AD-A043 023 ARMY ENVIRONMENTAL HYGIENE AGENCY ABERDEEN PROVING GR--ETC F/G 6/18

EVALUATION OF THE POTENTIAL RETINAL HAZARDS FROM OPTICAL RADIAT--ETC(U)

AUG 77 W J MARSHALL, D H SLINEY, T L LYON

UNCLASSIFIED USAEHA-42-0312-77 NL

1 OF 3

AD A043023

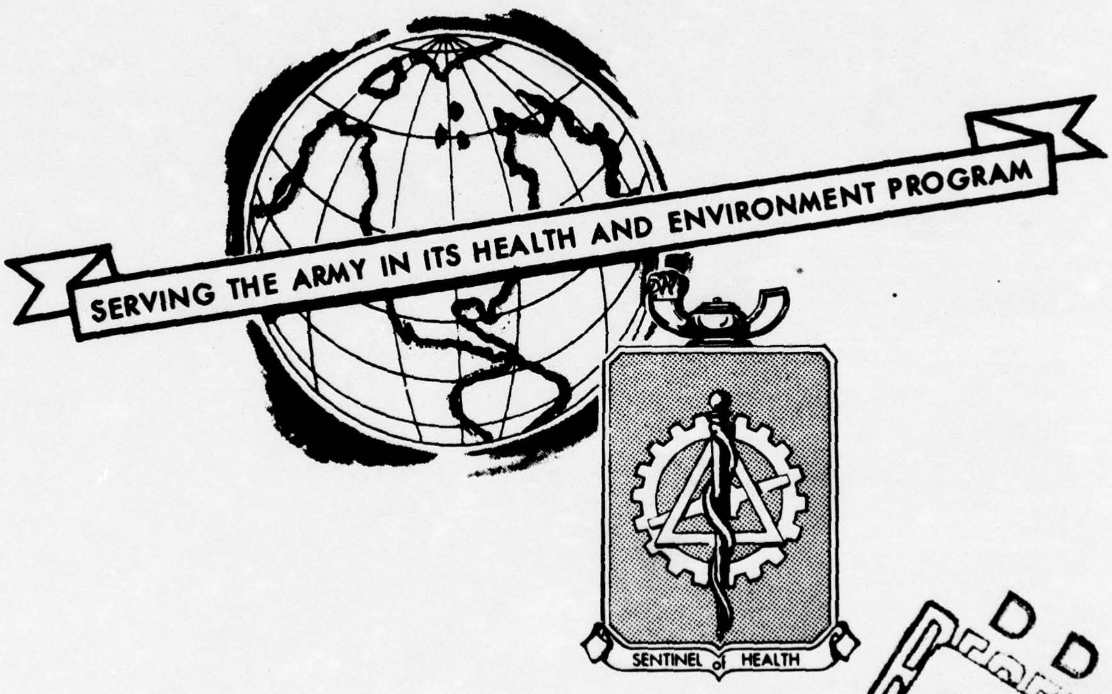
AD A043023

NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0312-77

EVALUATION OF THE POTENTIAL RETINAL HAZARDS FROM OPTICAL RADIATION GENERATED BY ELECTRIC WELDING AND CUTTING ARCS

DECEMBER 1975 - APRIL 1977

Approved for public release; distribution unlimited.



DDC
AUG 18 1977
C

US ARMY

ENVIRONMENTAL HYGIENE AGENCY

ABERDEEN PROVING GROUND, MD 21010

AD NO.
DDC FILE COPY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
42-0312-77

(6)

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle) NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0312-77, EVALUATION OF THE POTENTIAL RETINAL HAZARDS FROM OPTICAL RADIATION GENERATED BY ELECTRIC WELDING AND CUTTING ARCS DECEMBER 1975 - APRIL 1977.

5. TYPE OF REPORT & PERIOD COVERED
Special Study
Dec 75 - Apr 77

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) Wesley J./Marshall, Nicholas P./Krial, David H./Sliney, Pedro F./Del Valle, Terry L./Lyon

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
USA Environmental Hygiene Agency
Aberdeen Proving Ground, MD 21010

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

(12) 268p.

11. CONTROLLING OFFICE NAME AND ADDRESS
Commander
USA Health Services Command
Fort Sam Houston, TX 78234

12. REPORT DATE
(11) 16 Aug 77

13. NUMBER OF PAGES
264

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
(9) Nonionizing radiation protection special study,

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

(14) USAEHA-42-0312-77

DDC
AUG 18 1977
C

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Welding Arc
Light
Infrared
Hazards

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A special study of the potential retinal hazards from direct viewing of various welding processes was conducted by the US Army Environmental Hygiene Agency as part of a cooperative effort with the American Welding Society Committee on Safety and Health of the Project Committee on Radiation. It was determined that potentially hazardous levels of visible radiation were emitted by all of the welding processes that were evaluated and that recommended filter shade numbers were generally adequate. These processes included: gas tungsten arc welding,

over

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

LB

038 150

20. flux cored arc welding, plasma arc cutting, plasma arc welding and shielded metal arc welding.

ACCESSION for
NTIS White Section
DDC Buff Section
UNANNOUNCED
JUSTIFICATION
BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

CONTENTS

DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

HSE-RL/WP

16 AUG 1977

NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0312-77 EVALUATION OF THE POTENTIAL RETINAL HAZARDS FROM OPTICAL RADIATION GENERATED BY ELECTRIC WELDING AND CUTTING ARCS DECEMBER 1975 - APRIL 1977

ABSTRACT

A special study of the potential retinal hazards from direct viewing of various welding processes was conducted by the US Army Environmental Hygiene Agency as part of a cooperative effort with the American Welding Society Committee on Safety and Health of the Project Committee on Radiation. It was determined that potentially hazardous levels of visible radiation were emitted by all of the welding processes that were evaluated and that recommended filter shade numbers were generally adequate. These processes included: gas tungsten arc welding, gas metal arc welding, flux cored arc welding, plasma arc cutting, plasma arc welding and shielded metal arc welding.

It is recommended that: needless staring at the arcs be avoided; viewing the arcs without protection be limited to the durations given in Appendix E; operators should wear protective shields which absorb not only the ultraviolet radiation, but also the visible radiation (with preferential absorption in the blue) to the extent specified by filter shades given in Appendix F; and welding and cutting operations should be shielded whenever possible.

Approved for public release; distribution unlimited.

DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

HSE-RL/WP

NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 42-0312-77 EVALUATION OF THE POTENTIAL RETINAL HAZARDS FROM OPTICAL RADIATION GENERATED BY ELECTRIC WELDING AND CUTTING ARCS DECEMBER 1975 - APRIL 1977

1. AUTHORITY. AR 40-5, Health and Environment, 25 September 1974.

2. REFERENCES.

a. AR 10-5, Organization and Functions, Department of the Army, 1 April 1975.

b. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, 6 February 1974.

c. TM 9-237, Operator's Manual Welding Theory and Application, 6 November 1967.

d. Report, HSE-RL/WP, this Agency, Nonionizing Radiation Protection Special Study No. 42-0053-77, Evaluation of the Potential Hazards from Actinic Ultraviolet Radiation Generated by Electric Welding and Cutting Arcs, December 1975 - September 1976, 21 December 1976.

3. *PURPOSE*. To evaluate the potential health hazards from visible and near-infrared radiation generated by electric welding and cutting arcs, to attempt to develop a simplified method of evaluating welding operations without the need for lengthy and costly measurements, and to make recommendations designed to limit exposure of personnel operating and in the vicinity of this equipment.

4. GENERAL.

a. Background. Although open welding operations are common within many Army maintenance facilities and in industry, only a few previous attempts have been performed to define the optical radiation hazards generated by a wide variety of electric welding and cutting arcs although there have been many studies of hazards of specific types of arcs (Appendix A provides 57 such references). These processes produce substantial levels of optical radiation which can cause retinal injury. In the past it has often been assumed that the visible radiation from the arc was not hazardous, but merely a source of glare. Some studies overseas have suggested that subtle visual functional defects such as changes in color vision and some loss of night

Approved for public release; distribution unlimited.

vision may occur in welding workers who are without adequate eye protection.[22] Presumably these effects would be due to radiation between 400 nm and 1400 nm which reaches the retina.[23 48] Over the past 75 years, protective methods have been developed empirically to protect the welder himself.[11] With the increased usage of welding equipment in the past decade, exposure of welder's helpers and other personnel in the vicinity of open welding operations has increased significantly. There has been insufficient information available regarding the visible and near-infrared radiation emitted from welding arcs which would permit the calculation of safe exposure conditions in the vicinity of welding operations.

b. Objective. A major objective of this study was to determine if fundamental relationships exist between arc current, arc length and radiometric and photometric quantities such as actinic ultraviolet irradiance, luminance, spectral distribution, and total irradiance for several welding processes with different work materials and shielding gases. Information on these relationships would permit the derivation of formulas for permissible exposure durations as a function of distance between the exposed individual and the arc. In this project, many uncommon arc currents and arc lengths were used simply to obtain a better physical understanding of the influence of arc parameters upon the potential hazards to the retina. A secondary objective of this study was to compare the performance of less expensive light meters with that of more sophisticated instrumentation. These comparisons are not presented in this report. Although the present study is concerned primarily with retinal hazards for six welding and cutting processes, future studies are planned for other processes such as carbon-arc gouging and plasma spraying (PSP). Measurements taken on carbon-arc gouging will be presented in Report No. 42-0326-77. Also, a separate report (No. 42-0053-77) dealt with the potential actinic ultraviolet hazards from these sources.

---

11 Coblentz, W. W., and Stair, R., Correlation of the Shade numbers and densities of eye-protective glasses, J. Opt. Soc. Am., 20:624-629 (November 1930)

22 Gupta, M. N., and Singh, H., "Ocular Effects and Visual Performance in Welders," Report No. 27 of the Central Labor Institute, Ministry of Labour, Govement of India, Sion-Bombay (1968)

23 Ham, W. T., Mueller, H. A., Williams, R. C., and Geeraets, W. J., Ocular hazard from viewing the sun unprotected and through various windows and filters, Appl. Optics, 12(9):2122-2129 (September 1973)

48 Sliney, D. H., and Freasier, B. C., Evaluation of optical radiation hazards, Appl. Optics, 12(1):1-24 (1973)

c. Welding Processes Studied. Radiometric and photometric measurements of over 100 different arc welding and cutting conditions (called events in this report) were performed by personnel from the US Army Environmental Hygiene Agency (USAEHA) at the Union Carbide Corporation facility in Florence, SC. Six processes were evaluated: gas tungsten arc welding (GTAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), plasma arc cutting (PAC), plasma arc welding (PAW), and shielded metal arc welding (SMAW).

d. American Welding Society (AWS) Contribution. This cooperative effort with the Union Carbide Corporation was made possible through the coordinating efforts of the Project Committee on Radiation of the AWS Committee on Safety and Health. Dr. John A. Hogan, formerly Laboratory Division Head at Union Carbide, Mr. O. A. Ullrich, of Battelle Memorial Institute, and Mr. William B. Murray from the National Institute of Occupational Safety and Health (NIOSH) participated in the measurement program with USAEHA personnel at Union Carbide. Prior to these measurements, Mr. Ullrich had measured the angular dependence of the irradiance to determine the optimum measurement position for the major study. Appendix B lists the membership of the AWS Committee which reviewed this report.

e. Instr[illegible]ation. A partial list of the instrumentation used to measure the [illegible]etric and photometric quantities follows. Data collected with all o[illegible] instruments have not been completely reduced.

(1) Tektronix Model J20 Rapid - Scan Spectrometer with Corning Type 9-54 order-blocking filter.

(2) EG&G Model 585 Spectroradiometer System with "C" slits.

(3) Molectron Model PR-100 Pyroelectric Radiometer.

(4) United Detector Technology (UDT) Model 40x Optometer with Radiometric and Photometric Filters.

(5) Photo-Research Model 1980 Pritchard Photometer.

(6) Questar Telephoto Radiometer System with Nikon-F 35-mm Camera.

(7) International Light Model IL 730 U.V. Actinic Radiometer.

(8) CBS U.V. Hazard Monitor developed for NIOSH.

(9) Solar Light Co., Ultraviolet Meter.

(10) Calibrated Neutral Density Filters.

(11) Ultraviolet Products Inc., Model J225, Ultraviolet Meter.

(12) Photometrics, Inc., Model 200 EDP Scanning Microscope.

(13) Varian Model F-80A X-Y Recorder (used with IL 730 and UDT 40X systems to provide a time history of irradiance).

(14) Hewlett-Packard Model 7035B X-Y Recorder (used with EG&G Model 585 System).

(15) Calibrated Metal Plates for measuring electrode separation.

f. Measurement Techniques.

(1) To reduce erroneous measurements from other electromagnetic radiation generated by the various arcs, these instruments were either operated from internal batteries or from a constant voltage isolation transformer. Detector cables were shielded with coaxial braid and carefully grounded to the detector and readout chassis. These shielding techniques were periodically checked by placing a nonmetallic opaque shield over the detector aperture during operation of the arc.

(2) The spectroradiometric instruments were calibrated against a 1000-W standard lamp for total and spectral irradiance. The calibration lamp was checked before and after this study by the US Army Metrology and Calibration Center, Redstone Arsenal, AL, which maintains intercomparisons with the National Bureau of Standards. These instruments' reading tolerances are within 10 percent. This degree of accuracy is far in excess of what was required for this study, since very slight changes in arc conditions caused measured values to fluctuate by 20 percent. Photometric instruments were calibrated against Photoresearch standards of luminance, and irradiance instruments were calibrated against a Scientech Disc Calorimeter, Model 136.

g. Radiometric and Photometric Terms and Units. Appendix C contains a table of the radiometric and photometric terms and units utilized in this report. In addition, a listing of symbols unique to this study is provided in this Appendix.

h. Definitions. A glossary of various terms used in welding technology and optical radiation hazard analysis is contained in Appendix D.

i. Bibliography. A bibliography of articles related to welding-arc measurements is provided in Appendix A.

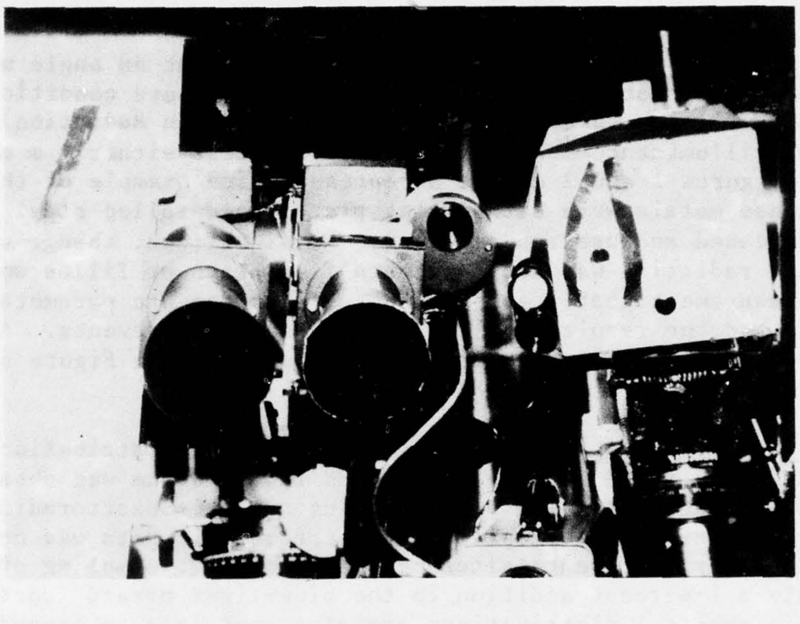
5. FINDINGS.

a. General. Radiometric measurements were made at an angle where the irradiance was the greatest to depict worst-case exposure conditions (as reported by Mr. Ullrich to the AWS Project Committee on Radiation). Most irradiance and illuminance measurement distances were either 1 m or 2 m from tne source. Figures 1 and 2 depict a representative example of the equipment setup. The base metals were either flat plate, cold rolled steel or aluminum which was degreased and used as received. No significant change within the output optical radiation was noted between flat plate or fillet weld during an initial measurement test. Appendix E contains the arc parameters, the measured data and the results for the various series of events. All Figures associated with a particular numbered Table have the same Figure number as the Table.

