programs are really needed and worth the cost, and consider how to equip the Army in quantity and as soon as possible.

William H. Campbell
WILLIAM H. CAMPBELL
COL, MI
Program Executive Officer
Intelligence & Electronic Warfare

Paul D. Travesky
PAUL D. TRAVESKY
Dirctor, CNVEO

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SECOND AND THIRD GENERATION IMAGE INTENSIFIERS—GOGGLES

OPERATIONAL REQUIREMENTS

SYSTEM PERFORMANCE PARAMETERS

IMAGE TUBE OPERATIONAL LIFE

Operational Requirements

- The current operational requirements documents for fielded image intensifier systems will be discussed in this portion.

System Performance Parameters

- Those parameters which dictate and drive or limit the performance of image intensifier systems will also be discussed, including those which are system parameters and those which are specifically tube parameters.

Image Tube Operational Life

- The various considerations and concepts which make up image tube operational life—including tube mean-time-to-failure (MTTF), system mean-time-between- failures (MTBF), and attrition due to catastrophic damage, misuse or carelessness—will be discussed.

WHY GOGGLES?

INITIAL

Man Target Detection

Driving Wheeled and Tracked Vehicles

Perform Various Close-In Tasks

Provide Hands-Free Operations

FUTURE

Rifle Firing

Helicopter Pilotage

Initial

The initial requirements for goggles involved four general areas:

1 Detect man targets
2 Effectively drive various military vehicles, both wheeled and tracked
3 Perform various essential arm's-length tasks common to all soldiers, and
4 Allow full hands- free operation and performance of tasks.

Close-in tasks (25 centimeters to 10 meters) included:

- Assemble/disassemble weapons, rifles, machine guns
- Read dials on calibrated devices and instruments
- Read tactical maps
- Remove and replace electronic circuit boards
- Perform preventative and repair maintenance on vehicles
- Perform emergency first aid and medical tasks to include administering blood transfusions; identifying veins and inserting needles into those veins; clamping off bleeding veins and arteries; clearing throat of obstruction; and inserting emergency breathing apparatus.

Other longer range tasks (10 to 150 meters) included:

- Locate and remove wounded from the battle area
- Load and unload supplies
- Orient on a roadway
- Avoid obstacles and potholes while driving
- Read road signs
- Travel cross-country, avoiding hazards to navigation such as trees, ravines, disabled vehicles, and personnel.

Future

Future requirements were added to fire weapons using the AN/PAQ-4 aiming light and as an interim device for helicopter pilotage. These may require ranges of 150 meters or more.

Large objects such as tanks and structures may be observed at ranges up to 1,700 meters and goggles can be useful in detecting lights, such as aircraft running lights, at ranges up to several miles.

IMAGE INTENSIFIER OPERATIONAL PERFORMANCE REQUIREMENTS— AN/PVS-5 AND AN/PVS-7

NIGHT VISION GOGGLES AN/PVS-5, QMR 1964

- **Man Target:** 150 meters moonlight
  100 meters starlight
- **Driving:** 100 meters moonlight
  25 meters starlight
- **Close-In Tasks:** 25 centimeters to 12 meters, moonlight
  (May be augmented by infrared LED.)
- Focus from 25 centimeters to infinity with no more than 20% reduction in acuity throughout focus setting.

NIGHT VISION GOGGLES AN/PVS-7, ROC 10 Feb 82

- Performance characteristics comparable to the AN/PVS-5 from starlight to full moonlight.
- Have improved operational capability at starlight (10^{-4} fc) and down to 3×10^{-5} fc.
- Man target 150 meters, starlight.

The QMR for the AN/PVS-5 dates to 1964. In this, the initial design intent of the goggles was to perform varied tasks ranging from map reading, emergency medical aid, and vehicle under- the-hood maintenance (short range 25+ centimeters); establishing terrain features and self-orientation (12+ meters); and vehicle driving (50 to 100 meters), to interpersonnel visual communication (hand signals) and target detection (150 meters).

During the 1970s, the standard Army uniform was the olive drab fatigues. These uniforms had a flat spectral reflectivity from .400 to 1.000 microns, while later versions exhibited a somewhat increased response in the near infrared (IR) region (.73 to 1.00 microns). These uniforms tended to provide high contrast targets. Detection range characteristics were determined using these uniforms and man targets. Early PVS-5 tubes with nominal photocathode sensitivities of 150 to 175 micro amperes/lumen demonstrated detection ranges of 100 meters for starlight conditions and up to 150 meters for moonlight.

Though not an original requirement, the PVS-5 is widely used today for pilotage of Army helicopters UH-1, UH-60, and OH-58A.

No requirement for weapon firing was originally included since the goggles could not be used with iron sights on the M-16 and M-14 rifles. While area fire may be delivered, aimed fire could not be delivered until the AN/PAQ-4 aiming light was deployed. Aimed fire can be accomplished with an M-16 assault rifle using the AN/PAQ-4 in conjunction with the AN/PVS-5 out to a maximum range of 150 meters.

The 1982 PVS-7 ROC stated that *"The operational capability of the current standard goggle NVG-5 is restricted to high starlight illumination conditions or above. The range and resolution aspects of the device are severely diminished as ambient light decreases. The light and weather conditions, as well as the heavily wooded nature of the European operational area, a primary consideration, dictate that in order to be effective, night vision equipment must operate at as low a light level as possible. The year-round average light level in the Frankfurt area shows that levels are at starlight or below 50% of the time. The NVG-5 is marginally operational at starlight. The weight of a head-mounted device is critical as a negative operational factor as it induces fatigue, reduces the efficiency of the individual, and thereby impacts on the units' overall operational capability."*

During the timeframe associated with the development of this ROC, the PVS-7 was in full scale engineering development (prior to the omnibus NDI approach). At that time, the PVS-7 was third generation and performance measurements using olive drab man targets indicated that an improvement in performance over the PVS-5 to provide detection of a man target at 150 meters could be obtained, as well as improvements in overall performance below starlight conditions. Today, the basic metric for the PVS-7 is the PVS-5 performance. The LED built into the goggle assembly is useful for close-in tasks for both second and third generations, but provides no benefit much beyond arm's-length ranges.

IMAGE INTENSIFIER PERFORMANCE

FACTORS AFFECTING PERFORMANCE

- **Second generation versus third generation**
- **New considerations—**

  BDUs

  Laser filters

In this section, the basic factors of contrast, light level, and system factors will be discussed.

Second and third generation comparative performance will be discussed.

Two new considerations in performance will be introduced—

1 The Army's adoption of the Battle Dress Uniform (BDU) in place of the olive drab fatigues.

2 The need to incorporate laser filters into night vision goggle systems.

IMAGE INTENSIFIER (I^2) SYSTEM PERFORMANCE—AN/PVS-7

I^2 SYSTEM PERFORMANCE IS DETERMINED BY FIVE KEY PARAMETERS

1 Optical Performance of the Systems

2 Cathode Sensitivity } **Signal/Noise Ratio**

3 Light Level }

4 Target/Background Contrast

5 Atmospheric Conditions: Transmission
Smoke, etc.

Performance parameters of the system optics apart from the image tube, such as modulation transfer function, limiting resolution, and "f" number, are generally not very sensitive to light level and spectral content of incident light. The "f" number will, however, limit the amount of light which reaches the sensor.

The combination of photocathode sensitivity and incident light level (radiant flux) combined with the noise characteristics of the micro-channel plate (MCP) determine the output signal/noise (S/N) ratio as seen by the observer's eye.

The S/N ratio and target background contrast are key determinants of variation in range performance exhibited by an I^2 system.

The effect of atmospheric conditions may be considerable at long ranges; however, for the shorter ranges of operation of night vision goggles, only snow, sleet, rain, and ground fog impact performance.

Smoke directly degrades the performance of I^2 systems much as it does the performance of the human eye in daylight. Smoke is generally not transparent in the 400 to 1,000 nanometer wavelengths used by I^2 devices. Smoke and snow, sleet, or rain conditions were not considered in measurements completed by C^2NVEO during 1987.

