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EVALUATION OF AN IMAGE INTENSIFIER
SYSTEM FOR USE ON TRACKING TELESCOPES

Charles R. Hayslett

White Sands Missile Range
White Sands, New Mexico

November 1972

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TECHNICAL REPORT

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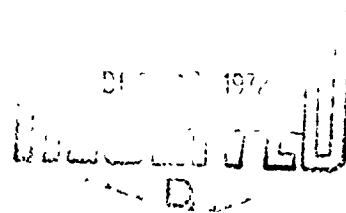
FINAL REPORT

BY

CHARLES R. HAYSLETT

NOVEMBER 1972

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13. ABSTRACT An image intensifier system has been designed and fabricated to mount on a long focal length telescope that is to be used for daytime missile tracking. The image intensifier system was evaluated both in the laboratory and on the telescope at a field site. The evaluation showed the image intensifier system provided adequate light gain to allow for faster sampling rates, longer focal lengths, and higher f/number telescopes. The results of degradation to image quality consequential to providing this light gain are discussed. The field evaluation showed that the system has the capability to record data on missiles from launch to impact, 25 miles up range.			

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ABSTRACT

An image intensifier system has been designed and fabricated to mount on a long focal length telescope that is to be used for daytime missile tracking. The image intensifier system was evaluated both in the laboratory and on the telescope at a field site.

The evaluation showed the image intensifier system provided adequate light gain to allow for faster sampling rates, longer focal lengths, and higher f/number telescopes. The results of degradation to image quality consequential to providing this light gain are discussed. The field evaluation showed that the system has the capability to record data on missiles from launch to impact, 25 miles up range.

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INTRODUCTION

The objective of the image intensifier evaluation project has been to investigate image intensifiers for potential use on optical tracking telescopes. The primary goals of the project were to provide more irradiance in the image of long focal length telescopes, to allow data recording of objects at greater distances, to improve data analysis capabilities by providing more "readable" film, and to investigate the image degradations inherent with image intensification devices.

This project was an outgrowth of an In-House Laboratory Independent Research (ILIR) Program. Under the ILIR project, the investigation of image intensifiers was initiated, and the first intensifier for WSMR was acquired. Also, funds for two other intensifiers were provided. A funds transfer to Fort Belvoir was made for the Night Vision Laboratories to purchase a (at the time) classified, single stage, electrostatic focused intensifier for WSMR. Unused funds were later used to obtain two single stage, electrostatically focused image intensifiers that were coupled together to function as a two-stage device.

The Image Intensifier Evaluation Project (this report is the completion of this project) was initiated in 1968. The first task was to obtain a complete system for evaluation on a WSMR telescope. A two-stage magnetically focused intensifier was procured for this purpose.

In 1969, a few other pieces of supporting equipment were obtained, the image intensifier tube was received and tested, the system was designed and fabrication was initiated. The Image Intensifier Evaluation System was designed to be mounted on the Ground Optical Recorder for Intercept Determination (GORID) MK1A telescope.

The system was completed and subsequent performance tests in the laboratory began in 1970. Potential loss of use of the GORID telescope led to the decision to prematurely install the system on the GORID before all laboratory tests had been completed. The GORID was used for the short period available and data was obtained on both nighttime and daytime objects including some missile tests.

In 1971, the system was brought back into the laboratory for further laboratory testing, for modifications, and for adjustments to the system in anticipation of further field testing on the GORID when it again became available.

Throughout the remainder of 1971 and early 1972, the project ground to a halt waiting to remount the system on the GORID. The delays accumulated, and in May 1972, it was decided (due to manpower limitations and scheduling problems) to terminate the project. This report is the final milestone.

/

SYSTEM DESIGN

A schematic diagram of the Image Intensifier Evaluation System is shown in Figure 1.

The system is a two-stage magnetically focused image intensifier, focused by a cooled, segmented, electromagnetic coil, enclosed in a magnetic shield. Also included are a 1:1 f/1.25 relay lens and a 10 to 8 frame per second 70mm framing camera. Figure 2 shows a partially disassembled view of the system looking at the phosphor screen end of the image intensifier tube.

IMAGE INTENSIFIER

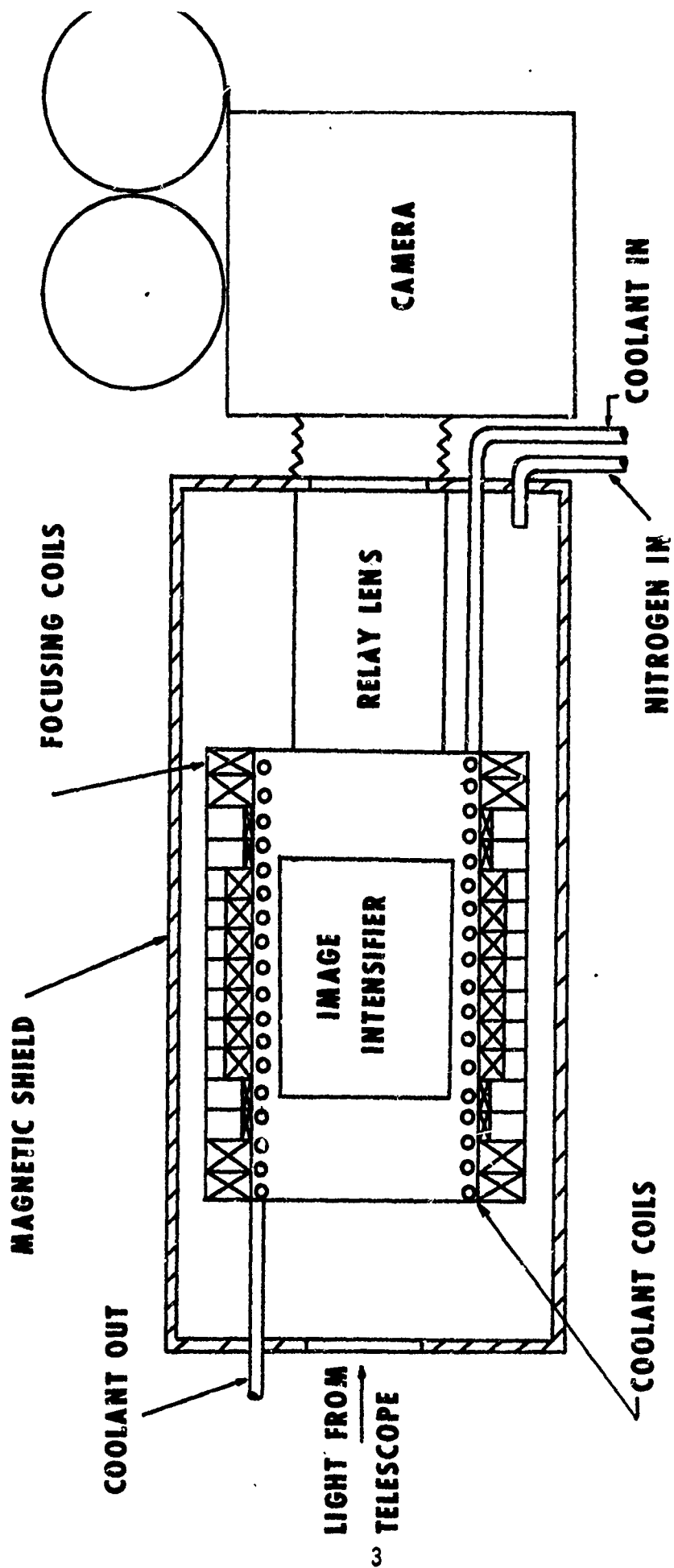
The Image Intensifier Evaluation System is built around an RCA two-stage magnetically focused image intensifier (Model 70012BP2). This device has usable input and output diameters of 89mm, borosilicate glass windows, an S-20 photocathode and a P-11 phosphor screen. The minimum specified center and edge resolutions of the tube are 40 and 30 line-pairs (ln-pr)/mm, respectively. The maximum radiant power gain is about 5000 for maximum operating voltage (26 kV) and about 2000 for the normal operating voltage (20 kV). The output distortion and magnification of this tube is specified at near 1 percent when operating the tube in a double node configuration with a uniform magnetic field of 270 gauss.

FOCUSING COIL

The supplier of the magnetically focused intensifier tube used in the system recommended, for operation, a uniform magnetic field of 270 gauss. This can be supplied with a focusing coil or a permanent magnet. A coil was chosen for this application.

The design of the coil is explained in Optics Division Engineering Memorandum 69-5, "Design Considerations for Focusing Coil and Magnetic Shield for a Magnetically Focused Image Intensifier," by C. R. Hayslett, 22 July 1969. The design, as developed in the above memorandum, was a 15 segment coil with various numbers of wire turns per segment.

