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| **Author:** | **Charlie Mesloh, Ph.D. ; Mark Henych, Ph.D. ; Ross Wolf, Ed.D., M.P.A. ; Kirt Gallatin, B.S.** |
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# Infrared Beacon Evaluation: Applications for Law Enforcement

**A report to the National Institute of Justice**

CHARLIE MESLOH, Ph.D.
Associate Professor, Florida Gulf Coast University

MARK HENYCH, Ph.D.
Senior Researcher, Weapons and Equipment Research Institute

ROSS WOLF, Ed.D., M.P.A.
Assistant Professor, University of Central Florida

KIRT GALLATIN, B.S.
Research Assistant, Florida Gulf Coast University

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## iv. EXECUTIVE SUMMARY

This project evaluated a range of infrared beacons (IR) currently available in the law enforcement marketplace in reference to their applicability, utility as safety devices for law enforcement officers, and as potential tools for operational deployments. Overall, the findings suggest that this technology has substantial application for tracking law enforcement officers involved in foot pursuits, as well as, monitoring police canines that are operating off-lead. While the visibility of IR beacons was increased by motion, a large number were detectable while stationary and on the ground. Hence, indicating new applications available for IR beacons such as assisting in recovering an injured officer or serving as a marker to identify evidence for later recovery.

For the purpose of this comparison evaluation, 13 IR beacons produced by 9 different manufacturers were tested. It was determined that each type of IR beacon had its own range of limitations which eliminated any one beacon from offering a one-size fits all solution. Consequently, different IR beacons were better suited for certain tasks and environments than others. Therefore, the authors recommend that chief administrators evaluate the conditions under which their departments operate and then select the appropriate IR beacon/s. To evaluate the IR beacons relative effectiveness, the researchers developed a scaled measure based on empirical principles.

At the analytical heart of this research was a scaled measure developed to rate the visibility of the particular IR beacon under study. To develop this scale a Delphi approach was used which anchored the scale at both the low and high ends in a standardized environment. The intermediate measures on this scale are not necessarily equidistant, and as such this is a measure that has interval qualities but is not an interval or a ratio level of measurement.

The obvious conclusion that all IR beacons would be more effective in lower light testing environments proved true. In the lowest light scenarios, the reduction in direct light allowed for the minimally present ambient light to be amplified by the night observation device (NOD) without the scattering or the haloing effects (optical noise) of other light sources. This allowed all the IR devices to be found and/or located and was considered a successful deployment for them. In cases where the outside light (non ambient external light sources) was less than starlight and/or moonlight, the IR beacons the easiest to locate were the most intense or powerful. As the more powerful or intense IR beacons tended to be larger, this resulted in a tradeoff between ease of which to carry the beacon, its size and visibility. The larger IR beacons may not offer ease of routine deployability on officers' uniforms or duty belts. Ultimately, the actual light and other environmental conditions in which a device is deployed becomes a major factor for selecting an IR beacon.

The larger beacons may have higher utility in K9 applications where a harness can carry the larger beacons with ease. Additionally, the ability for a K9 tracking team to be able to drop a low cost marker whenever evidence is located may also have utility. Forensic evidence is easily destroyed and creates substantial problems for officers pursuing a suspect. Markers of this type are invisible to persons without a night observation device (NOD) and could insure that the properly trained personnel would locate and subsequently collect these items of evidentiary value as opposed to them being lost or destroyed.

A key finding of this research was the relative effectiveness of all the IR beacons under review. As demonstrated in scenario testing in 8 test locations and detailed in this report, numerous IR devices were scored as being visible but did not score as high as possible on this scale. Despite some of the beacons scores being lower than others it was found that a mere score of “one or greater” was a successful deployment as it was located. Whereas, an IR beacon that scored a zero in a particular environment simply was not visible.

Another key finding in this research was that IR beacons utility was substantially increased when coupled with an aerial surveillance unit such as a helicopter. It became apparent during testing that the IR beacons visibility from a helicopter allowed for the coordination and efficient management of human and K9 assets on the ground during search and rescue or enforcement operations. Using this approach, K9 teams and officers could be deployed in a manner that increases the likelihood of success and minimizes the potential for friendly fire shooting scenarios. As most air units are equipped with thermal imaging and infrared detection systems, suspects not wearing an infrared beacon may be quickly discerned from the law enforcement officers and allows for rapid targeting, coordination, and containment tactics.

Another major component of applicability to law enforcement for the IR beacon is they do not have to be “seen” directly to be located. The infrared light from the device may reflect off other objects and this reflected light might be discerned by an observer. It was found when observing from the ground level, objects such as trees, grass, and buildings could completely shield the IR device and preclude it from being located. However, in the cases when the search was conducted from an aerial vantage point, the disadvantage of line-of-sight searches was almost immediately overcome as evidenced by the speed with which the observer in the aerial unit was able to locate the IR beacon.

Finally, the cost considerations for the purchase and implementation of the IR beacons and the night observation devices are well within the budgetary limit of even the most financially conservative law enforcement agency. Technology transfer programs provide night vision technology to agencies at little or no cost and the individual beacon cost is lower than that of an expandable baton.

## 1. THE NATURE OF THE PROBLEM

A problem faced by law enforcement agencies is the tracking of their officers once they leave their motor vehicles. Frequently officers exit their vehicles in pursuit of a suspect without communicating an updated location to dispatch or other officers. An officer in a foot pursuit could travel great distances from their vehicle before the first back-up unit arrives. Consequently, if the officer is incapacitated, they are difficult to locate, particularly in nighttime or low-level light conditions. This is not an infrequently occurring event; according to the UCR reports 57,546 (12%) law enforcement officers were injured in 2005, and the largest number of officers tended to be injured in the line of duty between the hours of midnight and 2 am (FBI, 2005).

Nighttime and low light conditions create an added potential for injury as friendly fire incidents may occur due to the difficulty in differentiating fellow officers from suspects. Perimeters established by SWAT and tactical units create the operational necessity to know where each officer is stationed in a manner that is undetectable to the suspect, but known to other officers.

Another problem is the relative lack of research in the area of IR beacons applicability for domestic law enforcement. The researchers conducted a review of the literature and found no current academic or scientific study on the applicability of IR beacons and night observation devices for law enforcement. In order to begin research in this area, this study attempted to measure the utility of IR beacons in simulated law enforcement deployments in different environments.

Ultimately the researchers sought to determine whether or not IR beacons could be used as a low-cost, easily implemented solution for tracking police officers engaged in foot pursuits in urban and rural environments.

## 2. LITERATURE REVIEW

There are several categories of technology, which can be used to help locate personnel. These can be classified into broad categories of visual devices (including image intensifiers and infrared devices) and global positioning devices (including emergency transponders and latitude/longitude locators). While certainly global positioning (GPS) devices may have a use in the tracking and location of police officers, this current study seeks to examine visual devices with the anticipation of finding a less-costly alternative. The following section addresses the historical use of night vision technology.

## 2.1. Overview of Night Vision Technology

Night vision has been in use for approximately 60 years. There are two types of night vision: infrared thermal imagers and image intensifiers. This current study focuses on image intensifiers, of which there are 5 different generations, “Generation Zero” through “Generation Four” (Tyson, 2007). Generation 0 was originally invented by the US Army and used by American, British, and Russian soldiers in World War II (ABCnews.com, 2001). These night vision devices used active infrared by attaching an IR illuminator to the night vision device. The IR illuminator served as a flashlight, but instead of projecting visible light, it projected infrared light. There were two problems with “Gen 0” night vision. First, they used an image-intensifier tube (utilizing an anode and cathode to accelerate the electrons) that would distort the image. Second, as they used active infrared, anyone using night vision would be able to spot the source using it. This, inherently, made it dangerous to use if enemy troops had night vision technology (Tyson, 2007).

Generation 1 solved this problem by switching to passive infrared. Instead of relying on an IR illuminator to light up an area, Generation 1 used ambient light to supplement any available light source. By no longer needing an IR spotlight, soldiers using Generation 1 night vision would not be clearly visible to enemy troops with night vision capabilities. However, Gen 1 was not without issue, as a reduction in ambient light reduced the amount of light enhanced thereby reducing functionality. Typical scenarios such as cloud cover proved troublesome if it blocked moonlight or starlight, thus rendering the Generation 1 night vision ineffective without an IR light. Additionally, Generation 1 used the same image-intensifier tube as Generation 0 and the image was still distorted or blurry (Tyson, 2007).

The Generation 2 design offered many improvements in its image-intensifier tubes to help with image distortion. This was accomplished by adding a microchannel plate (MCP) to the image-intensifier tube. Instead of just accelerating the electrons, which distorts the image, the MCP increases the amount of electrons. This increase in electrons effectively allows the user to see in near-dark environments without compromising the quality of the image (Tyson, 2007).

Generation 3 night vision technology is currently being used by the military. Although there are no significant changes between Generation 3 and Generation 2, the cathode in Generation 3 is made using gallium arsenide, which is far more efficient in converting photons to electrons. This rise in efficiency produces a clearer image. Generation 3 also uses a coated microchannel plate (MCP) with an ion barrier to increase the life of the image-intensifier tube (Tyson, 2007).

Generation 4 removed the coated ion barrier from the MCP to allow more electrons to pass though and therefore increase the clarity of the image. Generation 4 also addresses a major problem with previous generations of night vision in their inability to adjust to rapid changes in light levels. Dramatic increases in light magnitude could have damaged earlier models. Generation 4 solves this problem by adding an automatic gated power supply that allows the cathode voltage to turn on or off quickly. Therefore, if night vision is being used in a low-light environment and lights are turned on abruptly, the amount of voltage going to the cathode will adjust accordingly preventing any temporary blindness or equipment damage (Tyson, 2007). Some argue that Generation 4 is a misnomer and this technology should be classified as an extension of Generation 3. The following section addresses the use of night vision technology, infrared beacons and their use by the US military and applicability to law enforcement.

## 2.2. Law Enforcement's and the Military's Use of NVG and IR

Infrared imaging systems are used to help the operator see in the non-visible infrared spectrum by converting wavelengths out of range of the human eye. The earliest such systems, used by German tanks in 1944, used an infrared radiation transmitter to illuminate an area, which was then viewed through special receiver devices. Modern systems use "passive" devices that form visible images from naturally occurring infrared energy, even in the absence of ambient light. While the infrared region of light covers a substantial portion of the electromagnetic spectrum, from .75 to 1000 μm (microns), only a minor part of that range is used for infrared imaging systems, the 3-5 μm and 8-12 μm bands. Energy in those bands may be radiated or reflected by the target and several factors form the resultant visible infrared image to include temperature, surface finish, surroundings, and atmospheric conditions (McCracken, 1992).

The utility of night vision technology has been evaluated and tested by the United States Coast Guard (USCG). The United States Coast Guard (1995) compared the ability of two helicopters fitted with Generation 3 night vision technology to find test boats "lost at sea". One of the helicopters was equipped with an IR illuminator, and the other was not. The difference in the helicopters ability to find "lost boats" was significant, and the study concluded that the IR illuminator made searching "much better" and that it "helped by reducing 'optical noise' due to high NVG (night vision goggle) gain" (Pp. 56). The quantitative data in this study showed that the probability of detecting life rafts and boats in the water significantly increased when an IR illuminator was used, especially when no moon was present (McClay, Raunig, Robe, & Marsee, 1995). Ultimately, using night vision technology in search and rescue produces a sizeable advantage particularly when in cooperation with an IR illuminator.

The use of infrared imaging systems allows for a significant advantage for both the military mission, as well as, for the law enforcement mission. According to Sarusi (2003), the use of IR is a major differentiating factor on the modern battlefield in its applications for surveillance, navigation, piloting and night fire. IR devices may be used as an option to mark targets for airborne troops to fire upon; additionally they can be coded to aid in the acquisition of the target. Another use for IR technology, strobes or "fireflies" is in the identification of friendly ground troops, thereby avoiding fratricide, or to assist in the rescue of downed pilots (Comstock, 1997; Global Security, 2006). A detriment of the IR strobe in combat situations is that it is visible to anyone with night vision capability (Global Security, 2006).

The military, as the primary end-user of infrared technology, has employed these devices for an extensive time period in tactical environments and has been the primary motivating force in the development of new infrared technology. The utilization of IR devices in law enforcement began in earnest in the 1990's when military-derived hardware was transferred to local and state law enforcement agencies through federal technology transfer programs.

In 1994, the U.S. Department of Justice (DOJ) and the U.S. Department of Defense (DOD) cooperated to develop a Memorandum of Understanding (MOU) to manage technology development (NIJ Research Report, 1997). As a result of the declassification of IR technology and the ongoing military-to-law enforcement technology transfer, these programs have resulted in a proliferation of infrared imagers on the civilian market.

With these infrared imaging systems available for law enforcement today, they can be used for a variety of potential purposes including: surveillance (Kiley, 1998; Weiss & Davis, 2003), avoiding fratricide (Comstock, 1997; Doton, 1996), vehicle identification (Lim, Choi, & Jun, 2002), vehicle and personnel tracking (Carstens, Bonnett & Redden, 2006; Stahl, Haisch, & Wolf, 2002; Stahl & Schoppmann, 2000), search and rescue (Anderson, Greenbaum, McClay, & Wilson, 2006), crime scene investigation (Tahtouh, Despland, Shimmon, Kalman, & Reedy, 2007), and pursuit of suspects (Riedel, Coffin, & Prokoski, 1992).

Thermal imaging is not the same as night vision. Thermal imaging systems detect infrared light that is emitted by heat sources (Weiss & Davis, 2003). Although the human eye cannot see this light, it can be adapted in the same way as conventional light. In contrast to image intensification devices (low-light devices), thermal-imaging systems can be used in total darkness because they do not rely on light reflected by an object.