GENERIC FACTORS AFFECTING PERFORMANCE

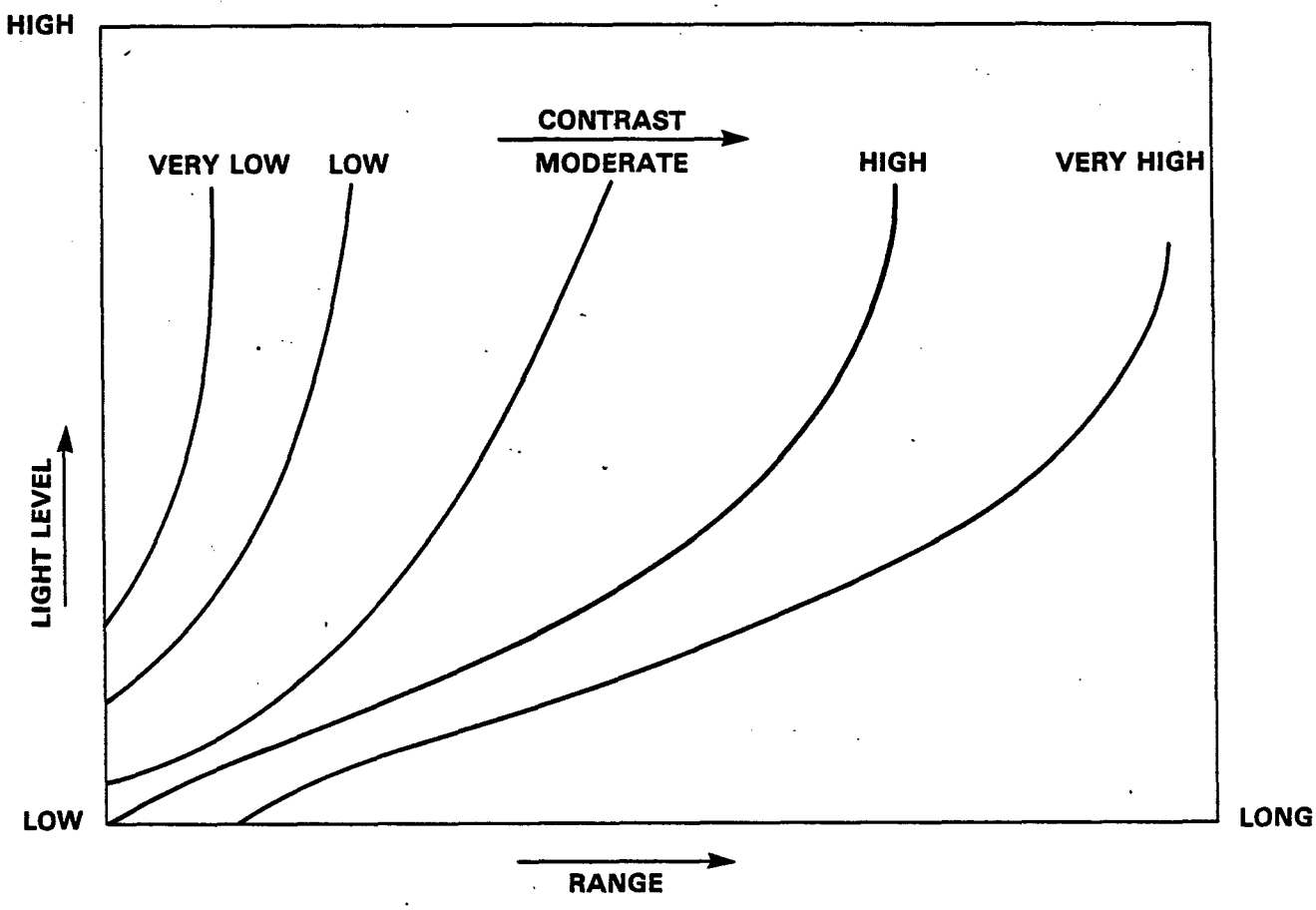

Figure 1. Generic Factors

There are two inseparable generic factors affecting all electro-optic devices and all optical devices including the human eye. These are:

1 Light level, meaning the total amount and spectral distribution of radiant and/or reflected energy reaching the sensor, and

2 The contrast or difference between the radiant energy reflected from the target of interest and its surrounding background.

Visual acuity and the corresponding property of an image intensifier device diminishes directly as light level decreases, ultimately going to zero.

Similarly, acuity goes to zero when contrast goes to zero, thus you don't use black chalk on a blackboard. Another case is "white out" in a winter storm; contrast is zero. In addition, however, contrast is itself a variable function of light level.

DETECTOR RESPONSE

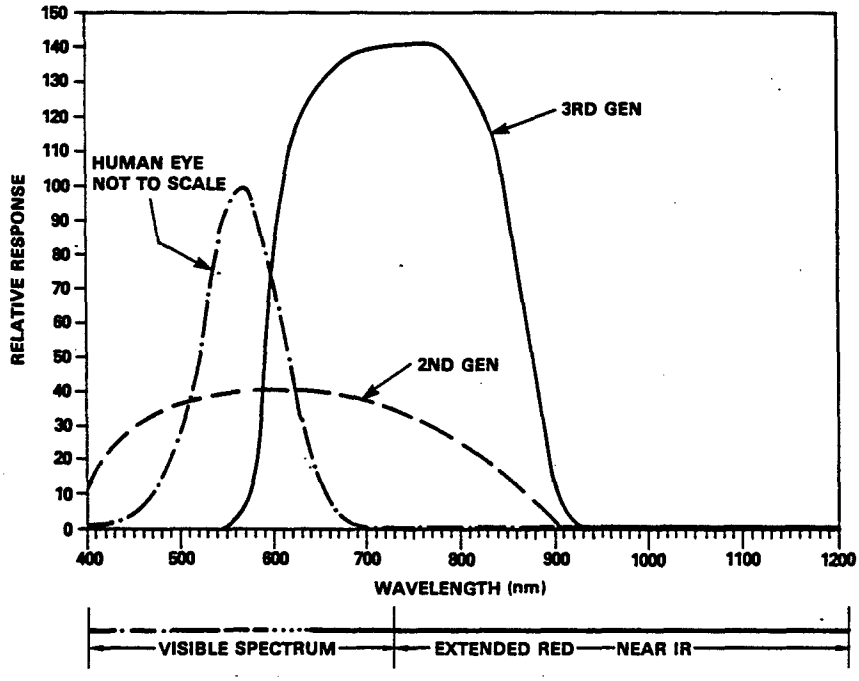

Figure 2. Detector Response

This chart shows the relative spectral response of the second and third generation photocathodes. Third generation is the —— curve and second generation is the ------- curve. The vertical scale is in milliamperes per watt, and the horizontal scale is wavelength in nanometers (millimicrons). The cathode sensitivity of an image tube is represented by the integral of the spectral response curve; i.e., the area under the curve. Stated in illuminance units, nominal photocathode sensitivity for second generation is 300 micro-amperes per lumen, and for third generation is 1,100 micro-amperes per lumen. In general, detection range performance is directly proportional to the square root of the cathode sensitivity.

The —·—·— curve shown for reference purposes is the spectral response curve for the human eye. The curve is spectrally correct but the amplitude (i.e, the area under the curve) is magnified relative to the second and third generation curves simply for clarity and readability.

The human eye functions only in the visible spectrum region. Radiation in the region of the bar labeled "extended red—near IR" is invisible to the eye, but readily used by both second and third generation intensifier tubes. Note also that there is a portion of the visible spectrum 0.4 to about 0.54 microns to which both the eye and second generation are sensitive but to which third generation is not.