This design was incomplete due to assumptions made as to actual coil diameters and end effects caused by the magnetic shield. Dr. William Baum of the Lowell Observatory, Flagstaff, Arizona, performed some experiments to determine the effects of a cylindrical magnetic shield on the field produced by a coil. This data, along with changes in coil diameters due to design constraints, was input to the computer design program described in Engineering Memorandum 69-5. The final coil design parameters are as follows:



SCHEMATIC OF IMAGE INTENSIFIER SYSTEM

FIGURE 1

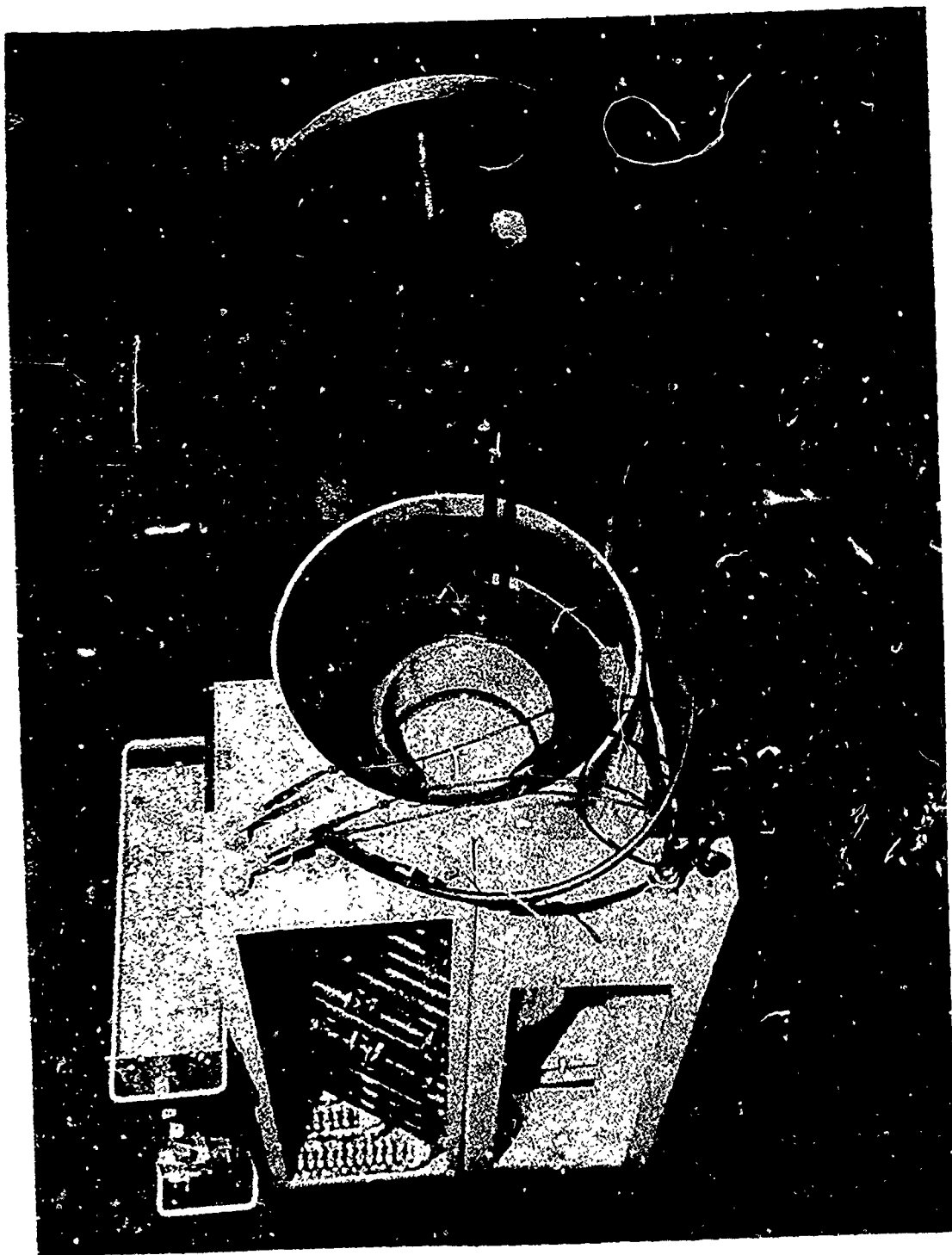


FIGURE 2. DISASSEMBLED VIEW OF IMAGE INTENSIFIER SYSTEM

1. A segmented, stacked coil, with 15 one inch wide segments.
2. Regulated current through the coil stack to produce 270 gauss is 9.2 amps.
3. Using 14 gage wire, the expected power dissipation is 950 watts.

The number of turns of each segment and their stacked configuration is as shown in Figure 3. Figure 4 is a photograph of the coil on the test bench with the intensifier tube inside.

The field produced by this coil is calculated to be uniform within 0.11 percent to ± 4.5 inches (on axis) from the center of the coil.

In the final design, each coil segment had a parallel variable resistor attached. These were used in an attempt to trim and adjust the field for best performance. These variable resistors can be seen in Figure 2.

ENVIRONMENTAL SYSTEM

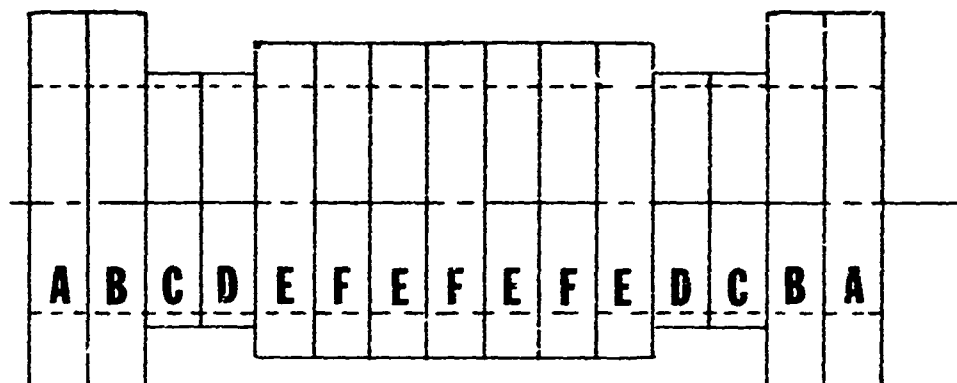
Due to the power dissipation of the focusing coil (950 watts) and the maximum operating temperature specification on the image tube (50 degrees Centigrade), provisions were made for cooling the tube environment. Copper cooling coils were placed between the heat producing focusing coils and the tube. An Electro-Impulse, Model No. RU-75, cooling unit chills a refrigerant and forces it through the cooling coils. In order to prevent problems due to condensation from the cooling coils, the space around the tube and coils is enclosed and supplied with dry nitrogen while the system is operating.

The focusing coils are also surrounded by a cylindrical magnetic shield made of 1/4 inch thick Armco iron. This prevents adjacent materials and changes in orientation of the system in the earth's magnetic field from appreciably affecting the uniform magnetic field.

POWER EQUIPMENT

The high voltage required by the image intensifier is supplied by a Power Designs, Model 1579, power supply. This supply has an output continuously variable from 10 kV to 30 kV.

The focusing coils are supplied current from two Raytheon, Model DCR 60-13A, power supplies connected in series. This combination will supply variable, constant current up to 13 amps at 120 volts.



COIL TYPE	A	B	C	D	E	F
NO. OF YURNS	210	211	5	11	59	58

CONFIGURATION OF SEGMENTED COIL

FIGURE 3



FOCUSING COIL

FIGURE 4

OPTICAL SYSTEM

The Image Intensifier Evaluation System mounts on the GORID MK1A telescope. This telescope has an 18 inch primary mirror and has selectable focal lengths of 90, 180 and 360 inches. Due to the different positions of the telescope focal planes and consequent mechanical limitations, only the 180 and 360 inch configurations could be used with the intensifier system.

The image from the telescope is focused on the photocathode of the image intensifier. The image produced on the phosphor screen is relayed to the film plane of the camera with two Kodak Aero-Ektar 7 inch, f/2.5 lenses placed face to face. This lens pair is positioned so that the image relayed to the film has unity magnification.

Cameras used for testing included a 70mm Photo-Sonics 10A capable of recording from 10 to 80 frames per second, 35mm single lens reflex cameras, a 70mm single lens reflex camera, and a 4 x 5 plate camera.

LABORATORY EVALUATION

FOCUSING COIL FIELD AND COOLING TESTS

The coil was first tested for uniformity without its magnetic shield. The field, on axis and within the axial dimensions that the image intensifier would fill, had negligible nonuniformity. With the coil inside the magnetic shield, the field, within the entire volume that would be filled by the intensifier tube, was uniform to within ± 0.5 percent. The magnetic shield increased the field strength by about 10 percent as was expected from Dr. Baum's experiments.

Without the cooling equipment running, the focusing coil heated up rapidly. The air temperature, in the area of the image tube, rose from 23 degrees Centigrade to the maximum operating temperature of 50 degrees Centigrade in 90 minutes. With the cooling equipment running, the temperature around the image tube was maintained at under 15 degrees Centigrade for over two hours of continuous operation.

A shell of the image intensifier tube was used to determine what effects the materials in the tube had upon the magnetic field. This shell was open on either end and contained all of the magnetic materials that the operational tube contained. This shell, or dummy tube, was placed in the normal tube position, power was supplied to the focusing coils and the interior volume of the dummy tube was probed with a gaussmeter. Similar experiments with a smaller intensifier tube had shown that the

field strength would vary by less than ± 5 percent within the volume of the tube. In the hopes that this variation could be compensated for, and thus lead to better resolution and distortion performance from the intensifier tube, shunting resistors were added to each coil segment to change the current through each coil segment and thus vary the shape of the magnetic field.