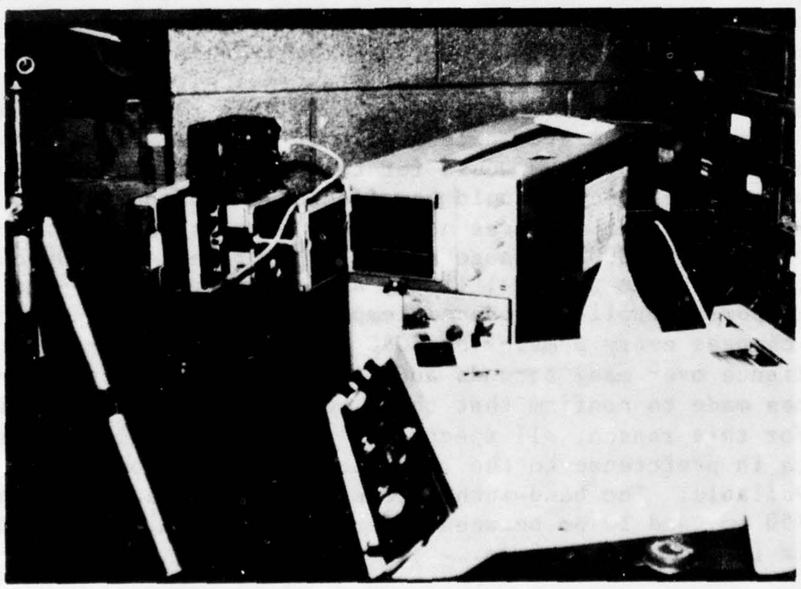
b. Spectral Distribution. The absolute spectral distribution in the visible and near-infrared between 400 nm and 1000-1100 nm was obtained for each type of welding or cutting process using an EG&G Spectroradiometer System and the Tektronix J20 Rapid Scan Spectrometer. Data was not reduced in the infrared for all events since measurements on a sampling of events indicated only a 1-percent addition to the blue-light hazard function. Several sample spectral distributions are also contained in Appendix E. The intercomparisons of spectra of the same arc measurement events from the two spectroradiometers often revealed inconsistencies. Some lines present in one spectrum were not present in the spectrum obtained by the other instrument. The source of this problem was the very short measurement duration of the Tektronix Rapid-Scan Spectroradiometer. Normally a 10-ms scan duration was used. During such a scan the instrument electronically scanned a spectrum which was integrated over a 10-ms period. For this reason oscillations and temperature changes in the arc could result in spectral variations from one run to another. The continuum would for the most part show no appreciable change. However line spectra could be affected. For instance, Glickstein[21] in his studies of arc temperatures noted that a relatively small change in arc temperature (e.g., 800°K change at 10,000°K) resulted a 10-fold change in the intensity of certain spectral lines; he further explained that the 360 Hz ripple of all power supplies produced temporary contractions of the arc and temperature changes every 3 ms. The EG&G Spectroradiometer averaged the spectral radiance over many seconds and repeated sweeps across the spectrum were sometimes made to confirm that there were no irregularities in a spectrum. For this reason, all spectrally weighted calculations made use of the EG&G data in preference to the rapid scan data when both sets of spectral data were available. The bandwidth of the EG&G instrument was 5 nm between 400 nm and 750 nm, and 10 nm between 750 nm and 1100 nm. The bandwidth of the Tektronix instrument was 5 nm.

---

[21] Glickstein, S. S., Temperature Measurements in a free-burning arc, Welding J. Res. Suppl., 55(8):2225-2275 (August 1976)

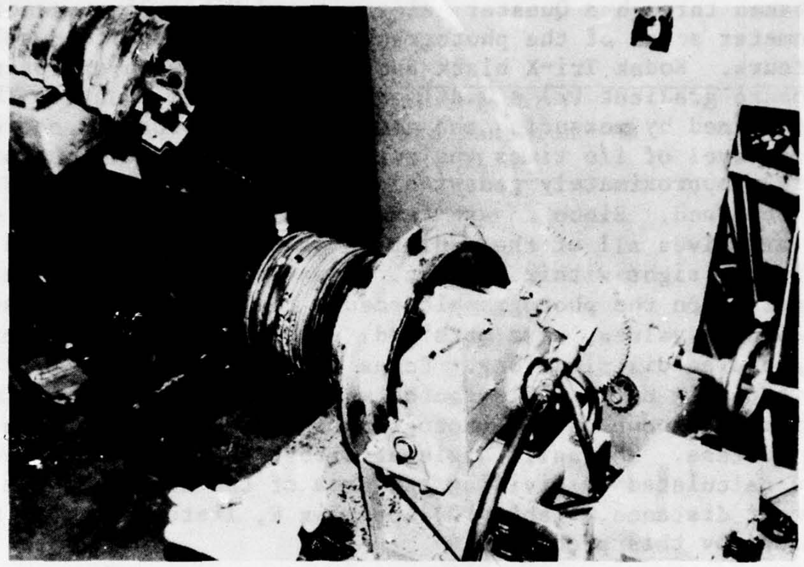


Spectral Detectors and Related Instrumentation

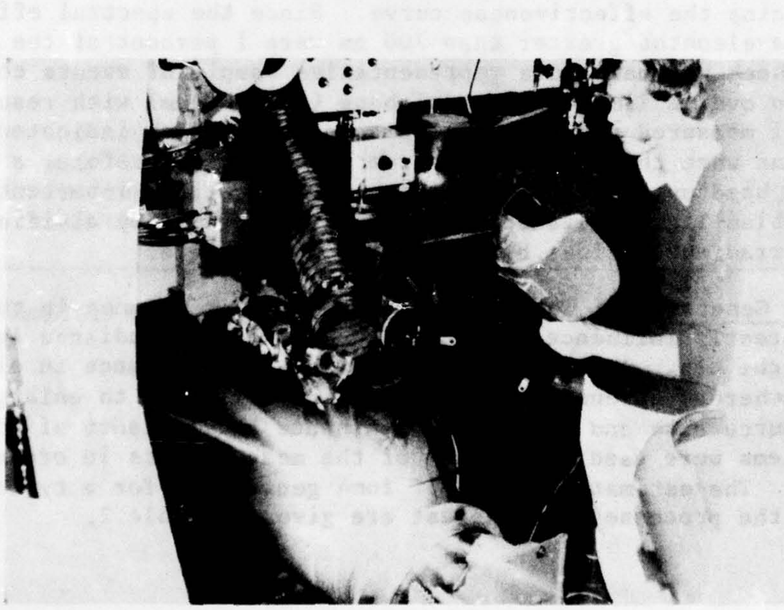


Spectral Output was recorded either photographically or with x-y Plotters

FIGURE 1. INSTRUMENTATION LAYOUT FOR MEASUREMENT OF GTAW AND GMAW



Rotating Pipe Fixture



Face shields were used for eye protection

FIGURE 2. GTAW WELDING ARRANGEMENT USING A ROTATING PIPE FIXTURE AND CYLINDRICAL DRUM TO MAINTAIN A CONSTANT ARC POSITION AND ARC LENGTH

c. Source Solid Angle. The source size was determined from photographs of the arc taken through a Questar telescope and Nikon 35-mm camera. Microdensitometer scans of the photographic negatives provided calibrated density contours. Kodak Tri-X black and white film [with a measured density/exposure gradient (γ) = 0.84] was used for all events. The source size was determined by measuring the area inside the contour corresponding to an irradiance level of 1/e times the peak irradiance. For most of the arcs, the profile was approximately gaussian at the camera angle for which the photos were obtained. Since an arc transmits optical radiation, viewing one point on an arc gives all of the radiation contributions from all points along the line of sight within the arc. Then by selecting 1/e-peak-irradiance points on the photographic scans, the peak radiance, and hence retinal irradiance values, were obtained. Viewing at other angles may produce nongaussian distributions. Scans of the various arc processes are provided in Appendix E. A scale factor was determined by comparing the electrode diameter shown on the photograph to the known electrode diameter used in the process. The solid angle at either the 1-m or 2-m measurement distance was calculated by dividing the area of the source by the square of the measurement distance. Table 17, Appendix E, lists the arcs' areas which were determined by this procedure.

d. Blue-light Hazard. Blue-light-hazard irradiance values were calculated by weighting the spectral irradiance values to the relative blue light spectral effectiveness curve used by USAEHA between 400 nm and 700 nm. Table 1 contains the effectiveness curve. Since the spectral effectiveness values for wavelengths greater than 700 nm were 1 percent of the maximum, a comparison check was made on a representative sample of events comparing results taken over a limited spectral base (400-700 nm) with results obtained from the full measured spectrum. This comparison check indicated an error of only 1 percent when the reduced spectrum was used. Therefore, a reduced spectrum was used on the remainder of the events with a 1-percent correction added. The blue-light radiance values were calculated by dividing the blue-light irradiance values by the source solid angle.

e. Fume Generation. The generation of smoke and fumes in the vicinity of the arc greatly influenced the total luminance and radiance levels surrounding the arc. Absorption will reduce the irradiance in all directions; whereas attenuation by scattering will tend to enlarge the effective source size and reduce the luminance and radiance of the arc. Exhaust systems were used during all of the measurements in order to minimize this effect. The estimated levels of fume generation for a typical current setting for the processes of interest are given in Table 2.

TABLE 1. SPECTRAL WEIGHTING FUNCTIONS FOR ASSESSING RETINAL HAZARDS FROM BROAD-BAND OPTICAL SOURCES*

Wavelength (nm)	Blue-light Hazard Function $B\lambda$	Burn Hazard Function $R\lambda$
400	0.10	1.0
405	0.20	2.0
410	0.40	4.0
415	0.80	8.0
420	0.90	9.0
425	0.95	9.5
430	0.98	9.8
435	1.0	10
440	1.0	10
445	0.97	9.7
450	0.94	9.4
455	0.90	9.0
460	0.80	8.0
465	0.70	7.0
470	0.62	6.2
475	0.55	5.5
480	0.45	4.5
485	0.40	4.0
490	0.22	2.2
495	0.16	1.6
500-600	$10^{[(450-\lambda)/50]}$	1.0
600-700	0.001	1.0
700-1060	0.001	$10^{[(700-\lambda)/515]}$
1060-1400	0.001	0.2

* 1976 Committee on Physical Agents ACGIH

TABLE 2. APPROXIMATE FUME GENERATION RATES FOR SOME WELDING PROCESSES AND ELECTRODES

Process	Electrode	Shielding Gas	Approx Current Amps	Polarity	Approx Fume Generation Rate g/min
		MILD STEEL TEST PLATE			
GTAW	EWTh-2	Ar	50-300	DCSP	less than 0.2
GTAW	EWTh-2	He	50-275	DCSP	less than 0.2
GMAW	E70S-4	CO_2	90-350	DCRP	0.2 - 0.4
GMAW	E70S-4	95% Ar, 5% O_2	150-350	DCRP	0.2 - 0.4
FCAW	E70T-1	CO_2	175-350	DCRP	0.9 - 1.3
SMAW	E6013	none	100-200	DCRP	0.8 - 1.2
SMAW	E7018	none	100-200	DCRP	0.5 - 0.7
SMAW	E7024	none	100-200	DCRP	0.3 - 0.5
		ALUMINUM TEST PLATE			
GTAW	EWTh-2	Ar	50-265	AC-HF	less than 0.2
GTAW	EWTh-2	He	50-200	AC-HF	less than 0.2
GMAW	E5356	Ar	150-300	DCRP	less than 0.2
GMAW	E5356	He	125-300	DCRP	less than 0.2

6. DISCUSSION

a. Protection Standards.

(1) Visible and Near-Infrared Retinal Burn Hazards. Protection standards for visible and near-infrared radiation are dependent upon the size and spectral characteristics of the source and upon exposure duration (usually limited to 0.25-second aversion response of the eye to bright light). These standards describe maximum permissible exposure levels to eliminate thermal burns to the retina. When the spectral radiance of the source is weighted against the function R (from Table 1), this weighted spectral radiance should not exceed:

$$\sum_{400}^{1400} L_\lambda R_\lambda \Delta\lambda \leq L(Haz) = \sqrt{t}/\alpha t \quad W/(cm^2 \cdot sr) \qquad (1)$$

where: α is the angular subtense of the source in radians and t is the exposure duration. Formula 1 is applicable only for durations between 1 ms and 1 s.

This hazard, however, is overshadowed by the blue-light hazard function for these arc processes. Exposure durations and protective eyewear derived from these protection standards indicated more liberal results than the blue-light criteria; therefore, the retinal burn hazards were not reported.

(2) Blue-light Photochemical Hazard. The retina is most susceptible to photochemical damage from shorter wavelength visible light. This hazard is predominant over thermal hazards when the spectrum of the optical source contains significant amounts of the blue-light. The proposed protection standard and TLV® for exposure to extended-source blue-light is an accumulation of 100 $J/(cm^2 \cdot sr)$ of effective blue-light for exposure durations less than 2.8 hours and an effective irradiance level of blue-light of 10 $mW/(cm^2 \cdot sr)$ for exposure times greater than 2.8 hours. That is:

$$\sum_{400}^{1400} L_\lambda \cdot t \cdot B_\lambda \cdot \Delta\lambda \leq 100 \ J/(cm^2 \cdot sr) \ \text{for} \ t \leq 10^4 \ s \qquad (2)$$

$$\text{or} \ \sum_{400}^{1400} L_\lambda \cdot B_\lambda \cdot \Delta\lambda \leq 0.01 \ W/(cm^2 \cdot sr) \ \text{for} \ t > 10^4 \ s \qquad (3)$$

The blue-light radiant exposure for a "point source" should not exceed 1 mJ/cm^2.

® TLV for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1976, American Conference of Governmental Industrial Hygienists.

(3) Infrared Radiation Hazard.

(a) The Retina. The fraction of near-infrared radiation which actually reaches the retina and is absorbed in the retinal pigmented epithelium (RPE) is relatively small when compared to the fraction of visible light which also is absorbed in the RPE (Figure 3). It is the energy that is absorbed in the RPE that is primarily responsible for the thermal injury of the retina (a "retinal burn"). In general, an injury of the retina from an optical source that occurs within a fraction of a second is probably thermal in nature, whereas injury that requires many seconds or minutes is most likely to be the result of a photochemical damage mechanism. Figure 4 illustrates the very gradual decrease in retinal thermal injury threshold for a near-infrared wavelength (1064 nm) in contrast to the nearly reciprocal relation of exposure and duration for a photochemical injury from blue-light (e.g., 441.6 nm) at exposure durations greater than 16 seconds.[24]

(b) The Lens. Although long-term, repeated exposure of the retina to near-infrared radiation at levels well below the threshold for acute injury is not considered hazardous, the same is not necessarily true for exposure of the lens. The lens of the eye is normally exposed to levels of near-infrared (IR-A) radiation of 1-10 mW/cm^2 when a person is outdoors. Therefore, it seems reasonable that the protective filter should reduce the IR-A irradiance to a level of 1 mW/cm^2 or less. Essentially all of the standard glass welding protection filters provide more than sufficient protection in this regard. It is, however, worthy of note that a group in Germany (references 50 and 51) made similar arguments and came to different conclusions. They also compared the levels encountered in sunlight, but made the connection with welding-arc levels indirectly by relating the ratio of IR-A/visible in sunlight to the ratio of IR-A/visible in welding arcs.

b. Permissible Exposure Duration. The maximum permissible exposure duration for sources which emit blue-light levels in excess of 10 $mW/(cm^2 \cdot sr)$, may be computed in seconds by dividing the protection standard of 100 $J/(cm^2 \cdot sr)$ by the blue-light effective radiance in $W/(cm^2 \cdot sr)$.

---

[24] Ham, W. T., Mueller, H. A., and Sliney, D. H., Retinal sensitivity to damage from short wavelength light, Nature, 260(5547):153-155 (March 1976)

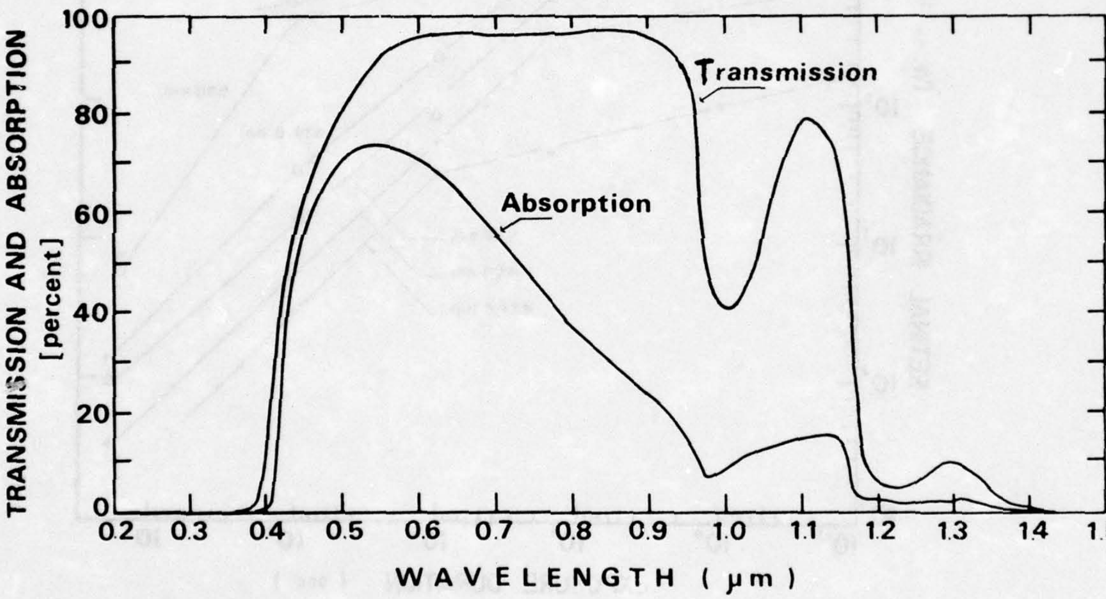


FIGURE 3. TYPICAL SPECTRAL TRANSMITTANCE OF THE OCULAR MEDIA (CORNEA, AQUEOUS, LENS, AND VITREOUS) AND ABSORPTION IN THE HUMAN RETINA