COMPARATIVE REFLECTANCE OF EASTERN BLOC UNIFORMS

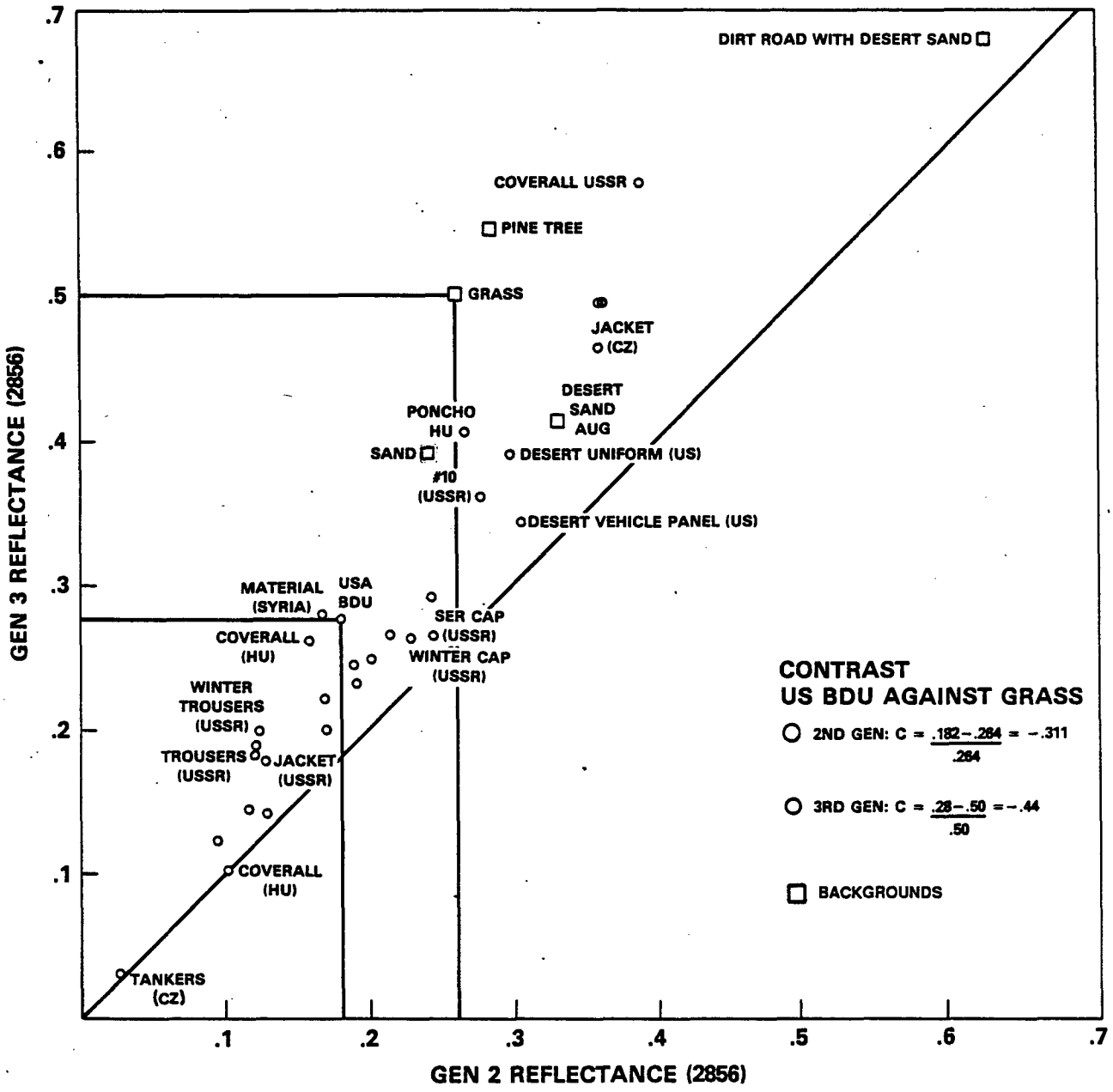

Figure 3. Contrast: US BDU Against Grass

COMPARATIVE REFLECTANCE OF EASTERN BLOC UNIFORMS – Continued

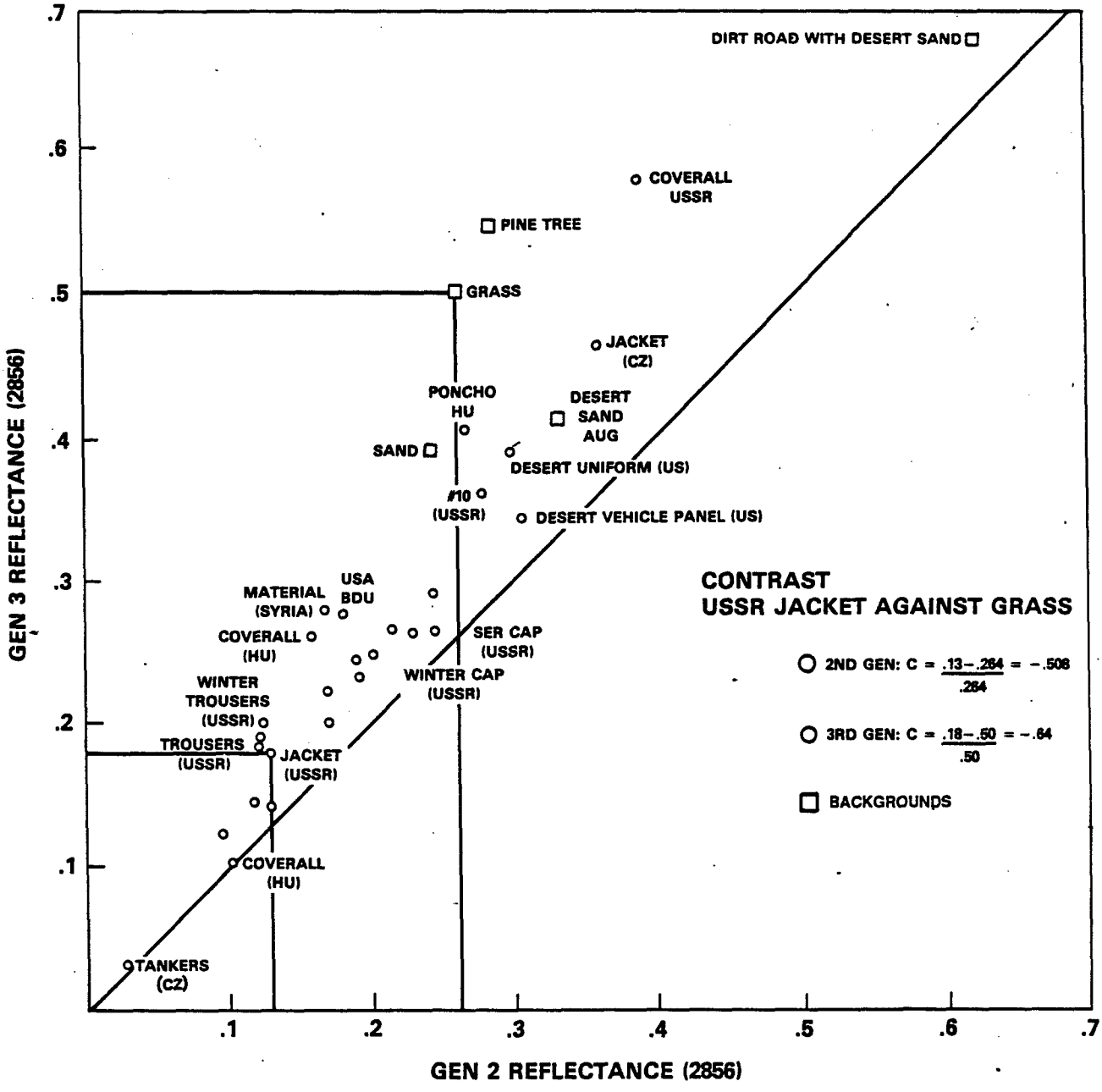

Figure 4. Contrast: USSR Jacket Against Grass

The two preceding charts show second and third generation reflectance data on Warsaw Pact and other sample uniforms. Contrast relative to specific backgrounds can be derived as in the first chart, BDU against green grass, and in the second chart, Soviet jacket against green grass.

Such data can be used to determine relative night visibility using goggles of US and foreign troops. Study has only recently begun.

This data shows most uniforms to be somewhat more reflective in the near IR and hence shows more third generation response than second generation under clear starlight conditions. Final performance of second and third generation can only be determined when specific contrast values are established for backgrounds of interest. The examples show derived contrast for a US BDU against green grass and a Soviet jacket against the same background as a sample comparison.

CONTRAST VERSUS LIGHT LEVEL UNIFORMS

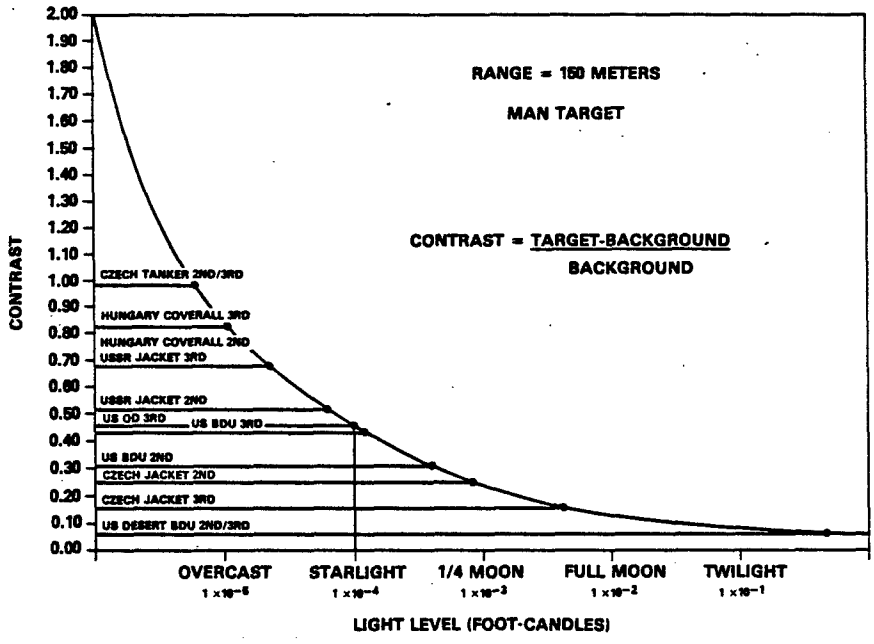

Figure 5. Contrast vs. Light Level

This chart shows that, in order to achieve a 150-meter detection range, a contrast of 48% must exist at 10^{-4} foot-candles (starlight). If the light level increases, the allowable contrast to meet the range can be lower. If light level decreases, contrast must increase to achieve the required performance.