The magnetic field, internal to the dummy tube, as measured is shown in Figure 5. The variation in the field is on the order of ± 10 percent. This is more than twice as great as expected. The limitations in adjusting the field, by the current supply and the shunting resistors, were such that such large deviations in the field uniformity could not be compensated for. If the computer design of the coil were to be rerun sometime in the future, compensation for this large deviation would be included in the original optimization program. Then the large compensations could be taken care of by the coil design. This would allow for maximum adjustment capability with the shunting resistors.

GAIN

The gain of the image intensifier tube and of the image intensifier evaluation system were evaluated by three methods.

The first method was to measure the output image emittance on the intensifier with the same photomultiplier. This procedure was used at various tube operating voltages to obtain the results shown in Figure 6. Figure 6 is a plot of radiant power gain versus tube voltage. Radiant power gain is the total measured output power density from the screen divided by the total incident radiant power density at the wavelength of maximum response. The input light was filtered to obtain the wavelength of maximum response (about 4200 angstroms).

The gain of the tube was also measured with a Macbeth illuminometer. With the high voltage at 18 kV, the gain of the tube measured in this way was 1000.

Finally, system gain was evaluated by comparing results on photographic emulsions. On Kodak 2484 film, equivalent photographs through the GORID telescope, with and without the intensifier system, were obtained. The exposure time to obtain the equivalent photographs was approximately 75 times less when using the image intensifier system. This is the system gain at 18 kV and the tube gain at 18 kV (considering the relay lens losses) works out to about 750 times.

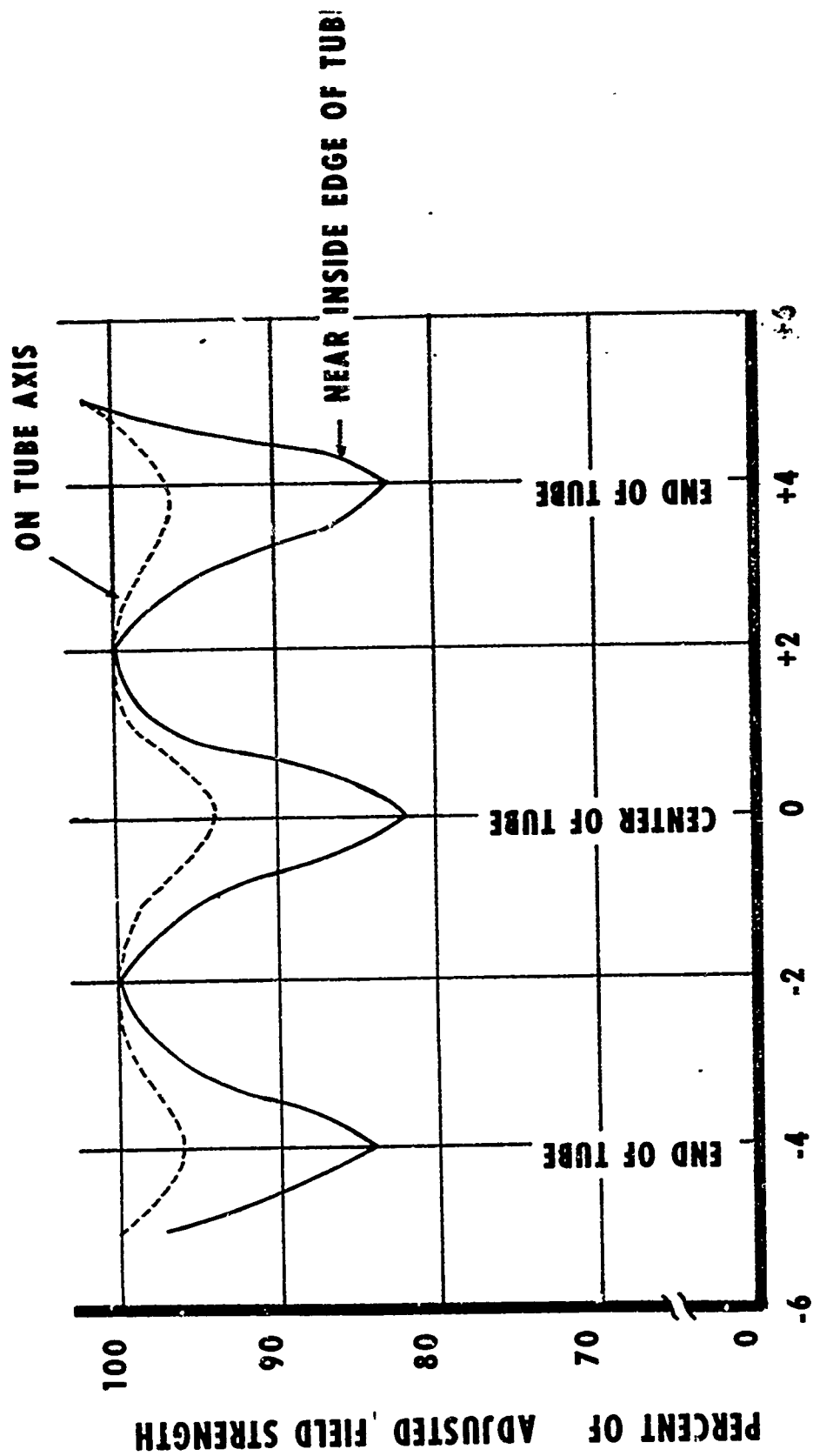


FIGURE 5

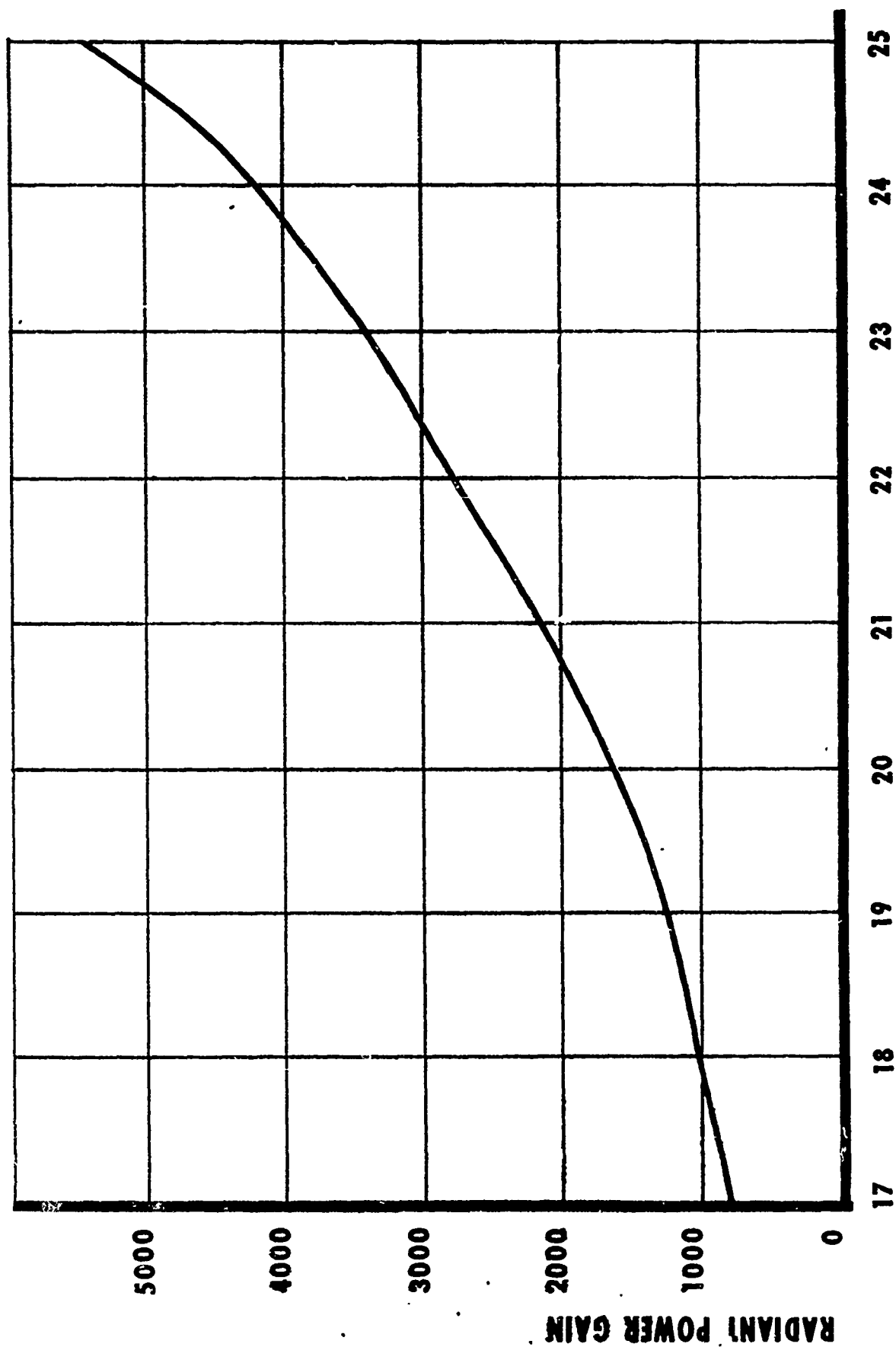


FIGURE 6

PHOSPHOR DECAY

The phosphor decay of the image intensifier is important because the phosphor must decay to a negligible brightness in a short period of time if it is to not smear the image on the film. P-11 phosphor was used on the tube in the Image Intensifier Evaluation System at the output of both the first and second stage.