In the late 1980's and early 1990's, law enforcement began using thermal tracking technology in helicopters, derived from the military, to track suspects (Parenti, 1997). This was accomplished through the use of forward looking infrared (FLIR) devices that were initially mounted on helicopters and later mounted on vehicles and used as hand-held devices similar in size and shape to video cameras (Raytheon Corporation, 2002; Weiss & Davis, 2003). FLIR systems perform thermal imaging in the 8-12 μm band, and consists of system optics, detector, electronics, and a display (Bayar & Farsakoğlu, 2001). Most recently, this technology has been evaluated for its ability to detect people carrying concealed weapons, and then electronically "tag" them so they can be surveilled (TECHbeat, 2007).

Historically law enforcement agencies obtained night vision under technology transfer programs from the military. These devices initially utilized image intensifier ($I^2$) technology only, allowing police officers the advantage of seeing in low-light conditions without the use of searchlights or flashlights that could reveal their position. These devices have transformed from 1960's era "Generation 1" equipment that could malfunction when exposed to bright light, to "Generation 3" monocular and binocular systems first available in the early 1980's that greatly improve visual acuity (Scoping Out Night Vision, 1996; Nighttime Eyes, 1998; Manaco, Weatherless, & Kalb, 2006).

When law enforcement is contemplating the implementation of night observation devices in an urban or metropolitan area, there are several considerations for agencies to take into account. First, there are the sudden increases or decreases in ambient light that occur when viewing a headlight or streetlamp. This becomes a factor since the night vision device must decrease its level of light amplification in order to prevent damage to the microchannel plate (Funsten, et al., 1997).

Secondly, the fields of view for night vision devices are restrictive, "…by optical aberrations introduced by a flat image plane in the image intensification tube" (Funsten, et al., 1997). To clarify, most night vision devices have a maximum field of view of $40^o$ x $40^o$ compared to the average human eye which has a field of view of $120^o$ x $150^o$ (Funsten, et al., 1997). This disproportion results in some difficulty for the human eye to become accustomed to night vision devices and negates peripheral vision. Other researchers have found this field of vision to be limited to between 30 and 40 degrees, taking away nearly 160 degrees of peripheral vision (Osterman, 2007).

For ground based searches, several IR devices have been manufactured that may make tracking or locating an object with NVG's easier. In addition to military derived "firefly" devices, which are small IR lights that attach to an external 9-volt battery, there have been numerous applications of IR devices for law enforcement use. These detection and location tools include: thermal IR marking film, chemical and battery-powered glow sticks, reflective tape, IR lasers (McClay, Raunig, Robe, & Marsee, 1995; O'Keefe, 2005), rescue beacons (Patraboy, Farrington, & Donaldson, 1997), and other strobe devices.

Comprehensive agency acceptance and law enforcement usage statistics are nearly impossible to ascertain. However some limited data is available, and according to the National Institute of Justice, 58.3% of small agencies (less than 20 officers) never use any generation of night vision devices, while only 3.5% used it often (National Institute of Justice, 2004). Furthermore small agencies gave their officers a rating of “no-competence” for their knowledge of night vision technology and “it should be noted that the technologies given ‘no-competence’ ratings were those perceived as unimportant and not used by the agencies” (National Institute of Justice, 2004).

As identified in both the scholarly and extant literature, it is clear that the night vision and strobe light technology has utility for increasing visibility, detectability, operational security in a variety of commercial, private, military and law enforcement applications. The following sections detail the researchers study and methodology used in testing a number of IR beacons commercially available and their respective detectability using vision devices in a variety of low light and nighttime scenarios both in rural and urban environments.

## 3. TECHNOLOGY UNDER EXAMINATION IN THIS STUDY

The following table illustrates the various infrared beacons/strobes that were tested in this project. Each IR beacon model is detailed with the manufacturers specification data, also included are the costs, battery type, run times and dimensions (photos and additional information can be found in the appendix).

**Figure 1. IR Devices**

| Make | Model | Cost (dollars) | Length (in) | Width (in) | Battery | Run time (hrs) |
|---|---|---|---|---|---|---|
| Cejay | Athena | $99 | 2.6 | 1 | CR123 | 100 |
| Cejay | Glo-wand MK8 | $7 | 6 | 0.75 | #675 (3) | 72 |
| Cejay | Glo-wand MK8 | $12 | 2.8 | 0.75 | #675 (3) | 72 |
| Cyalume | IR light stick | $4 | 6 | 0.59 | n/a | 3 |
| Phoenix | Firefly Jr. | $20 | 1.5 | 0.62 | 9 volt | 100 |
| Glo Toob | IR | $32 | 2.75 | 0.75 | A23 cell | 30 |
| MS 2000 | Rescue beacon | $95 | 4.5 | 2.2 | AA (2) | 8 |
| Powerflare | PF-200 Tactical | $110 | 4.25 | 1.25 | CR123 | 24 (dependent on flash pattern) |
| Surefire | Helmet light | $99 | 2.2 | 2.6 | CR123A | 120 |
| Tektite | IR Strobe 300 | $83 | 9.25 | 1.9 | C-cell (3) | 24 |
| Tektite | IR Strobe 200 | $74 | 7.25 | 1.9 | C-cell (2) | 30 |
| Tektite | IR Mark-lite | $50 | 5.75 | 1.2 | AA | 6 |
| Adventure Light | VIP | $108 | 2.75 | 2 | DL123A | 40 (varies by program) |

## 4. METHODOLOGY

In order to evaluate the technology as described in the preceding section, the researchers proposed a unique, multifaceted approach. The approach employed a focus group of law enforcement officers, followed by a field research data collection endeavor. The prescribed endeavor sought to field test various IR beacons under different conditions and locations at night. For the purposes of data collection and analysis, the research team opted to take a practical approach rather than superimpose a complex statistical analysis when analyzing the IR beacon's visibility and conspicuity.

In addition to the quantitative section, a qualitative section was incorporated into this study as it became apparent that a sterile analysis would not capture the nuances and idiosyncratic factors, which occurred during testing and data collection. Finally, the analysis is complimented with a review of the relevant findings for law enforcement agencies.

## 4.1. Stage 1

In the first stage of this project, the researchers conducted a review of the availability of infrared beacons, lights, and lasers in reference to their costs and suitability to the operational needs defined for this research. Once the products were identified, the research team purchased all readily available equipment to use for the testing stage of this project. Initially, some very basic field tests were conducted with each of the products to create a methodology for testing. Prior to the data collection, a coding instrument was developed using a grounded field approach. This grounded approach is discussed later in this section.

## 4.2. Stage 2

In the second stage of the project, the researchers utilized a data collection instrument to capture relevant variable data points through field observations. This data collection instrument was developed and operationalized to capture the key variable under examination in this research: visibility of the IR beacons under various conditions. The researchers then captured the relevant data observing the IR beacon technology from a fixed position on the ground and from a mobile platform on a helicopter.

## 4.3. Stage 3

In the third stage, the researchers collected data using the coding instrument developed during the qualitative examination of the IR strobes in various locations and environments. Ultimately a 9-point visibility scale was developed for the collection of this index level data and the data collected under this scale was entered into the Statistical Package for the Social Sciences (SPSS 12.0) to allow for the comparison of the various IR beacons in the different environments. Lastly, the various IR beacons were compared side-by-side and output charts were developed which graphically displayed the relative visibility of each IR beacon.

### *4.3.1. Grounded Approach*

During the initial trials and functionality orientation with the various IR strobes and devices, the researchers developed an understanding of the various IR beacons technology and their general capabilities. The researchers also evaluated several alternative methods for collecting appropriate data as it relates to the functionality of the devices. The devices were observed in various environments and environmental conditions, which served to familiarize the researchers with the IR strobes and devices, to develop a coding schematic, and define operational boundaries.

It was clear that various technologies performed differently in various environments. One of the goals of this study was to identify the feasibility of detection by law enforcement officers in various environments. Therefore, in order to test detection rates, the research team simulated potential environments. During this team-based approach, the researchers identified additional potential uses of the beacons that went further than the original scope of this project. In brief, the researchers found that some of the beacons could be used as evidence markers or have application for use by police canine units. As such, these functions should be considered as having utility and thus add value to some of the beacons.

This grounded field research approach also allowed the researchers to find that there were significant differences in the detection of the strobes based upon the positioning of the IR beacon. For example, different detection results were identified depending on whether the IR beacon was mobile, stationary or on an officer who was upright or downed. The “grounded” approach allows for the development of theory generated from the data. “The grounded approach advocates loosely structured research designs that allow theoretical ideas to emerge from the field in the course of study” (Miles & Huberman, 1994, p.17). Additionally, the density of vegetation and presence of background or foreground light were found to be significant factors in detection and visibility of the strobes. A review of the extant literature found that vegetation density can be a quantifiable measure which is derived from the total amount of bio mass and diverse structural types of vegetation found in an area (Nichol & Lee, 2003).

An additional factor discovered was the importance of directionality of some of the beacons relative to the researcher observer. This issue was identified with certain IR strobe lights, which required them to be pointed in the direction of the viewer. As a result of the field-testing and experimentation with the IR strobes, the researchers were able to create, modify and constantly develop an appropriate data collection technique. This is discussed in detail in the qualitative section.

## 4.4. Data Collection, Measurement and Analysis

To collect data, the researchers developed an instrument that captured the relevant variables. This instrument was the result of extensive field-testing, experimentation and data-coder training. The data collection instrument was designed to capture the key dependent and independent variables under examination in this project.

The key dependent variable in this project was defined as the visibility of the IR strobe under review. The intensity of the IR strobe from the perspective of the observers defines the level of visibility of the devices. The definition of visibility was not based upon brightness, which can be readily quantified by lumens, lux, candlepower or some other scientific measure. At the time of this study, the researchers were unaware of a method to measure “brightness” of an infrared source from a distance of 100 yards or greater.

## 4.5. Research Team Training

Prior to the onset of data collection the researchers briefed and trained a research team of participant/observers. This team consisted of eight research assistants at Florida Gulf Coast University. The principal investigators conducted approximately 40 hours of training with the team, covering the data collection methodology and the Delphi method. The research team training was conducted over a time frame of approximately seven weeks. During this time, the principal investigators and the research team met for intervals of about three hours twice per week.

Throughout the training period, the research team utilized and evaluated several different night observations devices (NOD’s). Because most law enforcement agencies have adopted Generation 3 NOD’s, the research team utilized this device throughout the assessment period of the project. Other devices, including Generation 1 and 2 NOD’s were excluded.

The team was trained on the activation and deactivation of the IR devices. However, the principal investigators were responsible for deployment (including activation and deactivation) during the actual field tests. During the team training deployments, the principal investigators led team discussions on the IR devices and posed questions related to their visibility and function. This method allowed the researchers to gather logical and incremental input into the key issues under review. Additionally, it enabled the researchers to deal with the complicated issues of visibility including the issue of the inability to see the IR beacon, but still detect its location from a halo effect on the surrounding flora.

Furthermore the research team, being trained in the Delphi method, was required to maintain notes of observations and was briefed on a method upon which to attain consensus when making observations. Over the forty-hour training period, and throughout the data collection period, it was noted that the research team developed into a cohesive group, which became highly vested in the project and its outcomes.

### 4.6. 9-Point Visibility Scale (Primary Data Collection Measure)

To measure the relative visibility of the IR strobes, a 9-point scaled measure was developed for this project and this measure became the primary data collection variable. To standardize this scale, the researchers created “anchors” for the scale by determining the low and high ends of the scale. Utilizing an environment with the least amount of ambient light to control for washout (background and foreground ambient light reducing IR strobe effectiveness), a standardized distance of 100 yards was used and a research team examined the IR strobes and scored them from least visible (scored as a 1) to most visible (scored as a 9). A score of 0 indicated that the IR strobe was not visible. All 13 IR strobes in this study were visible to the research team in this controlled environment.

An extremely important aspect of the scale creation was the method employed by researchers to develop the 9-point scale. In order to remove as much subjectivity or individual perception bias (vision) as possible, a modified Delphi approach was utilized in the formation of the scale. During the initial scale creation, the researchers and the research team arrived at consensus in determining which IR strobes were the most and least visible. These levels of visibility formed the scale anchors (least and most visible). A scale with at least 9 points was selected as opposed to smaller scales as this allowed for a greater range of variance in responses.

### 4.7. Observations and Data Coding

To collect data on the 9-point visibility scale, the researchers continued to utilize the Delphi technique, which was adapted for this project. When an observation was coded for each IR strobe, the research team came to consensus as to the appropriate scoring on the scale. While the measures on this scale cannot be categorized as ratio level data, they are deemed to have interval properties. Within this study, the distances on this scale were not validated as equidistant. This is a commonly accepted weakness in the Delphi method and is only of concern if advanced statistical techniques are used in an analysis.

## 4.8. Field Data Collection

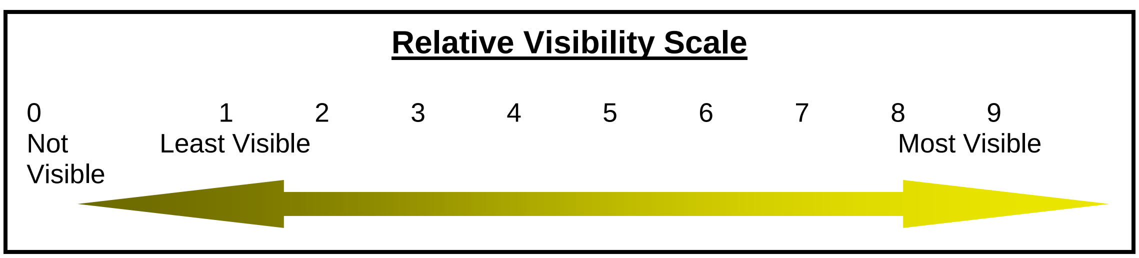
To capture data, an IR beacon was placed in the selected environments at a predetermined distance. The research team viewed the IR strobe being evaluated through the night observation device. Each individual researcher scored the visibility of the IR device and notated their score. After all the coders had examined the IR beacon and scored it individually, the scores were compared, and a consensus score was found. This score was recorded on the official project score sheet.