The chart also shows the relative contrast at 10^{-4} foot-candles of a selection of 9 out of a current inventory of 30 Eastern Bloc and US uniforms under study at C^2NVEO. Foreign uniforms include Soviet, Polish, Czech, Hungarian, Romanian, East German, Syrian, and Chinese. In principal, iso-range curves can be derived for any combination of measured target and background reflectances.

In the example given, any contrast and light level combination which occurs above the iso-range means that the target **can** be detected, while any combination falling below the curve means the target **cannot** be detected. Also, for the measured contrast of each example uniform, the curve shows the corresponding light level at which man target is detectable at 150 meters. A Czech tanker uniform is very high contrast and thus could be detected by both second and third generations at less than 1×10^{-5} foot-candles, or low overcast starlight. Conversely, the US desert BDU can have a contrast so low as to not be detectable at 150 meters until twilight conditions prevail. Uniforms will, in general, exhibit a different contrast for every different background.

FOE TEST DATA

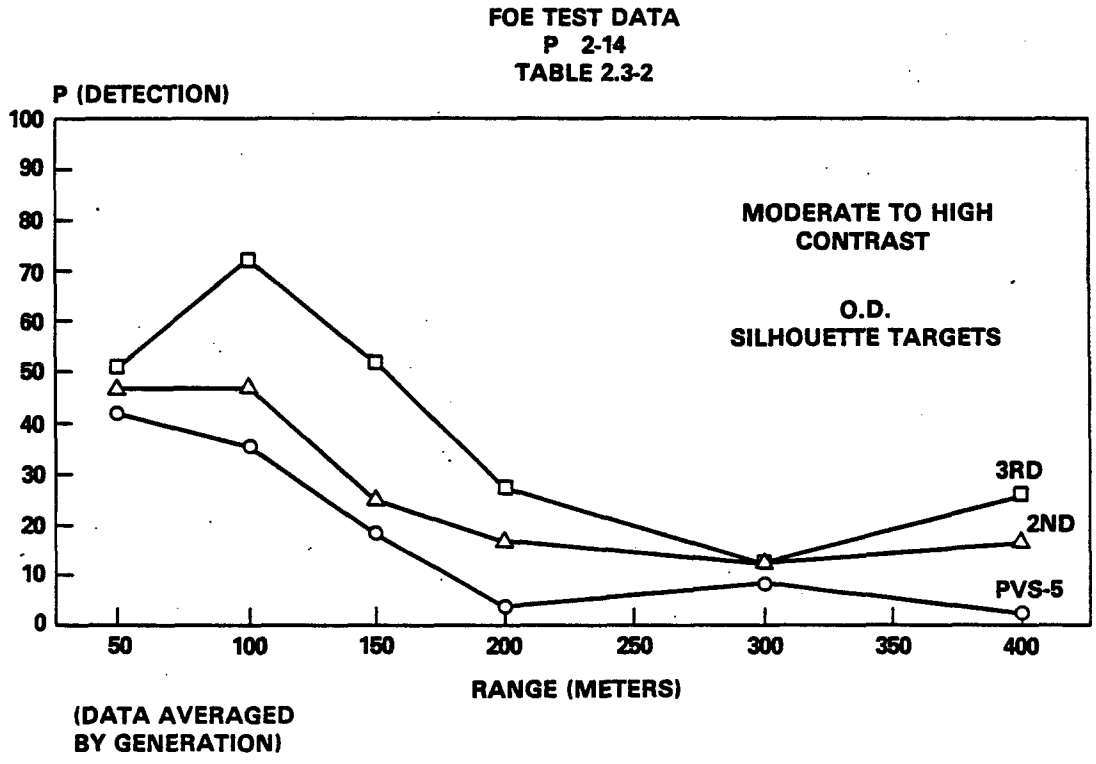

Figure 6. FOE Test Data

During FOE test, range and detection testing was conducted using O.D. silhouette targets in an open grass field under starlight illumination. The results of this test are shown in the above figure where the data for second and third generation systems has been averaged. The test conditions (i.e., O.D. against grass) present a high contrast situation where the background signal (grass) is large compared to the target signal. Test data indicates current AN/PVS-7 ROC compliance at the 50% point for third generation AN/PVS-7 but not for second generation. The AN/PVS-5 was not specified to meet the same requirement.

The data also shows that the maximum detection probability for second generation AN/PVS-7 is approximately 47% for ranges of 50 to 100 meters. For the AN/PVS-5, the maximum detection probability under this test was approximately 41% at 50 meters.

Modified AN/PVS-5s with faster optics equal to the AN/PVS-7 and brightness gain settings increased to AN/PVS-7 levels can be expected to perform on a par with the AN/PVS-7 (second generation). The AN/PVS-5 still requires two tubes to one for the AN/PVS-7.

FORT A.P. HILL, VA, RANGE DETECTION DATA

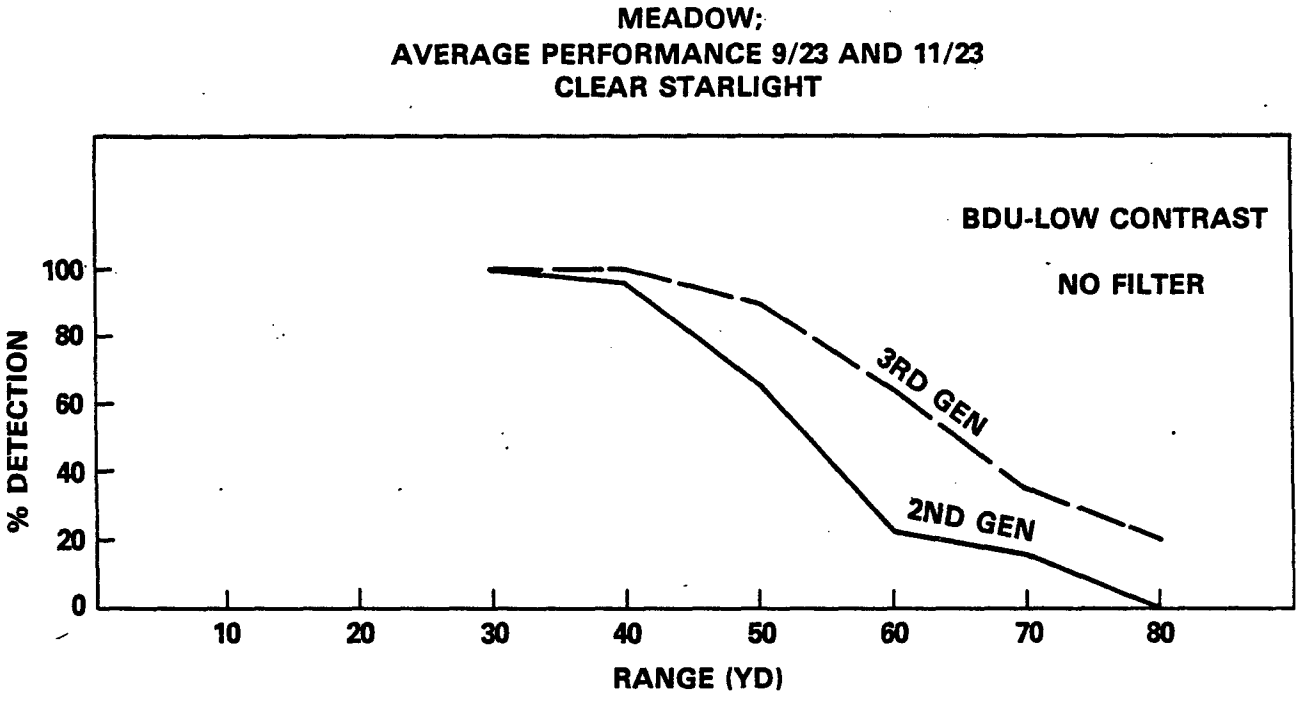

Figure 7. Range Detection Data

Range detection tests were performed at Fort A.P. Hill, VA, on 23 September and 23 November 1987. The data shown was collected at a grassland meadow site with bushes and forest in the background. Targets were soldiers in BDUs.

Data shows ranges at the 50% probability of detection point to be 65 meters for third generation and 53 meters for second generation.

The shorter ranges, when compared to the FOE test, are attributed to the lower effective contrast of the BDU when compared to O.D. silhouette targets used in the FOE.

A.P. HILL DATA USING LASER FILTER

Tests at Fort A.P. Hill as noted before were conducted in an open grassy meadow with bush and forest backdrop.

Soldier targets were dressed in BDUs.

Test conditions were clear starlight.