The phosphor decay was measured by using a pulsed Light Emitting Diode (LED) with a square wave input as a target for the image tube. The decay characteristics on the phosphor were detected by a photomultiplier and the results observed on an oscilloscope. The rise and fall times of the LED, photomultiplier, and oscilloscope combination were first measured and were found to be less than 10 microseconds. As will be seen, this amount of delay in response is negligible as compared to the response of the intensifier tube.

The decay time of the intensifier tube was measured for varying input illumination, pulse widths and repetition rates. The decay time is defined as the time required for the image to decay to 10 percent of peak brightness. The input illumination was set at four values. The LED provided predominately red light and the input illumination levels were estimated to range from about 0.01 to 0.50 foot candles, as adjusted for the spectral sensitivity of the tube. For constant pulse widths and constant or varying repetition rates, the decay time did not appreciably vary with changing input brightness.

The repetition rates chosen were 1000, 500, 200, 100, and 20 pulses per second. The decay time did not appreciably change with change in repetition rate.

The pulse widths used for evaluation were 0.1, 1.0, 10.0 microseconds and continuous operation. A substantial increase in decay time occurred with increasing pulse width out to about a 3.0 to 5.0 microseconds decay time for continuous operation. Figure 7 shows a plot of decay time versus pulse width for all brightness conditions and pulse widths.

Typical relative brightness versus time curves are shown in Figure 8. These curves are for the various pulse widths.

RESOLUTION

The resolutions of the intensifier tube and of the intensifier evaluation system were determined both visually and photographically. The resolution was evaluated at various tube operating voltages and at different areas on the output of the tube. Resolution charts were projected onto the tube photocathode. The resolution of the input image from the projection system was about 80 ln-pr/mm.

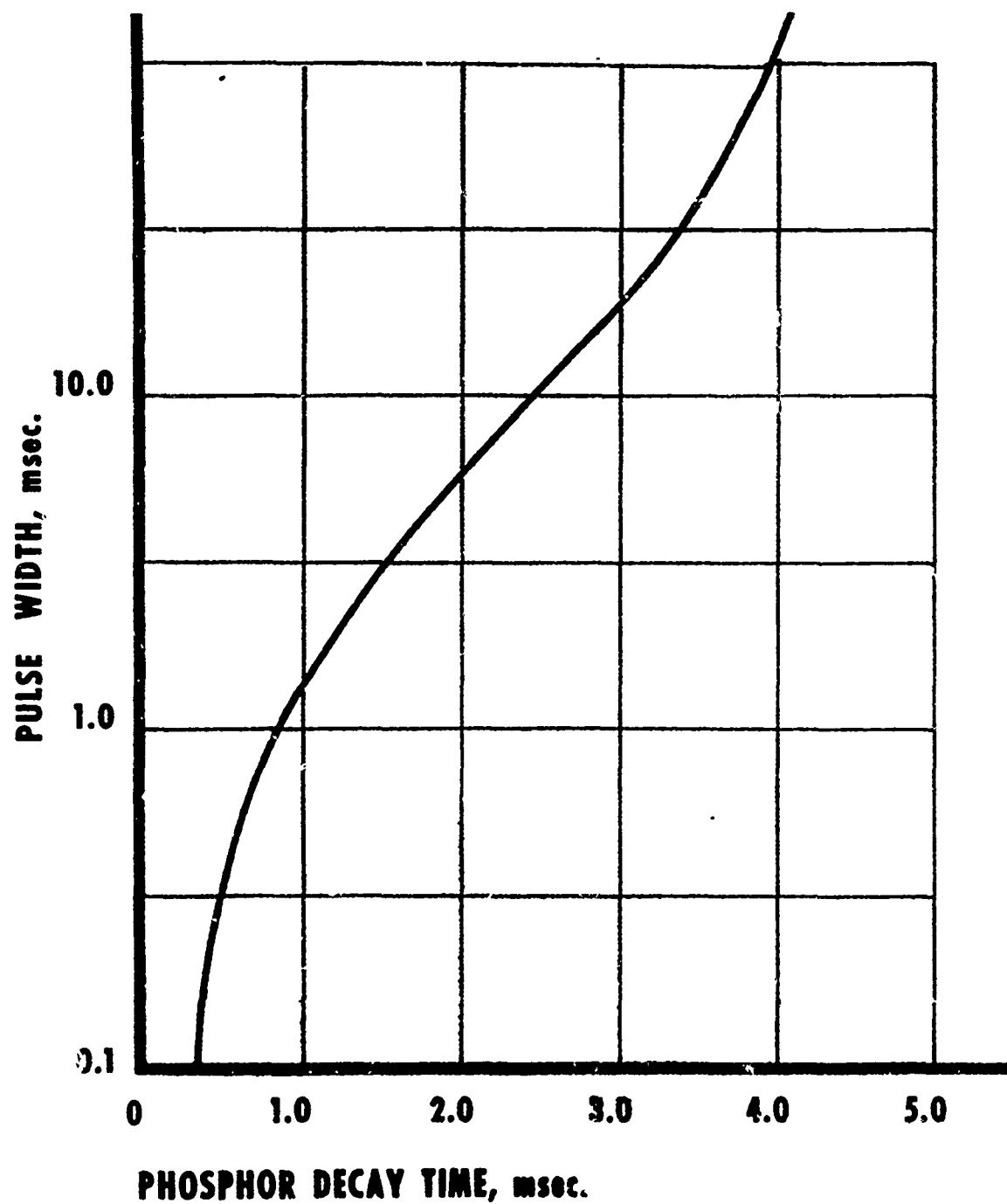


FIGURE 7

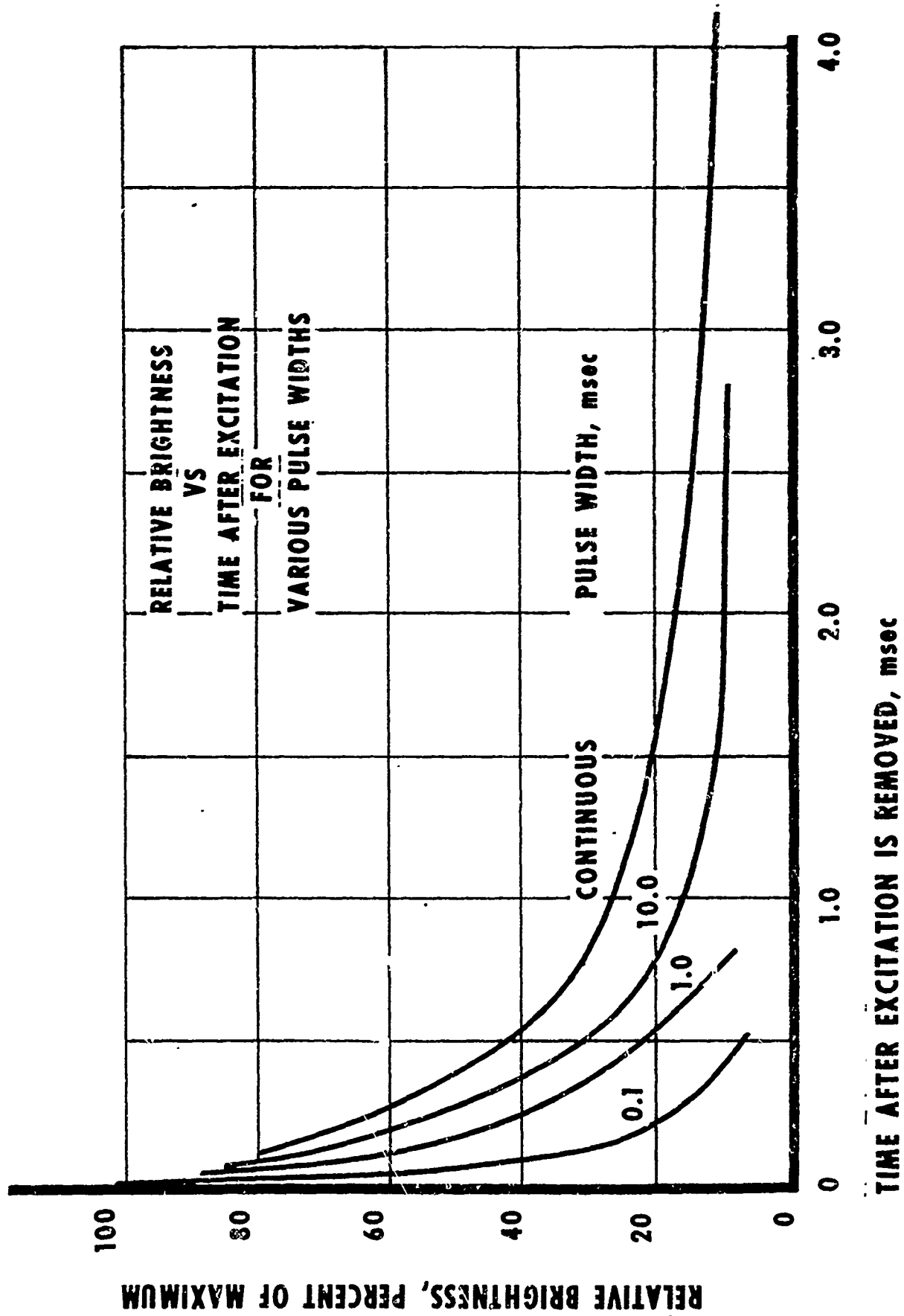


FIGURE 8

Visual evaluation of the resolution directly on the output screen of the image intensifier yielded a center resolution of 25 ln-pr/mm and at 35mm from the tube center, 22 ln-pr/mm. Visual evaluation of the image through the tube and then the relay system gave 22 ln-pr/mm at the tube center but closer to 16 ln-pr/mm near the edge. Photographic evaluation with "medium-high" resolution films (Pan-X and Adox) showed no significant degradation to those values stated for the tube and the relay lens.