## 5. QUANTITATIVE ANALYSIS

At the heart of this research is the scale measure developed and then used to rate the visibility of the particular IR beacon. The relative visibility scale, as discussed previously, was developed with the Delphi approach and is anchored at the low and high ends from a standardized environment (location 1). The intermediate measures are not necessarily equidistant and as such this is a measure that has interval qualities but is not an interval or ratio level of measurement (see Figure 2 below).

The visibility scale was used to measure the selected Delphi approach to quantifying the relative visibility of the various IR beacons.

**Figure 2. Visibility Scale**




## 5.1. Locations of Study

In order to examine the IR beacons in a variety of conditions, the research team selected and then utilized several environments that simulated conditions that may be potentially encountered in a law enforcement scenario. These conditions and environments were selected largely as they approximate the general conditions throughout the State of Florida, although these conditions were not exhaustively representative of all possible conditions that may be encountered.

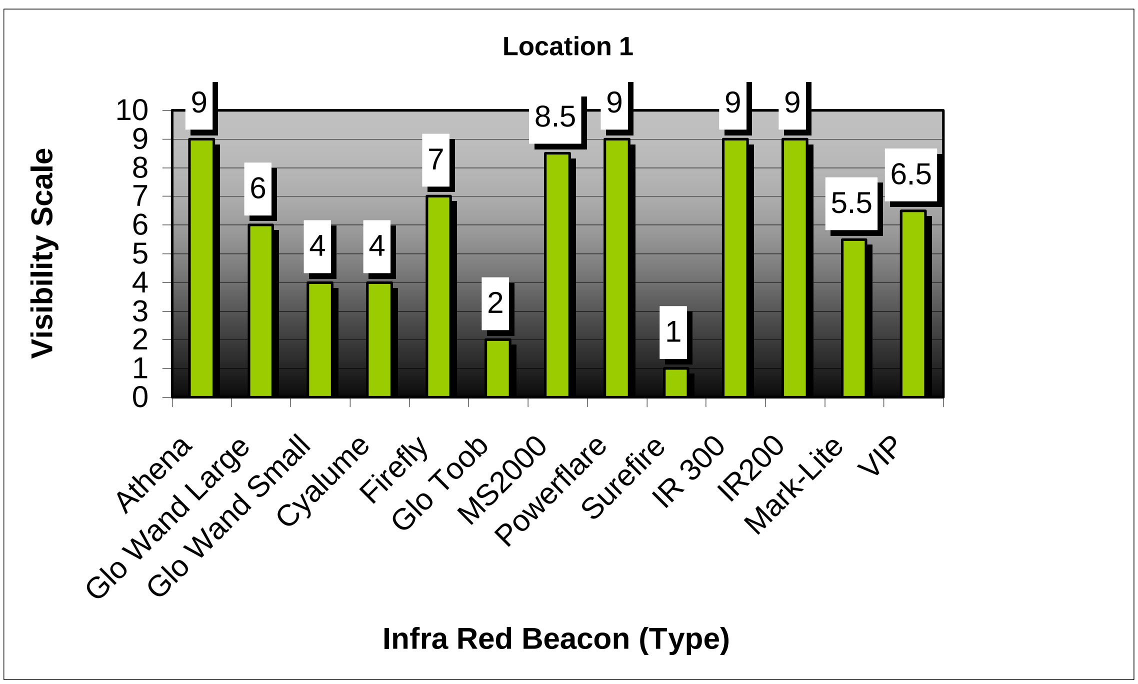
It is clear that the conditions in the state of Florida are not representative of the conditions across the United States. Even within the state of Florida the vegetation and ground topography varies. Other US states such as Alaska and Arizona, differ even more so when compared with Florida. Additionally, states that receive snowfall or that are desert-like, also present considerations for this type of research as the vegetation or lack thereof was found to be a major factor in visibility. Despite these weaknesses, the researchers attempted to examine the IR beacons in as many varied environments and different weather conditions that were available during the time of the evaluation.

## 5.2. Locations 1 – 8 (Ground Based Visibility Scoring)

### Figures 3 and 4. Location One

5.2.1. Location 1

This location was a relatively straight, dirt access road leading to a small cellular telephone tower. The road was lined by dense vegetation that blocked out other light sources in the fore and background. After sunset it became extremely dark and provided an optimal environment for using night observation devices. The ambient light in this location was relatively low. Standard nighttime conditions were present. Additionally, the general atmospheric conditions in the area of Ft. Myers (FL) are such that smog and pollution indices are not reported by the news medial outlets (unlike cities such as Los Angeles). An image of Location 1 is included above.




In location one, the research team collected observations on the relative visibility of each of the IR beacons using the previously discussed adapted Delphi technique. Using this technique the research team collectively arrived at an appropriate measure on the visibility scale for each IR beacon. The relative score at this, and subsequent locations, should not be interpreted to mean that a score of 4 is double the visibility of a score of 2; rather it should be interpreted as meaning only that it was more visible. At this location, several of the IR beacons performed at the high end of the visibility scale. The Athena, Powerflare and both the medium (IR 200) and larger (IR 300) Tektite IR beacons were scaled as being most visible.

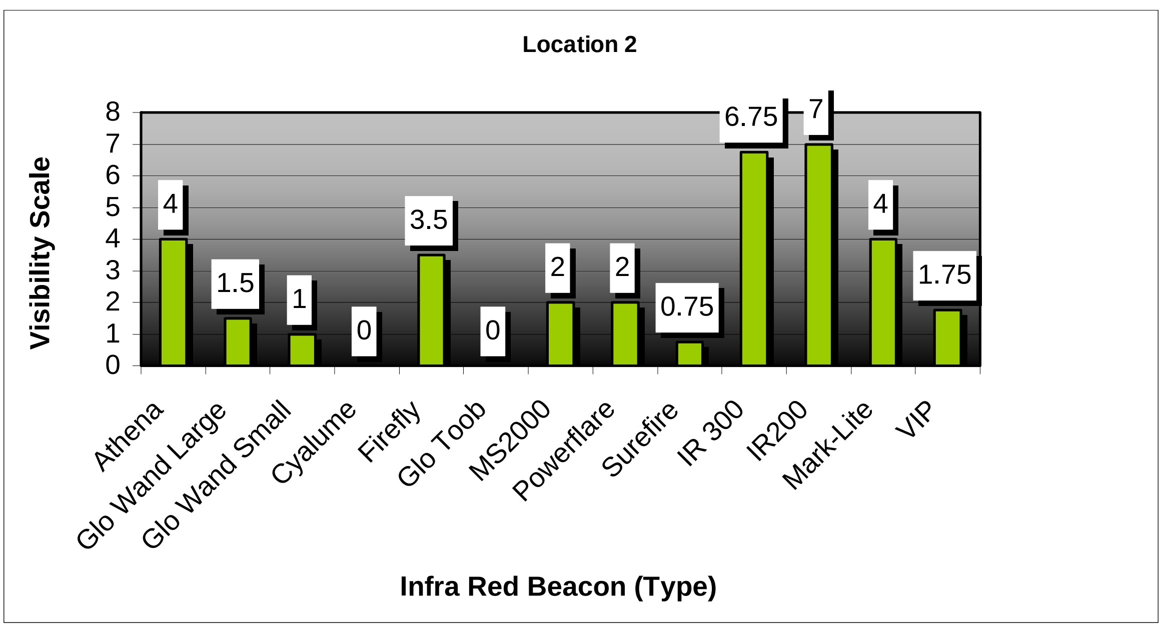
All IR beacons were visible at this location. The fact that all of the beacons were visible is an important distinction and this factor will be discussed in more detail in the implications of this research. The absence of ambient light was determined to be a significant factor in the ability to see certain devices.

**Figures 5 and 6. Location Two**

5.2.2. Location 2

This location was a grass field that bordered the rear of an office complex. Light was effectively blocked on one side by dense vegetation, while moderate amounts of light bled into the test field from the other side. The height of the grass varied from approximately six inches to a foot.

This environment was selected in an attempt to simulate the obstruction effects of grass at this height and some moderate amounts of ambient light. This location saw the relative visibility scores of the IR beacons reduced in comparison to location 1. The two main reduction factors were noted as the




presence of ambient light and the relative height of the grass. The relative scores of the IR beacons were directly affected by these factors as is evidenced by the reduction in their scores.

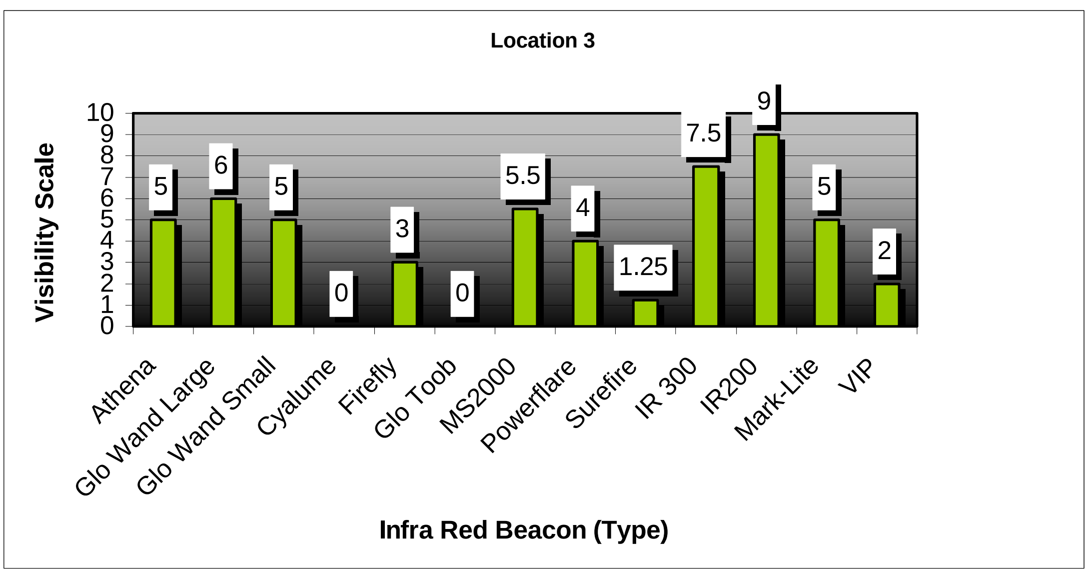
This factor became readily apparent in the scaled visibility measures. At this location the large (IR 300) and medium (IR 200) Tektite scored at 6.5 and 7 on this visibility scale. At this location, the Cyalume and Glo Toob were not visible. All other IR beacons were readily locatable, although less visible.

**Figures 7 and 8. Location Three**

5.2.3. Location 3

This location was a lit two-lane roadway covered in blacktop. Streetlights provided sufficient light that reading was possible. Further, light sources were in both the fore and background of the beacons during testing. This environment was selected, as it is fairly representative of a standard two-lane road with more ambient light than the previous locations.

Location three's results were similar to the results obtained from location two. However, the surface in this scenario was blacktop roadway instead of grass, which under certain conditions has a high amount of reflectivity. This is especially true when icy or initial rainy conditions occur and oil residue rises increasing the reflectivity of the road surface.



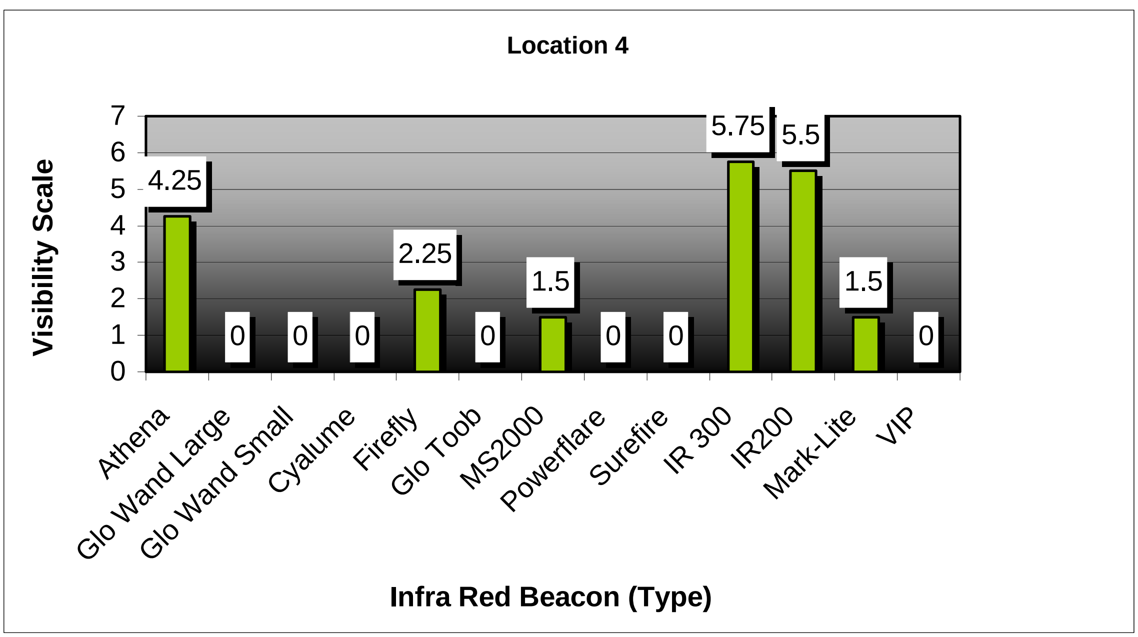
On this road surface with moderate amounts of foreground and background light, the Tektite IR Strobe 200 and 300 were most visible on the visibility scale, while the Cyalume and Glo Toob IR beacons were not visible. The other IR beacons were located and visible. As stated earlier, the relative "distances" between the scores are not equidistant and in this case the Firefly (3) was not three times less visible than the Tektite IR Strobe 200 (9). It must be added that the fact the beacons were visible and locatable should be considered a success for each one.