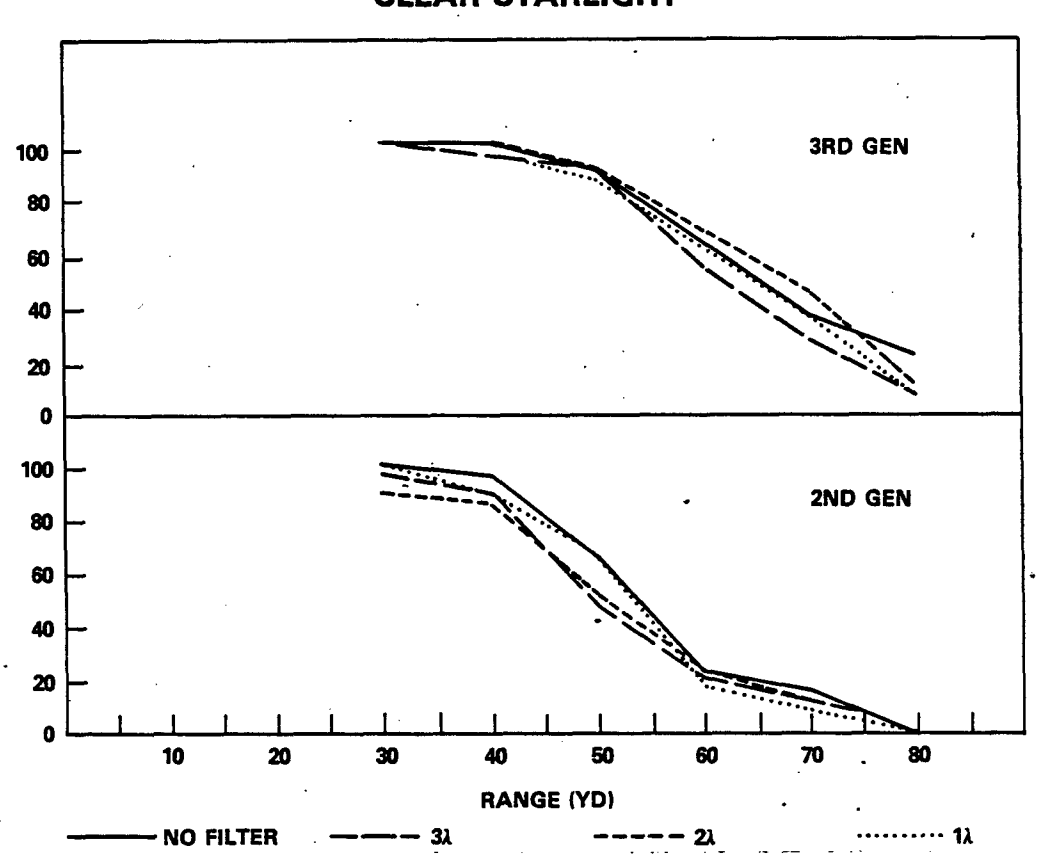

Figure 8. Range Detection Data

This chart shows two sets of detection probability *versus* range curves. The second and third generation performance curves are shown with no filter and each of the three filters tested.

In each case, the third generation systems show a performance advantage over the second generation. The data averaged for each case is:

No filter	18.2%
3 λ	16.0%
2 λ	24.3%
1 λ	17.7%

The filters are thus shown to have little, if any, impact. The 2 λ result could be the result of the type of contrast modification which can occur when these filters are used. The test represents a relatively small sample and the observed spread is within the uncertainty spread of the data for this type of test.

PART I—CONCLUSIONS

PERFORMANCE

- Third generation under static conditions out-performs second generation on average by 20 to 30%.
- Insufficient data available under search/dynamic conditions.

LASER FILTERS

- Under limited field test:

  1 λ filter has minimum effect on either second or third generation performance

  3 λ affects second generation more than third generation

GOGGLE LIFE

TUBE LIFE

SYSTEM LIFE

There are two key factors in goggle system operational life:

1 Image Tube Life

2 Goggle System Life

Because of the differing nature of the life and failure of these two, they must generally be treated separately and then combined in an appropriate way.

The image tube is characterized by a wear-out life—a mean-time-to-failure (MTTF)— which dominates its operational life. This is comparable to the tread life on an automobile tire. MTTFs are characterized by Gaussian failure distribution about some mean life; for the second generation tubes, the mean is 2,000 hours and for third generation the mean is 7,500 hours. The tube also has a mean-time-between-failure (MTBF) component. This is a measure of the random catastrophic failure mode of the tube. For an MTBF-characterized device, the probability of failure is always constant. The MTBF of the tube is similar to the condition of having a tire blow out because of hitting a rock or nail. This can happen after 1 mile or at 40,000 miles with equal probability. Tube MTBF is estimated from field data on attrition to be in the range of 7,000 to 22,000 hours depending upon the actual field usage rate of the tube, as previously discussed. For 86,000 tubes deployed, and if the attrition rate is 2.3%, then for—

Use rate = 180 MTBF = 7,800 hours

Use rate = 250 MTBF = 11,000 hours

Use rate = 500 MTBF = 22,000 hours

This characteristic is independent of the basic MTTF or life of the tube.

The goggle system itself, apart from the tube, is a complex system with at least five or six parts which produce periodic failure. The system is characterized by an MTBF. The goggle system may fail many times without a tube failure. Good tubes are simply transferred into other goggles and redeployed.

HOW FREQUENTLY ARE GOGGLES USED?

TRADOC OFFICIAL POSITION **500 hours/year**

CNVEO ESTIMATE OF ACTUAL USAGE BASED ON:

- **Spot checks as reported by five individual units in 1984** **232 hours/year**
- **Maintenance history 1984 - 1986** **174 hours/year**
- **Analysis of battery usage 1984 - 1986** **181 hours/year**
- **Maintenance history 1987** **418 hours/year**

The official usage rate provided by TRADOC based upon their analysis has been and is 500 hours per year average for all deployed units.

It has long been known that some units use their systems alot, particularly training base or school units, and others much less. It has always been very difficult to determine precisely what real-world usage rates really are.

C^2NVEO has analyzed data from three separate sources in order to provide an estimate of field usage:

1 Spot checks of five user units worldwide, including 1st Marine Brigade, 25th Infantry Division, 2d Infantry Division, etc. This was done for 1984.

2 Analysis of spare tube demands over the period 1984 - 1986, and 1987.

3 Analysis of battery usage 1984 - 1986.

It is shown that the three approaches agree reasonably well for 1984; notably, 232, 174, and 181 hours per year, respectively.

The analysis for 1987 shows an increase to an estimated 418 hours per year. This assumes a tube MTTF of 2,000 hours, an assumption C^2NVEO believes is supportable and will be covered at a later point in this briefing.

In support of the 418 hours per year, it appears that there is an actual increase in night vision training and, hence, usage. C^2NVEO's experience during 1987 has been a direct involvement in a significantly increased night vision training effort within the 2d Infantry Division in Korea. Similar efforts seem to be building in USAREUR also.

"700" HOUR MTTF SECOND GENERATION TUBE?

Second generation image intensifiers have consistently maintained an average reliability of approximately 2,000 hours. A variety of data sources confirm this result.

1 **Reliability demonstrations at the manufacturer and at C^2NVEO: 2,155 hours**

2 **Spot checks of field units monitoring both logged hours and tube failures: 1,492 - 2,699 hours**

3 **Battery consumption data (to confirm use rate) and demand data from the depot: 2,046 hours**

System-related failures such as face mask cracking, switches, knobs, and battery compartment failures combined with tube failures contribute to an overall failure rate for the image intensifier system which could approach 700 hours. System failures, however, do not affect the tube itself. Tubes from failed systems are typically recycled into the field at the direct support level.

The only known source of a reported "700" hour MTBF was from a 24 August 1984 DF which erroneously combined actual field failure rates with the known MTTF of the tube to arrive at an MTBF of 768 hours for a 2,000-hour MTTF tube.

Data from three areas demonstrate that the second generation tube consistently demonstrates an average life of 2,000 hours.

Evaluation of reliability demonstrations at the manufacturer and at C^2NVEO show a mean life of 2,155 hours for second generation.

Spot checks of field units monitoring both logged hours and tube failures yield a range of 1,492 - 2,699 hours.

Battery consumption data (used to confirm use rate) and demand data from the depot show 2,046 hours.

Goggle system may fail many times and be repaired many times without affecting the tube life. Only when the tube experiences a random catastrophic failure does it appropriately enter the system MTBF equation.

Estimates of a "700" hour goggle system MTBF when calculated using tube MTTF are erroneous. While the exact MTBF of the goggle system apart from the tube is not known, it is not driven by the tube nor is the tube materially affected by the repair frequency of the goggle.