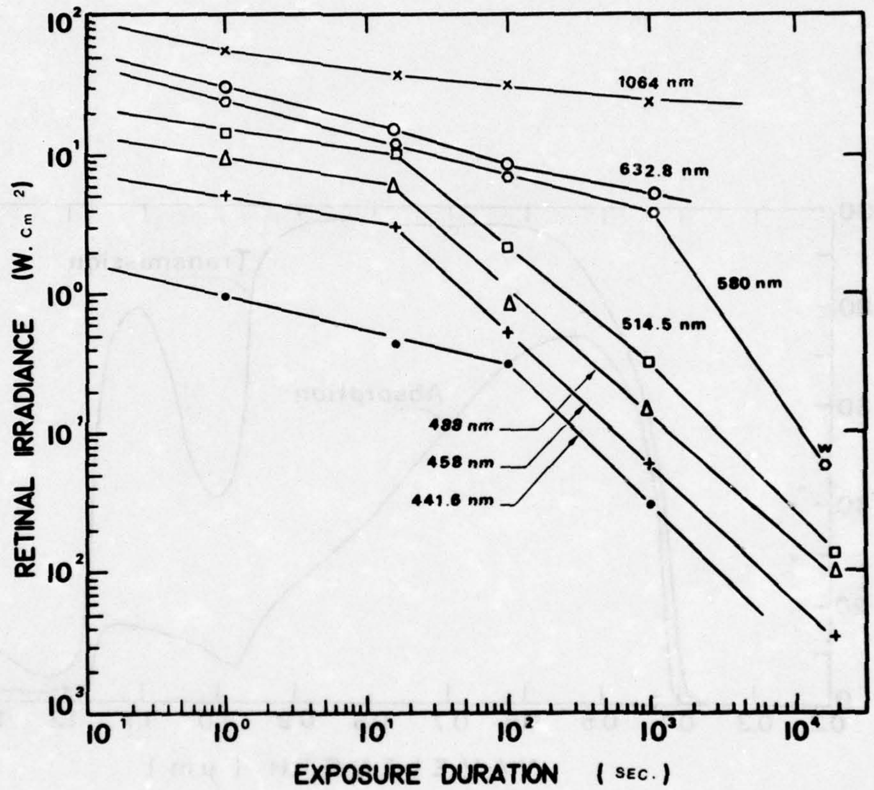


FIGURE 4. COLLECTIVE DATA FOR RETINAL INJURY FROM LONG-TERM EXPOSURES OF THE RHESUS MONKEY RETINA TO EXTENDED SOURCES. DATA POINTS FOR EXPOSURES LESS THAN 1.4 X 10^4 ARE FROM HAM, ET AL. (NATURE, 1976) AND DATA POINTS FOR 4-HOUR EXPOSURE (1.4 x 10^4s) ARE FROM LAWWILL (TO BE PUBLISHED, 1977). ALL DATA POINTS ARE FOR LASER LINES EXCEPT FOR POINT "W" WHICH IS FOR A WHITE-LIGHT SOURCE

c. Protective Filters. The shade number of a welding protective filter describes the ability of the filter to reduce the level of radiation reaching the operator's eyes. The level of attenuation needed, A, may be computed in several ways. To protect against the blue-light hazard, A was computed by dividing 1×10^4 by the permissible blue-light exposure time. These attenuation factors have been usually represented by either optical density values (OD) or shade numbers. Another means of computing the attenuation required is to compute a "comfortable shade number." In this case, it is presumed that a luminance of 1 cd/cm^2 is always comfortable to view for small sources sizes, and that the attenuation factor A is the luminance of the arc in cd/cm^2 divided by 1 cd/cm^2. Shade number or OD values may be obtained through the use of the following equations:

$$\text{Shade} = \ln A + 1 = (7/3) \log A + 1$$

$$\text{OD} = \log A$$

In the past, these shade numbers or optical density values have always represented attenuations specified photometrically across the visible spectrum. Actual filters, will vary in spectral transmittance over this region but must meet the photometric transmittance as specified in ANSI Z87.1-1968. Table 1, Appendix F, provides these values as well as limits at 405 nm (blue) and in the ultraviolet and infrared. Filters used should have an attenuation of at least the calculated value of Appendix E at the peak of the blue-light biological effectiveness curve (437 nm). Transmission at other wavelengths outside the 400-500 nm band may vary greatly without adverse effects. If large variations in optical density occur for a particular filter material, the filter should be analyzed spectrally with various welding processes to determine the degree of protection. Minimal shade numbers for the various welding processes are given in Appendix E as calculated from both luminous transmittance for "comfortable shade number" and for blue-light transmittance. Table 2, Appendix F, provides the shade number conventionally recommended.

d. Variation of Radiometric Parameters with Arc Current. In the previous report in this series, it was reported that the ultraviolet radiation most often increased with the square of the current. In this study, the irradiance and the source radiance generally did not follow such straightforward relations, largely because of arc constriction. As the arc current increased, the current density increased and a contraction, or "pinch effect," due to the magnetic field increase reduced the source size and, hence, the solid angle subtended by the arc. This caused an increase in radiance and luminance. At lower currents, the luminance often appeared to remain relatively constant. As the constriction of the arc takes place, the arc moves into a more stable configuration and metal transfer changes from globular transfer to a more uniform spray. The irradiance-time history of several representative arcs are shown in the last Figures for each group of events presented in Appendix E. Once the arc luminance and radiance increased, these parameters approached a relation proportional to the square of the current, although the approximate increase was most often closer to the current raised to the 1.8 power. Looking at Table 17, Appendix É, we see the summary of the measurements made by the EG&G Model 585 Spectroradiometer and the Pritchard photometer, which were generally the most reliable measurements. There were several instances of wildly fluctuating luminance values even from the Pritchard instrument which may be due to arc instabilities at those current levels. The field of view of the Pritchard photometer was 2 arc-minutes, which corresponded to 1-2 mm at the viewing distances used in these studies. For this reason, the luminances calculated using the EG&G 585 data and the photographically determined arc area were often greater when the arc size was small, since the area seen by the Pritchard photometer was a large portion of the arc.

7. CONCLUSION. Electric welding and cutting arcs emit sufficient optical radiation to exceed the current and proposed protection standards for the eye and skin to individuals exposed to the arc without protection. However, welding and cutting arcs may be operated safely provided that the operators and bystanders are informed of potential hazards, permissible viewing durations, and take appropriate precautions. Present welding filter specifications are adequate. Some increased visible transmittance of filters at longer wavelengths in the visible may be possible.

8. RECOMMENDATIONS. The following recommendations apply to personnel working in the vicinity of welding arcs.

a. Avoid staring into the arc without appropriate filter lenses (paragraph 1-4d, AR 40-46).

b. Limit the exposure duration to unprotected individuals such as bystanders, some welders' helpers, and passersby as necessary as determined from Appendix E (paragraph 1-4d, AR 40-46).

c. Operators should wear eye filter shields with shade numbers at least as great as the values provided in Appendix E (paragraph 1-4d, AR 40-46). The standard shade numbers presented in Appendix F provide more than adequate protection.

d. Welding and cutting operations should be screened or employ other structures to eliminate hazardous direct-exposure conditions for adjacent unprotected personnel whenever possible (paragraph 1-4d, AR 40-46).

WESLEY J. MARSHALL
Physicist
Laser Microwave Division

DAVID H. SLINEY
Chief, Laser Branch
Laser Microwave Division

TERRY L. LYON
Physicist
Laser Microwave Division

NICHOLAS P. KRIAL
Electronics Technician
Laser Microwave Division

PEDRO F. DEL VALLE
1LT, MSC
Nuclear Medical Science Officer
Laser Microwave Division

APPROVED:

DAVID H. SLINEY
Acting Chief, Laser Microwave Division

ROBERT T. WANGEMANN, Ph.D.
LTC, MSC
Director, Radiation and
Environmental Sciences

APPENDIX A

LITERATURE CITED

1. American National Standards Institute (ANSI) Standard No. Z49.1-1973, Safety in Welding and Cutting, New York (1973)

2. ANSI Standard No. Z87.1-1968, Standard Practice for Occupational and Educational Eye and Face Protection, New York (1968)

3. Anonymous, Plasma jet cutting technique -- the need to conform to safety rules, Bedrijf en Teckniek - A, 24(618):450-452 (1969)

4. Anonymous, Bright sunlight increases eye hazard when arc welding, a case history, Ind Med Surg., 36(7):478 (1967)

5. Bates, C. C., The effects on the human eye of the radiant energy given off by various welding processed, Sheet Metal Industries, 29:349-357 (April-May 1952)

6. Campbell, D. L., Welding Filter Plates, HEW Publication No. (NIOSH) 76-18, US Department of Health Education and Welfare, Washington, DC (1976)

7. Devore, R. K., "The Effective Spectral Irradiance of Ultraviolet Radiations from Inert-Gas-Shielded Welding Processes in Relation to the Arc Current Density," A Thesis submitted to the Texas A&M University (December 1973)

8. Chou, T. S., and Pfender, E., Spot formation at the anode of high intensity arcs, Warme und Stoff., 6:69-77 (1973)

9. Clark, B. A. J., "Spectral-transmissive Requirements for Welding Filters," International Institute of Welding, Document VII:365-369 (1969)

10. Clarke, A. M., Geeraets, W. J., and Ham, W. T., Jr., An equilibrium thermal model for retinal injury from optical sources, Appl. Optics, 8:1051-10 (1969)

11. Coblentz, W. W., and Stair, R., Correlation of the shade numbers and densities of eye-protective glasses, J. Opt. Soc. Am., 20:624-629 (November 1930)

12. Dahlberg, J. A., The intensity and spectral distribution of ultraviolet emission from welding arcs in relation to the photodecomposition of gases, Ann. Occup Hyg., 14:259-267 (1971)

13. Drinker, P., The measurement and prevention of eye flash, Welding J., 23(6):505-506 (1944)

14. Duke-Elder, S. and MacFaul, P. A., "Injuries, Non-Mechanical Injuries," in Duke-Elder, S., System of Opththalmology, Vol. 14, part 2, St Louis, C. V. Mosby, p. 893 (1972)

15. Edebrooke, C. M., and Edwards, C., Industrial radiation cataract: the hazards and the protective measures, Ann. Occ. Health, 10:293-304 (1967)

16. Emmett, E. A., and Horstman, S. W., Factors influencing the output of ultraviolet radiation during welding, J. Occ Med., 18(1):41-44 (January 1976)

17. English, W. P., Eye Protection for welders, ASSE Journal, :39-43 (July 1973)

18. Ferry, Ultraviolet emission during inert-arc welding, Industr. Hyg. Quart., :73-77 (March 1954)

19. Frant, R., Radiation Problems associated with welding, Z. Schweisstechnik - J. Soudure, 58(9)"285-289 (1968)

20. Geeraets, W. J., and Berry, E. R., Ocular spectral characteristics as related to hazards from lasers and other light sources, Amer. J. Ophthal., 66:15-20 (1968)

21. Glickstein, S. S., Temperature Measurements in a free-burning arc, Welding J. Pres Suppl., 55(8):2225-2275 (August 1976)

22. Gupta, M. N., and Singh, H., "Ocular Effects and Visual Performance in Welder," Report No. 27 of the Central Labour Institute, Ministry of Labour, Government of India, Sion-Bombay (1968)

23. Ham, W. T., Jr., Mueller, H. A., Williams, R. C., and Geeraets, W. J., Ocular hazard from viewing the sun unprotected and through various windows and filters, Appl. Optics, 12(9):2122-2129 (September 1973)

24. Ham, W. T., Mueller, H. A., and Sliney, D. H., Retinal sensitivity to damage from short wavelength light, Nature, 260(5547):153-155 (March 1976)

25. Högger, D., Die Gesundheitsgefasthrdungen im Berufe des Schweissers, Gesundh. u. Wohlf., 24:549-566 (1944)

26. Hornell, A., and Wulcan, J., "Spektralfordelningen hos Svetsljusbagar i Vaglangdsomradet 200-1200 nm," Thesis for the School of Electrical Engineering, Chalmers University of Technology, Goteborg, Sweden (1972)

27. Hoyaux, M. F., Arc Physics, Springer-Verlag, New York, 1968

28. Hubner, H. J., Krause, E., Ruge, J., and Sutter, E., Strahlungsmessungen beim Lichtbogenschweissen nach verschiedenen Verfahren (einschliesslich Plasmaschneiden)--Beitrag zur Uberarbeitung von DIN 4647 Blatt 1, "Verwendung von Sichtscheiben fur Augenschutzgerate; Schweisserschutzfilter," Schweissen und Schneiden (Welding and Cutting) 24:290 (1972)

29. Hubner, H. J., Sutter, E., and Wicke, K., Messung der Strahlungsleistung beim Schweissen und Folgerungen fur den Schutz der Augen gegen Infrarotstrahlung, Optik, 31:462-476 (Available in English translation as National Research Council of Canada translation TT-1563) (1970)

30. Kinsey, V. E., Cogan, D. G., and Drinker, P., Measuring eye flash from welding, J Am Med Assn, 123(7):403-4 (1943)

31. Kleinfeld, M., Giel, C., and Tabershaw, J. R., Health hazards associated with inert-gas-shielded metal-arc welding, AMA Arch. Industr. Health, 15(11):27-31 (1957)

32. Levin, M., Ostberg, O., Knave, B., and Ottosson, A., Matning av Optisk Stralning -- Arbetshygienisk Bedomning av Ljusbagen i plasmaskaannarc (Measurements and criteria of optical radiations of the plasma torch), Underokingsrapport AMMF 103/76, Arbetarskyddsstyrelsen (1976)

33. Malek, B., The problems with health protection plasma torch welding, Zvaranie, 19(2):46-52 (1970)

34. Malek, B., Novotna, J., and Trnka, J., "The Hygienic Significance of Radiation in the Wavelength Range from 200 nm to Visible Length in Electric Arc Welding," Document VIII-531-73, International Institute of Welding, Bratislava (June 1973)

35. Maurelli, C., Vetri di protezione per i saldatori nelle nuove norme della B.S.I., Securitas, 33:32-36 (1948)

36. Mechev, V. S., and Eroshenko, L. E., Research into the spectrum of radiation by the argon-shielded arc close to the electrodes, Automatic Weld., 25(8):57-61 (August 1972)

37. Mechev, V. W., and Eroshenko, L. E., Determining the temperature of the plasma in an arc discharge in argon, Avt. Svarka, 8:1-6 (1970)

38. Migai, K. V., Special clothing and footwear for electric welders, Automatic Welding, 22(10):63-67 (1969)

39. Minton, J., Occupational diseases of the lens and retina, Brit. Med. J., 1:392-5 (March 5, 1949)

40. Naidoff, M. A., and Sliney, D. H., Retinal injury from a welding arc, Am. J. Opthal., 77(5):663-668 (May 1974)

41. Olsen, H. N., "Determination of Properties of an Optically Thin Argon Plasma," in Temperature, Its Measurement and Control in Science and Industry, (Herzfeld, C. M., ed.) Vol III, pp. 593-606, Reinhold Publishing Co., NY, Part 1, 1962

42. Pattee, H. E., Myers, L. B., Evans, R. M., and Monroe, R. E., Effects of arc radiation and heat on welders, Welding J. Res., 52(5):297-308 (May 1973)

43. Powell, C. H., Goldman, L., and Key, M. M., Investigative studies of plasma torch hazards, Am. Industr. Hyg. Assn. J., 29(4):381-385 (July-August 1968)

44. Rauh, F., Ein eigenartiger Fall von Veranderung der Netzhautmitte, Z. f. Augenheilik., 63:48-64 (1927)

45. Rieke, F. E., Arc flash conjunctivitis: actinic conjunctivitis from electric welding arcs, J. Am. Med. Assn., 122:734-736 (July 10, 1943)

46. Rosskopf, T., Relation between welding current and appropriate transmission of filter glasses, Welding J., 32(8):689-691 (1953)

47. Rutgers, G. A. W., Protective glasses for welding, Doc. Ophthalmologica, 4:320-333 (1950)

48. Sliney, D. H., and Freasier, B. C., Evaluation of optical radiation hazards, Appl. Optics, 12(1):1-24 (1973)

49. Stutz, G. F. A., Observations of Spectro-photometric measurements of paint vehicles and pigments in the ultraviolet, J. Franklin Inst., 220:87-102 (1925)

50. Sutter, E., Hubner, H. J., Krause, E., and Ruge, J., Strahlungsmessungen an verschiedenen Lichtbogen-Schweissverfahren, Report No. Optik 2/72 of the Physikalisch-Technische Bundesanstalt, Braunschweig, W. Germany (April 1972)

51. Sutter, E., and Zander, K., Anforderungen an den IR- und UV-Transmissionsgrad von Augenschutzfiltern, Zentralblatt fur Arbeitsmedizin und Arbeitsschutz, 23(9):275-279 (September 1973)

52. Szafran, L., Znetnienia soczewki o cechach zacmy hutniczej u spawacza, (A lens opacity with the morphological features of smelting cataract in a welder), Med. Pracy, 16(3):246-249 (1965)

53. Tengroth, B., "Safety Glasses in Welding," presentation at the International Shipyard Health Conference, University of Southern California School of Medicine, Los Angeles (December 13, 1973)

54. Terrien, F., Des trouble visual provoque por l'electricete, Arch. Ophthalmol., 22:692- (French) (1902)

55. Van Someren, E., and Rollason, E. C., Radiation from the welding arc, Welding Journal Research Supplement, 27(9):448-452s (September 1948), and 28:566 (1949)

56. Wickstrom, Welding health hazards, Ehkaise Tapaturmia -- Forebygg Olycksfall, 2:4-9 (1972)

57. Wurdemann, H. V., The formation of a hole in the macula, light burn from exposure to electric welding, Am. J. Ophthalmol., 19:457-4 (1936)

