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IMAGE DISSECTOR PHOTOCATHODE SOLAR DAMAGE TEST PROGRAM

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Prepared By

Lockheed Electronics Company, Inc.
Systems and Services Division
Houston, Texas

Contract NAS 9-15200

For

CONTROL SYSTEMS DEVELOPMENT DIVISION

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

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IMAGE DISSECTOR PHOTOCATHODE SOLAR DAMAGE TEST PROGRAM

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1. SUMMARY

Designers of space oriented star trackers and scanners using image dissector tubes have generally used a mechanical sun shutter device to protect the sensor photocathode from damage when direct exposure to solar radiation is encountered. The protective device is normally an electromechanical unit which is controlled by a remote bright object sensor. The unit is probably the only mechanical moving portion of a system and is a major potential contributor to failure from shock, vibration and extreme temperature/humidity exposures. Image dissector sensors of the same type which will be used in the NASA Shuttle Star Tracker were used in a series of tests directed towards obtaining solar radiation/time damage criteria. Data was evaluated to determine the predicted level of operability of the Star Tracker if tube damage became a reality. During the test series a technique for reducing the solar damage effect was conceived and verified. This report outlines the damage concepts and presents test methods and data obtained which were used for verification of the technique's feasibility. The ability to operate an image dissector sensor with the solar image focussed on the photocathode by a fast optical lens under certain conditions is feasible and the elimination of a mechanical protection device is possible.

2. INTRODUCTION

The engineers who design space-oriented star tracking and scanning equipment which use image dissector sensors have traditionally included mechanical shutter devices to protect the sensor photocathodes in the event of solar exposure during operation. This design philosophy has been prompted by buyers and users of these devices who, in their specifications, require that the protective devices be included.

This leaves the designer no alternative but to supply the shutter contrivances or risk the possibility of being considered technically non-responsive in his proposals. The entire process has been further strengthened by tube manufacturers who indicate operating limits for their product in the "safe" region, thereby making it extremely difficult for both designers and users not to consider using the protective mechanisms. A lack of test data to show possible safe operation without special protection devices has made consideration of their non-use out of the question and too risky considering the cost and failure penalties which might result. In defense of the use of solar protection in most devices, it is the obligation of the author to point out that under some types of operation the image dissector photocathodes <u>will</u> be damaged by solar radiation. This premature warning is not intended to lessen the servicability of the technique to be described but to point out that it is not a complete panacea to all future designs and that as in everything worldly, operational caution and good engineering practices must prevail.

In order to provide a realistic baseline for this work it was decided to develop the protective technique around the NASA Shuttle Star Tracker System operational characteristics and physical layout. This arrangement offers a designated sensor type optical configuration and an operational plan which presents a distinct set of rules to follow.

3. DISCUSSION

The NASA Shuttle Orbiter will have two star trackers aboard for use in its orbital navigation system. The operational electrical, and mechanical parameters of these devices provide an excellent configuration baseline for evaluating the results of the data taken from the photo damage experiments to be described.

The prime objective of this test program was to define parameters of photocathode damage from solar exposure and secondarily to test a technique for using the Shuttle Orbiter Star Tracker without depending upon a mechanical sun shutter protection device.

3.1 THE SHUTTLE ORBITER STAR TRACKER

The NASA Shuttle Orbiter will have two star trackers aboard for use in its orbital navigation system (figure 3-1). These use an image dissector (S20 photocathode) for their primary target sensor. The optical system is scaled to permit a full field of ten degrees and the aperture is large enough to allow acquisitions and tracking through a target brightness range of +3 to -7 visual magnitude. This equates to an objective diameter of 33mm with a 56mm focal length (f no. 1.67). A light shade and mechanical shutter have been included in the design for protection of the tube faceplate from direct and scattered solar energy impingement. A bright object sensor remotely mounted on the front of the lightshade serves as a control element for the mechanical shutter vane motor. When activated by solar energy or excessively bright light horizon levels, it signals the electromechanical driving device to close the shutter vanes in the optical path to prevent damage to the tube photocathode. This device is the only mechanical moving portion of the Star Tracker and is a major potential contributor to decreased reliability of the unit. Elimination of the sun-shutter and bright object sensor would significantly increase operational reliability of the Star Tracker while

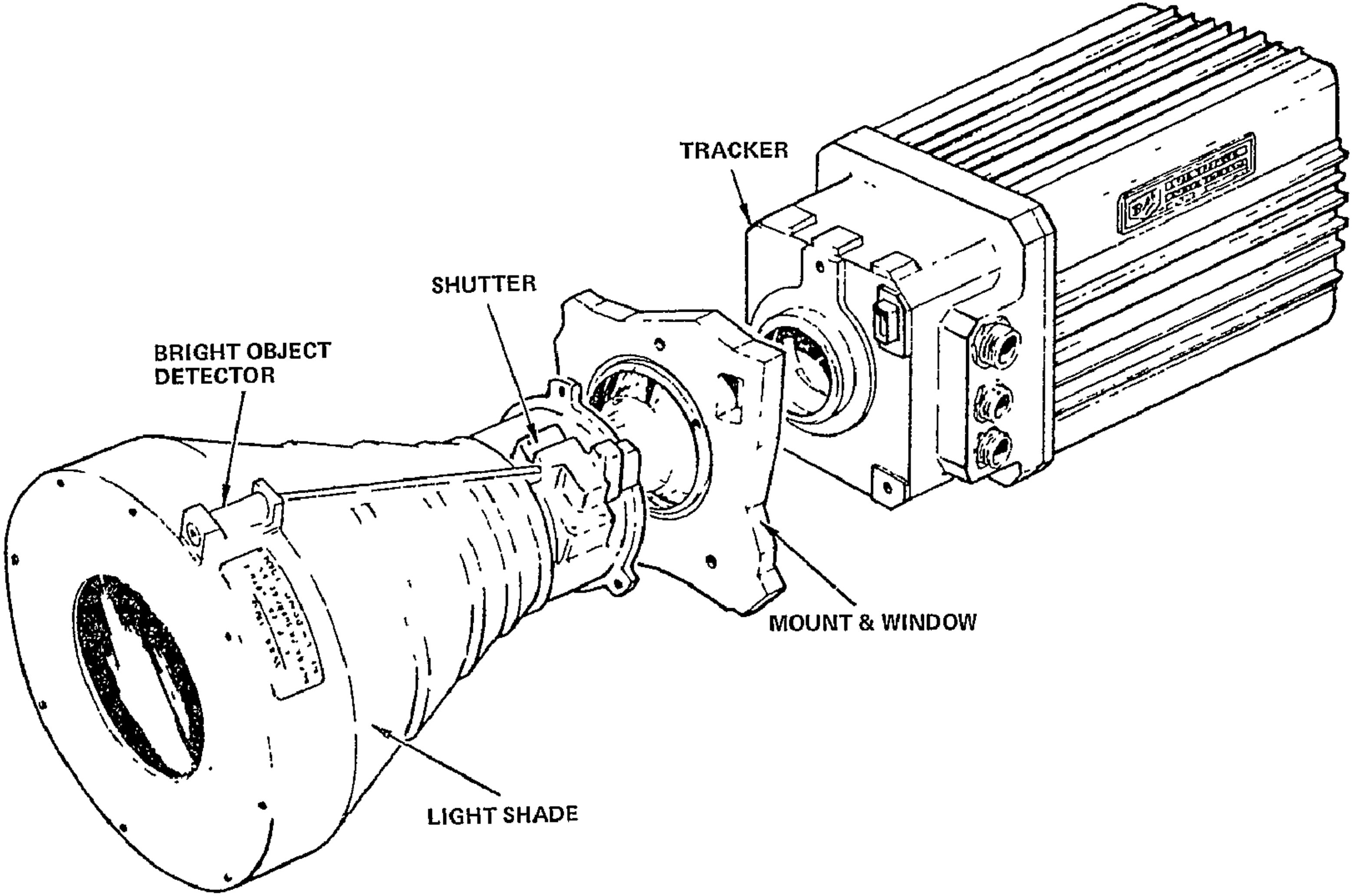

Figure 3-1.— Star Tracker/light shade physical configuration.

reducing its power requirements, weight, and production cost. The design and production of the Shuttle Star Tracker was possible because of the availability of an image dissector tube. This unique and versatile device has been proven to be very effective when used as a primary electro-optical sensor in star target acquisition and tracking units that do not use mechanical elements for target position sensing.

3.2 THE IMAGE DISSECTOR TUBE

An image dissector tube is a type of photomultiplier device in which the sensitive area can be sampled in an elemental fashion using electronic/magnetic scanning techniques. The tube has as its basic components a photocathode, an aperture plate, and an electron multipler. A typical image dissector is illustrated in figure 3-2. Exitation of the photocathode by optical radiation causes photo-electrons to be emitted in proportion to the level and spectral content of the flux applied. The electrons are then accelerated away from the cathode by a positive potential and pass through the mesh screen holes into a unipotential drift space. While in this volume, a magnetic focus (or electrostatic, depending upon the tube type) field is applied, so that the electrons move through a spiral path to arrive at the aperture plate with the same spatial relationship as the optical image on the photocathode. By this process the optical image has been changed into an electron image and transferred in space to the single plane aperture plate within the tube. At the center of the aperture plate, there is a small hole which will admit electrons from the transposed area of the photocathode. The size and shape of this aperture hole is chosen to satisfy the sampling technique and provide the resolution required.

In order to properly generate scan sequences for acquisition and tracking raster operation, it is necessary to apply transverse deflection fields in the drift space. These cause the complete

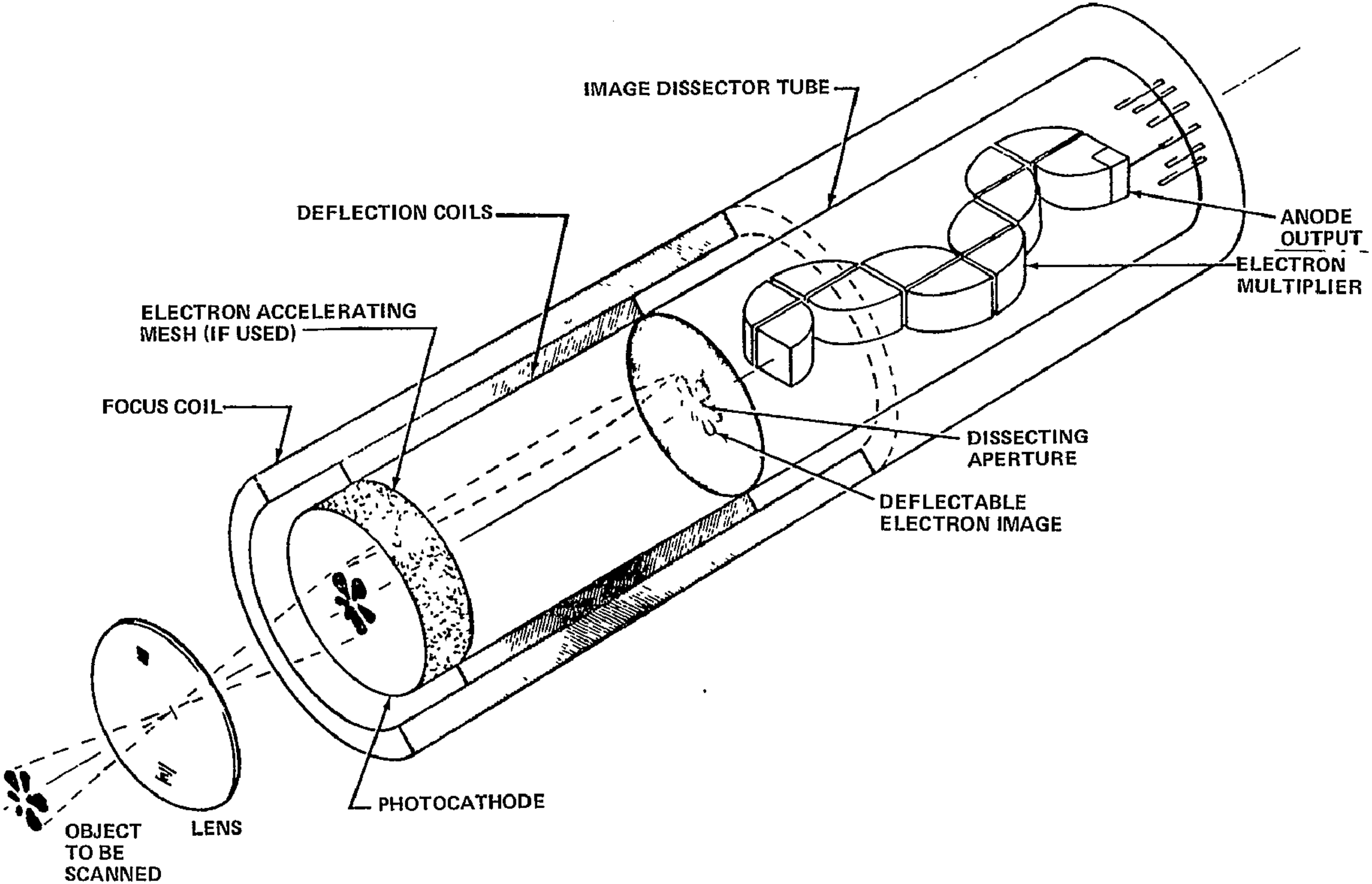

Figure 3-2.– Operating principle of an image dissector.