CORRELATION: INITIAL S/N AND TUBE LIFE

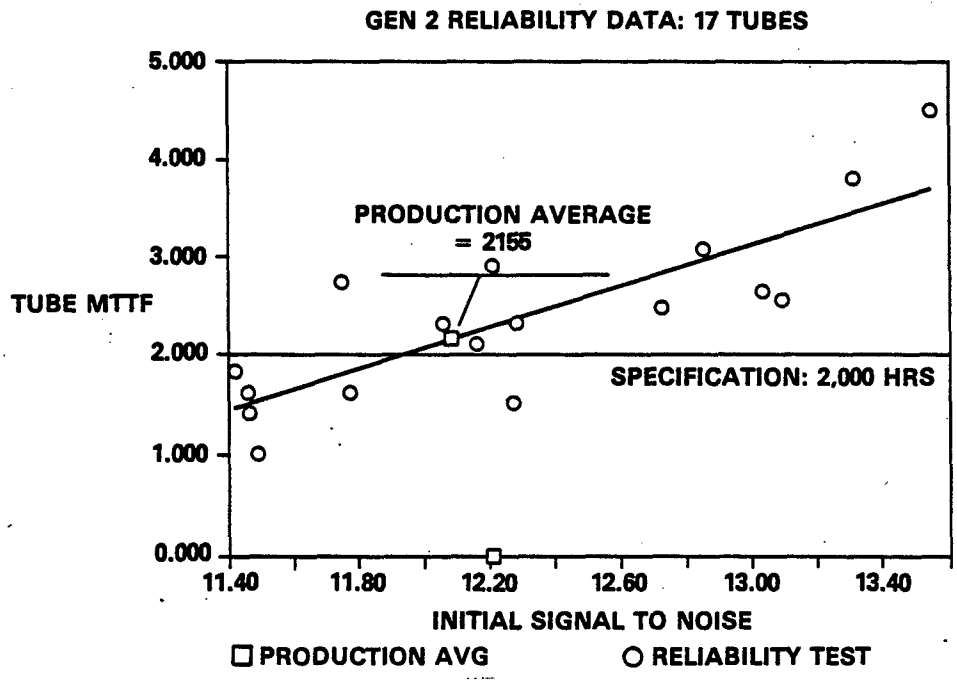

Figure 9. Correlation: Initial S/N and Tube Life

Tube MTTF correlates fairly well with the initial signal to noise (S/N) ratio of the tube. Shown above is a plot of time before failure of a group of second generation tubes versus S/N measured on the tubes prior to the beginning of reliability testing. A linear fit of the relationship between MTTF and S/N had been used to establish the expected life of production second generation tubes. The single point on the line is the production average S/N currently being delivered.

Although manufacturers may produce tubes that have significantly higher reliability, it is the production average which determines expected field performance. Notably, the average initial S/N of the relatively small sample of tubes tested for reliability has been somewhat higher than the production average.

The chart shows that there exists good correlation between the S/N ratio of a new second generation tube and its expected life. The data shows for a sample of 17 tubes, S/N ranges from 11.40 to a little above 13.40, and associated tube life times varied from 1,000 hours to 4,500 hours. The production average of tubes currently being delivered is 2,155 hours.

SECOND GENERATION RELIABILITY TEST DISTRIBUTION

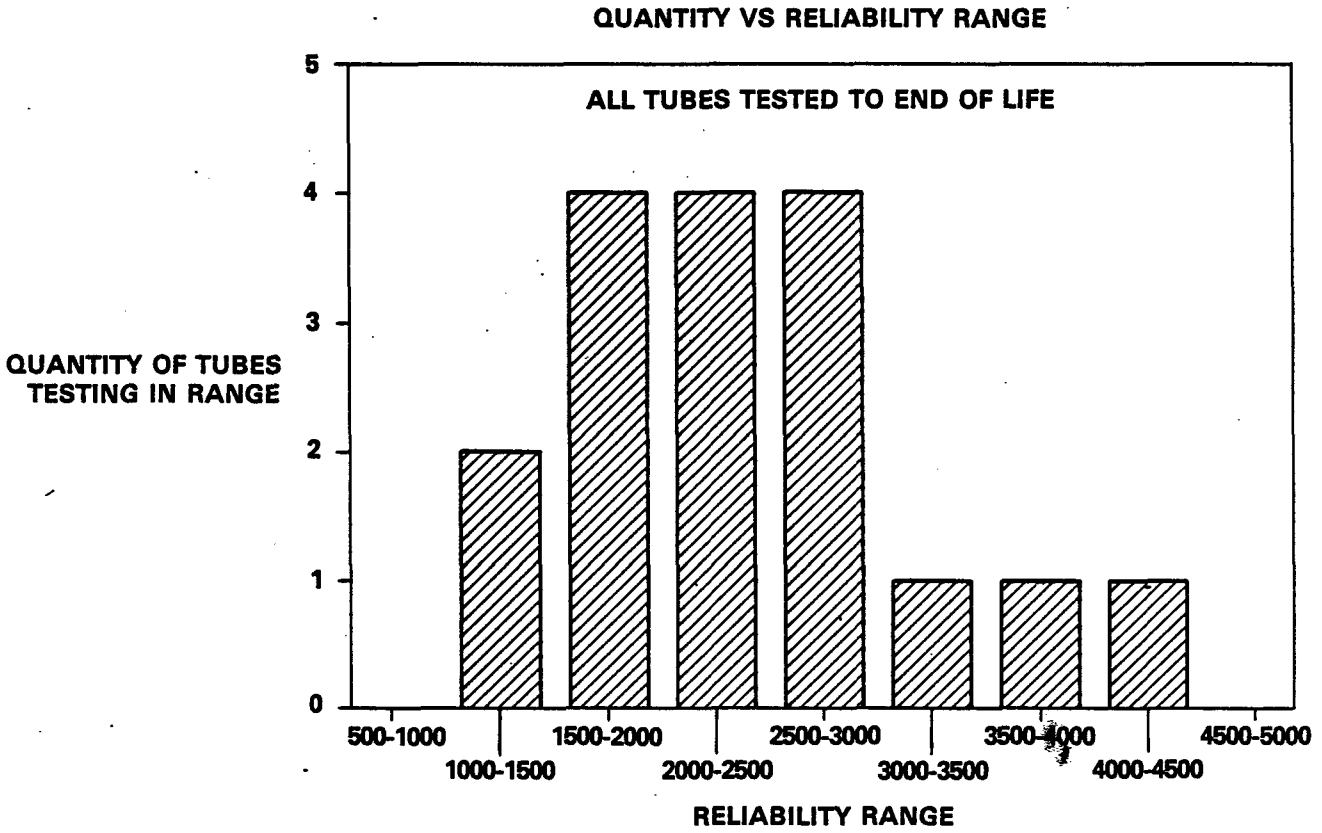

Figure 10. Second Generation Reliability Test Distribution

The above chart depicts the distribution of second generation tubes which were subjected to reliability testing to their end of life. The 17 tubes tested had an average reliability of 2,372 hours. This value is slightly above the predicted production average of 2,155 hours and represents the difference between the initial S/N of the reliability test lot and that of the production lot. Considering the small sample, such a difference is to be expected. The tubes testing in the 3,500 through 4,500 range represent about 12% of the total; however, this reliability would represent less than 5% of the production distribution.

SECOND GENERATION PRODUCTION TUBE RELIABILITY

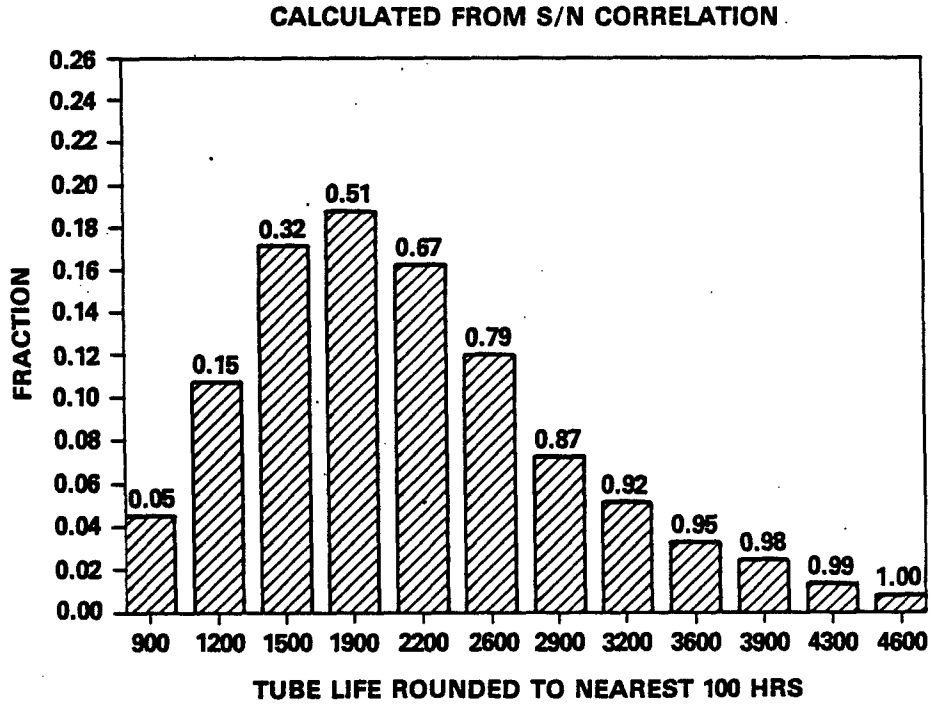

Figure 11. Second Generation Production Tube Reliability

The signal to noise distribution of new tubes from the manufacturer and the correlation between tube life and signal to noise were the source data for this graph.