**Figures 9 and 10. Location 4**

5.2.4. Location 4

This location was a palmetto grove approximately one mile across. Dense undergrowth measured from waist to chest height. Some background light from sources on the horizon provided a moderate amount of ambient light.

This location was selected as it provided an increasing level of relative obstructions and increased density of vegetation. While the actual increased levels of obstruction and ambient light was not quantified, the relative environment is certainly replicable. During the IR testing at this location, it was clear that the combination of the ambient light and high undergrowth caused a relatively larger reduction in




the visibility and conspicuity of the IR beacons. In this scenario, the Athena, Firefly, MS2000 and all three Tektites were able to be located and were visible.

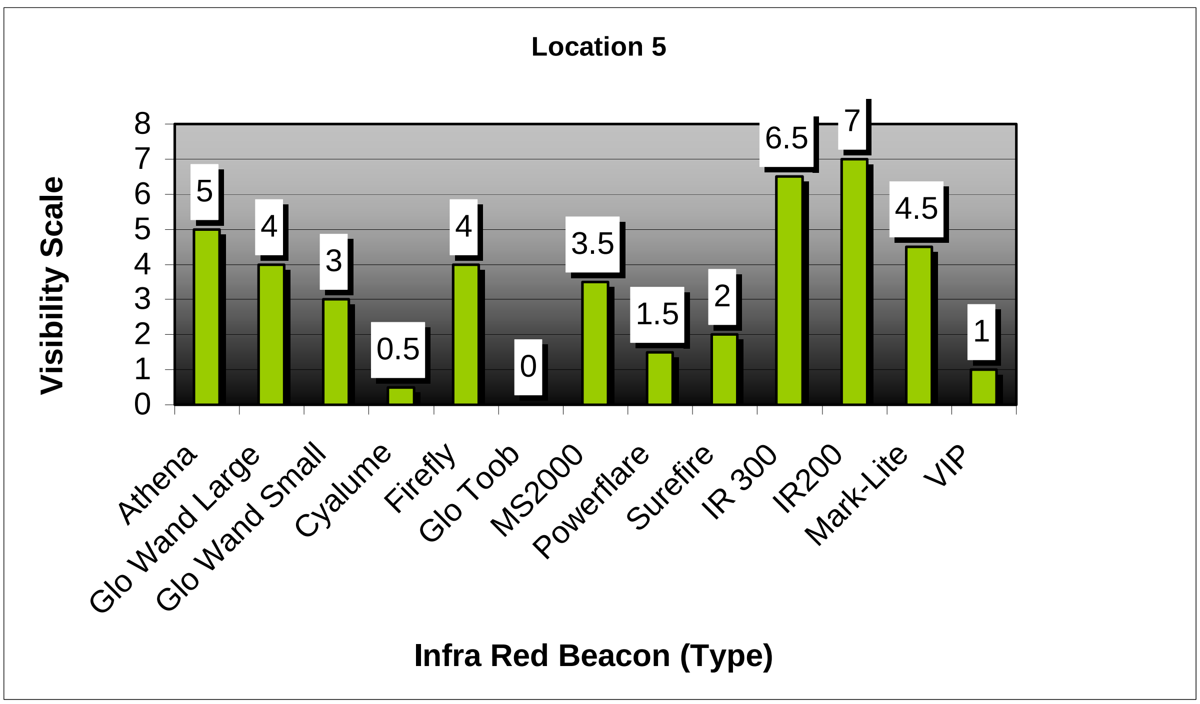
While these items were visible it must be noted that on the visibility scale the items were almost 50% reduced in effectiveness compared to ideal conditions. The other IR beacons were not visible.

**Figures 11 and 12. Location 5**

5.2.5. Location 5

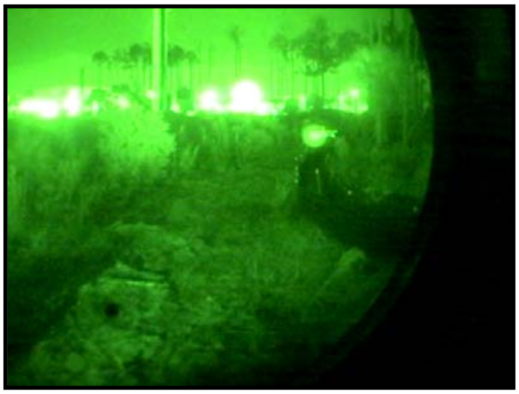
This location is a dirt pathway bordering a dense wooded area. The structure at the rear of the photo in Figure 7 is a fire station, which created a large amount of background light interference. Beacon scores as a group were negatively impacted across the board as a result.

This location was selected, as the ground surface was dirt and grass, while the grass density was extremely sparse. This location sought to examine the effectiveness of the IR beacons under conditions with a significant amount of background light.




The absence of high flora clearly allowed for a higher visibility of the IR beacons as evidenced by the overall beacon scores being higher across the items tested. Only the Glo Toob was not visible during testing at this location. It should be added that the Glo Toob is designed and marketed primarily for underwater usage at great depths and as such it may not produce the same intensity of IR light as the other beacons.

**Figure 13. NOD Washout from External Light sources**



As indicated in the literature review of NOD devices, the amount of light is a key factor in NOD's ability to perform. Often discussed is temporary flash blindness, which occurs when a bright light overwhelms the image intensifier tube of the NOD and causes a washout effect. In this scenario the presence of significant amounts of backlight caused a tremendous reduction in IR beacon visibility.

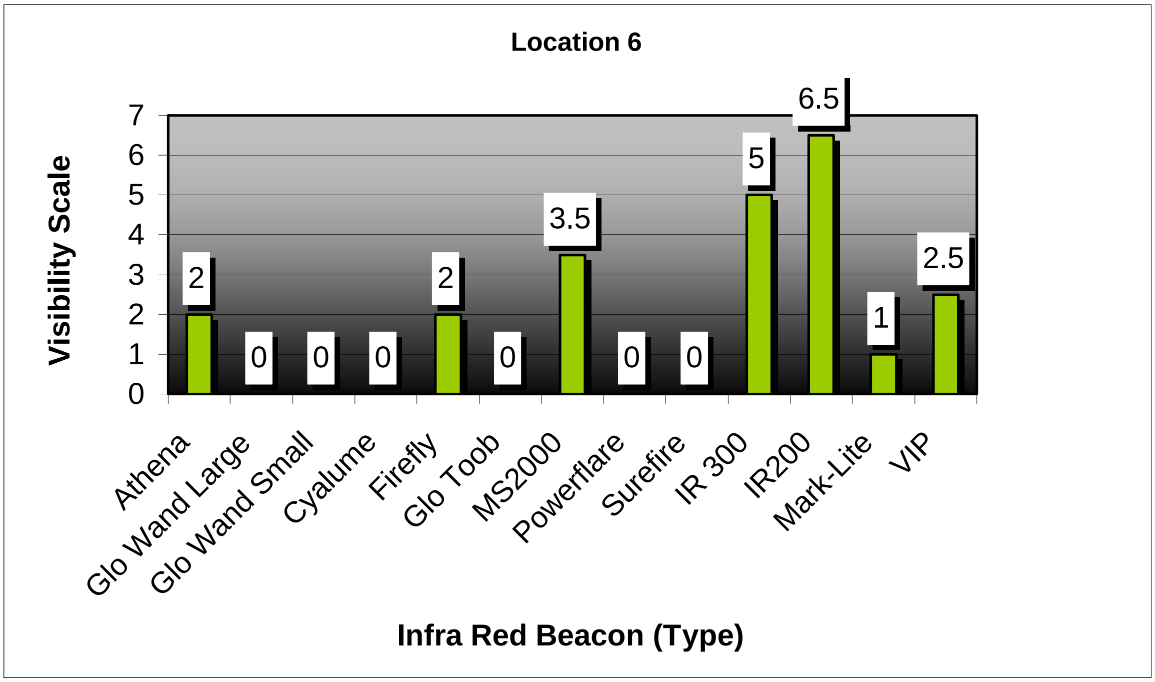
**Figure 14. Location 6**

5.2.6. Location 6

This location was a grass pathway into a dense wooded area. Although there were no background lights to washout the night observation device image, there was a well-lit roadway and athletic training fields behind the research team observation post. This location was selected in contrast to location 5 and seeks to simulate dense vegetation with relatively little ambient light. The actual density of the vegetation was not readily quantifiable.

In terms of perspective, the background of the viewing area was dark. As evidenced by the scores, it was clear that any amount of ambient light from relatively any direction appears to affect the visibility of the IR beacons to some degree.

**Figure 15. Location 6**




The largest units tested "Tektite IR Strobe 200 and 300 beacons" appeared to be the most visible. It is appropriate to add that there is a clear connection between size and visibility. The larger the power supply and IR lens or filter, the more visible an item becomes. In this location, six of the beacons were not visible. Additionally, this test serves to show that some of the smallest IR beacons (the Athena and the Firefly) were visible (albeit on the low end of the visibility scale).

**Figure 16. Location 7**

5.2.7. Location 7

This location was a large open field utilized for grazing cattle and the grass was relatively short. However, in some sections of the field, the grass was as high as 36 inches. This was an open field and there were a number of patches of sand. Due to the isolated location, very little background light was present. However, the open nature of the environment allowed the visible detection of several large antennas on the horizon that were equipped with numerous blinking lights.

At this location the amount of ambient light from sources nearby was negligible. However, there were towers in the distance providing minimal optical noise. As was evidenced in previous scenarios the Tektites were visible as were most of the other IR beacons. The Cyalume, Glo Toob and Surefire IR beacons were not visible. Again, it must be added that the beacons that have scores, even if they are relatively low, were still detectable.

**Figure 17. Location 7**

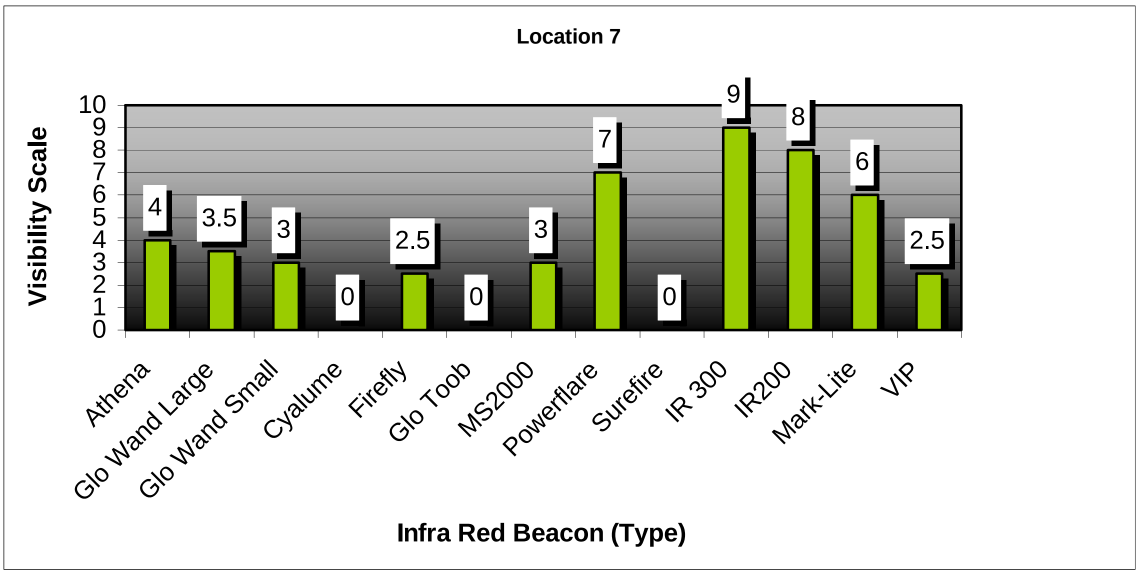


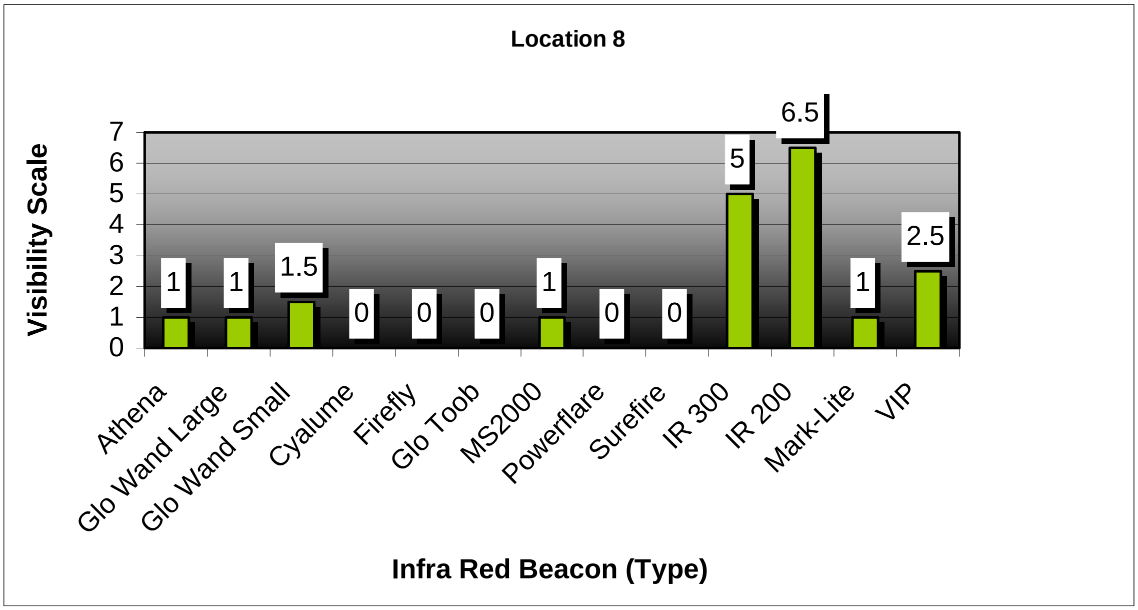

**Figure 18. Location 8**

5.2.8. Location 8

This location was a lighted roadway alongside an athletic complex and parking lot (to the left of photographed area). Light from the football and soccer field bled into the viewing area.