electron spatial image to shift orthogonally to the field direction, and as this electron image passes over the aperture, the tube signal output varies directly with the image intensity changes.

As with all other types of photoelectronic imaging tubes, the image dissector employs a photoemissive layer, or photocathode for photon/electron conversions. The surface largely determines the spectral range and detectivity of the sensor.

The electron multiplier and final output anode portions of the image dissector tube are equally important to its operation, and in general, they perform in the same manner as a standard photomultiplier tube. The electrons passing through the aperture hole have their current level amplified by dynode to dynode action to provide a detectable signal current flow at the final anode output.

3.3 PHOTOCATHODE DAMAGE CRITERIA

A recent report on image dissector tube photocathode damage and resultant shortened life parameters has produced information which indicates that the probable major cause of photocathode deterioration is caused by ion impact upon photomaterial surfaces. The damaging ions are formed by the photo-electron flow through the tube drift volume. The amount of ions produced is dependent upon the quantity of electrons flowing and their transit velocities. Resulting photocathode damage is proportional to the number of ions formed which eventually migrate to the photocathode and strike the material layer. In effect, if very high flux levels are introduced the resulting ion population could reduce the photocathode sensitivity within a very short time. The reduction would be general over the entire photomaterial area and most probably no "burns" would be visible. The process is irreversible and would reduce the device sensitivity to a useless state. Another type of damage can result from exposing the tube to high external temperatures either in an operating or nonoperating condition. This method of damage can be controlled by proper operational use and storage practices.

A third method of damage would result from imaging a high intensity energy source (such as the sun) on the photocathode resulting in a very high photon density over a small area. This is the type of damage which will primarily be addressed in this report.

3.4 A PROPOSED DAMAGE PREVENTING TECHNIQUE

A technique for operating the NASA Shuttle Star Tracker without a sun shutter was investigated by evaluating potential damage parameters and the Star Tracker image dissector/optical system. The Star Tracker uses an f 1.67 optical lens in conjunction with a light shade and a protective quartz window in front of the objective surface. The tube selected for the sensor is an ITT type 4012 with an S20 photocathode spectral response.

During normal operation the unit will be exposed to varying light flux levels from a $+3M_V$ star to $-7M_V$ point source targets. The flux density anticipated from the brightest target ($-7M_V$) is not considered to be harmful to the sensor operation; therefore, no protection is required up to this level. It is from the $-7M_V$ level to a brighter state that protection was deemed necessary. Hence, the mechanical sun shutter and bright object sensor were required in the original specification.

In order to protect the sensor from exposure to damaging levels of light, the following <u>must</u> be done:

a. Ionization of gas molecules by photoelectrons must be prevented.

b. Anode current must be limited or eliminated.

c. Flux density levels at the photocathode must be limited to a point where physical deterioration does not occur.

These requirements can be met without using the classical sun shutter by:

a. Removing or lowering tube voltages

b. Limiting energy flux by filtration in the optical path.

It is obvious that these two methods can save the sensor from damage, but each has its penalty which may or may not be too severe, depending upon operational requirements.

Turning off the tube voltages will prevent any operation during high flux exposures, and this is a feasible means of protection since acquisition and tracking of dimmer targets would not be possible under the high background conditions present. The voltages can be turned off by a remote bright object sensor or by sensing the tube photocathode current levels. Both methods are satisfactory as long as a sensing capability remains which can turn the sensor back on when the damaging energy is removed. The bright object sensor design does this directly; however, the image dissector tube can control itself if we adopt the approach that follows:

As previously discussed, high flux on the photocathode causes large numbers of photoelectrons to be emitted which, due to a typical 400 volt accelerating potential between the tube target and photocathode causes electron bombardment of gas molecules within the tube, subsequently creating photocathode damaging ions. This process is always present, even when the image dissector tube is sensing $+3M_V$ to $-7M_V$ targets; however, the massive quantity of ions formed from a very high flux greatly accelerates the damage rate and therefore should be avoided. The unique trick is to reduce the image section voltage from

400 volts to less than 10 volts when commanded by photocathode current sensing circuitry as flux levels reach the danger level (brighter than $-7M_V$). At this lower voltage, <u>no</u> ions will be formed, regardless of the photoelectron density, but the tube is still "seeing" incoming energy and the photocathode current sensing circuit will be able to signal a return to normal voltage operation when the bright source is gone. Hence, the tube serves as its own bright object sensor without risking damage by failure of another remote sensor. Of course, the removal of anode voltages is congruous with the sensing commands, so the second protection requirement is also fulfilled.

The third requirement of lowering the flux level to a safe heating level is more complex and requires special consideration in the optical design of the device. The amount of photocathode area flux density will be a function of optical aperture size, focal length, and energy transmission of the optical elements. Spectral purity and total bandpass may also have a significant effect. Each design must be evaluated and in the event of inability to create a workable optical system, the builder/designer would probably have to return to the mechanical sun shutter and live with its inherent low reliability, excessive weight and power, and high cost characteristics.

After conception of the technique a search was made for an optical filter which could replace the original quartz window. This filter must reduce the solar energy as much as possible and provide a minimal reduction in star target sensitivity. For example a Schott KG-1 glass filter will stop approximately 61% of the solar energy while at the same time only 22% attenuation to the S20 spectral region is encountered (figure 3-3). Another likely candidate is the Corion Instrumentation Corporation HP-90 dielectric filter which reflects 56% of the solar energy while passing an average of 78% in the S20 spectral area (figure 3-4). Probably a more comprehensive search or fabrication of a special

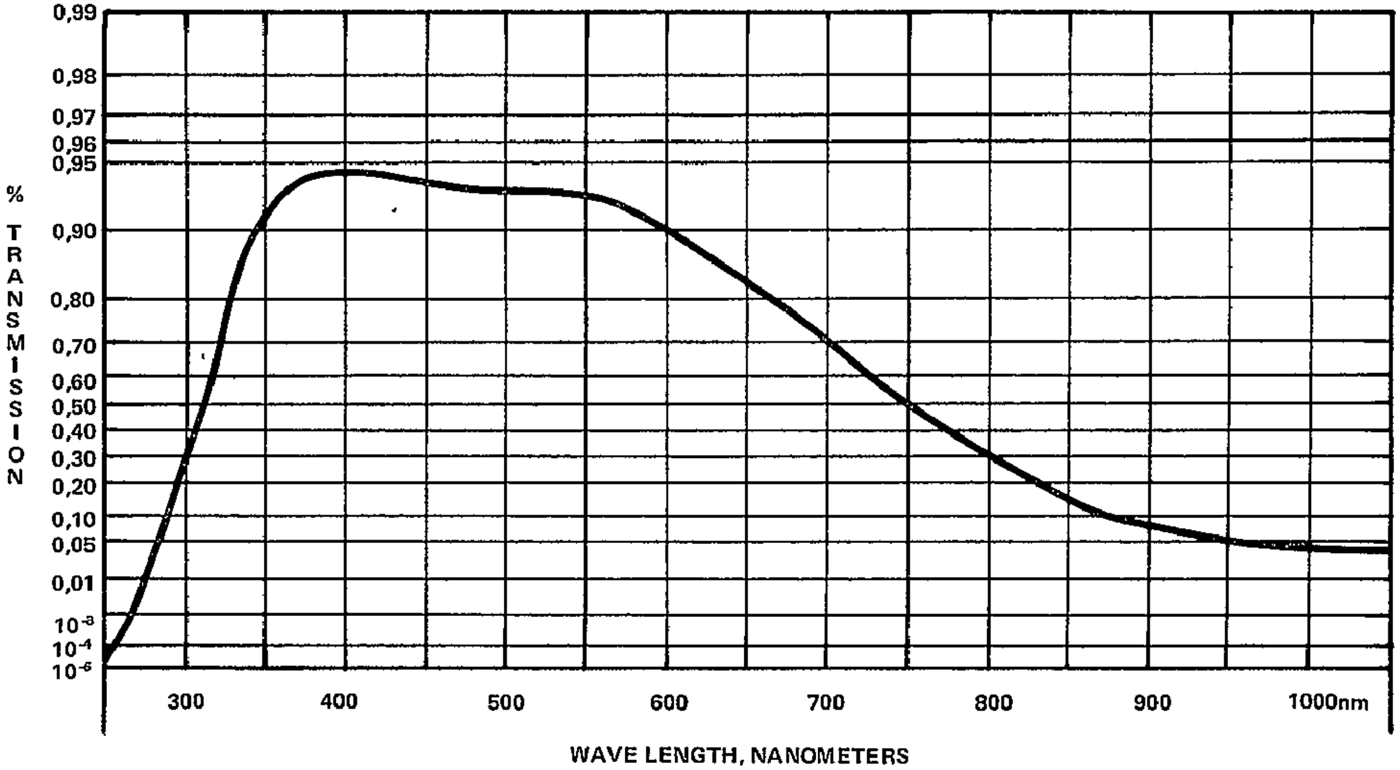

Figure 3-3.— Schott KG-1 heat absorbing glass filter- spectral response.