Resolution was also visually evaluated as a function of the image intensifier tube operating voltage. Figure 9 shows the data obtained from this test.

DISTORTION

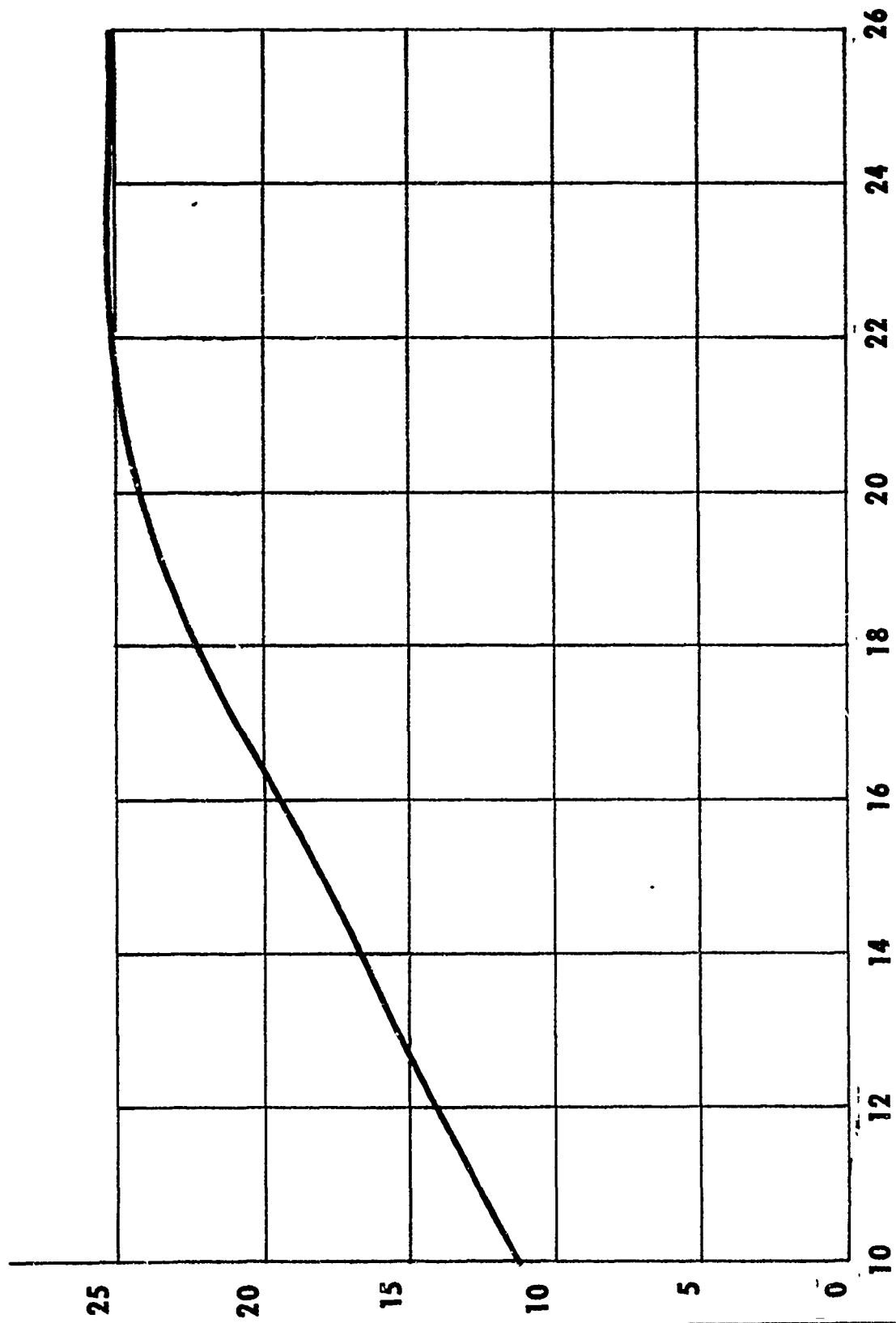
The distortion of the image intensifier system was evaluated by projecting a grid pattern onto the cathode and photographing the grid on the output of the image intensifier tube. The distortion of the photographed grid was then measured. Figure 10 shows one type of grid as distorted by the image intensifier tube. The picture shows that the distortion in the system is barely noticeable. Figure 11 is a plot of the data as obtained by measurement of the distorted grid. Image rotation and magnification were both found to be so small that they were not measureable.

Some concern was expressed as to the effect of electromagnetic interference generated by the framing camera motor on the image intensifier tube and the subsequent increase in distortion. The distortion tests were evaluated on film in the Photo-Sonics 10A camera for all framing rates. The results from these tests showed no appreciable change in distortion to those results already shown in Figure 11.

SYSTEM GRANULARITY

The image intensifier tube adds a "mottle" noise or granularity type noise to the normal film granularity. The system granularity was measured by photographing the image of a step wedge at the output of the image intensifier. A microdensitometer trace was made of the resulting photograph using a 100 x 50 micrometer slit. This trace was compared to similar traces made of the step wedge imaged directly onto film.

Two different films were used for this test: a medium grain film, linagraph shellburst (LSB), and a course grain film, Kodak 2485. The tests revealed a standard deviation of 0.022 density units for the image intensifier and LSB while only 0.015 for the LSB alone. On 2485 the standard deviation was 0.035 density units with the intensifier and 0.028 for the film alone. These results were determined for a density above fog of about 0.60.