APPENDIX B

MEMBERSHIP OF AMERICAN WELDING SOCIETY REVIEWING COMMITTEE

Mr. John F. Hinrichs (Chairman)	A. O. Smith Corp
Mr. Robert R. McCutchen (Vice Ch)	Caterpillar Tractor Co
Mr. Francis Eugene Smith (Sec'y)	Jackson Products
Mr. E. L. Alpaugh	International Harvester Co.
Mr. Michael Clissa	Chemetron Corp
Mr. Gerald R. Crawmer	General Electric Co
Mr. Robin K. DeVore	Los Alamos Scientific Laboratory
Mr. Stanley S. Glickstein	Westinghouse-Bettis Atomic Power Lab
Mr. John A. Hogan	Hypertherm Inc
Mr. Bill Koepnick	Harnischfeger Corp
Mr. David LaMarre	American Optical Corp
Mr. Terry Lyon	USA Environmental Hygiene Agency
Mr. William E. Murray	PAB/NIOSH
Dr. Wordie H. Parr	PAB/NIOSH
Mr. Donald E. Powers	Leybold-Heraeus Vacuum Systems Inc.
Dr. Al Sherr	American Cyanamid Co
Mr. David H. Sliney	USA Environmental Hygiene Agency
Mr. O. A. Ullrich	Batelle Columbus Laboratories

---

* American Welding Society Project Committee on Radiation

APPENDIX C

TABLES OF TERMS, UNITS AND SYMBOLS

TABLE 1. RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS[1 2]

RADIOMETRIC				PHOTOMETRIC			
Term	**Symbol**	**Defining Equation**	**SI Unit and Abbreviation**	**Term**	**Symbol**	**Defining Equation**	**SI Units and Abbreviation**
Radiant Energy	Q_e		Joule (J)	Quantity of Light	Q_v	$Q_v = \int \Phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	W_e	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter ($J\cdot m^{-3}$)	Luminous Energy Density	W_v	$W_v = \frac{dQ_v}{dV}$	talbot per square meter ($lm\cdot s\cdot m^{-3}$)
Radiant Power (Radiant Flux)	Φ_e, P	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	Φ_v	$\Phi_v = 680 \int \frac{d\Phi_e}{d\lambda} V(\lambda)\, d\lambda$	lumen (lm)
Radiant Exitance	M_e	$M_e = \frac{d\Phi_e}{dA} = \int L_e \cdot \cos\theta \cdot d\Omega$	Watt per square meter ($W\cdot m^{-2}$)	Luminous Exitance	M_v	$M_v = \frac{d\Phi_v}{dA} = \int L_v \cdot \cos\theta \cdot d\Omega$	lumen per square meter $lm\cdot m^{-2}$
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E_e	$E_e = \frac{d\Phi_e}{dA}$	Watt per square meter ($W\cdot m^{-2}$)	Illuminance (luminous flux density)	E_v	$E_v = \frac{d\Phi_v}{dA}$	lumen per square meter ($lm\cdot m^{-2}$) lux (lx)
Radiant Intensity	I_e	$I_e = \frac{d\Phi_e}{d\Omega}$	Watt per steradian ($W\cdot sr^{-1}$)	Luminous Intensity (candlepower)	I_v	$I_v = \frac{d\Phi_v}{dr}$	lumen per steradian (lm·sr) or candela (cd)
Radiance	L_e	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	Watt per steradian and per square meter ($W\cdot sr^{-1}\cdot m^{-2}$)	Luminance	L_v	$L_v = \frac{d^2\Phi_e}{dr \cdot dA \cdot \cos\theta}$ [5]	candela per square meter ($cd\cdot m^{-1}$)
Radiant Exposure (Dose, in Photobiology)	H_e	$H_e = \frac{dQ_e}{dA}$	Joule per square meter ($J\cdot m^{-2}$)	Light Exposure	H_v	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	K	$K = \frac{\Phi_v}{\Phi_e}$	lumen per watt ($lm\cdot W^{-1}$)
				Luminous Efficiency (of a broad band radiation)	V(•)	$V(\bullet) = \frac{K}{K_m} = \frac{K}{680}$	unitless
Radiant Efficiency [3] (of a source)	η_e	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy[3] (of a source)	η_v	$\eta_v = \frac{\Phi_v}{P_i}$	lumen per watt ($lm\cdot W^{-1}$)
Optical Density [4]	D_e	$D_e = -\log_{10} \tau_e$	unitless	Optical Density[4]	D_v	$D_v = -\log_{10} \tau_v$	unitless
				Retinal Illuminance in Trolands	E_t	$E_t = \frac{L_v}{S_p}$	troland (td) = luminance in $cd\cdot m^{-2}$ times pupil area in mm^2

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript λ. For example, spectral irradiance E_λ has units of $W\cdot m^{-2}\cdot m^{-1}$ or more often, $W\cdot cm^{-2}\cdot nm^{-1}$.
2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or um are most commonly used to express wavelength.
3. P_i is electrical input power in watts.
4. τ is the transmission
5. At the source $L = \frac{dI}{dA\cdot\cos\theta}$ and at a receptor $L = \frac{dE}{d\Omega}$

TABLE 2. SYMBOLS UNIQUE TO THIS REPORT

I	Arc current
L_v	Luminance of arc
L_e	Radiance of arc
L_b	Blue-light radiance of arc
t	Recommended maximum exposure duration at close distances
S_a	ANSI recommended shade number
S_c	Shade number required for comfortable viewing of the arc
S_b	Shade number required for eye protection for long-term viewing (blue-light hazard criteria)
d	Distance at which arc becomes a point image
CI	Contour Interval (difference in density between two consecutive contours)

APPENDIX D

GLOSSARY OF TERMS USED IN WELDING TECHNOLOGY AND OPTICAL RADIATION HAZARD ANALYSIS*

---

* Terms related to welding technology are from the AWS Welding Handbook, ed. with permission of the copyright owner - The American Welding Society.

accommodation - the ability of the eye to adjust focus for various distances

aphakia - having no lens in the eye, e.g., after cataract removal

aqueous humor - fluid in the anterior chamber of the eye

base metal (material) - the metal (material) to be welded, brazed, soldered, or cut - see also substrate

blepharitis - inflammation of the eyelids

blepharospasm - spasm of eyelid muscles

blind spot - normal defect in visual field due to position at which optic nerve enters the eye

cataract - an opacity (cloudiness) of the lens

incipient - any cataract in its early stages, or one which has sectors of opacity with clear spaces intervening

congenital - one which originates before birth

senile - a hard opacity of the lens occurring in the aged

chorioretinitis - inflammation of the choroid and retina

choroid - vascular layer adjacent to the retina - its function is to nourish the retina

coalescence - the growing together or growth into one body of the materials being welded

cone, retinal - specialized visual cell in the retina; the cones are responsible for sharpness of vision and color vision

conjunctiva - the delicate membrane that lines the eyelids and covers the exposed surface of the eyeball

constricted arc (plasma arc welding and cutting) - a plasma arc column that is shaped by a constricting nozzle orifice

constricting nozzle (plasma arc welding and cutting) - a water cooled copper nozzle surrounding the electrode and containing the constricting orifice

constricting orifice (plasma arc welding and cutting) - the hole in the constricting nozzle through which the arc passes contact tube - a device which transfers current to a continuous electrode

CO_2 welding - see preferred term gas metal arc welding

direct current electrode negative - the arrangement of direct current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc - see also straight polarity

direct current electrode positive - the arrangement of direct current arc welding leads in which the work is the negative pole and the electrode is the positive pole of the welding arc - see also reverse polarity

direct current reverse polarity (DCRP) - see reverse polarity and direct current electrode positive

direct current straight polarity (DCSP) - see straight polarity and direct current electrode negative

electrode -

arc welding electrode - a component of the welding circuit through which current is conducted between the electrode holder and the arc

bare electrode - a filler metal electrode consisting of a single metal or alloy that has been produced into a wire, strip, or bar form and that has had no coating or covering applied to it other than that which was incidental to its manufacture or preservation

covered electrode - a composite filler metal electrode consisting of a core of a bare electrode or metal cored electrode to which a covering sufficient to provide a slag layer on the weld metal has been applied - the covering may contain materials providing such functions as shielding from the atmosphere, deoxidation, and arc stabilization and can serve as a source of metallic additions to the weld

flux cored electrode - a composite filler metal electrode consisting of a metal tube or other hollow configuration containing ingredients to provide such functions as shielding atmosphere, deoxidation, arc stabilization and slag formation - alloying materials may be included in the core - external shielding may or may not be used

metal cored electrode - a composite filler metal electrode consisting of a metal tube or other hollow configuration containing alloying ingredients - minor amounts of ingredients providing such functions as arc stabilization and fluxing of oxides may be included - external shielding gas may or may not be used tungsten electrode - a nonfiller metal electrode used in arc welding or cutting, made principally of tungsten

electrode extension (gas metal arc welding, flux cored arc welding, submerged arc welding) - the length of unmelted electrode extending beyond the end of the contact tube during welding

electrode holder - a device used for mechanically holding the electrode while conducting current to it

electrode lead - the electrical conductor between the source of arc welding current and the electrode holder

electrode setback (plasma arc welding and cutting) - the distance the electrode is recessed behind the constricting orifice measured from the outer face of the nozzle

emmetropia - a state of perfect vision

etiology - the cause of a disease

flash blindness - temporary visual disturbance resulting from viewing an intense light source

flux cored arc welding (FCAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work - shielding is provided by a flux contained within the tubular electrode - additional shielding may or may not be obtained from an externally supplied gas or gas mixture - see flux cored electrode

flux cored electrode - see electrode

fovea - a depression or pit in the center of the macula; it is the area of clearest vision

fundus - the interior surface of a hollow organ, as the retina of the eye

fusion - the melting together of filler metal and base metal (substrate), or of base metal only, which results in coalescence

fusion welding - any welding process or method which used fusion to complete the weld gas metal arc welding (GMAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a continuous filler metal (consumable) electrode and the work - shielding is obtained entirely from an externally supplied gas or gas mixture - some methods of this process are called MIG or CO_2 welding

gas tungsten arc welding (GTAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a tungsten (nonconsumable) electrode and the work - shielding is obtained from a gas or gas mixture - pressure may or may not be used and filler metal may or may not be used (this process has sometimes been called TIG welding)

ground connection - an electrical connection of the welding machine frame to the earth for safety - see also work connection and work lead

ground lead - see preferred term work lead

gun - arc welding gun - in semiautomatic, machine, and automatic welding, a manipulating device to transfer current and guide the electrode into the arc - it may include provisions for shielding and arc initiation

heat-affected zone - that portion of the base metal which has not been melted, but whose mechanical properties or microstructure have been altered by the heat of welding, brazing, soldering, or cutting

inert gas - a gas which does not normally combine chemically with the base metal or filler metal - see also protective atmosphere

inert-gas metal arc welding - see preferred term gas metal arc welding

inert-gas tungsten arc welding - see preferred term gas tungsten arc welding

infrared radiation - electromagnetic energy with wavelengths from 770 nm to 12000 nanometers

iritis - inflammation of the iris

irradiance - (E) - radiant flux (radiant power) per unit area incident upon a given surface [units of W/cm^2]

keratitis - inflammation of the cornea; usually characterized by loss of transparency and dullness

keyhole - a technique of welding in which a concentrated heat source penetrates completely through a workpiece forming a hole at the leading edge of the molten weld metal - as the heat source progresses, the molten metal fills in behind the hole to form the weld bead lens, crystalline - lens of the eye: a transparent biconvex body situated between the anterior chamber (aqueous) and the posterior chamber (vitreous) through which the light rays are further focused on the retina - the cornea provides most of the refractive power of the eye

lenticular (adj) - pertaining to the lens of the eye

machine welding - welding with equipment which performs the welding operation under the constant observation and control of a welding operator - the equipment may or may not perform the loading and unloading of the work

macula - an oval area in the center of the retina devoid of blood vessels; the area most responsible for color vision

manual welding - a welding operation performed and controlled completely by hand

MIG welding - see preferred terms gas metal arc welding, flux cored arc welding

miosis - reduction in the size of the pupil

molten weld pool - the liquid state of a weld prior to solidification as weld metal

nanometer - 10^{-9} meter, preferred unit for wavelength in the ultraviolet, visible and near-infrared spectral region

nontransferred arc (plasma arc welding and cutting, and thermal spraying) - an arc established between the electrode and the constricting nozzle - the workpiece is not in the electrical circuit - see transferred arc

nozzle - a device which directs shielding media

opacity - the condition of being nontransparent, a cataract

open-circuit voltage - the voltage between the output terminals of the welding machine when no current is flowing in the welding circuit

ophthalmologist - a medical practitioner specializing in the medical and surgical care of the eyes

ophthalmoscopy, direct - the observation of an upright mirrored image of the interior of the eye through the use of an ophthalmoscope ophthalmoscopy, indirect - the observation of an inverted image of the interior of the eye

optic disc - the portion of the optic nerve within the eye which is formed by the meeting of all the retinal nerve fibers at the level of the retina

orbit - the cavity in the skull which contains the eyeball

orifice gas (plasma arc welding and cutting) - the gas that is directed into the torch to surround the electrode - it becomes ionized in the arc to form the plasma, and issues from the orifice in the torch nozzle as the plasma jet

orifice throat length (plasma arc welding and cutting) - the length of the constricting orifice

parent metal - see preferred term base metal

photophobia - abnormal sensitivity to and discomfort from light

pigment epithelium - a layer of cells in the retina containing pigment granules

pilot arc (plasma arc welding) - a low current continuous arc between the electrode and the constricting nozzle to ionize the gas and facilitate the start of the main welding arc

plasma - a gas that has been heated to an at least partially ionized condition, enabling it to conduct an electric current

plasma arc cutting (PAC) - an arc cutting process which severs metal by melting a localized area with a constricted arc and removing the molten material with a high velocity jet of hot, ionized gas issuing from the orifice

plasma arc welding (PAW) - an arc welding process which produces coalescence of metals by heating them with a constricted arc between an electrode and the workpiece (transferred arc) or the electrode and the constricting nozzle (nontransferred arc) - shielding is obtained from the hot, ionized gas issuing from the orifice which may be supplemented by an auxiliary source of shielding gas - shielding gas may be an inert gas or a mixture of gases - pressure may or may not be used, and filler metal may or may not be supplied

plenum (plasma arc welding and cutting, and thermal spraying) - the space between the inside wall of the constricting nozzle and the electrode polarity - see direct current electrode negative, direct current electrode positive, straight polarity, and reverse polarity

protective atmosphere - a gas envelope surrounding the part to be brazed, welded or thermal sprayed, with the gas composition controlled with respect to chemical composition, dew point, pressure, flow rate, etc

pterygium - a growth of the conjunctiva considered to be due to a degenerative process caused by long continued irritation as from exposure to wind, dust, and possibly to ultraviolet radiation

puddle - see preferred term molten weld pool

pupil - the opening at the center of the iris of the eye for the transmission of light - the pupil size varies from 2 mm to 8 mm

radiance - (L) - radiant flux (power) output per unit solid angle per unit area [units of $W/cm^2 .sr$)]

retina - the innermost coat of the posterior part of the eyeball, surrounding the vitreous body and responsible for vision

reverse polarity - the arrangement of direct current are welding leads with the work as the negative pole and the electrode as the positive pole of the welding arc

sclera - the tough, white, protective coat of the eye

scotoma - a blind or partially blind area in the visual field

semiautomatic arc welding - arc welding with equipment which controls only the filler metal feed - the advance of the welding is manually controlled

shielded metal arc welding (SMAW) - an arc welding process which produces coalescence of metals by heating them with an arc between a covered metal electrode and the work - shielding is obtained from decomposition of the electrode covering - pressure is not used and filler metal is obtained from the electrode

shielding gas - protective gas used to prevent atmospheric contamination

slit-lamp - an instrument producing a slender beam of light for illuminating any reasonably transparent structure, as the cornea, or lens

stick electrode - see electrode: covered electrode

stick electrode welding - see preferred term shielded metal arc welding stickout - see preferred term electrode extension

strabismus - squint; failure of the two eyes simultaneously to direct their gaze at the same object because of muscle imbalance

straight polarity - the arrangement of direct current arc welding leads in which the work is the positive pole and the electrode is the negative pole of the welding arc - a synonym for direct current electrode negative

substrate - any base material to which a thermal sprayed coating or surfacing weld is applied

tear film - microscopically thin lipid film which constantly bathes cornea

torch - see preferred terms welding torch, cutting torch, spray torch

transferred arc (plasma arc welding) - a plasma arc established between the electrode and the workpiece

tungsten electrode - see electrode: tungsten electrode

vision, photopic - vision attributed to cone function characterized by the ability to discriminate colors and small detail; daylight vision

vision, scotopic - vision attributed to rod function characterized by the lack of ability to discriminate colors and small detail and effective primarily in the detection of movement and low luminous intensities - night vision

visual acuity - ability of the eye to sharply perceive the shape of objects in the direct line of vision

visual axis - the central line of gaze

visual cortex - final station of visual impulses in the brain; sensory area of brain responsible for vision

visual field - the area of physical space visible to an eye in a given position

vitreous or vitreous body - transparent, colorless mass of soft gelatinous material filling the posterior chamber of the eyeball (behind the lens)

weld - a localized coalescence of metals or nonmetals produced either by heating the materials to suitable temperatures, with or without the application of pressure, or by the application of pressure alone, and with or without the use of filler material welder - one who performs a manual or semiautomatic welding operation (sometimes erroneously used to denote a welding machine)

welding - a materials joining process used in making welds (see the Master Chart of Welding and Allied Processes)

welding current - the current in the welding circuit during the making of a weld - in resistance welding, the current used during a preweld or postweld interval is excluded

welding electrode - see preferred term electrode

welding generator - a generator used for supplying current for welding

welding ground - see preferred term work connection

welding head - the part of a welding machine or automatic welding equipment in which a welding gun or torch is incorporated

welding leads - the work lead and electrode lead of an arc welding circuit

welding machine - equipment used to perform the welding operation - for example, spot welding machine, arc welding machine, seam welding machine, etc

welding operator - one who operates machine or automatic welding equipment

welding procedure - the detailed methods and practices including all joint welding procedures involved in the production of a weldment

welding process - a materials joining process which produces coalescence of materials by heating them to suitable temperatures, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal (see the Master Chart of Welding and Allied Processes)

welding rectifier - a device in a welding machine for converting alternating current to direct current

welding rod - a form of filler metal used for welding or brazing which does not conduct the electrical current

welding tip - a welding torch tip designed for welding

welding torch - a device used in oxyfuel gas welding or torch brazing for mixing and controlling the flow of gases welding transformer - a transformer used for supplying current for welding

welding wire - see preferred terms electrode and welding rod

weld metal - that portion of a weld which has been melted during welding

weld metal area - the area of the weld metal as measured on the cross section of a weld

weldor - see preferred term welder

wire feed speed - the rate of speed in mm/s or in/min at which a filler metal is consumed in arc welding or thermal spraying

wire straightener - a device used for controlling the cast of coiled wire to enable it to be easily feed into the gun

work connection - the connection of the work lead to the work

work lead - the electric conductor between the source of arc welding current and the work