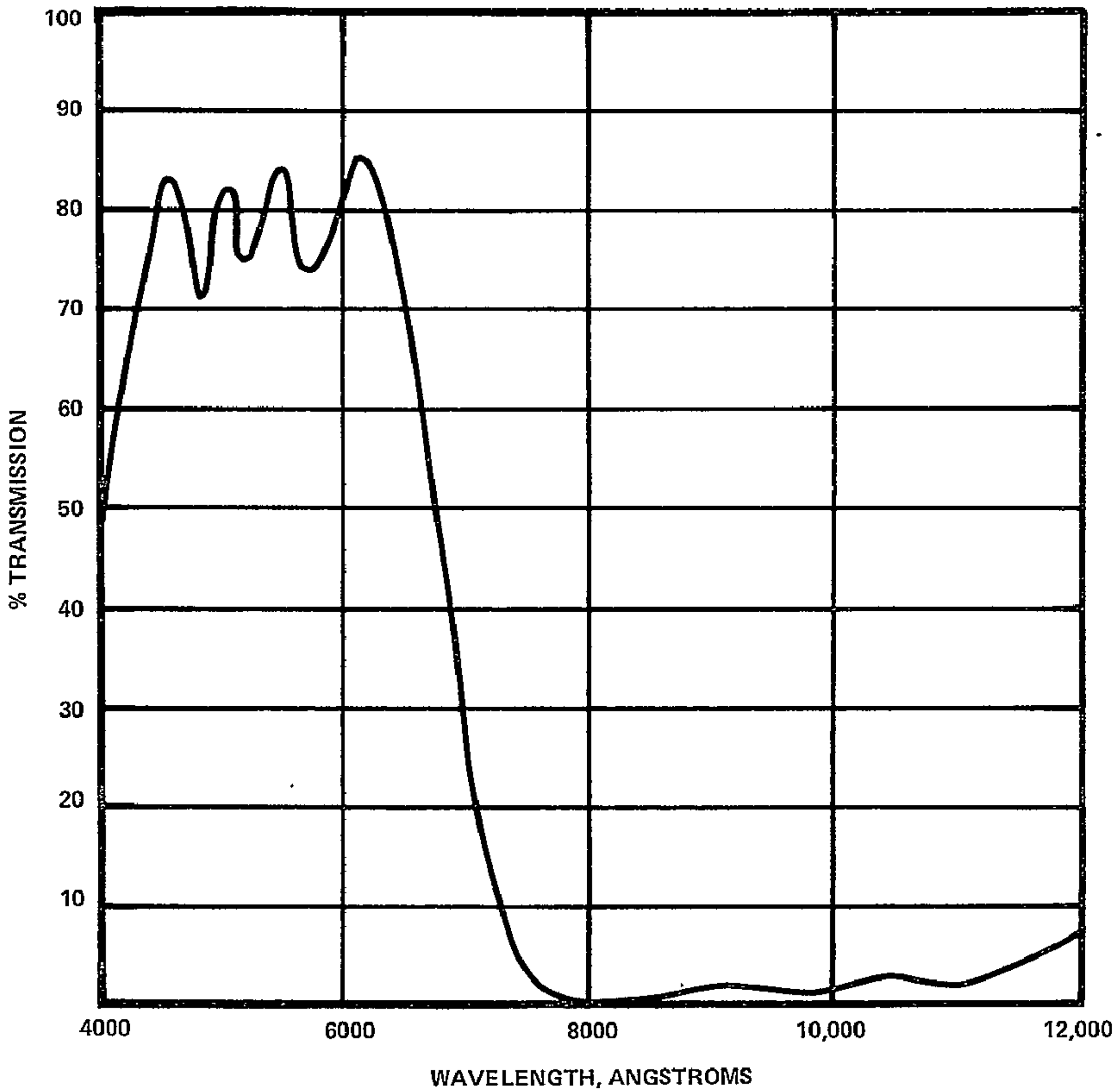

Figure 3-4.— Corion HP-90 dielectric filter-spectral response.

unit might provide even better characteristics although either of these mentioned seemed satisfactory in evaluation of the technique. The reduction of Star Tracker sensitivity would still allow a dim target of $+2.7M_V$ to be acquired.

4. TEST PLAN AND PROCEDURES

In order to evaluate the proposed technique and determine the feasibility of using it with the NASA Shuttle Orbiter Star Tracker and other subsequent designs, a series of tests directed towards production of base data of image dissector photocathode damage from solar energy was generated. To develop a systematic plan the tests were divided into two phases of effort.

Phase I - Photocathode exposure to full faceplate and focussed spot energy to determine a damage level.

Phase II - Verification of the proposed operating technique.

The entire effort of Phase I of the program was devoted to systematically exposing the photocathode of the subject tubes to varying exposure levels to determine when, and at what level, photocathode changes would take place.

Phase II was then undertaken to determine if the protective technique would be effective in changing or eliminating the damage point.

4.1 TEST OBJECTIVE

The primary objective was to determine the tube damage point in units of measurement which could be related to operative target performance and solar or bright light flux levels. Every effort was made to structure the test procedures towards providing a damage point defined in photocurrent/cm^2/second. This can also be expressed as Joules/cm^2 for those who prefer the latter terms.

4.2 TEST CONTROLS

In the early test planning stages no data was available which would indicate a base point in the photocathode exposure process where damage might occur. Questions arose as to what constituted true damage and where during the testing could one determine that hard tube damage or reduced sensitivity would occur. In view of this it was decided to check tube sensitivity as often as possible during the test program. Tube photocathodes were checked thoroughly before the program began and very closely monitored during the test period in an effort to determine any sign of deterioration.

4.2.1 TUBE SENSITIVITY MEASUREMENT TECHNIQUE

In order to evaluate tube parameters during the test program, a method of checking the image dissectors tube's photocathode relative sensitivity was conceived which would readily permit observation of any degradation from the original base value. This method is adequate if satisfactory repeatibility of measurement can be achieved. Rigid control of optical and geometrical setup, source color temperature, flux density, and current recording instrumentation were used throughout the testing period. This permitted all subsequent measurements to be referenced back to the beginning base point.

In addition to measurement of tube sensitivity at specific source color temperatures, it was considered useful to determine if any observed damage would be spectrally related. The tube manufacturer usually tests the photocathodes with white light (2870°K color temperature) and in the red and blue spectrums using the same white light source through Corning 2418 (red) and 5113 (blue) glass filters (figure 4-1). This technique was adopted for use in the test program for later phases of evaluation.

4.2.1.1 Test Equipment

A Photo Research Model 2396 Luminance Standard was used to provide the flux level and color temperature stability needs for the sensitivity tests. This instrument is an aboslute brightness source calibrated in foot lamberts at two color temperatures of

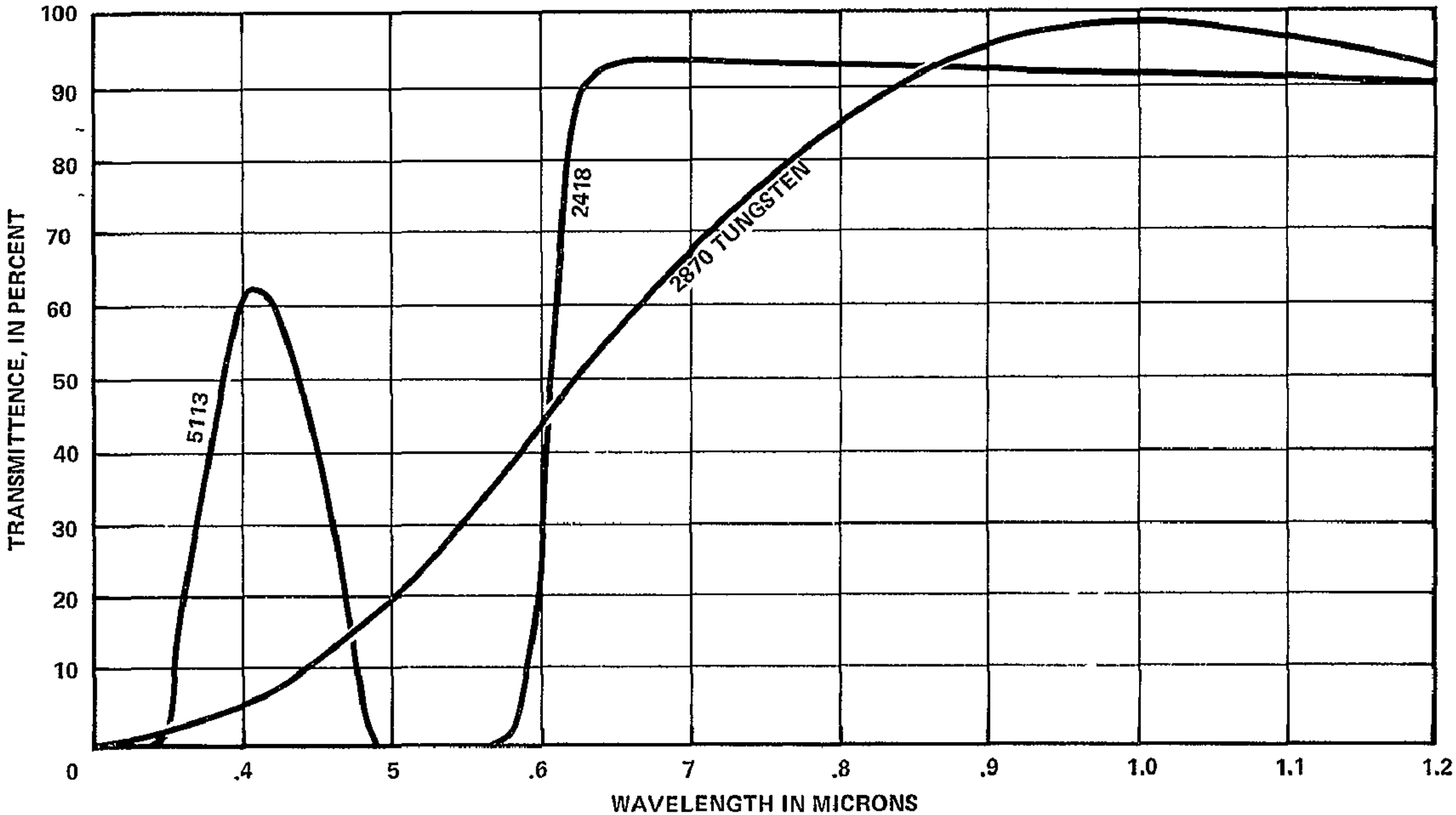

Figure 4-1.— Sensitivity measurement filters.

2854°K and 5500°K. Repeatability of measurement is obtained by carefully adjusting the light source voltage to a designated value.

Measurement of the image dissector photocathode current was accomplished with a Hewlett Packard Model 425A Microammeter connected in series with the test tube photocathode/drift tube aperture plate and a battery power source. The source lamp voltage was measured with a Hewlett Packard Digital Voltmeter. Lamp voltage was maintained to an accuracy of ±one millivolt.

4.2.1.2 Sensitivity Measurement Setup and Test Procedure

A specific setup was conceived which followed the guidelines outlines in section 4.2.1 and was successfully used during the test program.

The test image dissector tubes were mounted into specially constructed holders which would permit their installation on a laboratory optical bench to insure positioning repeatibility in the flux path of the light source. Likewise, the photometric source was mounted onto another optical bench placed at right angles to the tube support and adjusted to permit full flux illumination of the tube photocathode. Index marks of the source and tube positions were recorded and repeated for all subsequent tests (figure 4-2).

The flux source was connected to a regulated power supply and the HP Digital Voltmeter used to read the source lamp voltage.