TUBE OPERATING VOLTAGE, KILOVOLTS

FIGURE 9

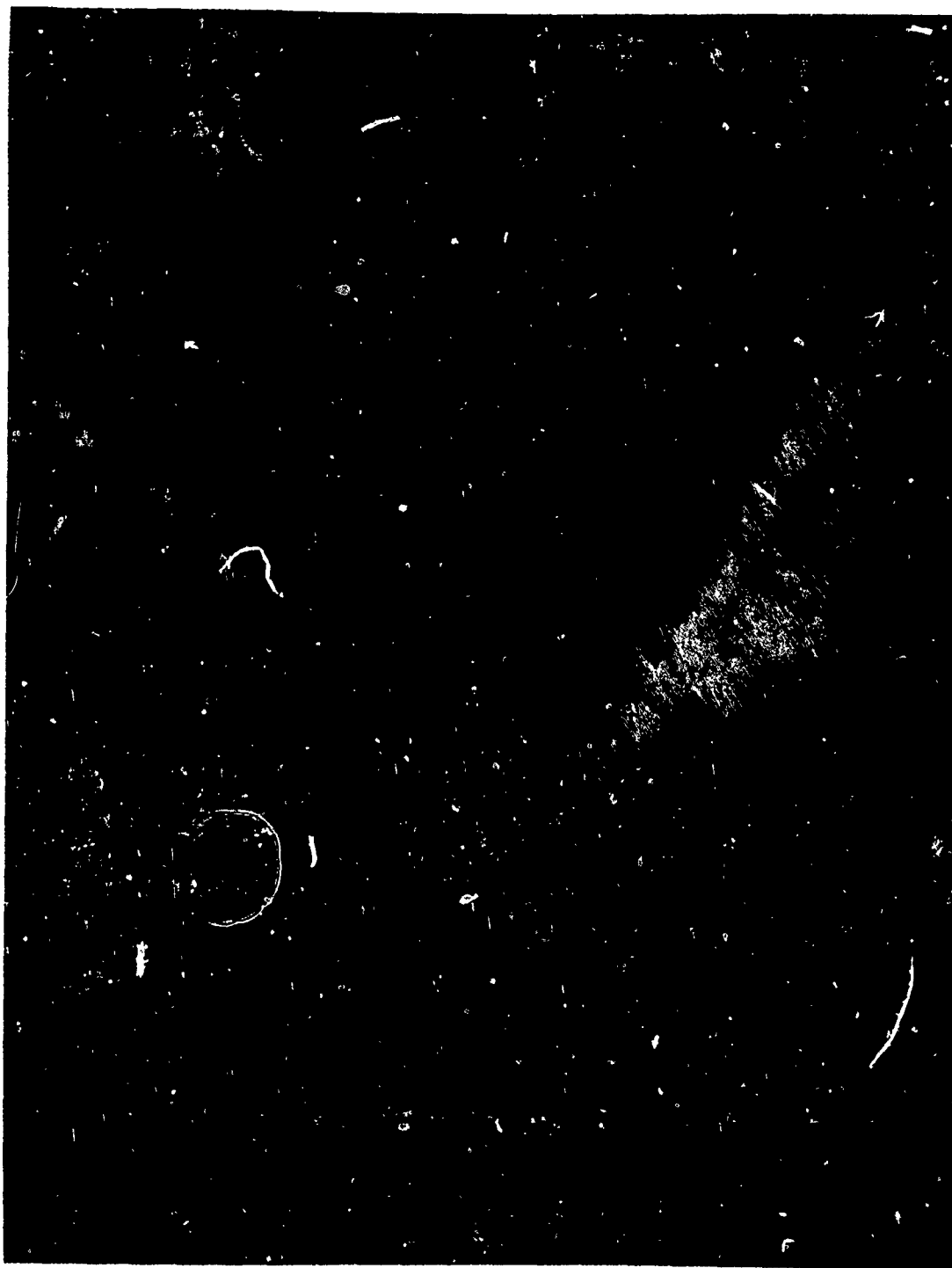


FIGURE 10. DISTORTED GRID ON OUTPUT SCREEN

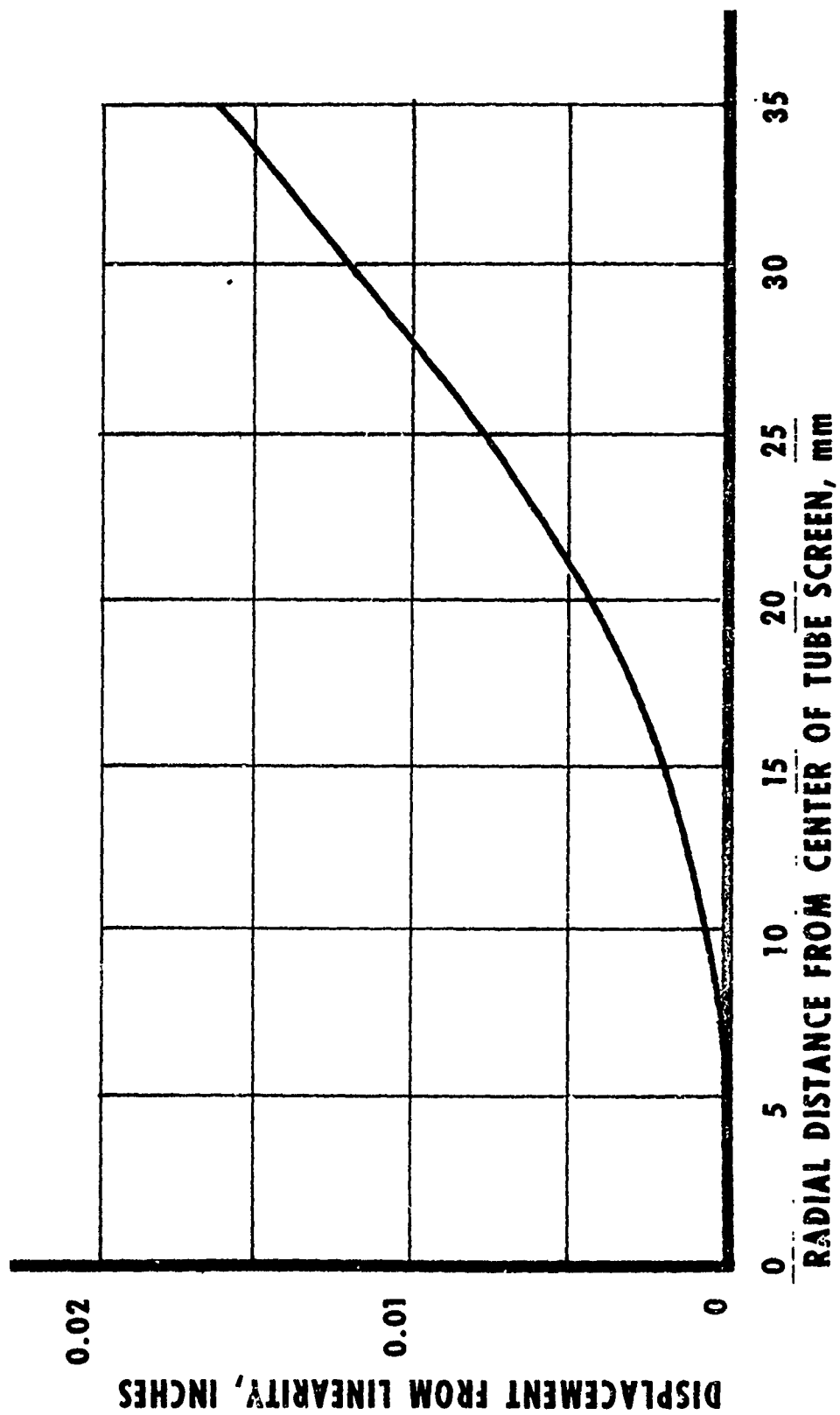


FIGURE 11

FIELD EVALUATION

During the short period of time that the image intensifier was on the GORID telescope, data was collected on stars, stationary targets at night, and missiles and other objects of interest both during the day and at night. Figures 12 and 13 show the system as mounted on the GORID MK1A telescope.

The first tests performed were focusing and aligning on stationary objects at night. This permitted obtaining gain versus exposure time data for the various films that were used during the tests. Figure 14 shows a photograph of a rectangular object at a distance of 10 miles as obtained with the telescope at the 180 inch focal length. The target is covered with some type of reflecting material and is illuminated only by starlight and illumination created by the WSMR base area, some two to three miles from the target.

Figure 15 shows a tower some 15 miles from the telescope. The picture on the left is without the image intensifier and on the right is through the intensifier. Both are in the daytime with the 360 inch focal length.

The first actual performance tests were obtained by photographing double stars. All results given are for the 180 inch focal length. The stars were first photographed without the image intensifier system and these results were later compared with pictures obtained through the image intensifier. On Kodak 2484 film, comparable pictures were obtained at 5 seconds exposure time without the image intensifier and 1/15 second exposure time with the intensifier. This implies a system gain of 75 times. These and the following results were obtained with the tube operating at 18 kV.

The resolution obtained through the telescope at the 180 inch focal length without the image intensifier was 5 arc seconds or 9 ln-pr/mm. With the intensifier the resolution obtained was about 7 arc seconds or 6.5 ln-pr/mm. Examples of other tests performed are shown in Figures 16 and 17. Figure 16 is a photograph of a helicopter at near 5 miles slant range. Figure 17 shows a sequence of photos for a missile launch at 12 miles slant range. In all, data for 10 missile launches was obtained, with some coverage and data from launch to impact 25 miles up range.