The graph plots the fraction of delivered tubes against the expected life of those tubes. The reliability values are a straight-forward application of the calculated linear relationship between reliability and S/N.

The values at the top of each bar are the cumulative fraction of the production quantity with an expected reliability less than or equal to the value on the X axis. Hence, if one wished to change the tube specification to net a higher reliability, the cumulative values provide a first cut benchmark for the fraction of the production yield which would have to be discarded. For example, if the yield were to be truncated to raise the reliability beyond 2,900 hours, then 87% of the production lot would be lost. This would result in a tube cost increase by a factor of 7.8 at the manufacturing level.

Note that the median value is somewhat less than the average due to the nonsymmetrical distribution. The asymmetric distribution is caused by the apriori truncation of the production manufactured distribution required to meet the existing production specification.

SPOT CHECKS OF INDIVIDUAL UNITS

UNIT DESIGNATION	UNKNOWN	1ST MARINE BRIGADE	25TH INFANTRY DIVISION
TYPE OF UNIT	AIR	GROUND	BOTH
YEAR	1979	1984	1984
TOTAL SYSTEMS IN UNIT	73	125	369
SYSTEMS IN USE	73	33	369
TOTAL TUBES	180	290	930
TUBES IN USE	146	66	792
FAILED TUBES PER YEAR	53	40	138
TOTAL HOURS TUBES USED	143,032	69,498	205,920
MEAN TIME BEFORE TUBE REPAIR	2,699	1,737	1,492

	ALL DATA	1984 DATA ONLY
MTBR	1,811	1,547
MTTF	2,013	1,836

In the past, C^{2}NVEO has conducted spot checks primarily to investigate a particular series of reported failures of night vision equipment. This data base has yielded information about the rate of failure of AN/PVS-5 goggle tubes, the number of hours per year that the systems were used, and the relative utilization of systems.

Although the 1979 data is shown for reference purposes, field failure criteria were immature at the time the data was collected and the Mean-Time-Before-Tube-Repair (MTBR) and MTTF calculations are subject to a variety of interpretations.

The MTBR is calculated by dividing the total number of hours by the number of tube failures that occurred. The average for 1984 data (*all hours/all failures*) is 1,547 hours.

The assumed attrition rate (failures not caused by tube wear-out) of 2.3% reduces the number of tubes failing due to wear out by the product *0.023 x total tubes in use*, which yields an MTTF for the tube of 1,836 hours. This result is in good agreement with the reliability test result of 2,155 hours.

Data from three units was used to estimate field MTTF for the second generation tube. This data is shown to produce good agreement with reliability test results and further corroborates the achievement of an average of at least 2,000 hours MTTF.

INDIVIDUAL TUBE PERFORMANCE— SECOND GENERATION

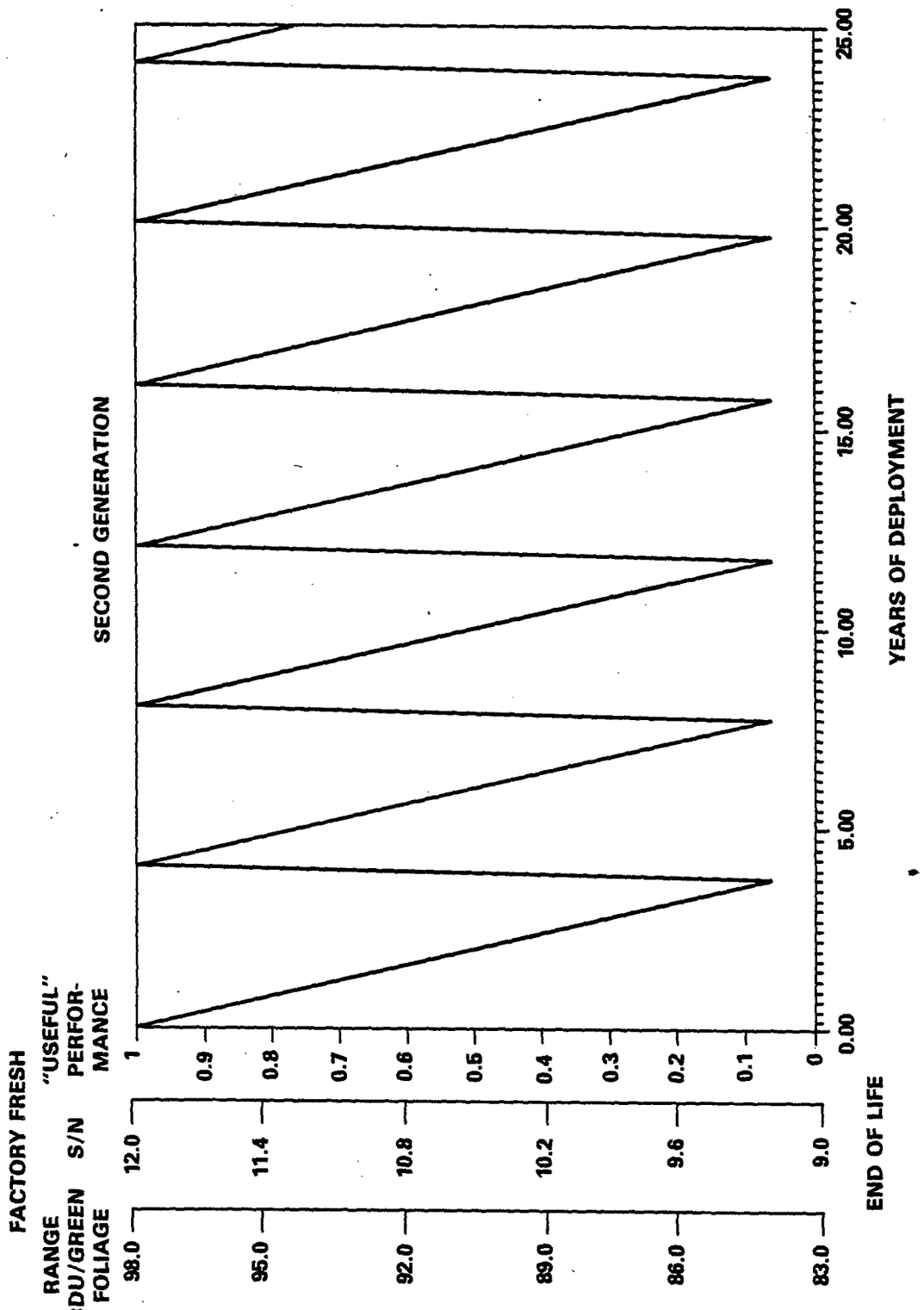

Figure 12. Individual Tube Performance—Second Generation

This chart is a rework for clarification showing the decay over operational life of the current second generation image tube. The sawtooth curve shows that for a nominal MTTF of 2,000 hours and an annual use rate of 500 hours/year, a second generation tube on average decays from its as-bought performance to the end of life failure level in 4 years. It will then be replaced by a new tube and the cycle repeated for the economic life of the system—5, 10, 15, or 20 years—as the case may be.

Three scales are shown on the vertical or Y axis. The useful performance scale is as originally shown, illustrating that over 4 years, the tube decays steadily to the end of life or 0% of useful performance.

The S/N scale shows that a "new" tube starts life with a S/N of 12.0 and decays steadily to an end of life value of 9.0.

Viewed a third way, for the specific condition of a BDU viewed against a background of green grass, the scale predicts a range detection at the 50% probability level of 98.0 meters for the "new" tube , degrading to a detection range at end of life of 83.0 meters.

While the "end of life" value of 83 meters may seem to be considerable, what is missing from the simplistic range detection metric is the noisy condition of a tube at end of life. The condition is similar to the signal received from a somewhat too distant TV station. A picture can be seen, but it is difficult to discern detail. Also, it causes considerable strain and effort to follow the picture. In addition, it may take concentration for some period of time to discern the only detail in the image.