The IR beacons that were most readily visible in this scenario were the Tektites, VIP, Athena, Glo Wand large and small and the MS2000. The other IR beacons were not visible. It was clear in this scenario that the more powerful IR beacons were more likely to overcome background light and the effects of washout (optical noise or halo effects) during NOD testing. This testing environment was exposed to ambient light from various positions and locations relative to the researchers and the IR beacons.

**Figure 19. Location 8**

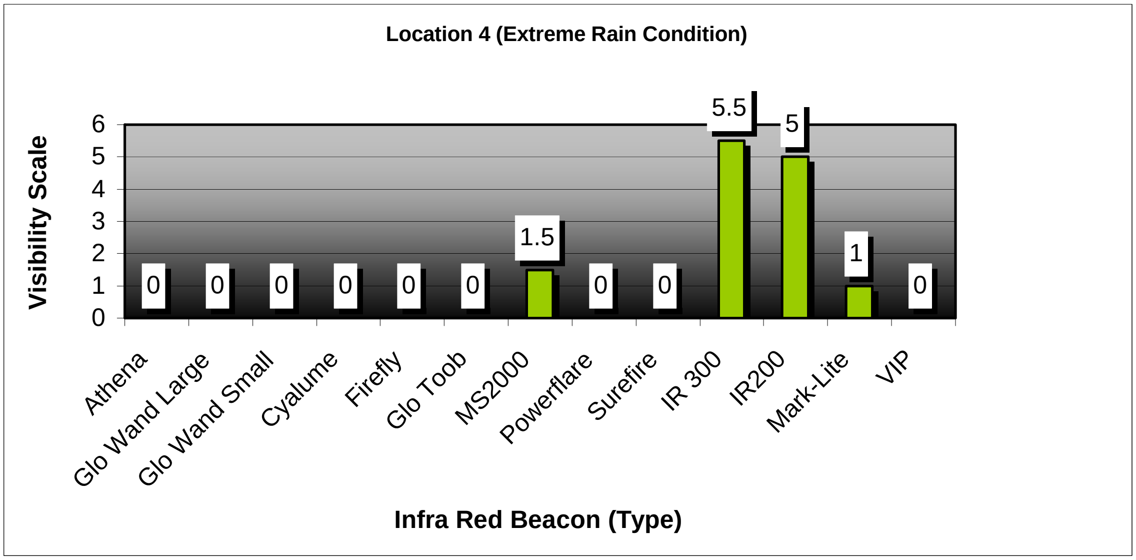



## 5.3. Rain Testing

In conducting environmental effect testing on the IR beacons, location four was utilized as a test location during rainy conditions. Location four was a palmetto grove approximately one mile across. Dense undergrowth measured from waist to chest height. Some background light from sources on the horizon provided a moderate amount of ambient light.

The presence of rain had a significant effect on the research team's ability to locate and score the various IR beacons. The rain affected the IR beacons visibility significantly and only the beacons with most intense IR lighting were able to be located and were visible by the research team. The MS2000 and all three Tektites were visible in this scenario. The majority of the beacons did not perform as expected. Agencies that utilize IR beacons need to consider the environment and the type of beacon they deploy in inclement weather conditions. The rain conditions during this test scenario were extreme and general visibility by the human eye was reduced to about 20 feet. This type of short but intense thunderstorm, even for the general thunderstorm activities in Florida, was more extreme than the norm. Consequently light rain may certainly affect IR beacon effectiveness, but likely to a lesser degree than was experienced in this scenario.

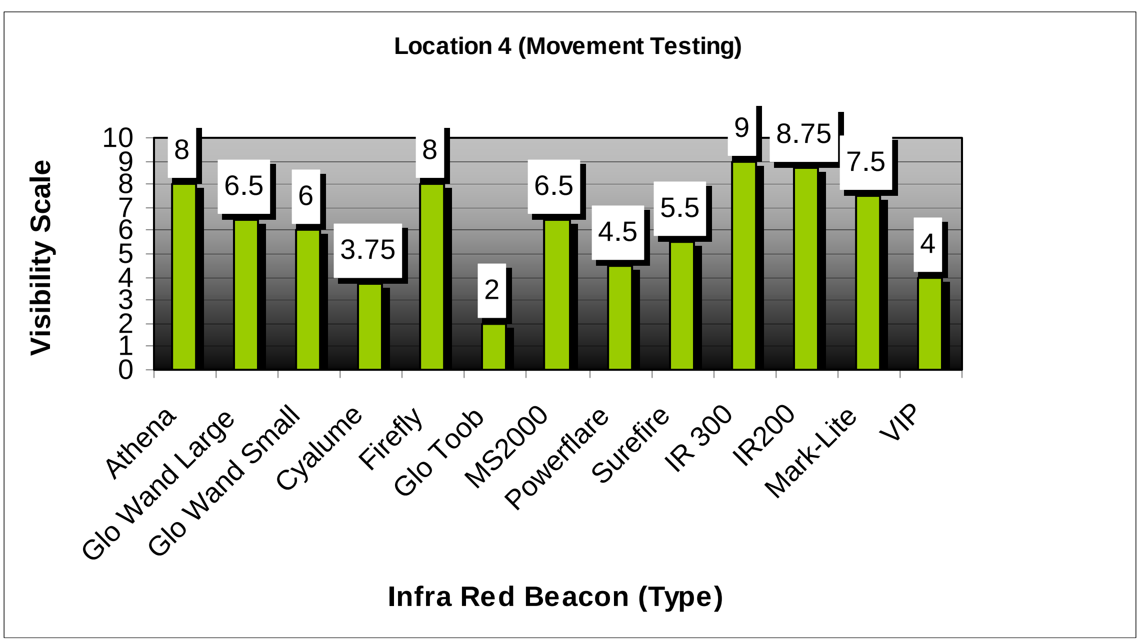
**Figure 20. Location Four Visibility during Rain Testing**




### 5.4. Movement

The research team conducted an exercise wherein the IR beacons were placed on a moving person who walked along a pre-designated path. This testing was also conducted at location four where the rain testing was completed.

**Figure 21. Human Movement Testing (Location 4)**



During the movement testing the IR beacons were placed on the moving research associate and then observed by the team. The relative position of the IR beacon (placed on a 5.11 tactical vest at the chest level) affected the conspicuity of the IR beacon significantly. This placement allowed the research team a line of sight view of the beacon with the NOD equipment. The absence of grass and object shielding were factors to consider in the visibility of the IR beacon.

In this testing scenario, all the IR beacons could be located and scored on the visibility scale. The smaller less intense beacons that were lower scorers to this point benefited greatly from the elevation of the beacon. Additionally, placing the beacon on a moving subject tended to catch the attention of the viewer, which resulted in a higher relative score. As it is commonly accepted that a moving target is easier to initially acquire visually than a stationary one, the application of this technology with police canines was examined.

### 5.5. IR Beacon and Applicability to K9

Law enforcement agencies around the country use police canines for a variety of tasks. The cost effectiveness of this interaction between dogs and officers has been strongly documented in the literature (Mesloh, Wolf & Henych, 2002). Generally, patrol officers are utilizing canines primarily for their intimidating presence when confronting potential combatants or fleeing felons. It is estimated that there are over 15,000 police dogs currently operating in America (NAPWDA, 2003). Not only do canines assist law enforcement in performing their jobs more efficiently, but previous research has consistently found that the use of canines in police agencies improves officer morale, deters would-be attackers from attempting an assault and allows agencies to send operatives into a building limiting potential loss of human life (Mesloh, Holmes & Wolf, 2002).

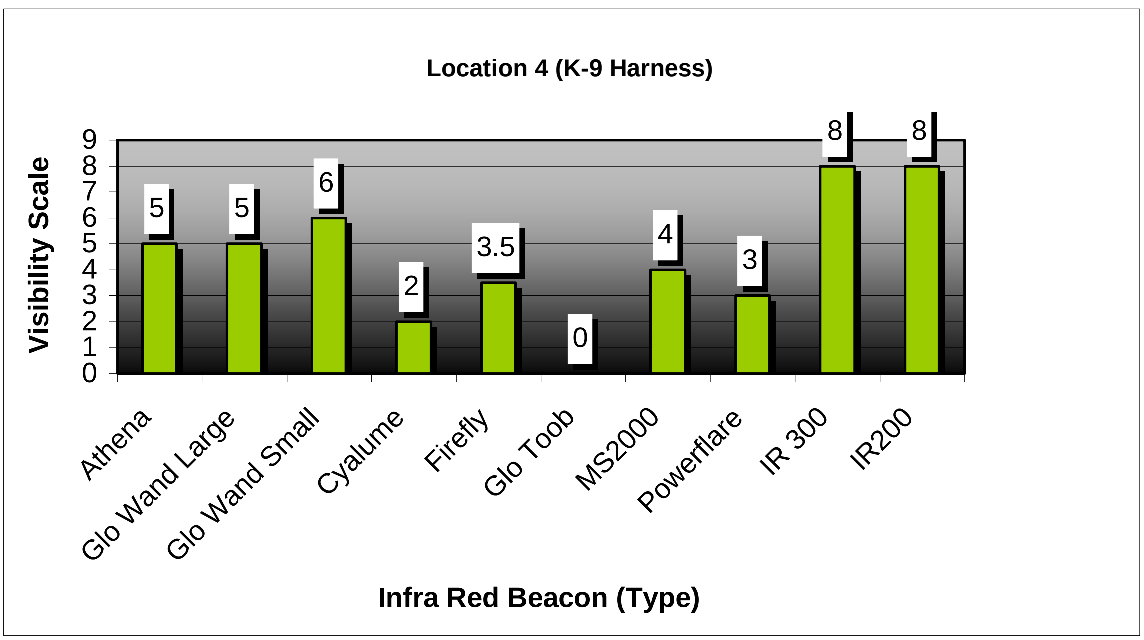
The use of canine teams to supplement traditional patrol and investigative functions can thus be broken into a typology of tasks. Each task is dependent upon specific overlapping skills and training, which include: building searches, areas searches, tracking and physical apprehensions. During these functions, the canine may or may not be operating within sight of the handler. As a result, handlers and dogs can easily become separated, placing both at risk. It is these situations that NOD and IR beacons have tremendous utility.

The U.S. Army Limited War Laboratory commissioned a series of studies to examine the use of trained dogs in an off-lead capacity. Carr-Harris & Siebert (1969) trained several dogs to work off-lead and in conjunction with a helicopter to locate enemy personnel. They found that canines were able to work independently of a handler. Similarly, Westinghouse (1973) tested an electronic dog handler system that allowed a harness worn by the dog to transmit heading, range and action data back to a control unit. The harness also functioned as a receiver of audio tones that allowed the dog to be controlled at great distances. Finally, Woestman (1974) developed and evaluated a radio-controlled infrared light that enabled the handler to visualize the dog's location through the use of a special IR viewing device.

It would appear that none of these studies stimulated significant interest in using IR beacons to monitor police dogs. However, as substantial advances in technology have taken place over the past twenty years, the individual unit price for infrared scopes and goggles has placed them within budgetary reach of even the smallest law enforcement agency. As canine teams pursue the most violent or active resistors as a normal component of their job description, the addition of an IR beacon to the dog's harness might provide an additional safety tool to enable both aerial and ground-based units the ability to track their progress. Additionally, the beacon would allow observers from a helicopter to identify and direct the canine team to a specific area for a directed search. Finally, should the dog become separated from the handler and/or injured, recovery from dense woods would be substantially easier than relying solely upon thermal imaging.

The following section examines the testing of IR beacons mounted to a standard police canine tracking harness to determine the feasibility of use during deployments.

**Figure 22. Location 4 (K9 Harness Application) Testing**



In this testing scenario the K9 was allowed to "roam" off-lead within a pre-designated area. IR beacons were attached to the K9 harness and the research team captured their relative scores. It was found that the relative height of the K9 was a factor as this allowed them to carry the IR beacon "above" objects that would interfere in the line of sight. Clearly, the height of the IR beacon above the ground makes for increased visibility, in addition to the other identified factor of ambient light.

Unfortunately, these K9 harnesses were not designed to attach beacons and zip ties were used in the initial stages of testing. Consequently, they tended to bounce and move, which caused some distraction for the dog. However, after an initial breaking-in period, the K9 did not appear to be bothered by the beacon's presence. As a low-cost implementation strategy, IR beacons zip-tied to a standard tracking harness might be feasible, provided that the dog becomes familiarized and comfortable with the additional equipment.