The image dissector tube was wired as shown in figure 4-3 with the HP425A used in a current measuring mode. A nine volt dry battery was connected to provide photocathode/target potential of less than ten volts to insure that no ions would be formed in the drift space. The red and blue glass filters were placed

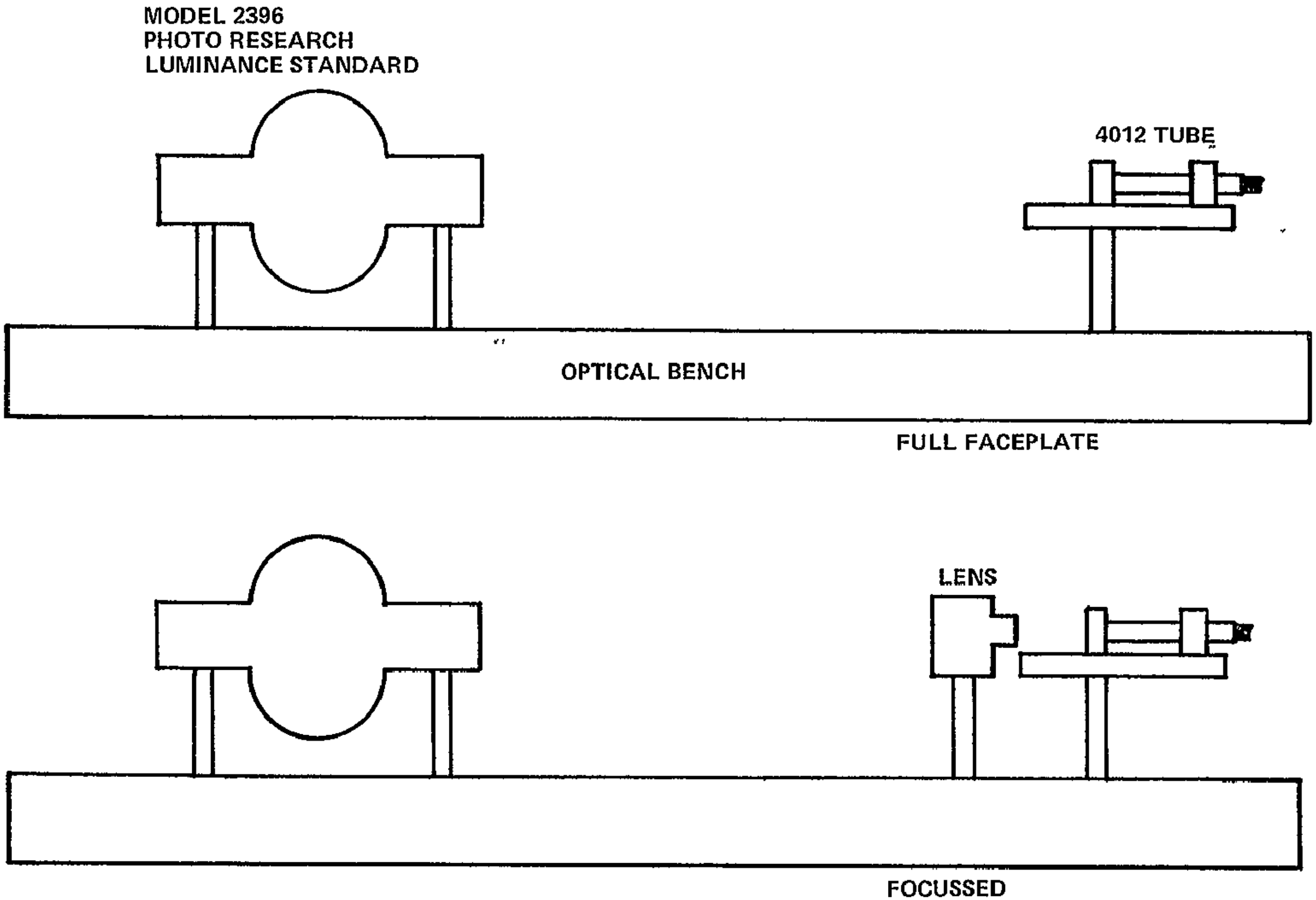

Figure 4-2.— Sensitivity check.

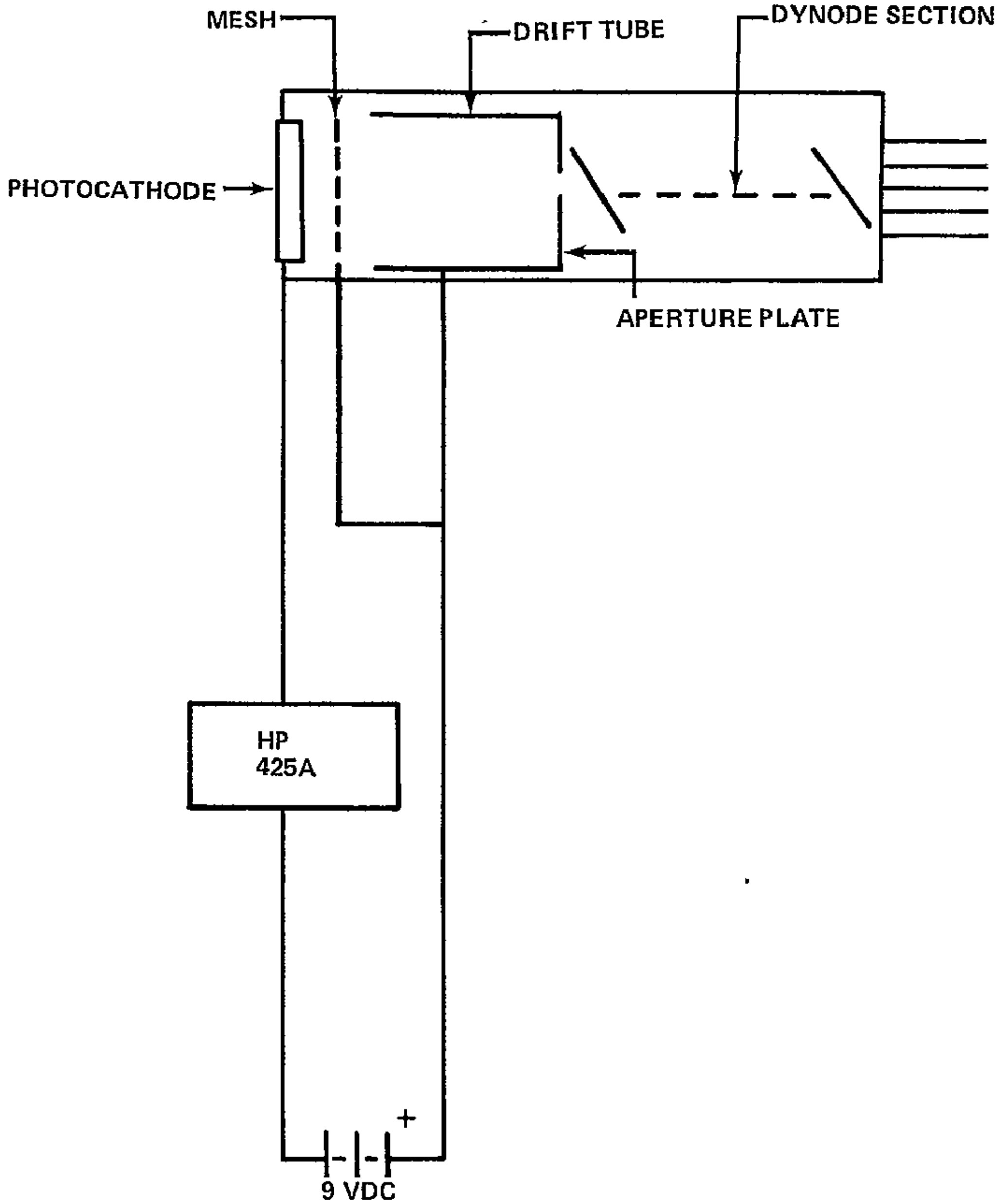

Figure 4-3.— Image dissector test circuit.

on the source as required and color temperature was changed when needed.

The following procedure was used for each case of setup and sensitivity measurement.

a. Position image dissector tube
   (Check index mark)

b. Position flux source
   (Check index mark)

c. Adjust flux micrometer setting and bulb current (repeat settings)

d. Insert filter (as required)

e. Read photocathode current

Of course, all readings of photocathode currents were taken in a totally dark environment. The distance of the source to the photocathode faceplate was adjusted and set during the first setup to insure that photocathode current was not in the HP noise level and result in possible erroneous readings.

Where later tests were made using lenses in front of the dissector faceplate, sensitivity tests were made with the lens in place and the flux source focussed on the photocathode. Although this method did not expose the total tube faceplate, the image of the flux source was much larger in area than the subsequent energy exposure and, therefore, insured that any exposed area would have a "before and after" sensitivity verification.

4.2.2 TUBE HIGH ENERGY EXPOSURE TECHNIQUE

One of the most difficult problems associated with the test program was the locating of a laboratory light source with color temperature and energy output levels adequate to produce a believable test solar source. One requirement, considered mandatory for success of the experiment, was the need for the color temperature and spectral output of the device to be similar to that of the sun. Using the sun itself as a source meets with some difficulty due to atmospheric attenuation and spectral shaping of the energy before it arrives at the earth's surface.

For practical purposes the sun can be considered as a 5800°K black body source with a peak radiation point of 500 nanometers and effective radiation extending from 250 to 3900 nanometers. This covers approximately 99% of the total amount of energy emitted. When viewing the sun from the earth surface this amount is lessened by the atmosphere attenuation and spectral shaping. However, the total radiation is not greatly diminished and under some clear weather conditions solar energy at the earth's surface may only be attenuated from 5 to 20 per cent. The greatest energy loss is in the ultra-violet region where atmosphere will reduce the lower wavelength response between 250 and 320 nanometers.

4.2.2.1 Laboratory Solar Simulator

The obvious choice for a laboratory sun simulator was a system using a high pressure xenon short-arc illuminator. A commercial unit, Eimac/Varian VL-150-2 Xenon Short-Arc Illuminator System, was available and offered characteristics of color temperature, energy level output, and adaptability which met the test requirements. The heart of the system is a xenon illuminator type 150XBS, which provides high-intensity visible, ultraviolet, and infrared radiations closely approximating the spectral distribution of the sun (figure 3-4). It has a synthetic sapphire window featuring spectral transmission from 180 to 5000 nanometers. The beam angle, nominal ten percent points, is eight degrees thereby offering a nearly uniform illumination to the image dissector faceplace when placed near the source.

4.2.2.2 Solar Simulator Intensity Measurement

Another very important measurement required for the program was the power level at the image dissector faceplate or the lens front surface produced by the solar simulator. A Hewlett Packard Radiant Flux Meter, Model 8330A, with a Model 8334-A Radiant Flux Detector was used to make accurate flux measurements.

The instrument is capable of measuring irradiance from 3 w/cm^2 to 100 mw/cm^2 in overlapping ranges. The detector is a multi-junction, thin film thermopile exhibiting a flat broadband spectral response. When the instrument is used to measure irradiance from a source with a color temperature approximating that of the sun, the resulting value is reasonably comparable to solar illumination at the earth's surface. The popular value of 0.135 $watts/cm^2$ was used as a one solar constant reference point.

4.3 GENERAL TEST PROCEDURE

The testing of the dissector tubes followed a specific pattern of operations.

a. Sensitivity Measurement

b. Exposure to a bright source for a specific time and intensity

c. Sensitivity Measurement

d. Exposure continues

e. Recheck sensitivity

This cycle continued until a tube showed lowered sensitivity and/or appearance damage. Exposure times and intensity were increased for each test in a controlled and cautious manner. Data taken included intensity levels and time of exposure. As the Phase I test series progressed, the procedure changed use of a focussed spot exposure as a means of further increasing the area density exposures. Finally, if a tube was damaged, the tests were continued on other areas of the photocathode in an attempt to refine the data.

Both laboratory and outdoor field tests were completed during the series. Phase II was begun after the damage point was finally reached. For purposes of clarity to the reader, the Phase II tests will be discussed later in the report. Various test modifications will be described as they evolve in the test result narrative.

4.4 TEST RESULTS

Tests were conducted on six image dissector tubes which were loaned by the ITT Electro-Optical Products Division-Tube and Sensor Laboratories, Fort Wayne, Indiana for the program. The units were serialized and a log of useage and damage was kept.

Phase I tests were begun at NASA/JSC in January 1976 and continued until May 1977.