APPENDIX E

TABLE 1. WELDING PARAMETERS FOR EVENTS 1 to 7.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 300 A

Polarity: DCSP

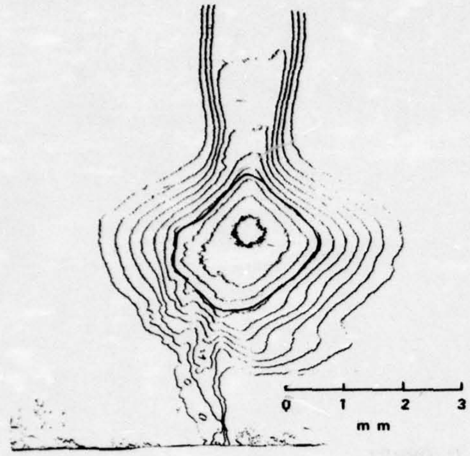
Shielding Gas: Ar at 20 cfm

Arc Length: 1/16" (0.062" to 0.089")

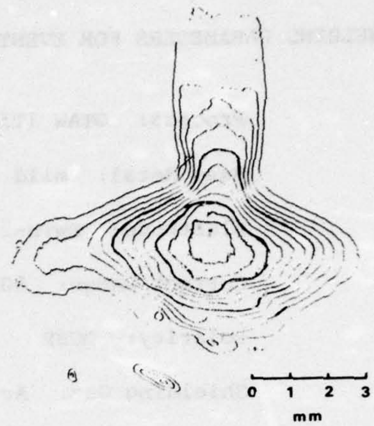
Electrode Diameter: 1/16" (50 to 100A), 3/32" (150 to 200A), and 1/8" (250 to 300A)

SUMMARY OF RESULTS

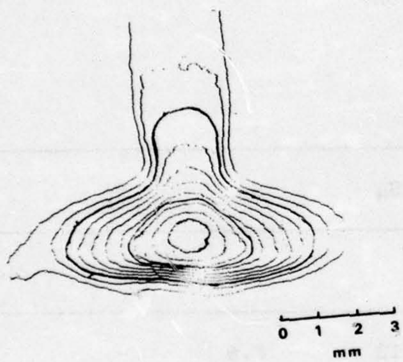
I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[$W/(cm^2 \cdot sr)$]		(s)				(cm)
50	2,100	-	-	-	12	8.6	-	-
100	3,900	94.6	9.26	10.8	12	9.3	7.8	59
150	4,500	76.6	12.0	8.3	12	9.4	8.1	79
200	6,400	474	22.5	4.4	12	9.8	8.7	66
250	9,000	353	60.7	1.6	12	10.1	9.7	66
300	10,000	738	135	0.7	12	10.3	10.5	54



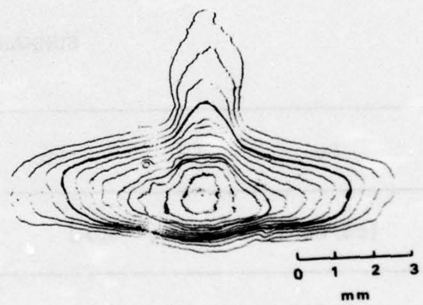
Event 2, 100 A, CI=0.14



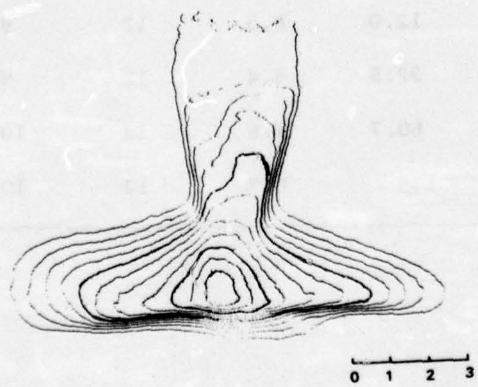
Event 3, 150 A, CI=0.15



Event 4, 200 A, CI=0.12



Event 5, 250 A, CI=0.12



Event 6, 300 A, CI=0.15

Figure 1a. Microdensitometer Scans of 35 mm Processed Negatives Exposed 4 m from the Welding Arcs for Events 1 to 7.

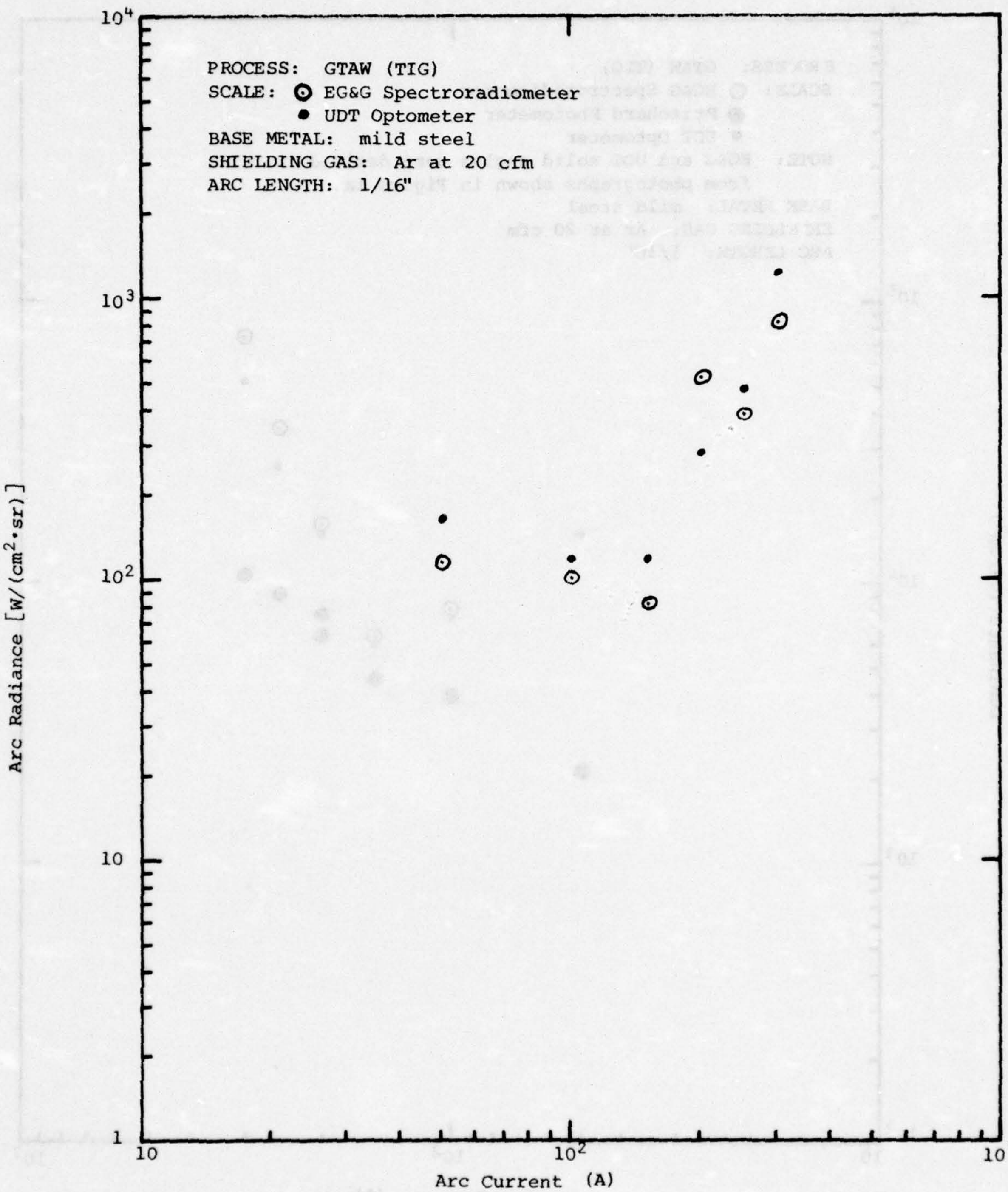


Figure 1b. Arc Radiance as a Function of Arc Current for Events 1 to 7.

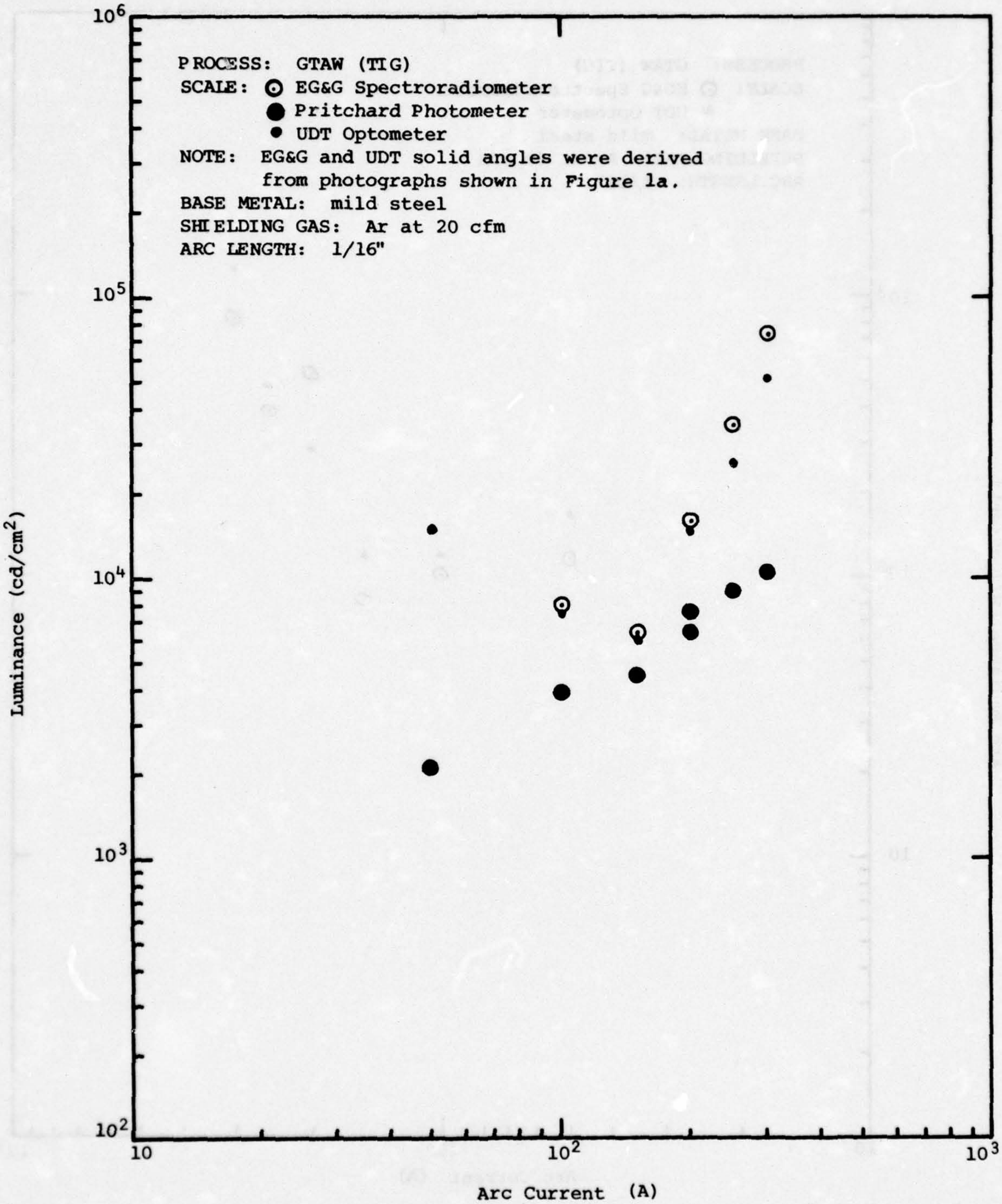


Figure 1c. Arc Luminance as a Function of Arc Current for Events 1 to 7.

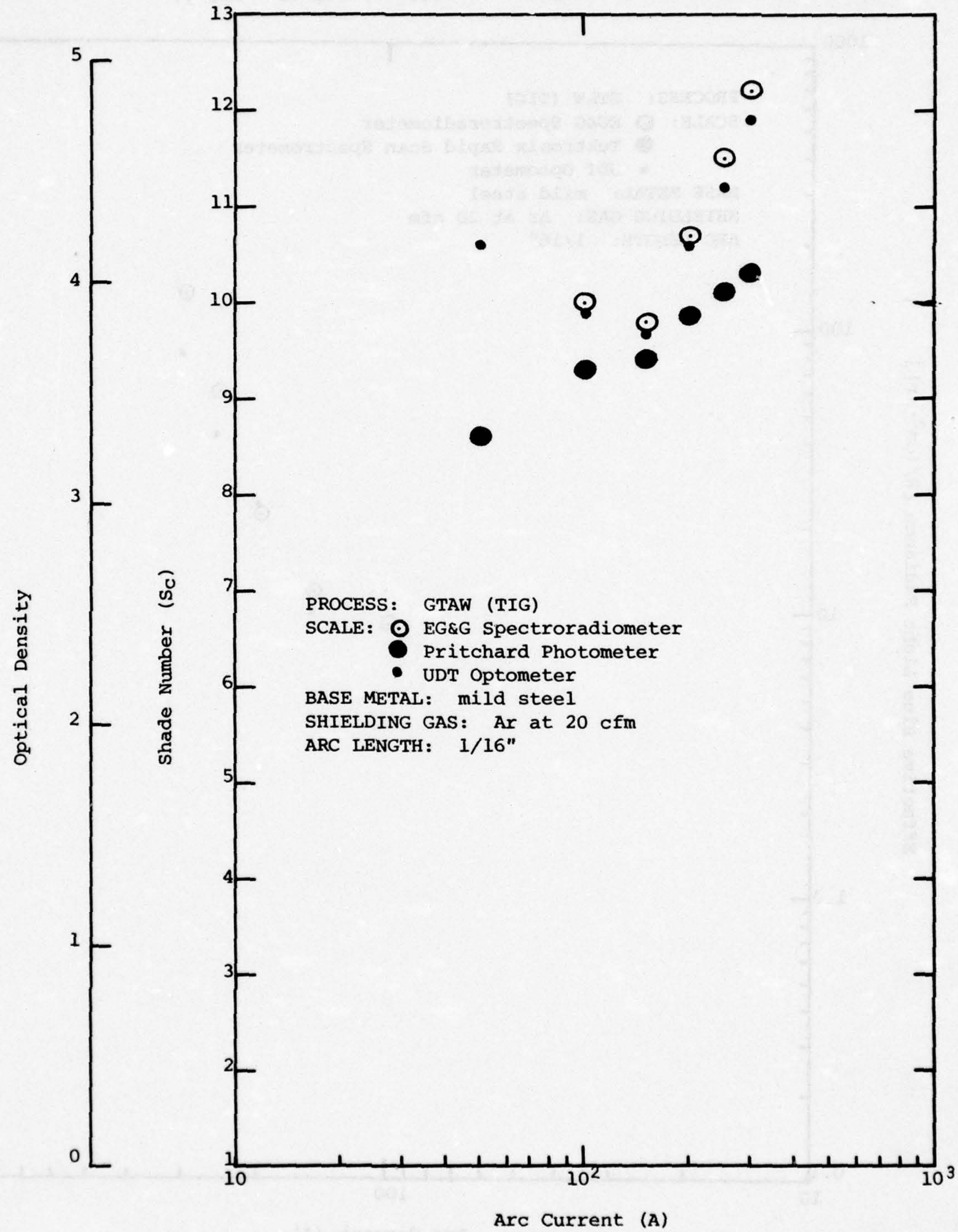


Figure 1d. Comfortable Shade Number (S_C) or Optical Density for Arc Viewing as a Function of Arc Current for Events 1 to 7.