In the final stages of this project, the researchers contacted Jack Ellis[1] in Budapest, Hungary to create a K9 harness designed specifically upon which to mount an infrared beacon. Ellis is most recognized as a leading expert in training law enforcement working dogs and the author of *Establish and Maintain a Successful Canine Program and Effective Canine Unit Management* (1990). Further, Ellis has produced harnesses and leads for the Military Working Dog Program for a number of years and was uniquely qualified for this project.

**Figure 23. K9 Harness and Nighttime Deployment**

[1] Jack Ellis may be contacted at: JEllis5738@aol.com.

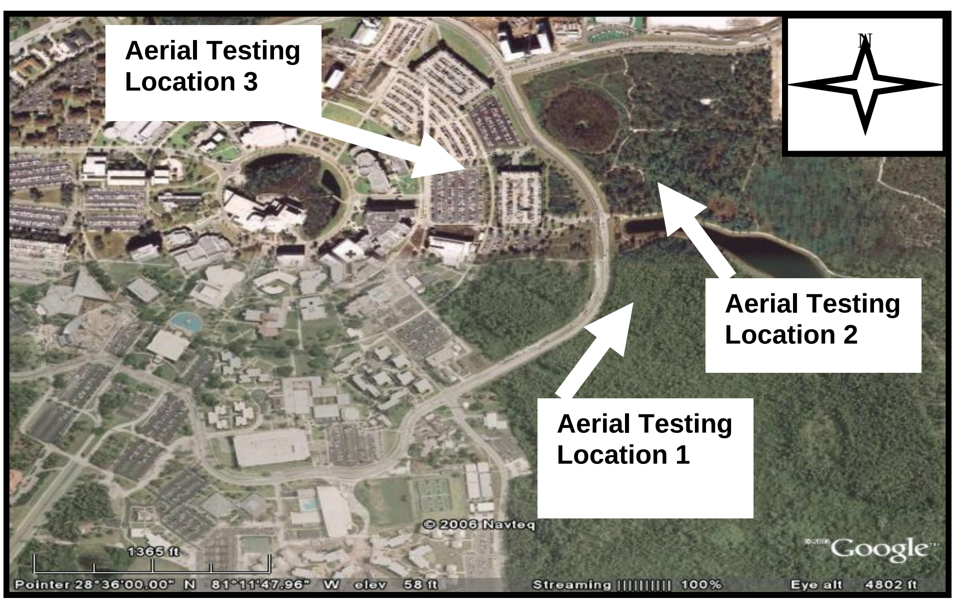
Three harnesses were created to house the Athena, Firefly, and the Tektite 200 and 300 strobes. Each harness provided substantial protection for the beacon, which was held firmly in place through several attachment points. The IR beacons were mounted on the right side of the harness and a secondary mounting position was provided on the left. Thus, it was possible to move the beacon to a preferred side or mount two beacons simultaneously. Additionally, a retro-reflective strip covered the strap across the dog's chest, allowing for increased visibility and safety for roadside operations. The cost for production of each harness was $40, which is within the acceptable cost range for this type of equipment.

### 5.6. Aerial Testing Locations 1 – 3

Aerial testing of the IR beacons was conducted in Orange County (FL). The University of Central Florida campus served as this test location. In order to conduct the elevation testing the researchers partnered with the Orange County Sheriffs Office (OCSO) aviation unit.

The OCSO aerial unit is located a short flight from the campus and was deployed after the researchers entered the field and set up for the IR visibility testing. The image below from Google Earth™ is an aerial overview of the type of conditions that were included in the aerial testing.

**Figure 24. Aerial Image of Aerial Testing Locations 1-3**



For aerial testing of the IR beacons, a circular flight plan over the three different areas to be tested was utilized. This search method allowed for the aerial unit to be present in the area of the IR beacon without actually knowing the exact coordinates. The aerial unit was deployed at an elevation 750 feet and conducted circular flight patterns over the general area of the researchers with a trained researcher on board as an observer. The trained observer would attempt to locate the IR beacons and record them on the visibility index.

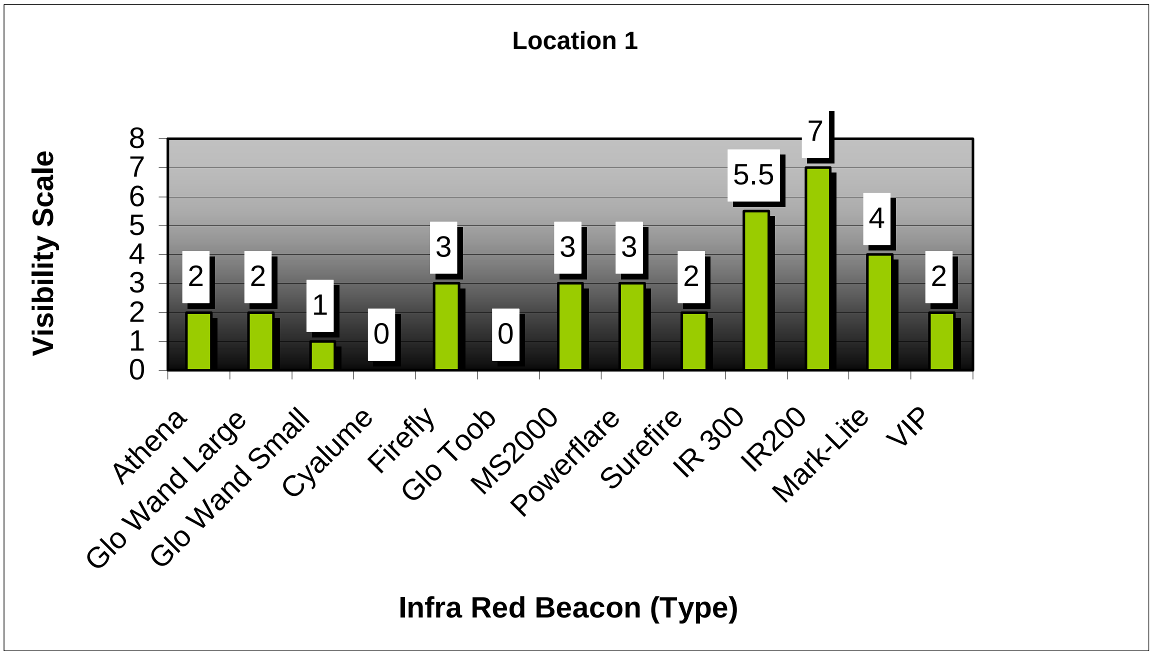
*5.6.1. Aerial Location One*

This location was an extremely dense wooded swamp area which had little or no background light sources in the area. It was selected as a testing site because it had previously been a location that a jogger had been lost and not located for five days. Therefore, due to its previous history and extensive brush density it was determined this location represented the type of challenging environment that might be encountered in a worst-case scenario. At the beacon placement location, only small sections of the sky were visible and the helicopter could only be identified by the sound of its engine (as it was not visible to the research team on the ground). Location One for aerial testing was operationalized as the densest of the three aerial testing environments.

**Figures 25 and 26. Aerial Testing Location One**

At location one of night aerial testing, the Tektites were more easily located and they scored higher on the visibility scale. Only the Cyalume and Glo Toob IR beacons were unable to be detected by the helicopter observer. The other IR beacons were scored relatively equally. This result is consistent with the types of results found during ground based testing and K9 and human movement testing.

**Figure 27. Scaled Visibility Measures at Aerial Testing Location One**



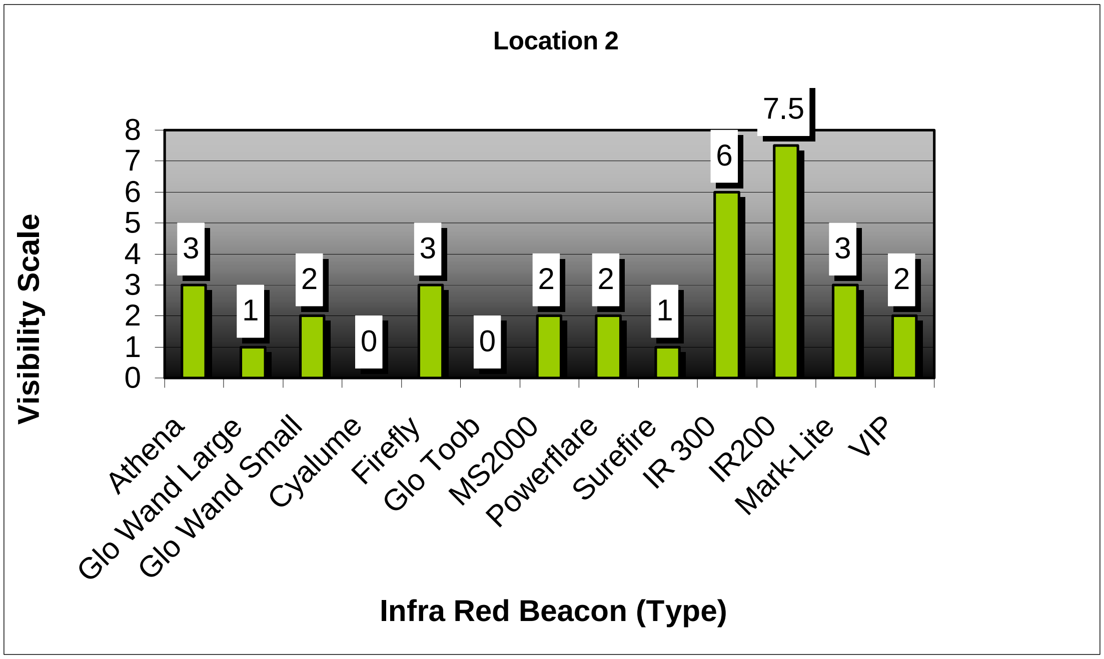

*5.6.2. Aerial Location Two*

This location was a moderately wooded area within one hundred yards of a lighted roadway and was selected in order to offer differentiation in the various types of environments. Although the woods were heavy in some areas, sufficient open space was present to be able to see the sky and the helicopter in orbit. This location was selected as the density of the vegetation was less than the previous location.

**Figure 28. Aerial Location 2**

The scores obtained during aerial testing at location two were extremely similar to location one aerial testing. In this environment, which was operationalized as a moderately dense wooded area, the larger IR beacons were more readily visible and detectable by the observer.

**Figure 29. Scaled Visibility Measures at Aerial Testing Location Two**




The aerial observer was able to locate the IR beacons with relative ease. The relative advantage of the helicopter allowed the aerial observer to spot the IR beacons whether they strobed or were constantly lit. The breaks in the trees and brush allowed the observer to see the IR beacons and notate their visibility and location. As in aerial testing location one, there was an absence of ambient light, which as evidenced in previous testing offers conditions which tend to be more ideal for locating and scoring IR beacons.

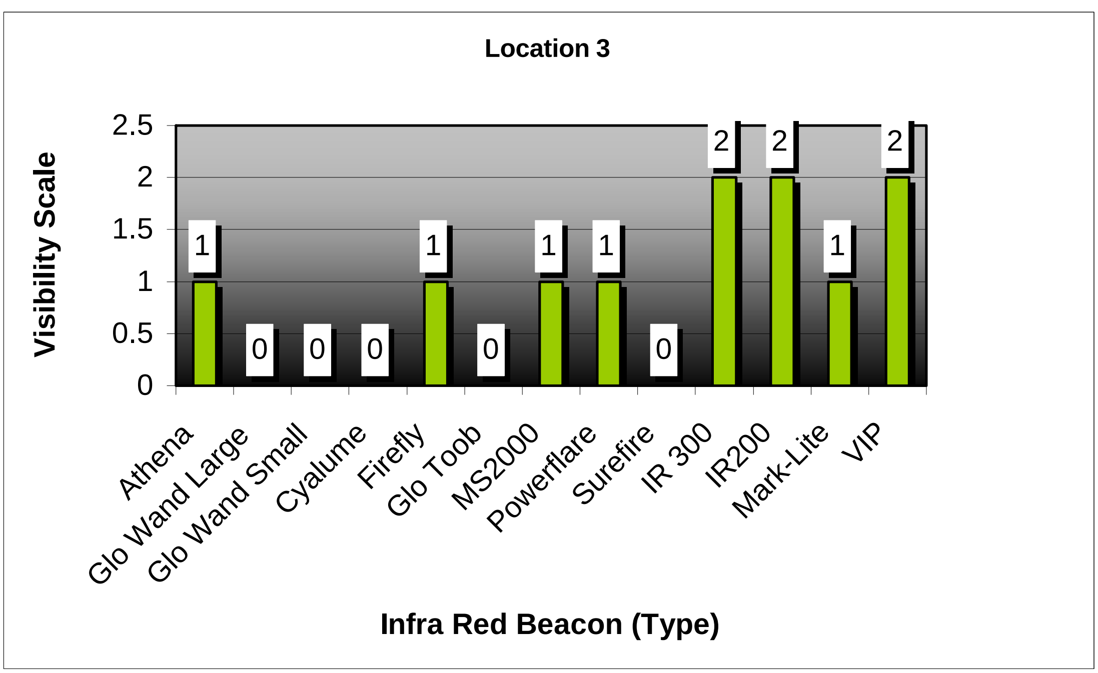
*5.6.3. Aerial Location Three*

This location was a large highly lit parking lot between numerous buildings and a parking garage. Lighting was sufficient that reading was possible. There were no physical obstructions between the beacons and the helicopter in orbit.