4.4.1 TEST DATA-TUBE #17306

Since no information was available on results to be expected from high intensity exposure, the first test series using tube #17306 exposed the photocathode to a full faceplate illumination level of one solar constant from the Xenon source (see figure 4-4). The setup was completed, tube and source indexed, and the source level set to provide one solar constant at the tube faceplate. Prior to the test the tube had undergone a reference sensitivity test which resulted in a photocurrent of 2.8×10^{-8} A which came from illumination by the standard source. A 5500°K color temperature was used.

The tube was exposed continuously at one solar constant and the photocathode current carefully monitored. Table 4-1 records the test data.

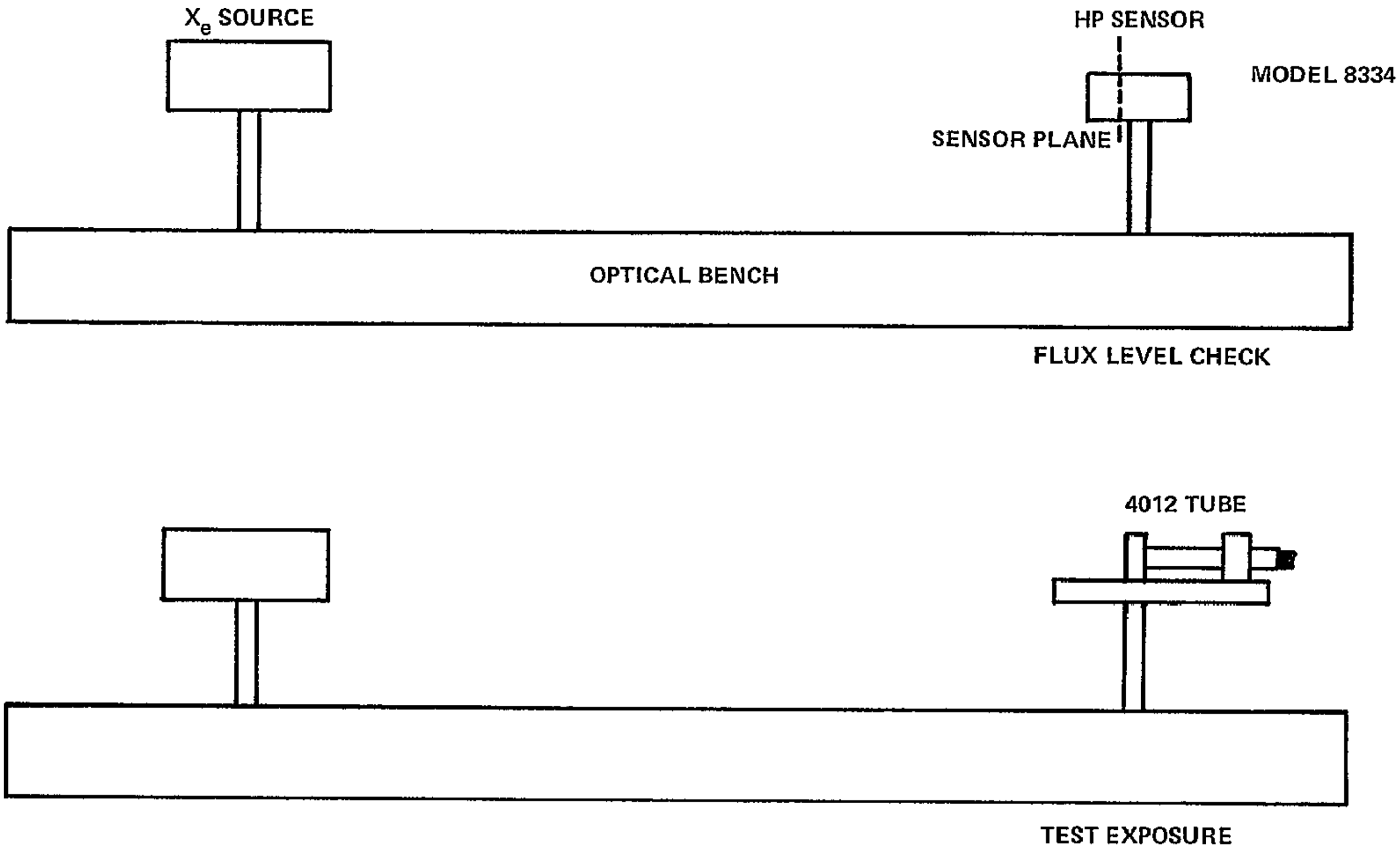

Figure 4-4.— Full faceplate illumination test.

TABLE 4-1.– FULL FACEPLATE EXPOSURE TEST – TUBE #17306

Time	Energy Level	Photocurrent
0	1 SC	2.275×10^{-3}A
15 Min.	1 SC	2.3×10^{-3}A
30 Min.	1 Sc	2.275×10^{-3}A
45 Min.	1 SC	2.275×10^{-3}A
60 Min.	1 SC	2.275×10^{-3}A
70 Min.	1 SC	2.275×10^{-3}A

Test stopped at 70 min.

Beginning sensitivity 2.8×10^{-8}A (white light - 5500°K)
Ending sensitivity 2.8×10^{-8}A (white light - 5500°K)

After the tube had survived one solar constant full faceplate exposure for over an hour without any signs of deterioration it was obvious that something had to be done to increase the energy density/unit area on the photocathode before tests could continue.

The next step to provide increased unit area flux density was to include an optical lens to focus the energy into a smaller photo-cathode area. A new test setup (figure 4-5) was established using an available lens which had an effective aperture of 45 mm with a focal length of 51 mm. The test layout, source size, and lens parameters provided a focused spot size of ≈ 2 mm on the dissector faceplate. Care was taken in the procedure to insure that the focused energy was on the rear of the faceplate which contained the photoemissive material. This was done in the sensitivity check as well as the exposure tests.

The sensitivity check used the standard technique previously described and now included the lens into the energy path. The focused spot caused by the standard source was slightly larger than the ≈ 2 mm area covered by the high intensity source. Care was taken to insure that the test geometry would provide full measurement of the yet to be exposed area and that the post test measurement would check the identical area.

Since the transition from full faceplate exposure to a focused energy mode seemed to be rather drastic, it was decided to lower the intensity level at the lens objective plane. Although the initial set up and source measurement was made to provide one solar contant level at the lens, tests were started at 0.1 solar constant by inclusion of neutral density filters in the source to lens optical path.

Now the following data (Table 4-2) was obtained.

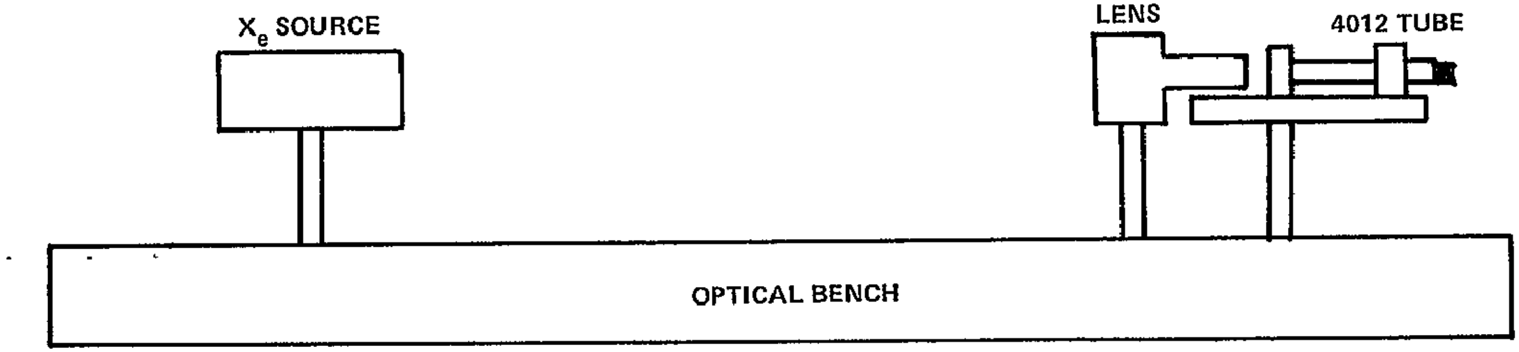

Figure 4-5.— Focussed spot test.

TABLE 4-2.— FOCUSED SPOT INTENSITY TEST — TUBE #17306

Time	Energy Level	ND	Photocurrent
0	0.1	1.0	3.2 X 10^{-4}A
1 Hr.	0.1	1.0	3.3 X 10^{-4}A
Check Sensitivity 4.9 X 10-8A			
2 Hr.	0.1	1.0	3.3 X 10^{-4}A
3 Hr.	0.1	1.0	3.4 X 10^{-4}A
Check Sensitivity 5.0 X 10^{-8}A			
4 Hr.	0.16	0.8	3.9 X 10^{-4}A
Check Sensitivity 5.0 X 10^{-8}A			
5 Hr.	0.25	0.6	4.7 X 10^{-4}A
Check Sensitivity 5.2 X 10^{-8}A			
6 Hr.	0.4	0.4	5.4 X 10^{-4}A
Check Sensitivity 5.0 X 10^{-8}A			
7 Hr.	0.63	0.2	6.4 X 10^{-4}A
Check Sensitivity 4.6 X 10^{-8}A			
8 Hr.	1.0	0	7.8 X 10^{-8}A
Check Sensitivity 4.2 X 10^{-8}A			

CHANGED TO NEW SPOT POSITION

Initial Sensitivity 4.4 X 10^{-8}A			
1 Hr.	1.0	0	7.1 X 10^{-4}A
Check Sensitivity 4.3 X 10^{-8}A			

At this point in time it became distressingly obvious that it was not possible to damage the photocathode with the available test source in the time allotted. In order to verify this conclusion and possibly to provide a last desperate attempt to create a damaged tube it was decided to do a one solar constant focused spot test for six continuous hours. This time was selected because in the Shuttle Orbiter Star Tracker specification there is a requirement for the tracker to survive six hours direct exposure (through the front) of sunlight. The tracker was to be nonoperating with the sun shutter closed.

The test setup was checked, source level verified, and sensitivity checked.

Table 4-3 shows the result of this test.

At the conclusion of the six hour exposure test, another attempt to provide damage to the tube was made by increasing the source input until 2.78 w/cm^2 (20 solar constants) was on the objective lens front surface. This test was run for one hour and at the conclusion a sensitivity check of the tube indicated a photocurrent of 4.2×10^{-7} A. During the test a photocurrent of 1.5×10^{-3}A was experienced. Since the starting sensitivity of this frightful seven hour exposure was 4.1×10^{-7}A, it can only be concluded that all attempts to damage the tube with the available source were fruitless.

4.4.2 TEST DATA-TUBE #107206

After the experience of providing such dramatic exposure to the original tube #17306, it was decided to try one more test with another tube (107206) to see if the original data was an accident and to offset the possibility that tube #17306 was not ordinary in its response.

TABLE 4-3.– SIX HOUR FOCUS SPOT TEST – TUBE #17306

Time	Energy Level	Photocurrent
0	1 SC	7.8×10^{-4}A
1 Hr.	1 SC	7.6×10^{-4}A
2 Hr.	1 SC	7.4×10^{-4}A
3 Hr.	1 SC	7.3×10^{-4}A
4 Hr.	1 SC	7.2×10^{-4}A
5 Hr.	1 SC	7.2×10^{-4}A
6 Hr.	1 SC	7.2×10^{-4}A

Sensitivity check (white light 5500°K)

Pre-test 4.1×10^{-7}A
Post-test 4.4×10^{-7}A

Again the setup was repeated as before and the source was set to provide 0.324 w/cm^2 at the lens (2.4 solar constants).

Table 4-4 shows the results.