FIGURE 12. IMAGE INTENSIFIER ON GORIP TELESCOPE



FIGURE 13. IMAGE INTENSIFIER ON GORID TELESCOPE



FIGURE 14. RECTANGULAR OBJECT AT NIGHT THROUGH THE SYSTEM



WITHOUT IMAGE INTENSIFIER

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WITH IMAGE INTENSIFIER

FIGURE 15. COMPARISON OF TOWER THROUGH THE TELESCOPE

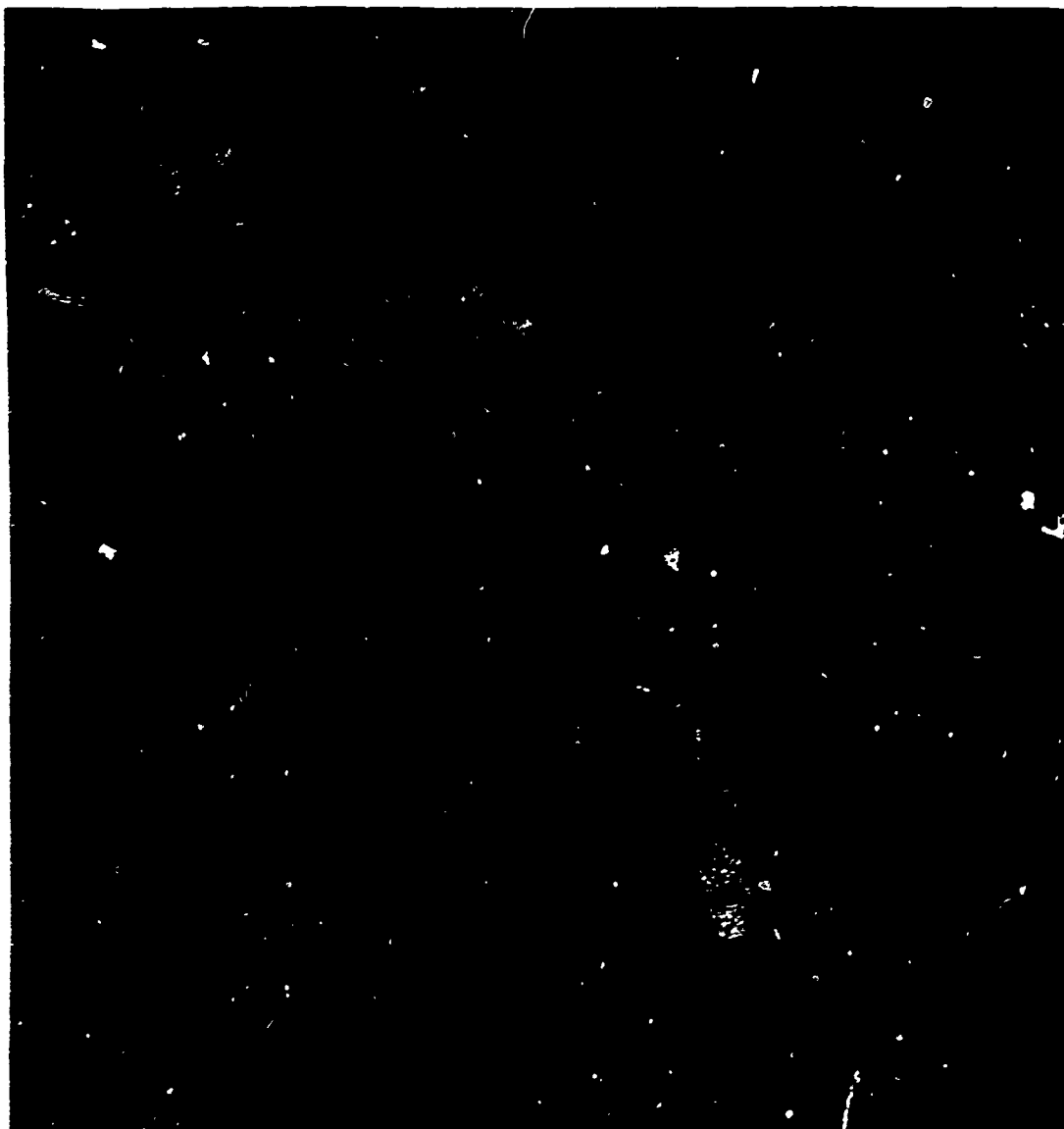


FIGURE 16. HELICOPTER AT 5 MILES THROUGH THE SYSTEM

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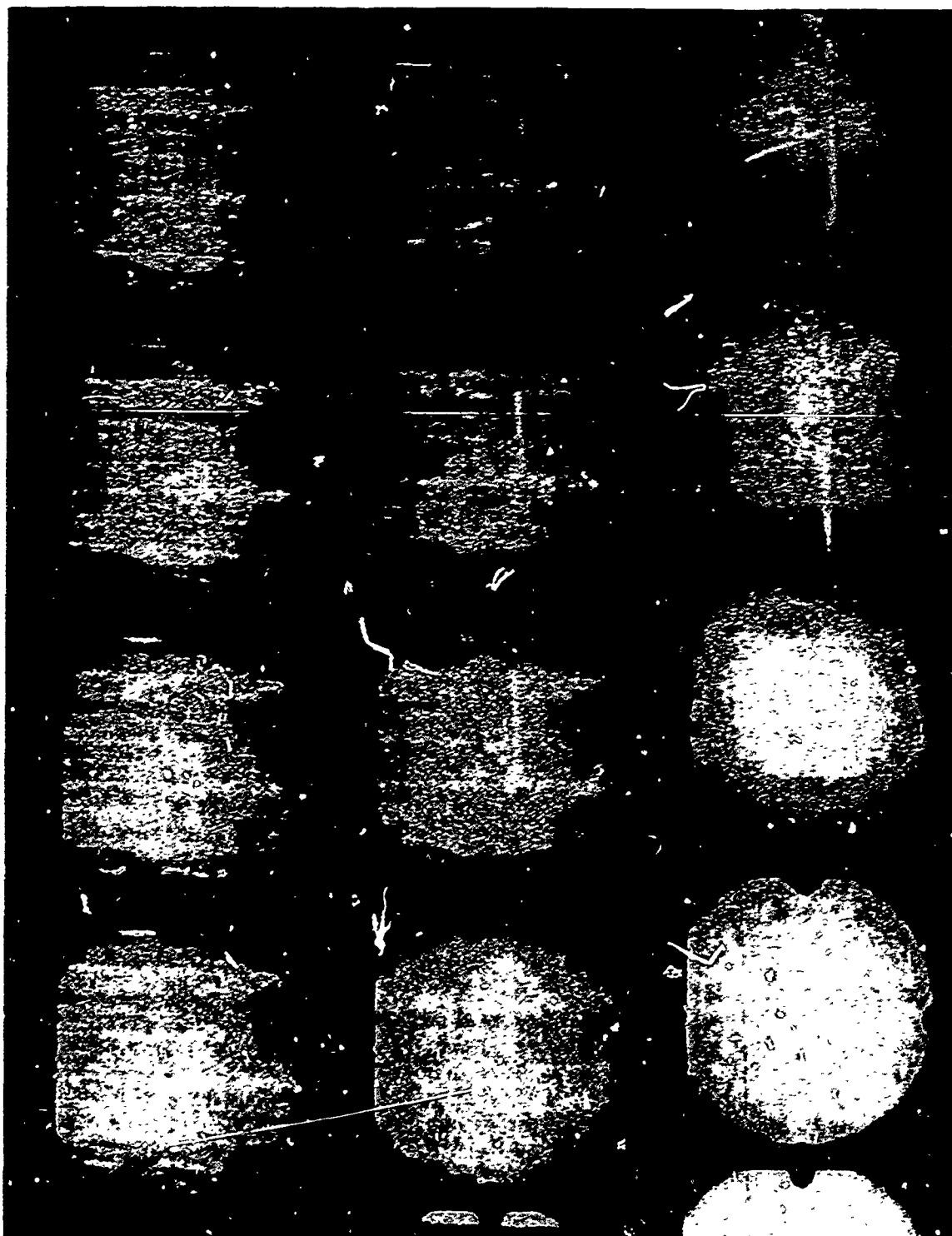


FIGURE 17. MISSILE LAUNCH AT 12 MILES

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DISCUSSION OF EVALUATION

The accuracy of most of the data collected is subject to question. All of the data was examined carefully, but only as critically as time permitted. In most cases, the results should be considered "ballpark" or of order of magnitude accuracy. Such things as linearity of response of the photomultiplier and the films were not taken into account. Human evaluation of resolution is always subject to question. In any event, the numbers presented should not be considered exact, but should be taken as about correct.

Many of the tests performed relate directly to expected performance while others require further evaluation. Following is a further discussion of some of the evaluations performed.

The tests of the focusing field show that the uniform field becomes quite distorted once the image intensifier tube is in position. The tube specifications are met under these distorted conditions, but it is felt that better performance (resolution and screen distortion) could be obtained by designing the focusing coil to compensate for the distorted field. The amount of improvement possible is not known but future designs might take this into consideration.

The phosphor decay was evaluated by imaging a pulsed LED on the tube photocathode. It is felt that this test might relate fairly directly to the decay time one could expect on a gated two-stage tube with P-11 phosphors or with nongated tube with a mechanical shutter in front of the tube. Thus, for 1.0 microsecond exposure time, a decay time at around 1.0 microsecond could be expected, and camera framing rates up to 500 frames per second could be used, as far as not smearing the adjacent frame is concerned. The tube used in this evaluation, however, is not a gated tube and thus one might expect the decay time to be closer to that obtained for continuous operation (5 microseconds). Considering a 5 microsecond decay time and a 1.0 microsecond exposure time a frame rate of over 160 frames per second could be used.

One complicating factor is that the tests were obtained in the LED target in a stationary position. Any real target will not be stationary in the field. A target moving in the field, realistically, might be more like a pulsed target than one applied constantly at one given point. In any event, at the maximum framing rates of the framing camera used for these tests (80 frames per second), phosphor decay time was not a problem even though the tube was not gated.

The system irradiance gain, 50 to 100 times, relates directly to improved performance over a telescope system without image intensification. With gains this great, higher frame rates and spectral filtering to obtain better contrast and detection are possible.

The resolution and the granularity of the image intensifier system degrade the total telescope system performance and are related to information and signal/noise characteristics of the system. The telescope resolution might be degraded by about 30 percent by adding an image intensifier system. The system granularity would be increased by 50 percent on medium grain film and 25 percent on coarse grain films, with the addition of an image intensifier. It is not within the scope of this report to relate these performance degradations to measurement capability.

The distortion measured on the image intensifier system output can be directly related to attitude measurement capability. The distortion characteristics of this system would rotate a missile image proportionately as the missile were displaced from the center of the field. Figure 18 shows the expected error in attitude measurement at increasing radial distance from the center of the tube. Note that this error depends on the "attitude" of the missile in the field, as well as its radial distance. "Attitude" in this case means the angle relationship of the missile orientation with a radial line drawn through the center of the field to the missile image. Figure 18 is calculated for a 1mm missile image and is an average for a given radial distance irrespective of orientation on the tube.