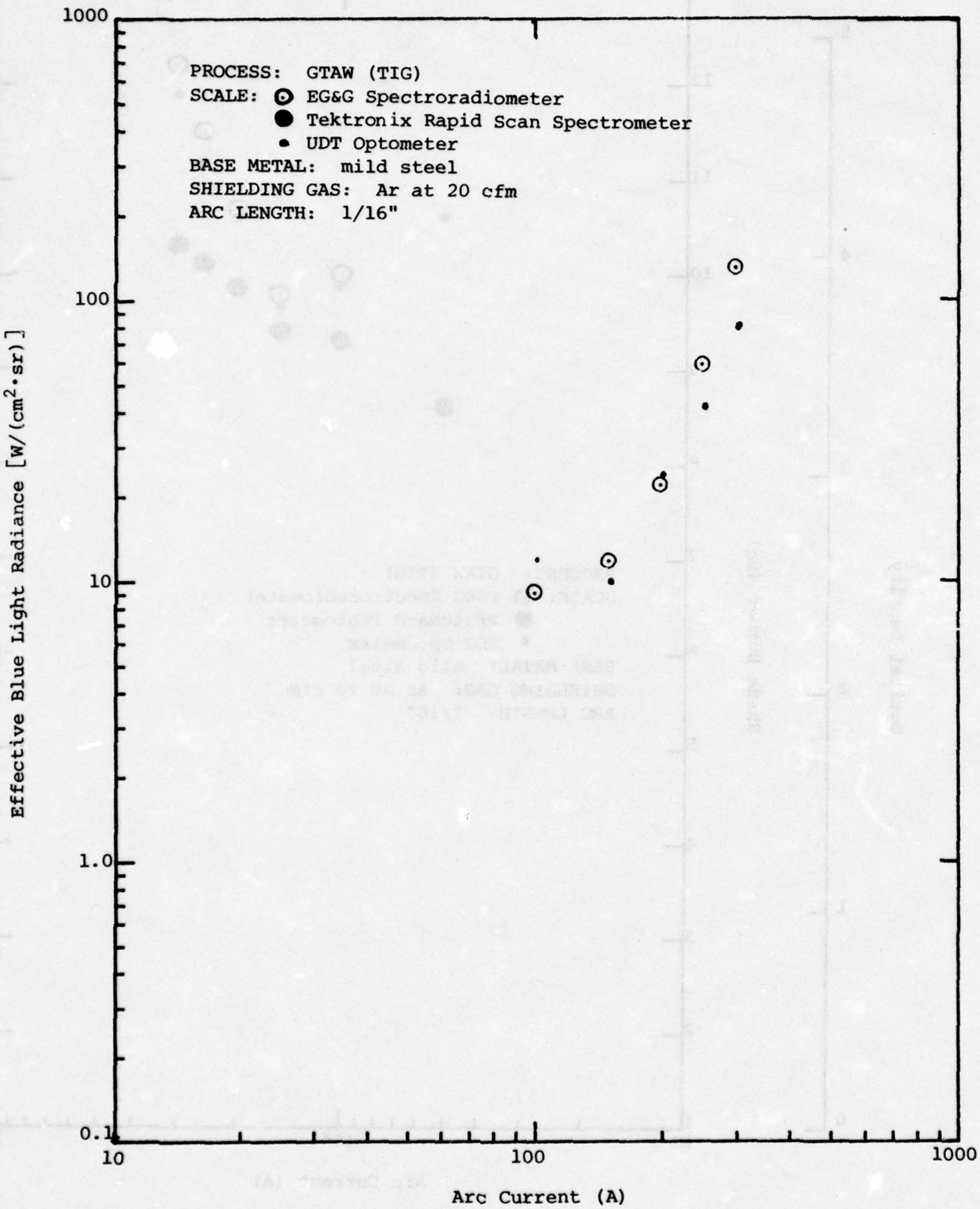


Figure 1e. Effective Blue Light Radiance as a Function of Arc Current for Events 1 to 7.

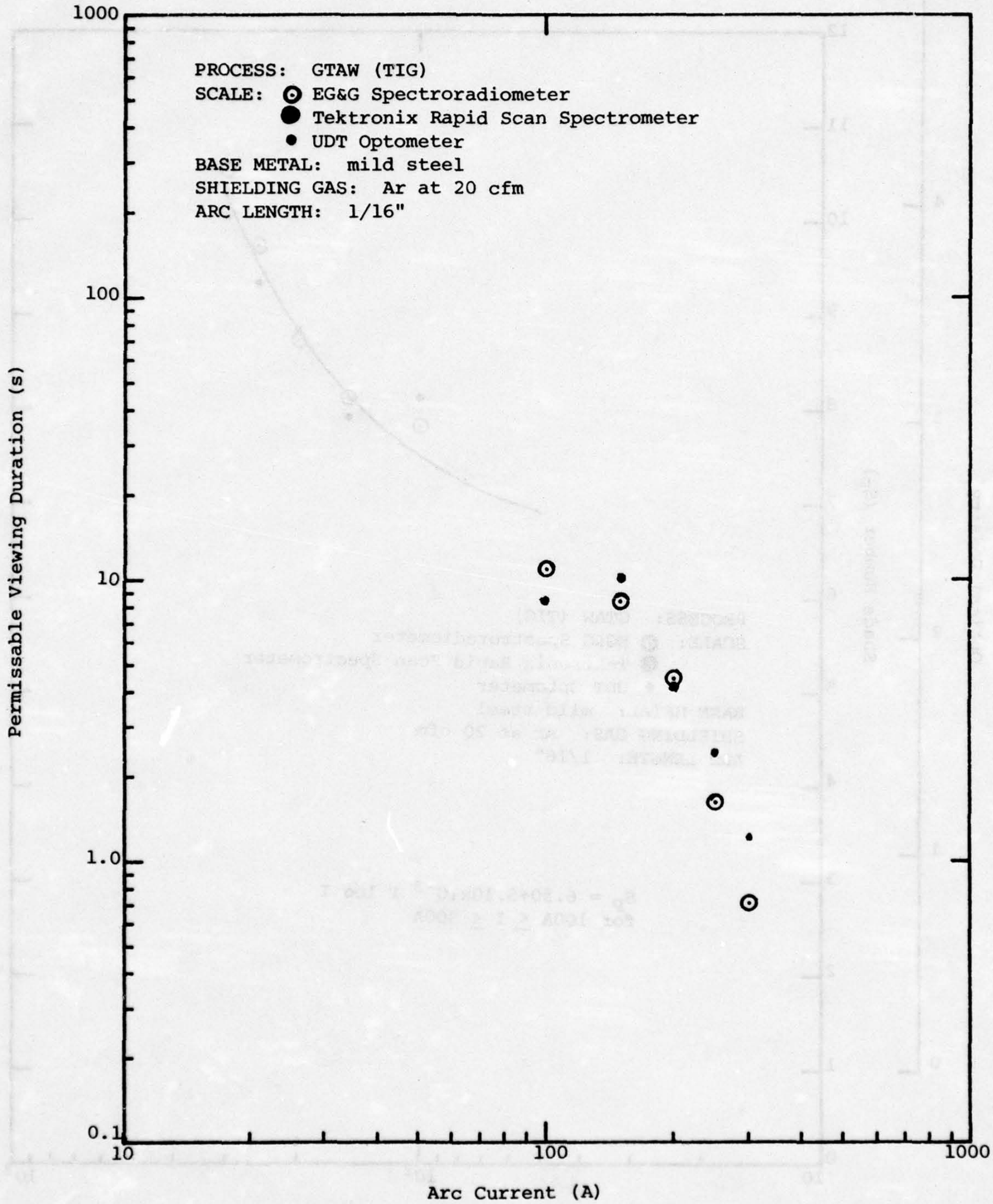


Figure 1f. Recommended Maximum Viewing Duration as a Function of Arc Current for Events 1 to 7 at Distances Less Than 0.8 m.

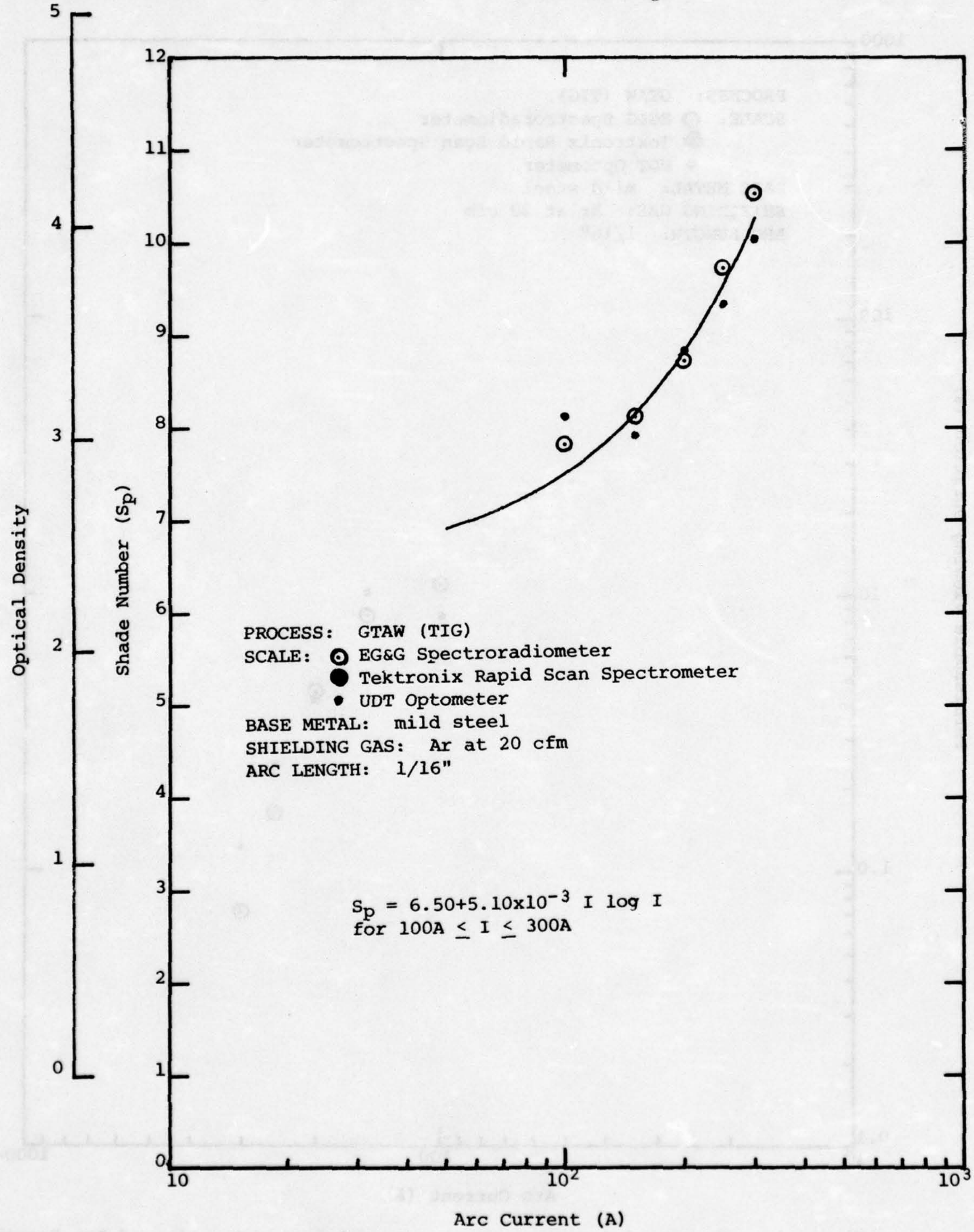


Figure 1g. Shade Number or Optical Density Necessary for Eye Protection Against Blue Light Emitted During Events 1 to 7.

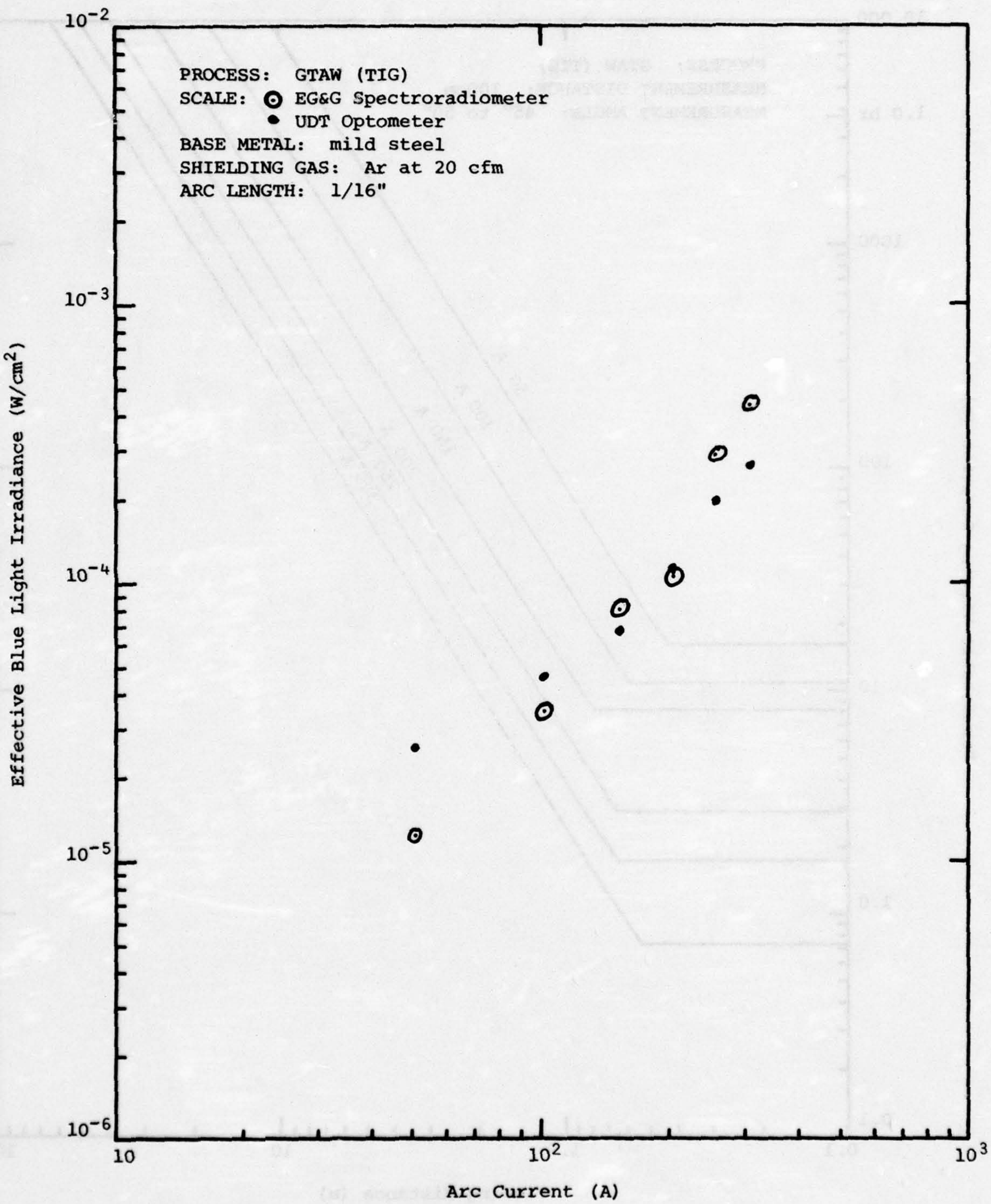


Figure 1h. Effective Blue Light Irradiance as a Function of Arc Current for Events 1 to 7.