4.5 TEST MODIFICATIONS AND PROCEDURE CHANGES

The tests outlined in 4.1 and 4.2 were productive in that they provided data which showed that the image dissector tubes could be exposed to high energy levels without apparent damage. The laboratory source and collecting lens combination did not completely simulate a solar target because the image size on the photocathode was too large. The typical 8° beam dispersion of the source coupled with the optical lens used produced an image which had approximately a sixteen times greater area than that which would be presented by a true solar disc. Hence, the flux density per unit target area could only be increased by using the sun as a target image. To meet this requirement the equipment and tubes were taken to Ball Brothers Research Corporation, Boulder, Colorado, (BBRC) to perform tests on an outdoor sun tracking pedestal facility.

For these tests, the sensitivity measurement procedure was modified by providing optical filters for measurement of the dissector tubes in the blue and red spectrum as well as with white light exposure. The filters are the same as those used by the tube vendor when he measures the photocathode sensitivity during manufacture and prior to delivery. The filters used were the Corning 5113 "Blue" and a Corning 2540 "IR" types (figure 3-4).

The purpose of using these filters was to determine if any changes in sensitivity in their respective spectral regions could be detected. Previous life tests of these type dissector tubes under other operating conditions (Ref 1) have shown that first loss of sensitivity occurs in the red portion of the response.

TABLE 4-4.— TEST DATA TUBE #107206

Time	Energy Level	Photocurrent
0	2.4 SC	9.6×10^{-3}A
1 Min.	2.4 SC	1.0×10^{-2}A
1 Hr.	2.4 SC	9.9×10^{-3}A
2 Hr.	2.4 SC	9.8×10^{-3}A
3 Hr.	2.4 SC	9.9×10^{-3}A

Sensitivity test

Pre-test 6.1×10^{-7}A
Post-test 6.0×10^{-7}A

In white light tests any small losses in the red portion may easily become masked by the remaining responses. However, in the event any burns or blemishes appear the overall tube sensitivity would be probably lowered and the changes observed spectrally would become academic information to provide fuel for further investigation.

Since the primary objective of the tests was to find the burn or blemish point, not too much credence was to be placed on the sensitivity test results due to the data obtained from the laboratory source tests. Nevertheless, data was taken and tubes sensitivity closely monitored even though blemishes were not present.

The BBRC test facility provided a stable platform for the tube fixture and permitted tracking of better than one arc minute. Solar exposures were made in a track mode and in the cases where the tube was moved to expose a new portion of the photocathode, subsequent data was taken while tracking. There was also an instrument available which provided a calibrated value of solar constant seen at the tracking platform. This value was checked with the HP Radiometer and found to be within 5% of agreement.

During the tests the arbitrary current value was recorded and, by using the BBRC calibration of current/one solar constant, it was recalculated and appears in the data tables as the percent of one solar constant.

For the BBRC tests an Angenieux f 0.95 52 mm focal length lens was used to collect the energy and focus it upon the dissector photocathode. A distinct advantage was gained by using this fast lens for the tests. Since the solar energy level at the earth's surface can never be equal to one solar constant, a test performed on the earth's surface will not produce the same effects as those which would be encountered outside the atmosphere. Therefore, to truly simulate the Star Tracker performance to be anticipated in space a method of increasing the available solar energy on the sensor photocathode must be used. The Angenieux lens provides the means to do this. Simulation is achieved by opening the aperture "f" stop to a value which increases the focused spot energy to that level which would be presented to the dissector tube by the Star Tracker lens when irradiated with one solar constant. Although not complete in spectral content and having a small difference in spot size the simulation is still considered practical and useful to the test program. Calculations were made and a table was prepared to be used in the BBRC field tests. (See appendix A.)

Testing under outdoor sunlight exposure conditions revealed a major problem not previously present in the laboratory. The weather at the test site became a dominant controlling factor. Obviously testing during overcast and heavy cloud cover was not possible. During the test period, the sun was visible with high thin clouds filtrating the sun energy and varying the ground values of energy. After several days of waiting for perfect conditions hope finally waned and it was decided to test under less than perfect conditions. This made the data somewhat erratic and difficult to interpret. However, persistence was rewarded with several runs which were productive and a pattern of consistency finally began to emerge.

4.6 TEST RESULTS

4.6.1 TEST DATA TUBE #17306, SECOND SERIES

Because this test incorporated a new technique, previously used cautionary methods were repeated and the full sun was not permitted to impinge upon the lens front surface without ND filtration. This was done in an effort to more closely define the tube damage point. If the tube had been immediately harmed by full sun exposure, the test series would have had to be repeated. Therefore, the ND series began at 2.0 and was progressively reduced by 0.2 increments. Table 4-5 presents the data taken.

During the test while ND filters were being used no blemish was noted on the tube surface. Inspection was made at a filter change with each check taking only a few seconds before the next exposure was quickly started. At 65 min the 0.2 filter was removed and the tube given the full 0.88 solar constant exposure. At the end of thirty minutes of this total illumination a very small blemish was observed. Obviously from the data, it was concluded that the burn took place during that thirty minute period of full sun exposure.

The first goal of the test series had now been achieved. A blemish had appeared with 0.88 SC (solar constant) on a lens set at f 1.4 within the period of 0-30 minutes elapsed time. Even though the tube was blemished, the measured spot sensitivity was unchanged. This would tend to indicate that the general tube sensitivity would be unaffected except for the blemished area.

4.6.2 TEST DATA TUBE #27408

It was decided, now that it was established that a tube could be damaged if certain parameters of sun intensity and image forming optics were used, to attempt a test which would refine this information. As a result of the test data in Table 4-5 it was apparent that an objective lens setting of f 1.4 and a solar level of approximately 0.88 solar constant would produce a blemish in a time period of less than thirty minutes. It seemed primarily important to find out how long it took to create the

TABLE 4-5.— TEST DATA TUBE #17306, SECOND SERIES

Time	Energy Level	ND	Photocurrent
0 (start)	.011 SC	2.0	3.3×10^{-6}
15 min.	.014 SC	1.8	3.5×10^{-5}
20 min.	.134 SC	0.8	4.0×10^{-3}
30 min.	.221 SC	0.6	5.2×10^{-3}
35 min.	.350 SC	0.4	7.3×10^{-4}
50 min.	.555 SC	0.2	9.2×10^{-4}
	NO BLEMISH		
65 min.	.88 SC	0	9.8×10^{-4}
95 min. (end)	.88 SC	0	9.7×10^{-4}

Sensitivity Check

With Lens (Before Test)

White	Red	Blue
1.9×10^{-7}	2.5×10^{-9}	1×10^{-7}

After Test

White	Red	Blue
1.9×10^{-7}	2.6×10^{-9}	1×10^{-7}

Angenieux Lens f 1.4

the damage from zero time and secondarily to find an exposure level of less than 0.88 SC which would not damage the tube in the thirty minute time previously observed. It was hoped to find this value either by adjusting the objective f no. or by inclusion of a properly selected ND filter. Such a test would have been easy to perform if the sun intensity level remained constant throughout the test. Unfortunately this was not the case during the tests of tube #27408, and although much data was taken and seven blemishes made on the tube photocathode, time/energy relationships remained elusive.

The test was done with the substitution of a prototype Star Tracker lens instead of the Angenieux previously used. The new lens had a 56 mm focal length and a speed of f 1.4. This computes to an effective aperture of 33.5 mm. The lens does not have an adjustable f stop so adjustments to the effective energy applied to the tube faceplate was controlled by use of ND filters. Table 4-6 presents the data taken during the test series.

4.6.3 TEST DATA TUBE #117312

In order to expand the data base, tests were continued on an unblemished tube #117312. The usual sensitivity tests were not done since the time to blemish/energy the surface was considered a more paramount requirement for the data to define. The Angenieux lens was used to control the energy of the focussed spot (appendix A). No ND filtration was employed (Table 4-7).

4.7 TEST MODIFICATIONS AND PROCEDURE CHANGES

Although the data taken in the previous tests was not totally conclusive a distinct pattern of tube survival was discerned. Table 4-5 of section 4.6.1 showed that the tube was not burned with a 0.55 solar constant for at least fifteen minutes and with a 0.88 solar constant a very slight blemish appeared in thirty minutes. In a subsequent test (section 4.6.2, table 4-6) an

TABLE 4-6.— TEST DATA TUBE #27408

Time	Energy Level	ND	Photocurrent
0	0.18 SC	0.6	4.8×10^{-4}
5 min.	0.18 SC	0.6	4.8×10^{-4}
	TUBE NOT BLEMISHED		
0	0.25 SC	0.4	5.6×10^{-4}
6 min.	0.25 SC	0.4	5.7×10^{-4}
	TUBE NOT BLEMISHED		
0	0.36 SC	0.2	5.9×10^{-4}
85 min.	0.48 SC	0.2	6.2×10^{-4}
90 min.	0.48 SC	0.2	6.2×10^{-4}
93 min.	0.50 SC	0.2	7.4×10^{-4}
135 min.	0.50 SC	0.2	7.6×10^{-4}
	TUBE NOT BLEMISHED		
0	0.75	NONE	--
12 min.	0.75	NONE	--
	SMALL SPOT VISIBLE		

TABLE 4-6.— Continued

NEW SPOT POSITION

Time	Energy Level	ND	Photocurrent
0	0.44 SC	NONE	9.1×10^{-4}
8 min.	0.44 SC	NONE	--
12 min.	0.49 SC	NONE	--
17 min.	0.48 SC	NONE	--
18 min.	0.53 SC	NONE	8.8×10^{-4}
22 min.	0.53 SC	NONE	--
27 min.	0.55 SC	NONE	--

TUBE NOT BLEMISHED

CHANGED TO NEW SPOT POSITION

0	0.53 SC	NONE	9.1×10^{-3}
2 min.	0.58 SC	NONE	--
5 min.	0.55 SC	NONE	--
7 min.	0.51 SC	NONE	--
8 min.	0.53 SC	NONE	9.4×10^{-3}
16 min.	0.53 SC	NONE	--

BLEMISH APPEARS

TABLE 4-6.– Continued

NEW SPOT POSITION

Time	Energy Level	ND	Photocurrent
0 min.	0.55	NONE	Not Recorded
3 min.	0.53	NONE	Not Recorded
5 min.	0.53	NONE	Not Recorded
8 min.	0.55	NONE	Not Recorded
16 min.	0.49	NONE	Not Recorded
23 min.	0.55	NONE	Not Recorded

BLEMISH APPEARS (Barely)

NEW SPOT POSITION

0	0.53 SC	NONE	Not Recorded
5	0.49 SC	NONE	Not Recorded
9	0.44 SC	NONE	Not Recorded
62	0.58 SC	NONE	Not Recorded
102	0.66 SC	NONE	Not Recorded
104	0.66 SC	NONE	Not Recorded

NO BLEMISH AT 104 MIN.

107	0.66 SC	NONE	Not Recorded

SMALL BLEMISH AT 107 MIN.