Figure 19 shows how location on the tube creates a different effect from the average information above. Figure 19 is for the 60 degrees "attitude" case, but it takes into account the differences in distortion around the tube. The contour lines show expected measurement error at all points on the tube surface for the 60 degrees "attitude" case. In any event, whether the average information or the exact contour information is used, they both are constant with time and could be removed in data reduction, thus removing image intensifier distortion as a major source of measurement error.

CONCLUSIONS AND RECOMMENDATIONS

Although the initial goals of the Image Intensifier Evaluation Project have not all been completely accomplished, due primarily to not being able to continue the field testing, much has been accomplished. The system evaluated has adequate gain to allow for full use of maximum framing rates for current and proposed cameras on telescopes with focal lengths of 180 to 700 inches (f/40). There is adequate light gain to allow for better use of spectral filtering to improve the data record.

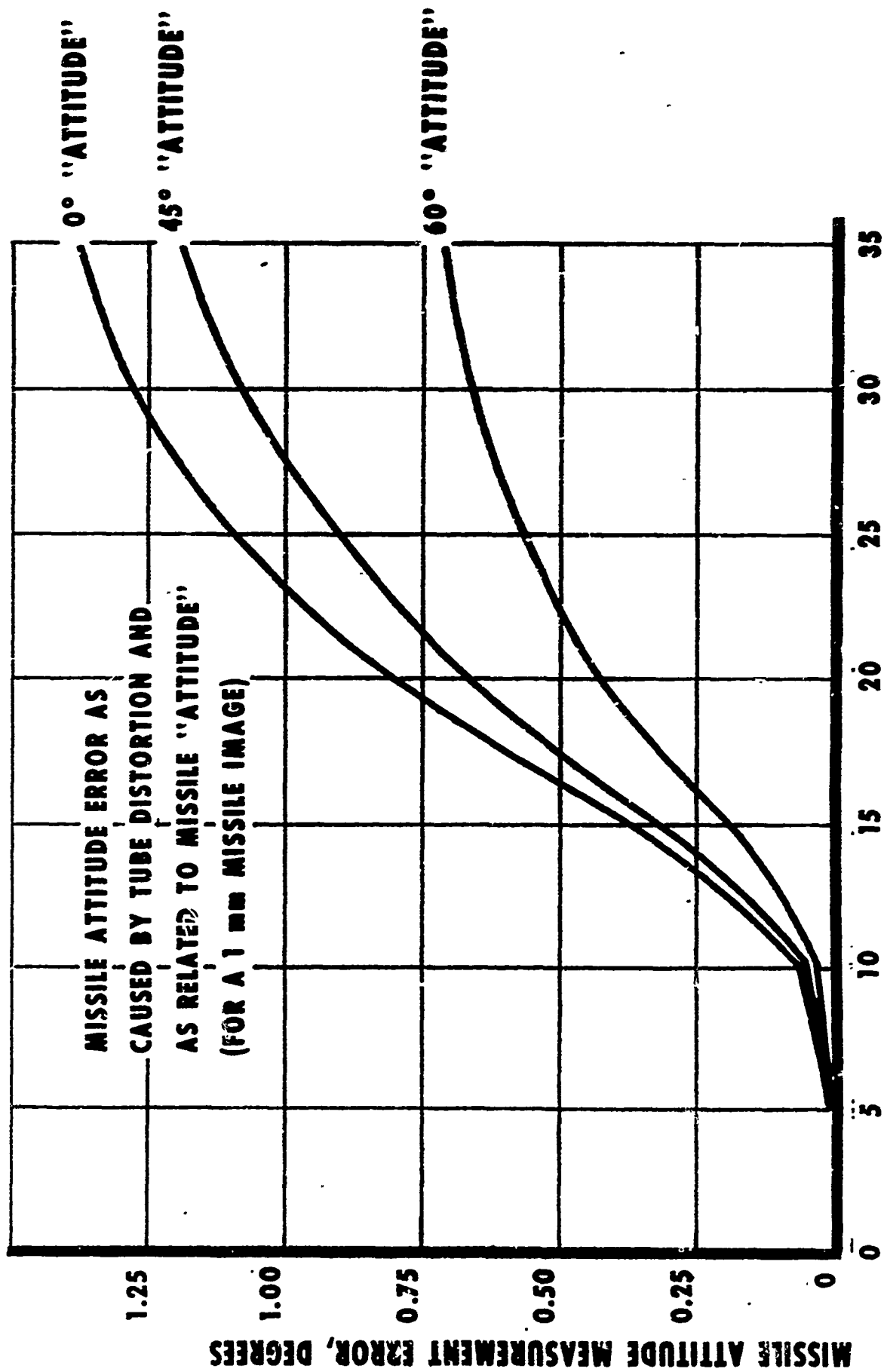
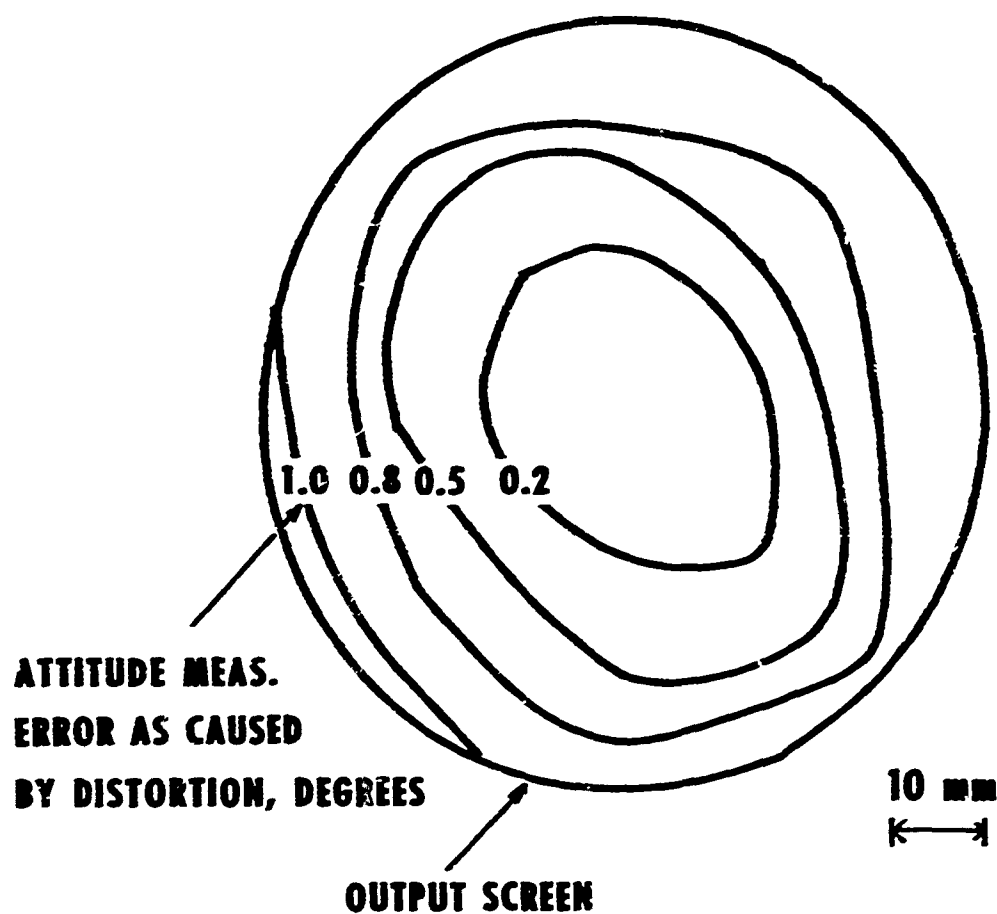


FIGURE 18



**MISSILE ATTITUDE MEASUREMENT ERROR
AS RELATED TO POSITION ON THE TUBE
SCREEN (FOR A 1 mm IMAGE AT 60° "ATTITUDE")**

FIGURE 19

Considering the atmospheric "seeing" limitations, the degradation of resolution contributed by the image intensifier system is probably acceptable and surely can be improved upon. The granularity added by the image intensifier system is an important degradation when considering using fine or medium grain film, but decreases substantially for coarse grain films.

Distortions in the type of image intensifier evaluated are small and will be insignificant for many uses. Further, they are constant with time and can be accounted for in data reduction, thus reducing their contribution to measurement errors to near zero.

Preliminary field testing showed capability of this type of system to provide data on missions (about 10 missile missions) from launch to impact some 25 miles up range. The field tests also brought out many problems, the most important being the capability to adequately focus the system for a given mission. During the preliminary field tests, the automatic refocus capability of the GORID telescope was not operating. This was to be corrected for the field testing that was cancelled. The capability to view the input image to the image intensifier for better focusing was also to be added. Other operational changes were also being made.

Recommendations for further effort include the following:

1. Provide a better performing relay lens, even with the loss of some gain. The lens system used was fast, but it is felt that the degradation to resolution (particularly on the edge of the field of view) and distortion can be improved upon.
2. Improve the focusing capability under operational conditions.
3. Evaluate a gated image intensifier for phosphor decay characteristics plus further evaluate the decay characteristics for a stationary and nonstationary target.
4. Finally, install a system in the field to provide comparative data on missions that are covered by conventional optical systems.