Testing at location three was again based upon fly-over's by an aerial observer. In this scenario, the relative visibility of the IR beacons was found to be reduced the most. A rain shower had recently affected the environment and the environment was still wet. The IR beacons suffered from the amount of reflective ambient light as well as the amount of direct light that was present. The washout affected the IR beacons that tended to be less intense in their light output.

**Figure 30. Aerial Testing Location Three**


**Figure 31. Scaled Visibility Measures at Aerial Testing Location Three**



An important point to add in this testing is that while some of the IR beacons were at least detectable to some extent, several of them were not. It is clear that in a well-lit environment, the utility of the IR beacons decreases due to extreme amounts of external ambient light causing halo wash-out or optical noise. Agencies operating in this environment should consider the potential for optical noise to decrease the visibility of the beacons. Thus, the actual utility of the IR beacons is significantly higher in extremely low light conditions.

## 6. QUALITATIVE OBSERVATIONS/OPINIONS

During the 40 hrs of team training continuing until the conclusion of data collection, the research team collected notes and observations about various aspects of the IR beacons. The principal investigators reviewed these notes and the individual opinions and perceptions of the research team have been collected and condensed in the following qualitative section.

### 6.1. Disposable or Reusable as Evidence Markers

It was the opinion of several research members that the IR beacons could serve an additional purpose other than for pinpointing position. The comments centered on whether or not an IR beacon could be deployed during pursuits when evidence is thrown or dropped by fleeing vehicles. The research team discussed the IR beacons under investigation and determined that some of them had more utility in this area than others. The Powerflare with its circular shape was tested and found that at high speeds it frequently rolled excessively far from the point of drop. On occasion, the Powerflare would land in grass and its visibility was largely dependent upon its orientation.

The Cyalume light stick served well as a disposable evidence marker as it was resistant to breakage and inexpensive. Other beacons like the Tektites were highly visible but prone to breakage as their plastic casings were not suitable for dropping. The Firefly suffered a similar problem, as the battery would frequently separate on impact. As a result of the Firefly's battery separating on impact, CJ Engineering provides a clear hard shell plastic casing (Poseidon®) to encase and protect the beacon. The Athena's durability was tested through repeated high-speed drops from moving vehicles and it continued to operate without failure.

For foot pursuits an IR evidence marker may offer the highest utility under certain circumstances. An officer engaged in an active pursuit may encounter physical evidence that if collected at this time could potentially destroy forensic evidence. Additionally, the physical size characteristics of the evidence may preclude ease of carry for the officer. Therefore the dropping of an evidence marker that does not display visible light offers an agency the ability to locate this item and appropriately process it without the possible loss of forensic evidence. A visible light marker may allow for inappropriate retrieval by non law enforcement personnel. As the placement of the IR marker can be controlled, unlike high-speed drops from a moving vehicle, the officer can place the IR beacon is a manner that takes advantage of its IR characteristics.

### 6.2. Injured Officers

As a number of officers are injured during foot pursuits, there exists the possibility that an officer will not be able to radio their location for assistance. Syrotuck's (1974) early research on locating an unconscious person suggests that the probability of detection with a sweep spacing of 100 feet is only 50 percent. Sweep width is the primary performance measure used by search and rescue coordinators to plan searches (McClay et al, 2005). This is determined by the probability of detection (P.O.D.) and the number of searchers.

In a spontaneous or unplanned search operation, a single helicopter might make repeated sweeps over the area of the officer's last known position in an attempt to quickly locate him/her. When a helicopter is not available, ground units may spend valuable time in a frantic search. If this is unsuccessful, a time consuming operation may be necessary to locate an injured officer. Consequently, the use of an IR beacon to extend the visible detection range has substantial utility to the law enforcement community. The halo effects of an IR beacon increase the likelihood of detection of a downed officer as a search pattern has a higher probability of overlapping the halo of the IR beacon.

### 6.3. Price

The researchers found that the more expensive IR beacons tended to be smaller, more visible and more durable. However, a lower priced IR beacon that is placed by an officer in a controlled manner can be as effective as the more expensive beacons, as the officers placement can compensate for the IR beacons lower visibility score. Thus a $4 IR beacon can be successfully located if well placed. The most cost effective models balance the dollar cost for their purchase with their relative visibility in the various environments.

### 6.4. Durability

As a result of the IR testing the research team found that the Cyalume light stick and the Athena beacon were the most durable. However, their individual performances were extremely different as were their prices compared at $4 and $99. Despite having lower visibility scores, the Cyalume light sticks may have utility in other specialized areas such deployment from a moving vehicle as an evidence marker in a high-speed pursuit and as an extremely low cost disposable IR marker.

### 6.5. Ease of Use and Carry (Portability)

The research team handled and manipulated the IR beacons under review in this project. The IR beacons were carried and transported from location to location and comments were captured. The primary discussion in this area centered on the relative size of each item. This is intrinsically important in the context of this study as its ease of carry or deployability for officers is a major deciding factor in an agencies choice to acquire and use any particular item.

In terms of ease of carry, the research team concluded that the CJ Glow Wands and the helmet light were (as a result of their size, relative weight, and clips) easy to carry. The CJ Glo Wands were small, lightweight and were manufactured with clips and lanyard holes. The Surefire helmet light was also easy to carry especially when it was affixed to a Kevlar helmet for which it was designed. It contained an additional regular flash light feature, which is useful when affixed to the Kevlar helmet. However, when utilized in any other fashion, the helmet light's visibility and usefulness was limited. The Athena was extremely easily to carry as its lanyard could be attached to a ring on a belt or vest, or simply worn around the wrist. The clip on the back of the VIP allowed the user to clip the beacon to an item of clothing. The larger IR beacons posed more challenges because of their relative sizes and weights. These problems were not present for the larger IR beacons when testing their deployability on the K9 harness as the harness' surface area allowed for multiple attachment solutions.

### 6.6. Flash Patterns

During the course of the field-testing and orientation sessions, the research team quickly identified the flash pattern of an IR beacon as an issue that affected the visibility of an item; more specifically its conspicuity. For this study, the researchers determined that faster sequences of flash patterns were more quickly located when acquiring a sight picture. Several researchers noticed that a fast pan over an area combined with a slow flash rate on any particular IR beacon reduced their ability to quickly locate the beacon (and in some cases the IR beacon was missed). Beacons with faster flash rates were located sooner, as compared to IR beacons that did not flash. The Tektite IR 200 and the VIP were found to be highly visible because of their unique flash patterns.

### 6.7. Visibility

The research team was trained to internalize the concept of visibility as defined previously, as opposed to brightness. Clearly brightness can be measured under laboratory conditions using standard physical science units of measurement. With this in mind the researchers opted not to pursue measuring IR beacons in this fashion, as brightness and visibility are inherently different concepts. Despite the conspicuity and visibility of the IR beacons being partially dependent on the intensity of the light source and IR filter, in reality they are much more affected by environmental and human factors.

As discussed in the definition of the key dependent variable the visibility of the various IR beacons were found by the research team to be largely based upon the relative output of the beacon, its location (height above the ground, diffusing effects of fore and background light, its cyclic rate of flashing and interfering objects such as buildings, rocks and vegetation. The research team also found that a slow steady pan across a designated test area yielded quicker conspicuity of the beacons.

Distance was also found by the team to be a factor. This was even more so the case with the IR beacons that operated with less intensity. For example, the Glo-Toob and Helmet light were found to be less intense and were the first IR beacons to be significantly affected by distance and position.

### 6.8. Factors Affecting Performance

During the testing and evaluation of the beacons, the researchers and principal investigators quickly found that a major factor that reduced the IR beacons effectiveness was the presence of ambient background and foreground light. The presence of other light sources caused wash-out and halo effects when using the night vision equipment. These effects, depending on the intensity of the light source, in some cases completely wash-out and override the IR beacon. The team found that a strobing or flashing item was a major factor in the IR beacons visibility. The factor that enhanced all the IR devices the greatest were conditions wherein the amount of ambient light was the most reduced. The research team commented that moonlight without other light sources appeared to offer relatively ideal conditions. The other major factor affecting visibility of the beacons was their relative height placement above the ground. A beacon elevated was less likely to face obstructions and also produced a larger halo with a greater circumference making it much more visible.

### 6.9. Environment

One of the primary research questions of this project was to determine the performance of the beacons in various environments, in a variety of locations. Consistent with this project’s intention, the principal investigators trained the research team to be cognizant of the environment in which the IR beacons were tested. The team stated that a flat viewing area with no background light or interfering obstacles offered the quickest and easiest detection of the IR beacons. However, this condition does not realistically simulate search and rescue or officer detectability.

The research team found environments where obstacles and flora were positioned in a manner that allowed them to reflect IR light, which allowed the beacons to still be detected as a result of their coronas and halo effects, despite not being directly observable. In cases where the vegetation was dense and obstacles large and solid, the researcher found their ability to spot and locate the IR beacons was reduced.

# 7. ALTERNATIVE TECHNOLOGIES

This study has focused upon technology that once activated provides an autonomous and automated signal. The obvious advantage is that these technologies will continue to operate regardless of the condition of the user until their power source has been depleted. However, additional technologies exist that are manually operated and have substantial application for directing aerial assets.

Other items were examined and although the models tested were not IR functional at the time of data collection, they were nonetheless effective as signaling devices. However, as they are not IR devices, they may not be suitable for clandestine tracking. As they produce visible light, they reduce the element of surprise for the user. Despite this flaw, they are included in the project for consideration.

## 7.1. Emergency Signaling Lasers

The Rescue Laser Flare® manufactured by Greatland Laser allows the user to signal aircraft at distances up to thirty miles. Unlike laser pointers that produce a single point of light, rescue lasers creates a line (similar to a laser level) that increases with the amount of distance. As the rescue laser is aimed at the aircraft and moved back and forth, personnel on the aircraft will perceive this movement as a flashing light. These rescue lasers are produced in various colors, as well as infrared. While the infrared laser has some tactical benefits, the brightest and most visible is the Green Rescue Laser Flare®.

During aerial testing of the infrared beacons, a strong line of thunderstorms passed through the area that forced the helicopter to withdraw. As the helicopter orbited outside the storm, the Green Rescue Laser Flare® was deployed from within the heavy rain and was immediately visible to the observer in the aircraft at approximately two miles. Consequently, the value of this technology to law enforcement, search and rescue, as well as the civilian community is clear. The rescue laser has the ability to quickly capture the attention of aircraft that otherwise may have difficulty locating ground personnel.

## 7.2. Strobing Flashlights

Currently, there are a number of strobing flashlights in the law enforcement marketplace designed to provide a tactical advantage to officers by temporarily blinding or disorienting subjects. However, an additional application for this technology was identified during this study. As there were few landmarks for the helicopter to use to pinpoint the testing location for the infrared beacons, a ground-based signal was necessary. The Gladious Night-Ops Illumination Tool® manufactured by BlackHawk!®, which produces a high intensity white strobe light, was used for this purpose. Regardless of the density of the vegetation, the flashing light from the Gladious was clearly visible to the aircraft.

## 8. CONCLUSIONS

This project evaluated a range of infrared beacons currently available in the law enforcement marketplace. Overall the findings suggest that this technology has substantial application for tracking law enforcement officers involved in foot pursuits as well as for monitoring police canines that are operating off-lead. While the visibility of the beacons was increased by motion, a large number were detectable while stationary and on the ground. Consequently, these beacons would certainly aid in the discovery of an injured officer that was unable to respond or for creative uses such as a marker to identify evidence for later recovery.

The utility for a K9 tracking team to be able to drop a low cost marker whenever evidence is located cannot be underestimated. Forensic evidence is easily destroyed and creates substantial problems for officers pursuing a suspect. Markers of this type are invisible to anyone without a night observation device and would ensure that the proper trained personnel would collect these items of evidentiary value.

Additionally, their visibility from a helicopter would allow for the direction of assets on the ground. Canines and officers could be deployed in a manner that increases the likelihood of success and minimizes the potential for friendly fire shooting scenarios. As most air units are equipped with thermal imaging systems, suspects not wearing an infrared beacon can be quickly discerned from the law enforcement officers.

The IR beacons were found to be most effective in lower light environments. In the lowest light scenarios, the reduction in ambient light allowed for the minimally present light to be amplified by the NOD without the scattering or haloing effect of other light sources. This allowed all the IR devices to be found and/or detection and should be considered a success for them. In the cases where more light than simply the stars or moon was present, it became clear that the IR devices that were more powerful or intense tended to be more easily detected.

However, there is a tradeoff between size and ease of carry. The IR beacons, which were located during higher light scenarios, were also the larger devices. In this case, the tradeoff is locateability over bulkiness. Consequently, the actual light conditions in which a device is to be deployed becomes a major factor for consideration of deployment and device type.

The smaller IR beacons, which tended to have lower visibility scores, were also the easiest to carry without restriction and also appeared to be the type of item that could most easily be incorporated into a standard duty uniform. The larger IR beacons tended to be less comfortable to carry consistently and by extension the least likely to be incorporated into a standard duty uniform.

Another major factor for the IR beacon and its applicability to law enforcement is that to be detected the device does not always have to be “seen”, rather the IR light may reflect off of objects and this reflected light can be discerned by the observer. However, the single most detrimental factor to an IR beacons visibility is its relative height placement. Elevated IR beacons were much more easily detected. It was found that when observing from ground level or the same level as the beacon, objects such as trees and grass and buildings could completely shield the IR device and preclude it from being detected. When the search was conducted from an aerial vantage the disadvantage of line-of-sight searches was almost immediately overcome as evidenced by the speed with which the observer in the aerial unit was able to locate the IR beacon.