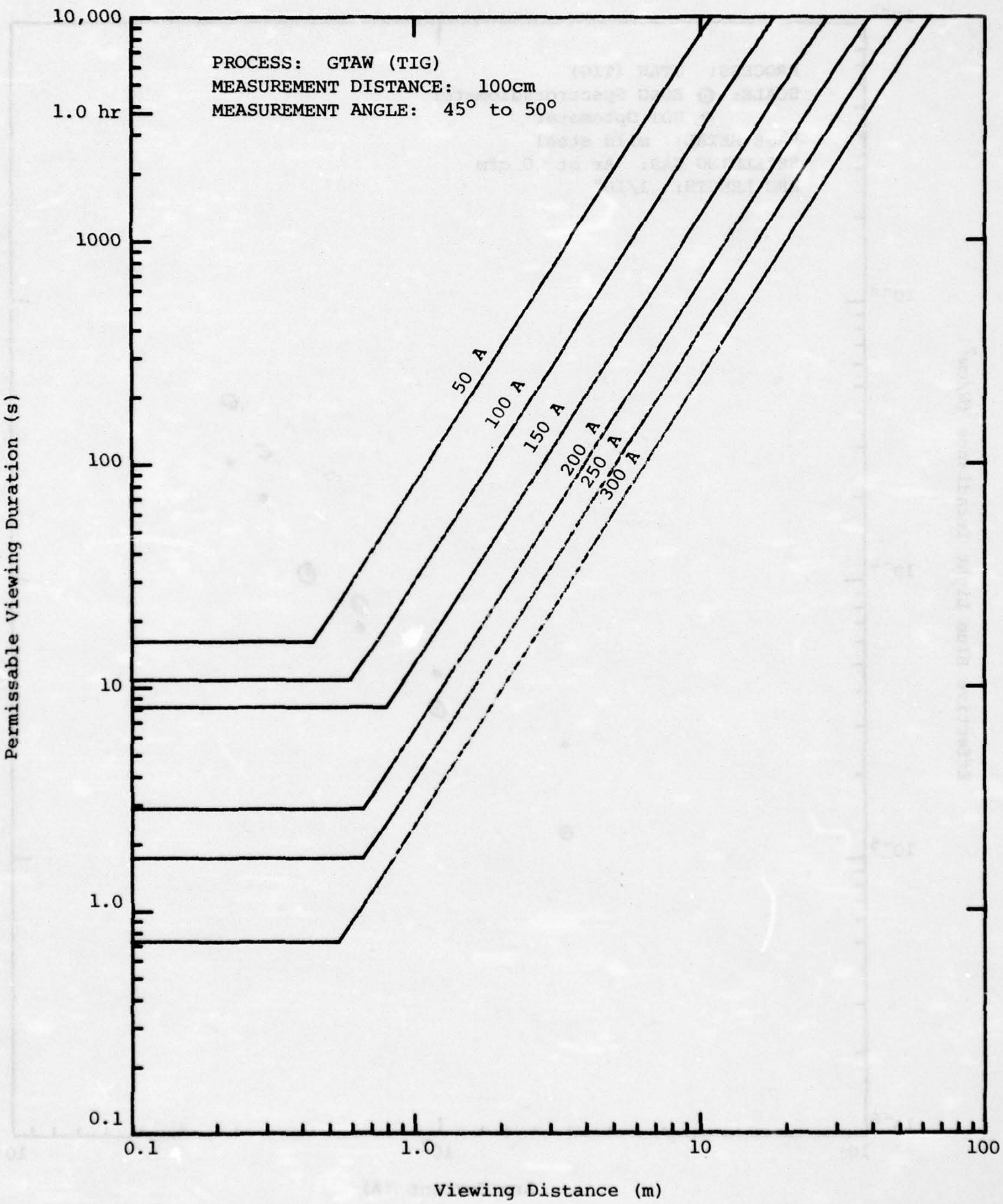


Figure 1i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 1 to 7.