TABLE 4-6.– Concluded

NEW TUBE POSITION

Time	Energy Level	ND	Photocurrent
0 min.	0.42 SC	0.2	Not Recorded
3 min.	0.45 SC	0.2	Not Recorded
8 min.	0.43 SC	0.2	Not Recorded
12 min.	0.45 SC	0.2	Not Recorded
15 min.	0.46 SC	0.2	Not Recorded
18 min.	0.45 SC	0.2	Not Recorded
20 min.	0.48 SC	0.2	Not Recorded
23 min.	0.49 SC	0.2	Not Recorded
31 min.	0.50 SC	0.2	Not Recorded
	NO BLEMISH		
32 min.	0.80	NONE	Not Recorded
	BLEMISH JUST SHOWING		
33 min.	0.82	NONE	
	BLEMISH LARGER		
35 min.	0.82	NONE	
	NO NOTICEABLE INCREASE		

TABLE 4-7.— TEST DATA TUBE #117312

Time	Energy Level	"f" No.	Photocurrent
0	0.44 SC	8	1.8×10^{-4}
2 Min.	0.66 SC	1.4	1.1×10^{-3}
7 Min.	0.71 SC	1.4	1.2×10^{-3}
10 Min.	0.62 SC	1.4	9.8×10^{-4}
17 Min.	0.75 SC	1.4	1.2×10^{-3}
	INSPECT SURFACE (NO BLEMISH)		
19 Min.	0.66 SC	0.95	1.4×10^{-3}
22 Min.	0.66 SC	0.95	1.3×10^{-3}
	INSPECTED SURFACE (LARGE BLEMISH) CHANGED SPOT POSITION		
0	0.70 SC	1.4	1.1×10^{-3}
7 Min.	0.67 SC	1.4	9.8×10^{-4}
9 Min.	0.70 SC	1.4	1.1×10^{-3}
22 Min.	0.58 SC	1.4	9.6×10^{-4}

INSPECTED (SLIGHT BLEMISH)

average exposure of 0.48 solar constant for one hundred thirty-five minutes produced no damage and then in twelve subsequent minutes at 0.75 solar constant a small blemish appeared. Later test data (same table) also indicated that with ~0.50 solar constant on the lens objective which was set at f 1.4 to establish focal length and spot size parameters, no damage existed. Any energy level over 0.50 solar constant seemed to cause damage in varying lengths of time up to fifteen to thirty minutes exposure. To simplify, an ND 0.3 filter used with 1.00 solar constant would adequately protect the tube when an f 1.4 objective lens was used for imaging. (Considering the ND 0.3 filter to have approximately 50 percent transmission of all energy from the source.)

The use of an ND 0.3 filter in practical applications such as the Shuttle Orbiter Star Tracker would not be desirable due to a loss in target star sensitivity of 0.8 visual magnitude. Reducing the total solar energy to the tube photocathode by a factor of 50 percent should allow the tube to be operated with solar image exposure of one solar constant; however, this must be done with a minimal loss in target sensitivity as determined by the S-20 photocathode spectral response. For example, a filter which reduced the solar energy by 50 percent and only caused a 20 percent reduction in target sensitivity would be practical and useful for protection since only 0.25 visual magnitude target sensitivity would be lost.

A component search for such a filter resulted in finding two types which would meet or exceed these requirements. A Schott Glass absorption type in the well known KG series and a heat reflecting mirror dielectric type, "Hot Mirror" "Corion" HR-90-1 were investigated and found adequate. Of the Schott KG series, the KG 1 was judgment selected to have the best predictibility of usefulness.

These filters were tested by several means to verify their potential as a "Guardian" optical unit. The filter tests were made using various energy sources in order to learn their characteristics of attenuation and transmission. Table 4-8 shows the result of these tests. All measurements are relative and no exposure energy units are used. It can be seen from the data that the KG-1 filter attenuates (56 percent) of the total solar energy while only reducing the S20 response by 19 percent, and the HR-90-1 filter attenuates 54 percent solar level while reducing S20 response by 23 percent. These figures are well within the requirements for an experimental filter. For the tests to be made the HR-90-1 unit was selected. Even though its performance figures were not quite as good as the KG-1 it was felt that the reflective mode of attenuation would result in a cooler filter plate which would be advantageous over a hot absorption unit in a subsequent star tracker design. The fulfillment of over ~50 percent solar attenuation (equivalent to ND 0.5) and no more than ~0.25 visual magnitude target attenuation could obviously be met by the HR-90-1 (or equivalent) filter.

During the previous tests it was determined that the sensitivity test was not useful due to the fact that the total photocathode was involved in the measurement. The blemishes and burns observed were extremely small in area and even though the total photocathode sensitivity was probably slightly reduced, the after test sensitivity measurement did not show this fact. It was decided to place a mask over the tube face with small hole entrance and test the sensitivity of this diminished area. Focused spot exposures would then be directed to the hole area and, in the event of a blemish, the sensitivity check change would hopefully become more discernible. It will be seen in later test data that this was the case and that the data is more representative of the actual situation.

TABLE 4-8.— FILTER ATTENUATION AND TRANSMISSION CHARACTERISTICS

THERMOPILE DETECTOR

Source	Full Exposure	KG-1	HR-90-1	Percent Trans. KG-1	Percent Trans. HR-90
2854°K	9.5×10^{-5}	1.2×10^{-5}	3.7×10^{-5}	13%	39%
5500°K	3.8×10^{-5}	6.0×10^{6}	2.2×10^{-5}	16%	58%
X_e	1.0×10^{-3}	3.3×10^{-4}	3.6×10^{-3}	33%	36%
Sun	1.0	0.40	0.44	40%	44%
S20 PHOTOCATHODE					
X_e	6.8×10^{-4}	5.6×10^{-4}	5.4×10^{-4}	82%	79%
Sun	1.0×10^{-3}	8.1×10^{-4}	7.7×10^{-4}	81%	77%

Another test feature which required a hard look as to its usefulness was the photocathode current measurement. Since the tube was not being operated in a scanning mode the photocurrent value came from the total surface emission. Ordinarily this would not be a problem if the tube were operating at low levels of energy but the high levels produced by the solar image resulted in irradiation of all the cathode area from scattering and reflection phenomena taking place in the tube's interior. Even if the tube front was masked the energy of the smaller focused spot passing through the photocathode material and being scattered by the crystalline structure and further scattered by the target mesh and finally reflected back to the back sides of the photocathode by the shiny inner metallic structure would result in an exposure of the entire photocathode area. Therefore, the photocurrent to input energy probably does not have the typical direct relationship expected. An effective photocurrent measurement of just the electrons emitted by the focused spot photocathode area could not be realized without operating the tube in a controlled scan mode. For the conclusion of this series of tests it was decided to record the photocurrent as just interesting data.

While preliminarily presenting some of the test data a constructive suggestion was offered which would require a monitoring of the photocathode temperature during testing. This would be done to determine if any direct relationship between operating ambient temperature and tube damage might exist. In other words, would a photocathode already at a much higher than ambient temperature be damaged sooner for a given sun exposure? It was considered useful to determine whether or not the tube photocathode surface became elevated in temperature due to prolonged sun exposures. With these questions in mind, a method of measuring the image dissector front face plate was devised and incorporated into the test series. Since the photocathode material surface is enclosed in the glass envelope it was only possible to connect a temperature sensor to the metallic ring around the tube faceplate. This ring has a direct electrical path to the inner faceplate photocathode and probably has a temperature close to the sensitive material level.

Now Phase II tests were ready to begin to determine if definition of the damage point could be refined and also to ascertain any advantages to be gained by using filtration to lessen damage without deleterious effects on the ability of the tube to "see" targets.

4.8 PHASE II TEST RESULTS

The advancement of the test program into Phase II was prompted by the establishment of an approximate damage criteria point. So far the testing verified the use of lowered image section voltage as a means of operating the tube to sense current flow without apparently causing damage or lowered sensitivity life. The addition of controlled spectral filtration was expected to substantially increase the "time to damage" parameter.

4.8.1 TEST DATA TUBE #097018

The test set up included an HR-90 filter, the usual electronic hookup utilizing 9 volts image section voltage with the addition of a temperature measuring technique as previously described in Paragraph 4.2. Table 4-9 lists the test data taken.

The data taken verifies that the tube could probably be operated for forty minutes without damage. The small blemish noted occurred between forty and sixty minutes and, as indicated by the sensitivity check, was extremely neglible in effect. Note the small change in photocurrent (1.7 percent) which occurred between forty-eight and sixty minutes. This effect was not observed in previous tests due to the large photocathode area

TABLE 4-9.– TEST DATA TUBE #097018

HR-90 Filter

Angenieux Lens set at f 1.4 (App. I)

Time	Temperature °F	Energy Level	Photocurrent
0	74	0.78 SC	6.2×10^{-4}
2 Min.	74	0.77 SC	6.2×10^{-4}
4 Min.	74	0.73 SC	6.1×10^{-4}
7 Min.	75	0.75 SC	6.1×10^{-4}
10 Min.	75	0.77 SC	6.1×10^{-4}
12 Min.	75	0.77 SC	6.0×10^{-4}
13 Min.	75	0.77 SC	6.0×10^{-4}
17 Min.	75	0.77 SC	6.0×10^{-4}
22 Min.	76	0.75 SC	6.0×10^{-4}
Photocathode Inspected (No Blemish)			
27 Min.	78	0.76 SC	6.0×10^{-4}
30 Min.	78	0.75 SC	6.0×10^{-4}
40 Min.	78	0.75 SC	6.0×10^{-4}
Photocathode Inspected (No Blemish)			
48	78	0.75 SC	6.0×10^{-4}
60	78	0.71 SC	5.9×10^{-4}

Photocathode Inspected (Slight Blemish)

Sensitivity Check

	White	Red	Blue
Pre-Test	1.3×10^{-8}	6.4×10^{-10}	3.6×10^{-9}
Post-Test	1.2×10^{-8}	6.1×10^{-10}	3.2×10^{9}

involved. During the test the sun level was extremely steady thereby increasing the validity of the test data.

4.8.2 TEST DATA TUBE #107304

This test is identical to that of Tube #097018 Paragraph 4.3.1. It served as verification of the data obtained and to provide a higher confidence level in the survival technique. Table 4-10 lists the test data.

The temperature of the photocathode was elevated with a thermal blanket wrapped around the test fixture and controlled by the test operator. No relation between elevated temperature and increased damage rate was noted.

4.8.3 TEST DATA TUBE #107206

This final test of the series was directed towards a demonstration of the proposed technique to protect the image dissector sensor of the Shuttle Orbiter Star Tracker. In addition, the data improves the confidence level of the previous test results. The limited aperture technique was used and the sensitivity was measured with three different diameter sizes of 0.281 inches, 0.175 inches, and 0.03 inches. This progressively smaller aperture was used to determine if any sensitivity degradation could be seen in smaller photocathode areas even though a blemish is not seen. The sensitivity measurements were taken on the source photocathode area that was exposed to the solar image. Table 4-11 contains the data for the test.

TABLE 4-10.— TEST DATA TUBE #107304

HR-90-Filter

Angenieux Lens - f 1.4

Time	Temperature °F	Energy Level	Photocathode Current
0	76	0.76 SC	4.5×10^{-4}
6 Min.	76	0.76 SC	4.5×10^{-4}
11 Min.	77	0.77 SC	4.6×10^{-4}
19 Min.	78	0.78 SC	4.6×10^{-4}
26 Min.	77	0.77 SC	4.6×10^{-4}
30 Min.	77	0.76 SC	4.6×10^{-4}

Photocathode Inspected (No Blemish)

36 Min.	77	0.78 SC	4.7×10^{-4}
41 Min.	78	0.79 SC	4.6×10^{-4}

Photocathode Inspected (No Blemish)

60 Min.	79	0.79 SC	4.6×10^{-4}

Photocathode Inspected (Slight Blemish)

CHANGED SPOT AREA AND ELEVATED TEMPERATURE

0	150	0.80 SC	4.4×10^{-4}
5	164	0.79 SC	4.4×10^{-4}
15	163	0.80 SC	4.5×10^{-4}
30	147	0.80 SC	4.5×10^{-4}
38	152	0.80 SC	4.5×10^{-4}
45	152	0.80 SC	4.4×10^{-4}

Photocathode Inspected at 30 Minutes (No Blemish)

TABLE 4-10.— Concluded

Photocathode Inspected at 45 Minutes (Blemished)

Changed Spot Area

Time	Temperature °F	Energy Level*	Photocathode Current
0	152	0.80 SC	4.4×10^{-4}
5	152	0.80 SC	4.4×10^{-4}
10	150	0.80 SC	4.4×10^{-4}
15	148	0.81 SC	4.4×10^{-4}
20	140	0.80 SC	4.4×10^{-4}
45	156	0.80 SC	4.4×10^{-4}

Photocathode Inspected (Blemished)

Sensitivity Check

	White	Red	Blue
Pre-Test	9.7×10^{-9}	2.9×10^{-9}	5.0×10^{-10}
Post-Test	6.7×10^{-9}	1.6×10^{-9}	4.0×10^{-10}

Three blemishes within photocathode area of ($\sim$0.32 cm^2).