Finally, the cost considerations for the implementation of the beacons and the IR devices are well within the budgetary limits of even the smallest law enforcement agency. Technology transfer programs provide night vision technology to agencies at little or no cost and the individual beacon cost is less than the cost of an expandable baton. Given the multiple functions of this technology, implementation of infrared beacons in actual field deployments is the next logical step in determining feasibility for nationwide implementation.

A key finding of this research was the relative effectiveness of the IR beacons. As demonstrated in locations 1 – 8 and detailed above, numerous IR devices were scored as being visible but did not score as high as possible on the visibility scale. Even with an IR beacon scoring a 1 on the 1 – 9 scale, it must be stated that despite this score, it was considered a successful detection simply because it was visible. Whereas an IR beacon that scored a zero in a particular environment simply was not visible and should be considered a “miss”.

An IR device that is smaller and always locatable due to it being visible may be considered to have more utility for carry or deployability. While the Tektites consistently were more visible under all conditions, it need also be added that they are also the largest of the IR beacons under consideration and may not offer the most ease of routine deployability.

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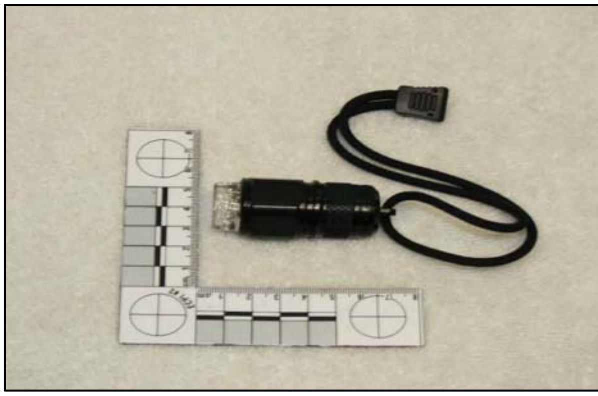
# 10. APPENDIX

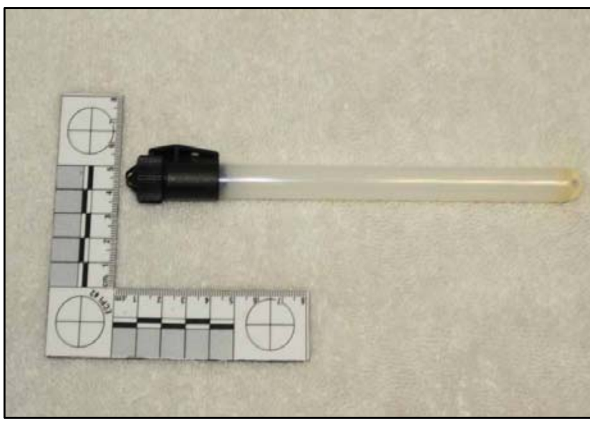
## Figure A1. Athena Infra Red Beacon



**Product Specifications**

COST: $99.05
LENGTH: 2.6 inches
WIDTH: 1 inch
BATTERY: Lithium 123
RUN TIME: 100 hours
MANUFACTURER: Cejay Engineering

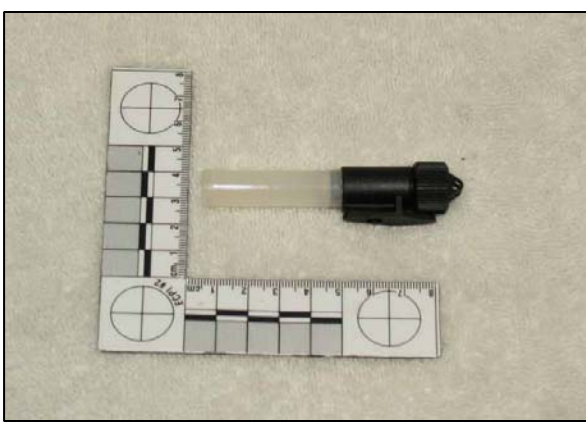
## Figure A2. Glo-wand MK-8 (large)



**Product Specifications**

COST: $6.62
LENGTH: 6 inches
WIDTH: 0.75 inches
BATTERY: #675 (three)
RUN TIME: 72 hours
MANUFACTURER: Cejay Engineering

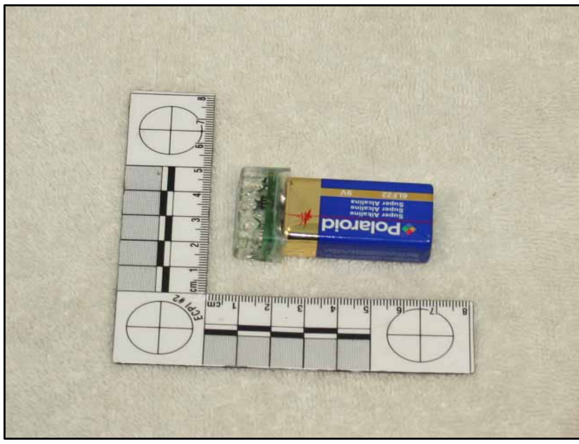
## Figure A3. Glo-wand MK-8 (small)



**Product Specifications**

COST: $11.51
LENGTH: 2.78 inches
WIDTH: 0.75 inches
BATTERY: #675 (three)
RUN TIME: 72 hours
MANUFACTURER: Cejay Engineering

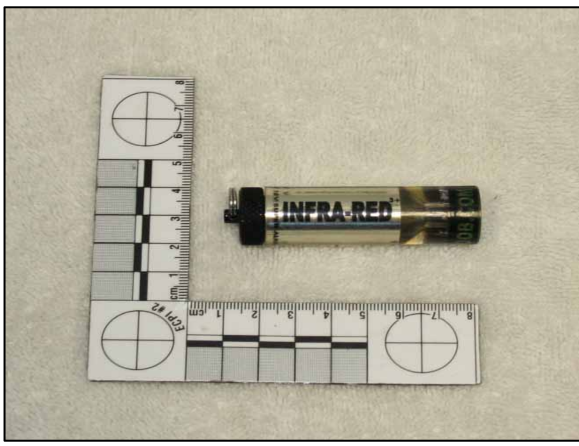
**Figure A4. Phoenix Firefly Jr.**




**Product Specifications**

| | |
|---|---|
| COST: | $20.09 |
| LENGTH: | 1.5 inches |
| WIDTH: | 0.62 inches |
| BATTERY: | 9 volt |
| RUN TIME: | 100 hours |
| MANUFACTURER: | Multiple (model used for testing from Cejay Engineering) |

**Figure A5. Glo-Toob IR**




**Product Specifications**

| | |
|---|---|
| COST: | $32.25 |
| LENGTH: | 2.75 inches |
| WIDTH: | 0.75 inches |
| BATTERY: | A23 |
| RUN TIME: | 30 hours |
| MANUFACTURER: | Glo-Toob |

**Figure A6. MS 2000 Rescue Beacon**

**Product Specifications**

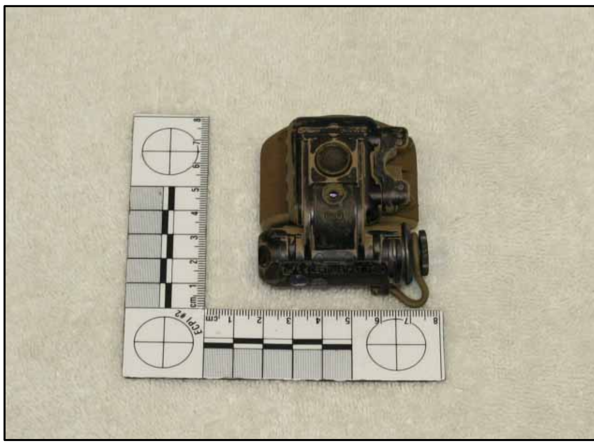
| | |
|---|---|
| COST: | $94.95 |
| LENGTH: | 4.5 inches |
| WIDTH: | 2.2 inches |
| BATTERY: | AA (two) |
| RUN TIME: | 8 hours |
| MANUFACTURER: | U.S. Military |

**Figure A7. Powerflare F 200 Tactical**

**Product Specifications**

| | |
|---|---|
| COST: | $109.95 |
| LENGTH: | 4.25 inches |
| WIDTH: | 1.25 inches |
| BATTERY: | CR123 |
| RUN TIME: | 24 hours |
| MANUFACTURER: | Powerflare |

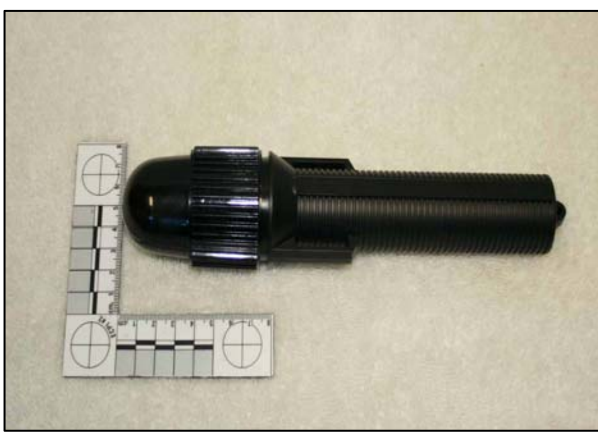
**Figure A8. Helmet IR Beacon**



**Product Specifications**

| | |
|---|---|
| COST: | $98.95 |
| LENGTH: | 2.2 inches |
| WIDTH: | 2.6 inches |
| BATTERY: | CR123A |
| RUN TIME: | 120 hours |
| MANUFACTURER: | Surefire |

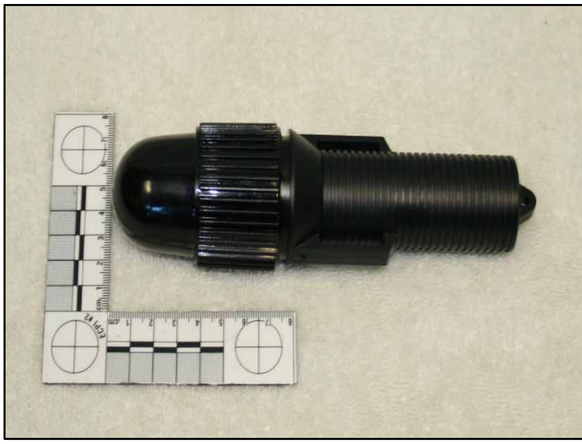
**Figure A9. IR Strobe 300**



**Product Specifications**

| | |
|---|---|
| COST: | $82.95 |
| LENGTH: | 9.25 inches |
| WIDTH: | 1.9 inches |
| BATTERY: | C cell (three) |
| RUN TIME: | 24 hours |
| MANFACTURER: | Tektite |

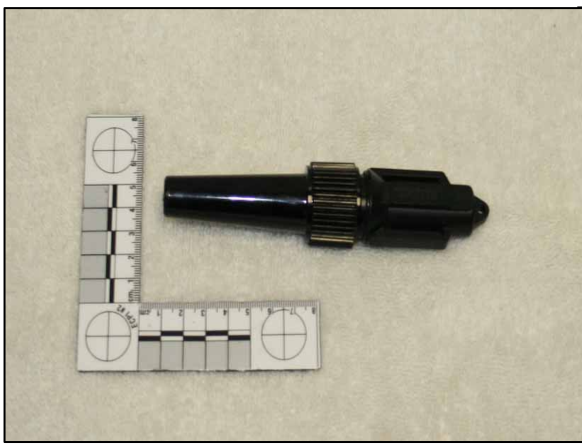
**Figure A10. IR Strobe 200**



**Product Specifications**

| | |
|---|---|
| COST: | $73.95 |
| LENGTH: | 7.25 inches |
| WIDTH: | 1.9 inches |
| BATTERY: | C cell (two) |
| RUN TIME: | 30 hours |
| MANUFACTURER: | Tektite |

**Figure A11. Mark-Lite**



**Product Specifications**

| | |
|---|---|
| COST: | $49.95 |
| LENGTH: | 5.75 inches |
| WIDTH: | 1.2 inches |
| BATTERY: | AA |
| RUN TIME: | 6 hours |
| MANUFACTURER: | Tektite |

**Figure A12. V.I.P.**

**Product Specifications**

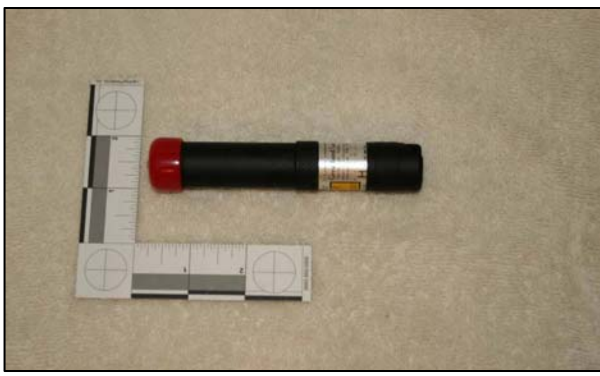
| | |
|---|---|
| COST: | $108.00 |
| LENGTH: | 2.75 inches |
| WIDTH: | 2 inches |
| BATTERY: | DL123A |
| RUN TIME: | 40 hours |
| MANUFACTURER: | Adventure Lights |

**Figure A13. Gladious Flashlight**


**Product Specifications**

| | |
|---|---|
| COST: | $185 |
| LENGTH: | 6.23 inches |
| WIDTH: | 1 inch |
| BATTERY: | 6 volt |
| RUN TIME: | varies with use |
| MANUFACTURER: | BlackHawk!® |

**Figure A14. Large Laser Flare**



**Product Specifications**

| | |
|---|---|
| COST: | $250 |
| LENGTH: | 4.88 inches |
| WIDTH: | 1 inch |
| BATTERY: | CR 123 |
| RUN TIME: | 5 hours |
| MANUFACTURER: | Greatland |