Such a condition as this becomes an issue of safety for a vehicle driver with goggles when personnel in low contrast target/background conditions can't be seen on the road or cross-country trail. The driving function is a common and critical function for goggles.

IMAGE INTENSIFIER END-OF-LIFE DEFINITION

	Old	New Test Method
• **End-of-life S/N specification**	**3.5**	**9.0**
• **End-of-life performance equivalent in the field**	**Detection of a man target on a road at 50 meters at starlight (static *versus* dynamic conditions)**	

During the development program for the AN/PVS-5, one of the primary military tasks was vehicle driving. The criteria for minimum system performance under clear starlight conditions of identification of a man target standing on a road at a 50-meter range was adopted. This type of target presents a high contrast scene when viewed through an image intensifier system. Using this criteria, the minimum S/N ratio at the end of tube life was established to be 3.5 when measured at 1.17×10^{-6} fc (equivalent of starlight at the photocathode of the tube). When viewing a scene with this S/N ratio, the display becomes very noisy and the noise content has begun to dominate the display with scene details becoming more and more obscured. Displays of this type induce high levels of user eye strain. Production tubes with an initial S/N ratio of 4.5 were found to be capable of meeting a 2,000-hour life minimum when tested in the laboratory.

NOTE: During the early development of the AN/PVS-5, the S/N ratio was measured at a light level input of 1.17×10^{-6} fc. This light level was found to be very difficult to measure and keep in calibration. With the agreement of industry, the S/N specifications and test methodology were altered to allow the increase of the light level to 1×10^{-5} fc and to correct a bandwidth factor found in the specification. The old S/N figure has been adjusted as follows:

$$3.5 \times \frac{10^{1/2}}{1.2} \times \frac{1.09}{1.24} = 9.0$$

3.5 x light level adjustment x bandwidth = the current S/N end-of-life.

SECOND GENERATION EXTEND LIFE

TWO APPROACHES

1 Change S/N and cathode sensitivity specification for current second generation

2 Add ion barrier film to current second generation

IMPACT

- Ion barrier results in S/N ratio and performance loss of 20.5%

- Both approaches result in yield impact on cathode sensitivity and S/N

Second generation tube life gradually decays as a result of bombardment of the photocathode by ions generated by electron impact inside of the microchannel plate (MCP). Ion impact on the cathode results in a decay in the cathode sensitivity with an accompanying degradation in field performance. Ion feedback from the MCP can be reduced by placing a very thin (30Å) film of aluminum oxide over the input of the MCP. The film prevents ions generated in the MCP from escaping to bombard the photocathode. Signal electrons from the photocathode are accelerated to a high energy and most of the electrons penetrate the film and participate in the gain mechanism of the MCP. Some signal electrons do not penetrate the film and are lost, which effectively reduces the MCP detection and gain characteristics and thus the S/N of the tube.

One of the measures of system performance is the S/N ratio of the image intensifier display:

$$S/N = \frac{K\theta^{1/2}}{N_F}$$

Where K = constant which includes measurement bandwidth and light level at which measurement is made

θ = cathode sensitivity

N_F = noise figure which is a measure of the detection statistics of the MCP.

The noise figure of a second generation image tube without an ion barrier film is 1.59, while a tube with an ion barrier has a noise figure of 2.0. The net effect of using an ion barrier film in an image tube is to reduce the S/N ratio by 1.59/2.0 = .795. The effective cathode sensitivity is reduced to the square of this number if $.795^2 = .632$ which is very close to the loss in cathode sensitivity at the end of life; i.e., .605. The use of an ion barrier film in a second generation tube will produce an extremely long life tube whose performance borders on unacceptable. If the effective S/N ratio specification remains unchanged, then acceptable tubes must have cathode sensitivity well in excess of current values and a significant tube yield impact will occur.

THIRD GENERATION TUBE LIFE: ITT FIRST ARTICLE

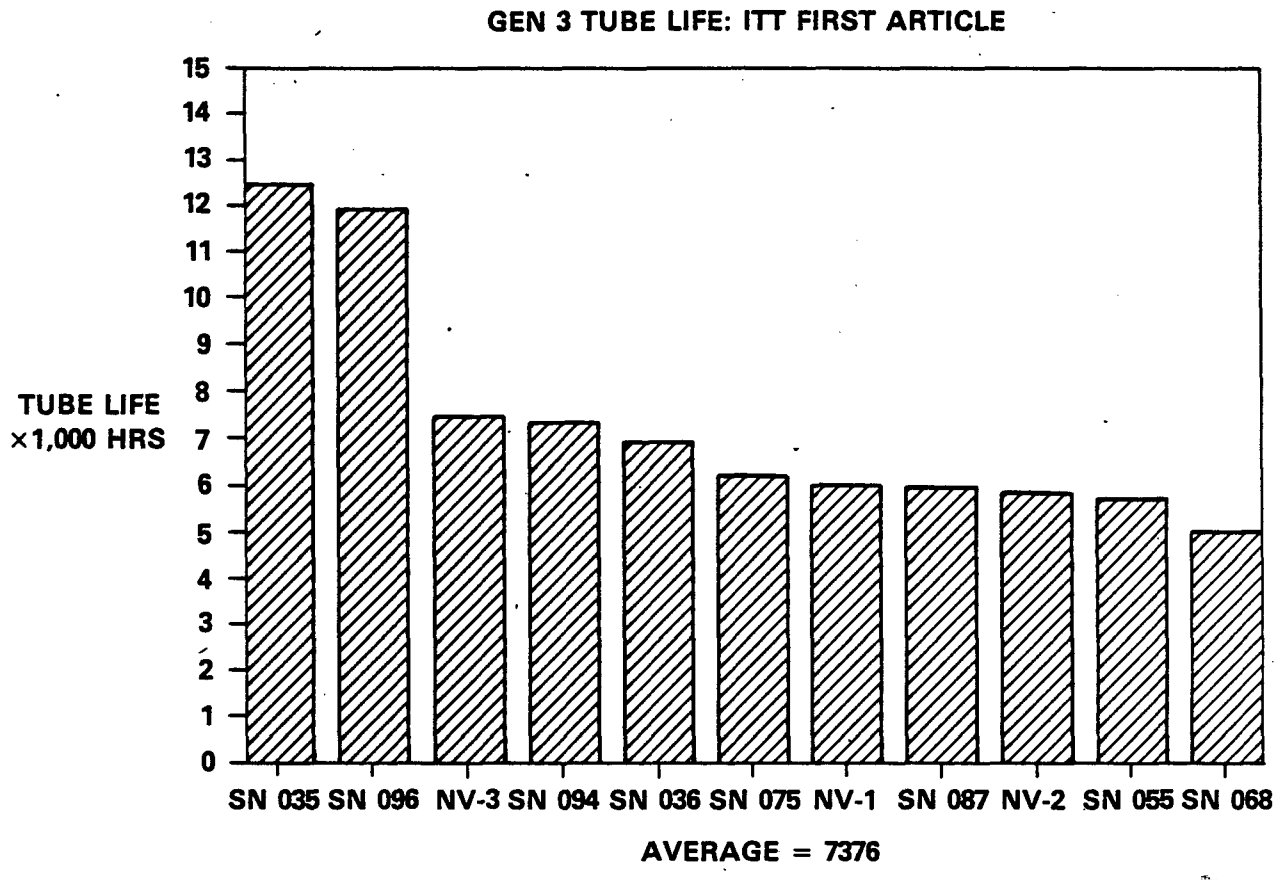

Figure 13. Third Generation Tube Life: ITT First Article

Third generation tube reliability test results on 11 production tubes demonstrate an average life for these tested items of 7,376 hours. When applied to the S/N distribution of production lot tubes, the average "as delivered" expected life becomes 7,500 hours. Tubes designated by "S/N___" were run at the manufacturer's facility. Those marked "NV-____" were run at C^2NVEO.

- Eight third generation tubes were tested at ITT and three at C^2NVEO. Tubes were run to the end-of-life in each case.
- Note that tube lives vary from a low of 5,000 hours to a high of 12,500 hours. The mean of this group is 7,376 hours.
- When the mean S/N ratio for this test group is compared to the current production mean S/N, the expected production mean life (MTTF) is 7,500 hours.

PART II—CONCLUSIONS

PERFORMANCE

- Third generation under static conditions out-performs second generation on the average by 20% to 30%.
- Insufficient data available under search/dynamic conditions.

LASER FILTERS

Under limited field test:

- 1 λ filter has minimum effect on either second or third generation performance.
- 3 λ filter effects second generation more than third generation.

TUBE LIFE

- Effective operational life of second generation tubes approaches 2,000 hours MTTF.
- Attrition is a nominal 2% to 3%.
- Third generation measured life is nominal 7,300 hours.
- Second generation life can be increased with yield impact.

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