*Level at lens front surface.

TABLE 4-11.— TEST DATA TUBE #10726

HR-90 Filter

Angenieux Lens f 1.4

Time	Energy Level	Effective Level (APP A)
0	0.78	1.07
30 Min.	0.78	1.07

Inspected (No Blemish)

Sensitivity Check

LARGE APERTURE (2854° K)

	White	Red	Blue
Pre-Test	1×10^{-9}	5.3×10^{-10}	1.2×10^{-11}
Post-Test	1×10^{-9}	5.6×10^{-10}	1.9×10^{-11}

MEDIUM APERTURE (2854° K)

Pre-Test	3.8×10^{-10}	2.1×10^{-10}	5.4×10^{-12}
Post-Test	3.9×10^{-10}	2.4×10^{-10}	5.7×10^{-12}

SMALL APERTURE (2854° K)

Pre-Test	8.8×10^{-11}	4.8×10^{-11}	2.8×10^{-12}
Post-Test	9.0×10^{-11}	5.0×10^{-11}	3.0×10^{-12}

Sensitivity Check

LARGE APERTURE (5500° K)

Pre-Test	1.8×10^{-10}	6.0×10^{-11}	8×10^{-12}
Post-Test	1.9×10^{-10}	6.5×10^{-11}	10×10^{-12}

TABLE 4-11.— Concluded

MEDIUM APERTURE (5500° K)

	White	Red	Blue
Pre-Test	7.1×10^{-11}	2.4×10^{-11}	4×10^{-12}
Post-Test	7.2×10^{-11}	2.3×10^{-11}	6×10^{-12}

SMALL APERTURE (5500° K)

	White	Red	Blue
Pre-Test	1.7×10^{-11}	6×10^{-11}	1.6×10^{-12}
Post-Test	2.4×10^{-11}	8×10^{-11}	1.6×10^{-12}

Dark Current

Pre-Test	5×10^{-13}
Post-Test	5×10^{-13}

5. DAMAGE PREDICTION

As previously stated one of the prime goals of this test program was to determine a method whereby damage to image dissectors used as device sensors could be prognosticated and possibly controlled. The device designer needs a method of predicting system performance in terms of expected damage.

Based upon the data taken from the test program the author cautiously offers an equation which could be used by the engineer as a guide in determining the need for mechanical protective devices in his system design concept.

Derivation of the equation is described in appendix II and is presented here in its final form.

$$J/cm^2 = \frac{1771.74(SC)T}{(f\ no.)^2}\ t$$

where

SC - Solar constant (1.0 equals 100% SC)

T - Transmission of optical system

t - Time in seconds

f no. - Lens value determined by focal length and objective aperture

The expression was used to obtain the J/cm^2 value from the test data found in tables 4-9, 4-10, and 4-11. Tables 4-12 through 4-14 show the results of these calculations.

The sparse data obtained is consistent in showing a damage point somewhere between 6.0×10^5 and 8.0×10^5 J/cm^2 values. The repeatibility of these tests, although not completely conclusive, is nevertheless encouraging since an approximate value of damage energy has appeared from the hodgepodge of data. Considering the many difficulties encountered during the program from cloudy skies, test procedure experiments, lack of constant observation of the photocathode surface, and the failure of seeing damage occurrences from speculated photocathode current drops (which never appeared), it can still be concluded that the test program was successful in finding base damage criteria which could be used to design future experiments and guide designers of devices using image dissectors.

6. CONCLUSIONS

Using the data taken during this test program combined with the visual observations made during testing, the author presents the following important conclusions:

a. Image dissector tubes used with low f no. optical systems can be permanently damaged from solar images focused upon the photocathode unless certain precautions are taken.

b. Image dissector sensors can withstand high flux levels if tube voltages are lowered to less than 10 volts in the image section during the exposure period.

c. A safe operating point for equipment using an image dissector (ITT Type 4012-S20) has been determined to be a 0.5 solar constant irradiation with an f 1.4 optical system up to a period of thirty minutes. This event can occur with the solar image held on one area of the photocathode without movement. Under these conditions the sensor will probably not be burned. The requirements of (b) above apply.

d. With use of a suitable optical filter, and adopting the diminished voltage technique, the safe exposure time could be extended to thirty minutes when a one solar constant run image is focused onto a dissector photocathode with a f 1.67, optical lens system.

7. EPILOGUE

Some of data obtained during the test program described in this report is rather startling in its content and implication. The concept of operating a device using an image dissector without sun protection is a drastic change to the design philosophy generally followed by most engineers. Doubtless there will be many who would not care to venture into this new technique without more conclusive data than that which has already been gathered. The success of the technique was somewhat surprising in that the author had no idea that the tubes could stand even a small portion of the exposures used. It was first thought that prevention of instantaneous destruction to the sensor would be adequate to anticipate continued operation if the sun protection devices failed. Now it is apparent that there is a distinct possibility of operation even after their complete removal. If operational cautions such as insuring that exposures do not exceed the designated limits of time and intensity are followed, a system can be built and safely operated. It is expected that work in this area will continue and that the damage levels will be defined to such a degree that designers will adopt the technique with a high level of confidence. Establishment of a more reliable Joules/cm^2 value would be a prime goal of the work to follow.

8. REFERENCES

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APPENDIX A

ANGENIEUX LENS ADJUSTMENTS

APPENDIX A

ANGENIEUX LENS ADJUSTMENTS

During the test program two types of lenses were used. Their characteristics are listed below:

	Angenieux Lens	Star Tracker Lens
Focal length	51.968 mm	56.0 mm
f no.	0.95	1.67
Effective aperture diameter	54.703 mm	33.53 mm
Variable f stop	0.95 - 22	None

Since the Star Tracker Lens was not usually available and because the BBRC test area solar constant rarely exceeded 0.8 it was necessary to compute conversion criteria so that the larger Angenieux Lens could be used to simulate 1.0 solar constant effects as might be experienced by the Shuttle Star Tracker while in orbital use. This was done by selecting an f stop on the Angenieux lens which provided the effective aperture diameter needed to increase focused spot energy flux/unit area equal to that of the Star Tracker lens focal plane density simulating the 1.0 solar constant present on the objective front surface.

Two variables existed which needed calculation before a conversion table could be generated.

a. An f stop setting of the Angenieux lens at values other than those marked on the lens barrel would be difficult to achieve and some inaccuracies of the imaged spot flux density would result. Calculations indicate that an f stop setting of 1.55 would produce an effective aperture equal to that of the Star Tracker lens but no increased flux density would be present, therefore no conversion advantage is achieved. If the Angenieux lens was set to f 1.4 the effective aperture diameter is increased by:

$$\frac{D_{AN}^2}{D_{ST}^2} = \frac{(37.12)^2}{(33.53)^2} = 1.22$$

b. Because the focal lengths of the two lenses are slightly different the spot size of the solar image is not equal.

Considering a solar disc subtense angle of approximately 0.5 degrees, the resulting focused image size on the photocathode can be determined by using the expression:

$$\frac{S(f)}{57.295} = d$$

where

S = Solar disc subtense ($\sim 0.5°$)

f = Focal length of subject lens

d = Focused spot size (dia)

For the two lenses the results indicate

Star Tracker Lens – 0.4887 mm dia (ST)

Angenieux Lens – 0.4535 mm dia (AN)

Considering these values the ratio of flux distribution can be shown from:

$$\frac{D_{AN}^2}{D_{ST}^2} = \frac{(.4535)^2}{(.4887)^2} = .8611$$

The Angenieux lens has the smaller solar disc focused spot size and therefore for a given irradiation, a higher ratio of flux/area is present. Inverting the above expression results in a value of $\frac{1}{.8611} = 1.16$.

Now a table of conversions can be generated. Using the plainly marked f 1.4 point of the Angenieux lens the following table was calculated. Solar constant value at the lens front surface was multiplied by a constant 1.42 to evaluate the total effective photocathode flux/area value.

TABLE A-1.— ANGENIEUX LENS f 1.4

Solar Constant	Total Effective Sun
0.65	0.92
0.66	0.94
0.67	0.95
0.68	0.97
0.69	0.98
0.70	0.99
0.71	1.00
0.72	1.02
0.73	1.04
0.74	1.05
0.75	1.07
0.76	1.08
0.77	1.09
0.78	1.11
0.79	1.12
0.80	1.14
0.81	1.15
0.82	1.16
0.83	1.18
0.84	1.19
0.85	1.20

APPENDIX B

DAMAGE PREDICTION EQUATION DERIVATION

APPENDIX B

DAMAGE EQUATION DERIVATION

The total energy (W_T) falling upon a surface from solar exposure is expressed by

$$W_T = 0.135A \tag{1}$$

where

W_T = Total watts of energy

0.135 = One solar constant (0.135 watts cm^2)

A = Area of surface (cm^2)

Energy can be related to power by the expression:

$$J = W_T t \tag{2}$$

where

J = Joules, (watt seconds)

t = Time in seconds

substituting:

$$J = 0.135At \tag{3}$$

In the case being illustrated, (A) is defined as the area of the objective lens being used in a system and can be shown to be:

$$A = \frac{\pi d^2}{4} \tag{4}$$

where

d = the objective diameter in centimeters.

Now the expression is shown to be:

$$J = \frac{0.135\pi d^2}{4}t \tag{5}$$

The objective lens focuses the total received energy into a smaller spot area which has a diameter (d_s) determined by the expression:

$$d_s = \frac{Sf}{57.28} \tag{6}$$

where

S = Angular subtense of solar disc $\approx 0.5°$

f = Focal length of objective lens

The area of the focused solar image is now represented by:

$$\left(\frac{0.5f}{57.28}\right)^2 \left(\frac{\pi}{4}\right) \tag{7}$$

Total substitution of equation (5) now results in:

$$J/cm^2 = \frac{0.135d^2\frac{\pi}{4}}{\left(\frac{0.5f}{57.28}\right)^2\left(\frac{\pi}{4}\right)}t \tag{8}$$

Collecting terms and simplifying:

$$J/cm^2 = \frac{1771.74d^2}{f^2}t \tag{9}$$

The objective lens f no. is determined by the diameter/focal length ratio

$$f \text{ no.} = \frac{f}{d} \tag{10}$$

or

$$\frac{1}{f\ no.} = \frac{d}{f} \tag{11}$$

squaring terms:

$$\frac{1}{(f\ no.)^2} = \frac{d^2}{f^2}$$

and finally substituting into (10)

$$J/cm^2 = \frac{1771.74t}{(f\ no.)^2} \tag{12}$$

This expression can be used to evaluate future designs by determining operational parameters which do not permit the damage "J" value to be exceeded within the time of full exposure that is permitted.

Author's note: The reader is reminded that the above statement only applies if the technique described elsewhere in this paper is followed.

Use of the expression assumes that <u>one</u> full solar constant of solar energy is allowed to impinge upon the <u>total</u> optical system (lens plus filter). If lesser amounts of energy are considered the J value is proportionally reduced.

Remember, the equation has been empirically established by the tests outlined in this report. Validity for other situations must be reviewed before its general use can be accepted.