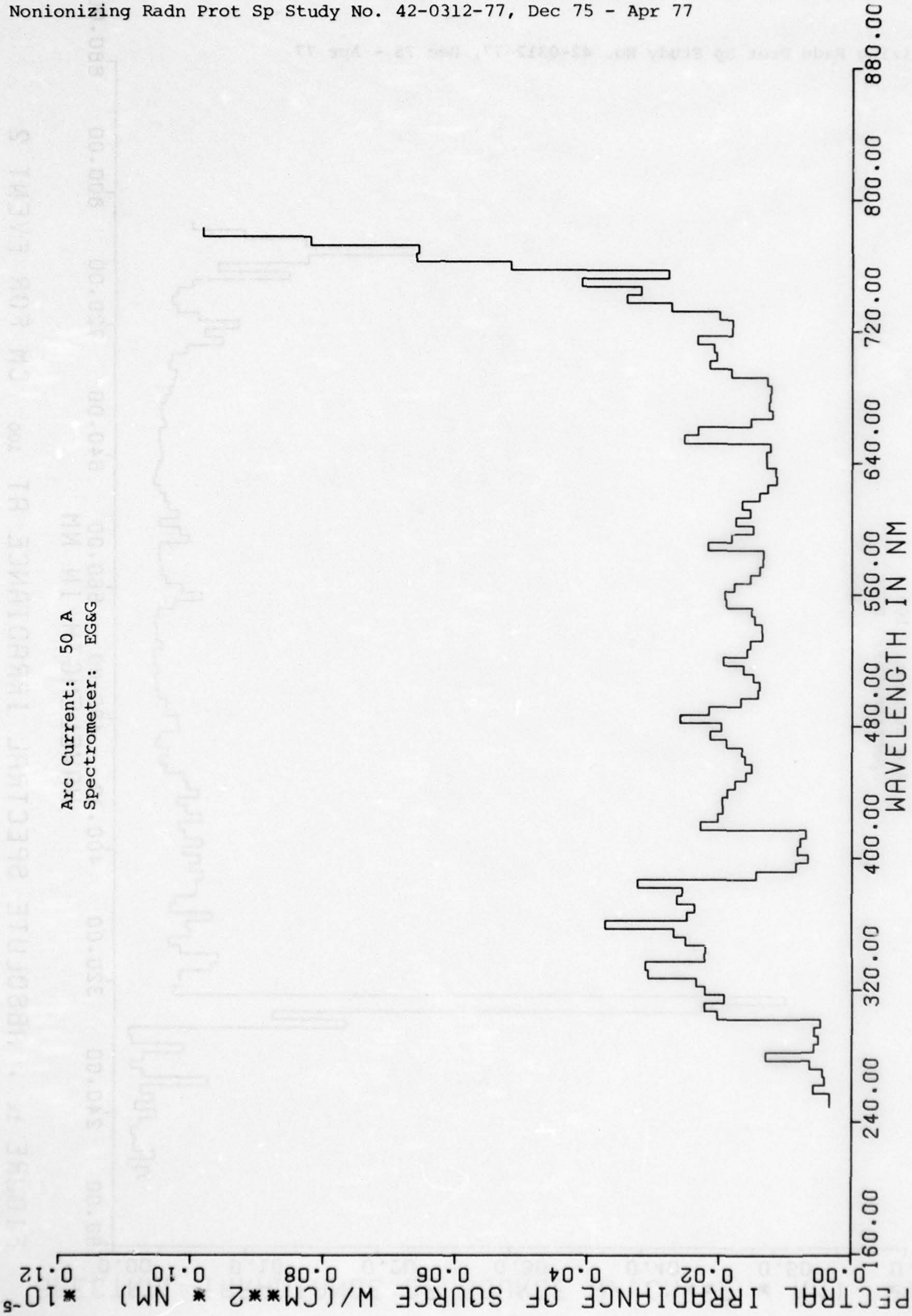


FIGURE 1j . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 1

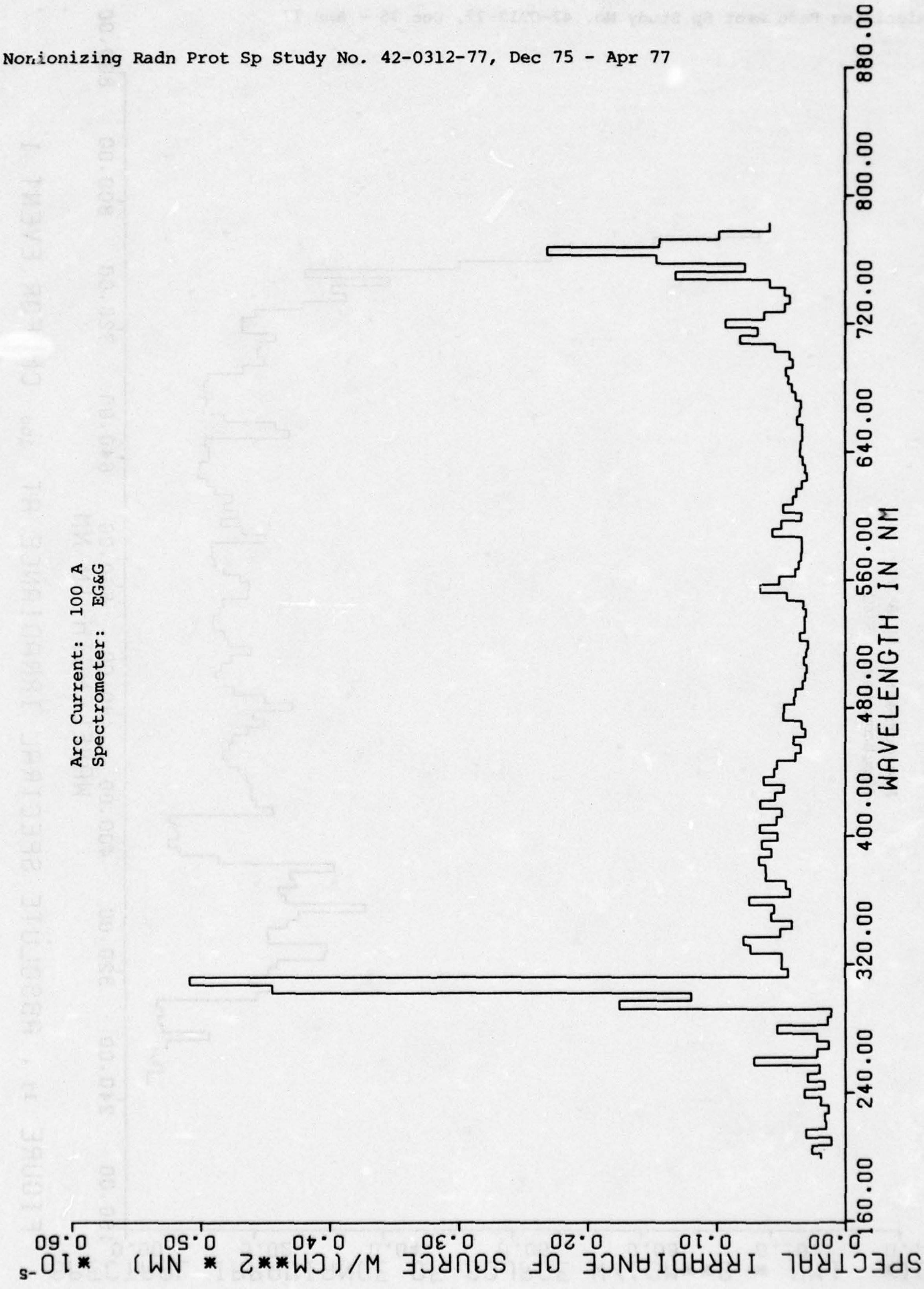


FIGURE 1k . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 2

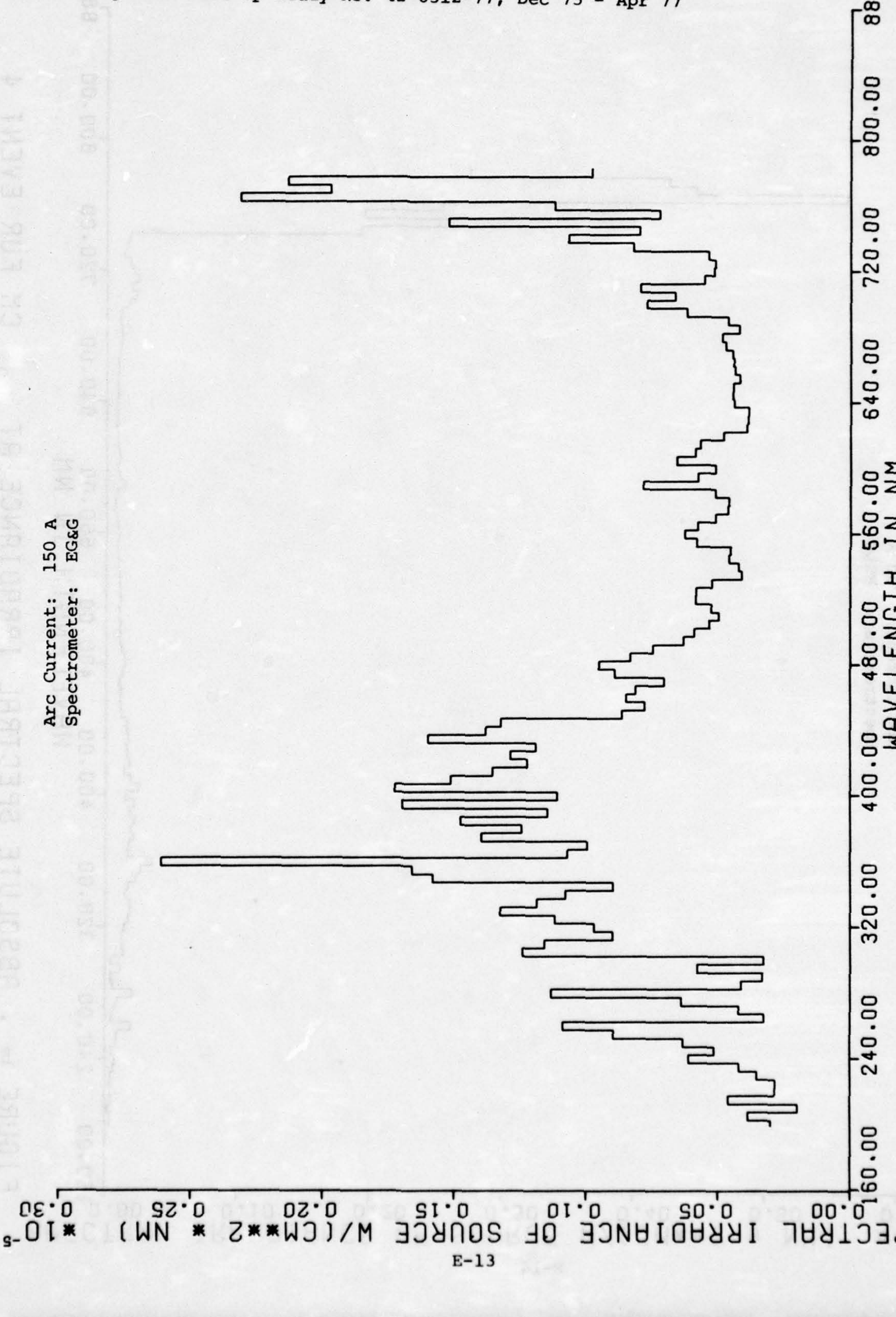


FIGURE 1ℓ . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 3

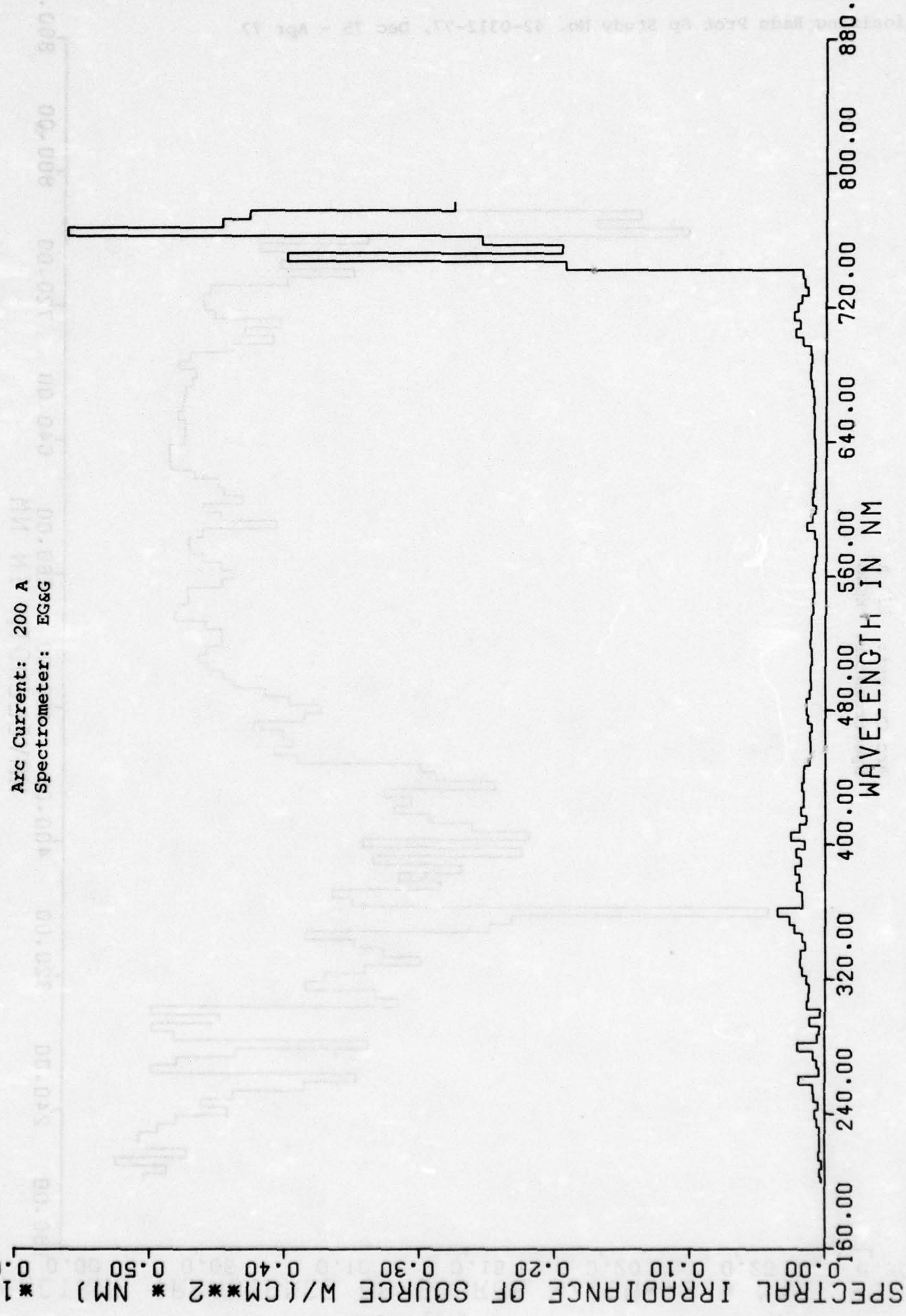


FIGURE 1m . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 4

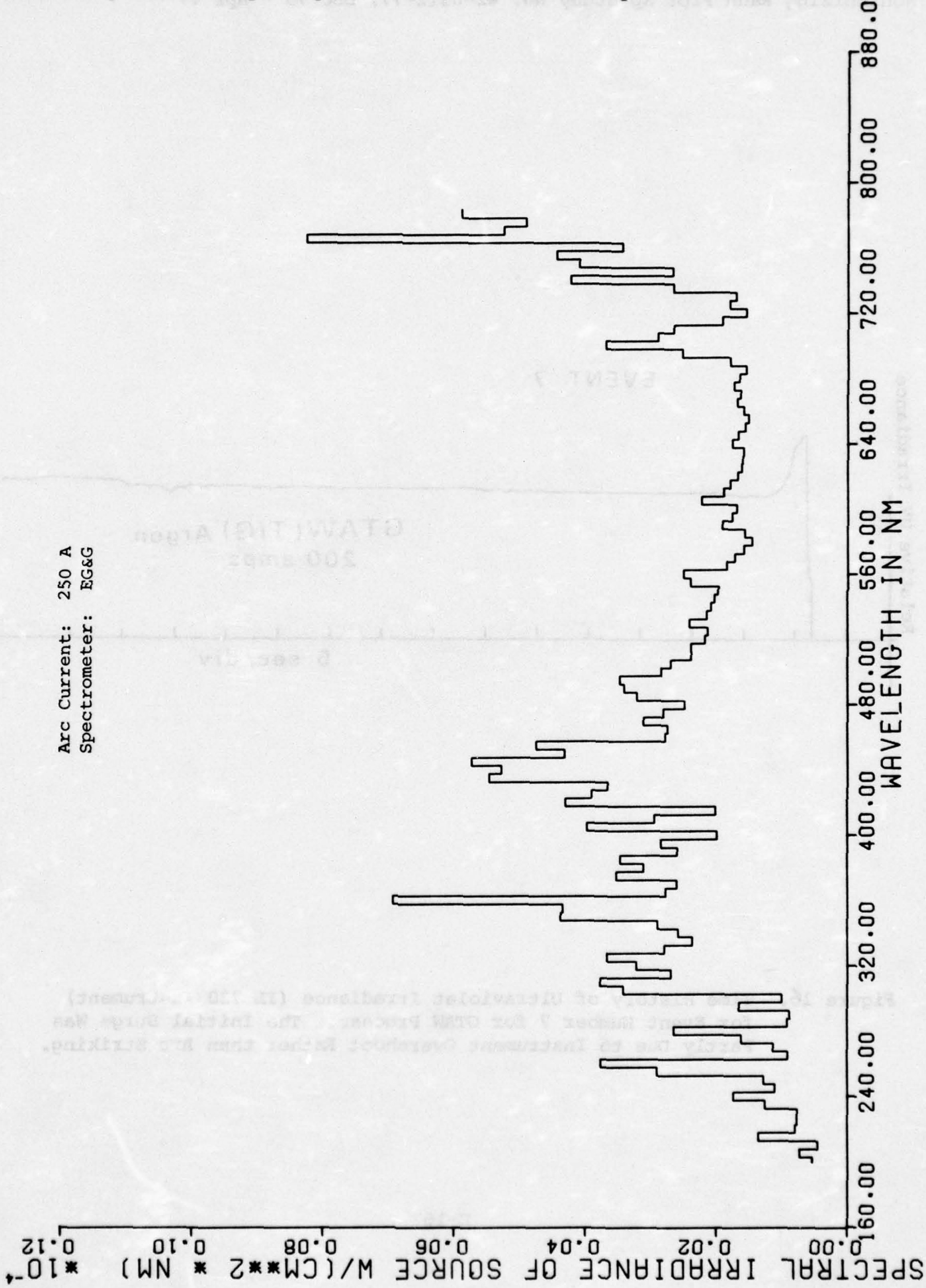


FIGURE 1n. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 5

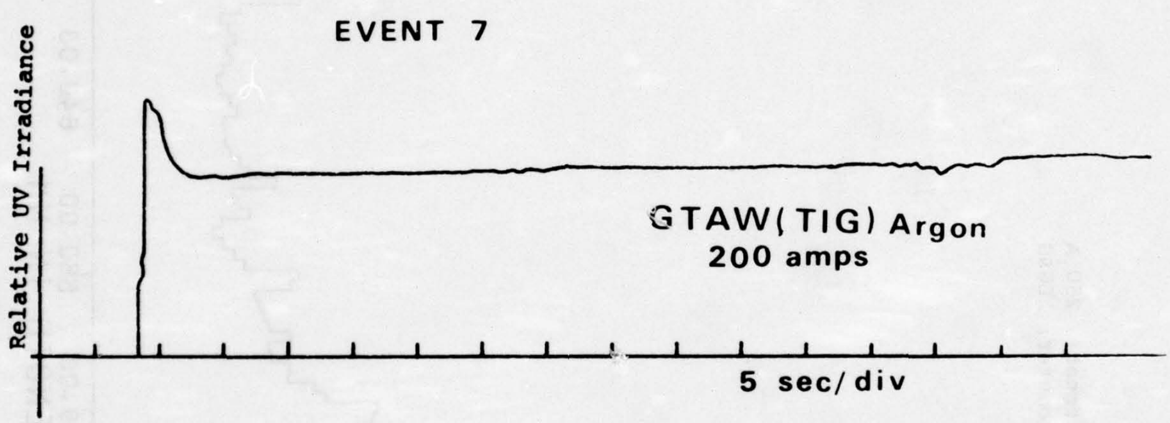


Figure 16. Time History of Ultraviolet Irradiance (IL 730 Instrument) for Event Number 7 for GTAW Process. The Initial Surge Was Partly Due to Instrument Overshoot Rather than Arc Striking.

TABLE 2. WELDING PARAMETERS FOR EVENTS 8 TO 11 AND 23.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 300 A

Polarity: DCSP

Shielding Gas: Ar at 20 cfm

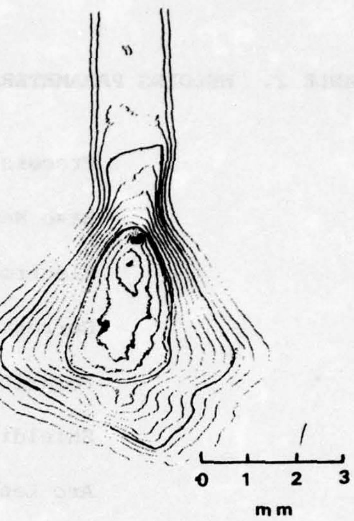
Arc Length: 1/8" (0.125" to 0.135")

Electrode Diameter: 1/16" (50 to 100A), 3/32" (188 to 200A), and 1/8" (300A)

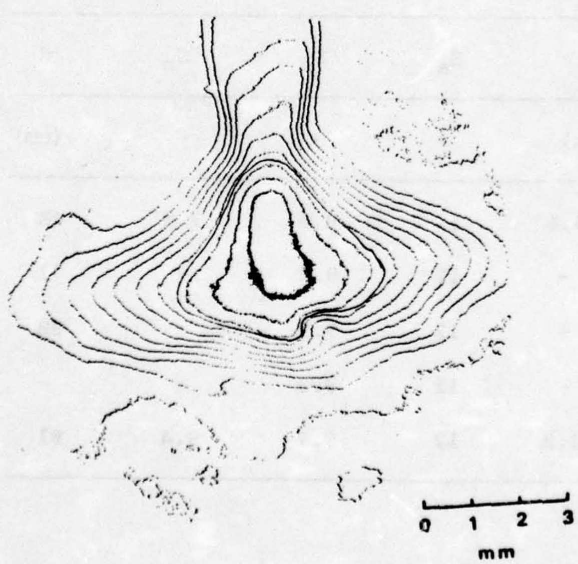
SUMMARY OF RESULTS

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[$W/(cm^2 \cdot sr)$]		(s)	-	-	-	(cm)
50	2500	60.4	8.7	11.6	12	8.8	7.8	48
100	4200	110	-	-	12	9.3	-	72
188	7500	160	-	-	12	9.9	-	98
200	6600	-	-	-	12	9.8	-	-
300	6300	345	45.2	2.2	12	9.7	9.4	91

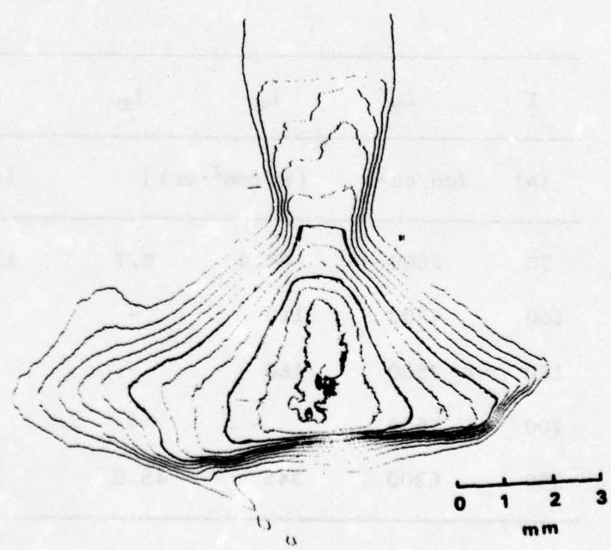
Event 8, 50 A, CI=0.10



Event 9, 100 A, CI=0.10



Event 10, 188 A, CI=0.12



Event 11, 300 A, CI=0.16

Figure 2a. Microdensitometer Scans of 35 mm Processed Photographic Negatives Exposed at 4 m from the Welding Arcs for Events 8-11 and 23.

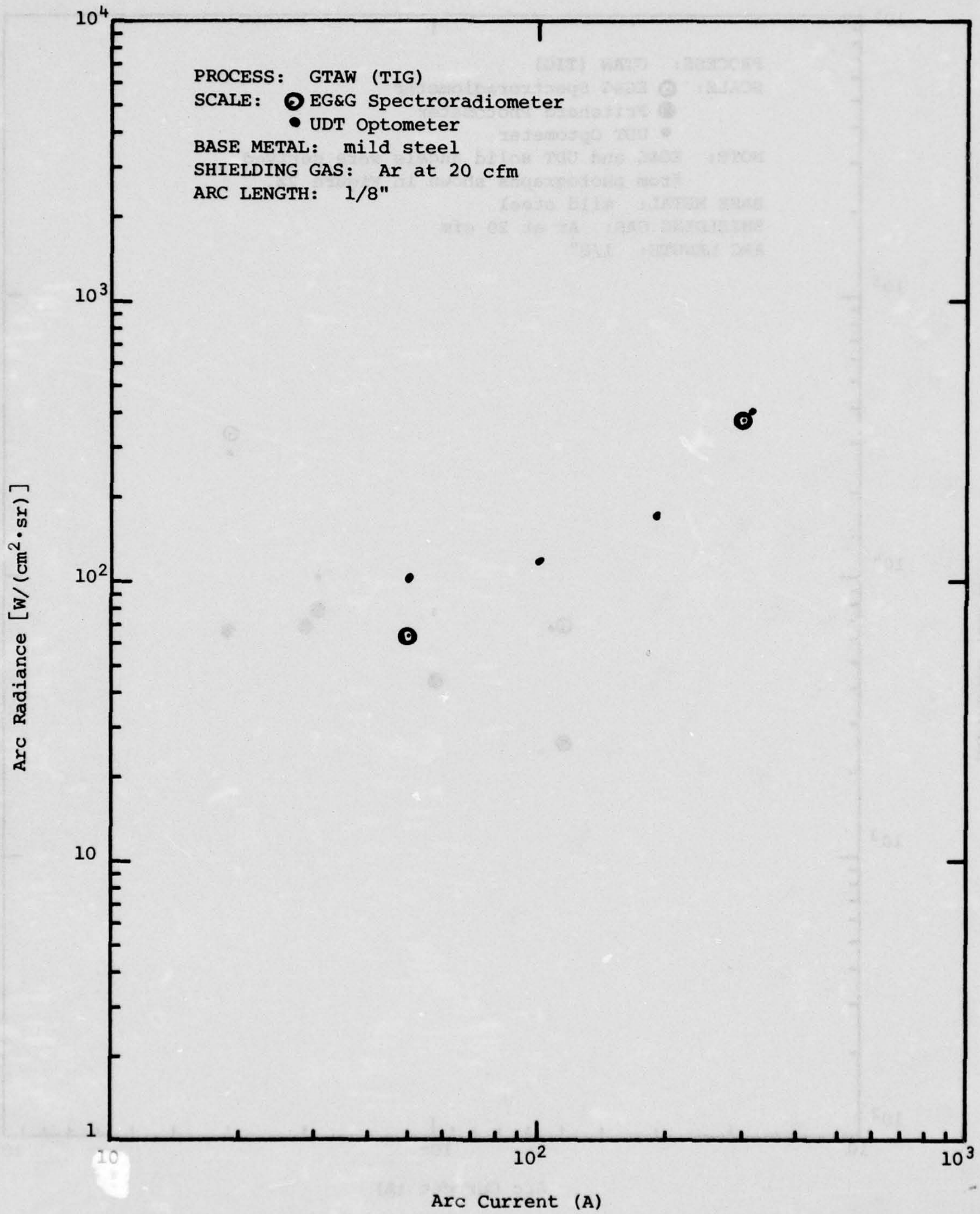


Figure 2b. Arc Radiance is a Function of Arc Current for Events 8 to 11 and 23.

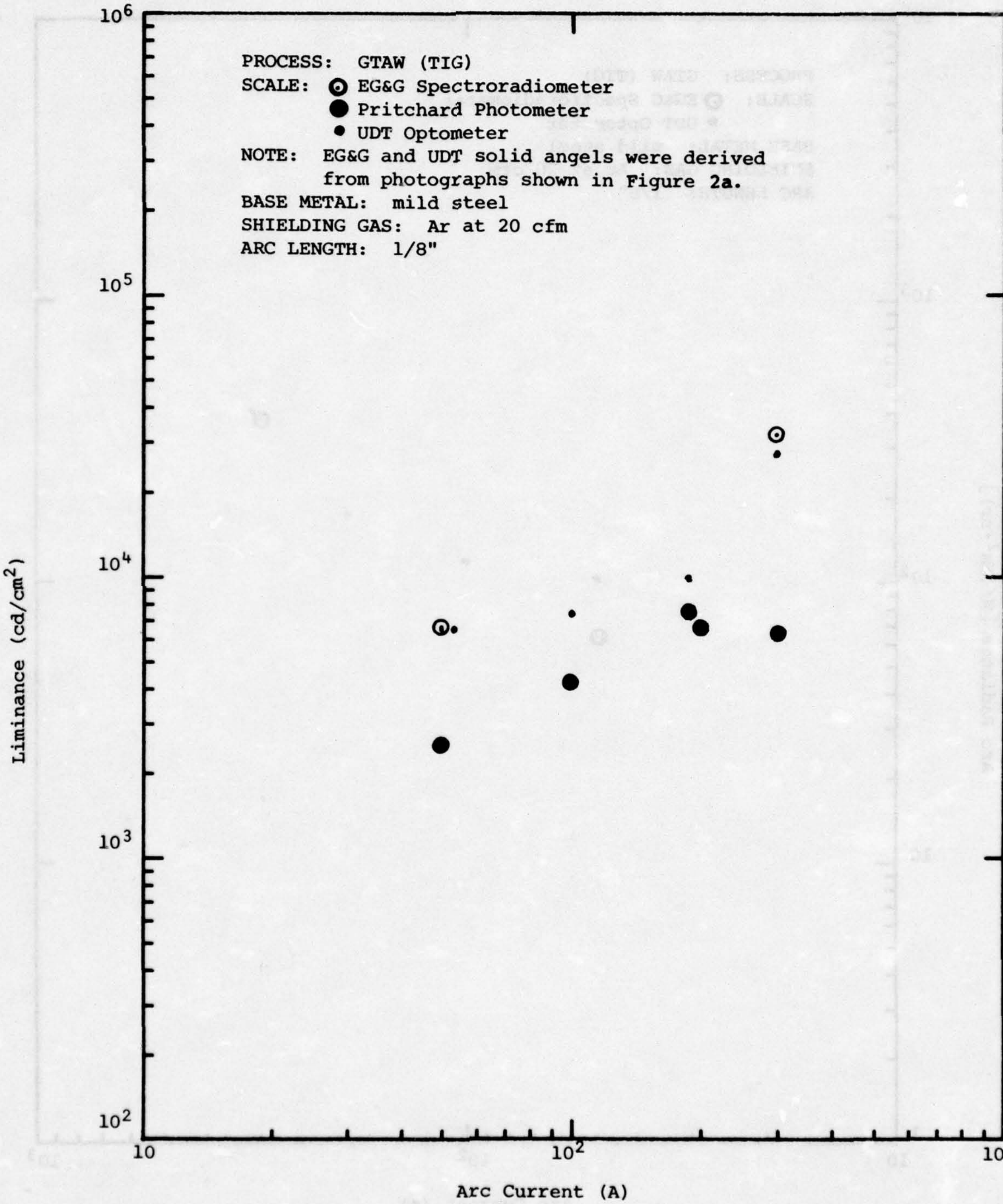


Figure 2c. Arc Luminance as a Function of Arc Current for Events 8 to 11 and 23.

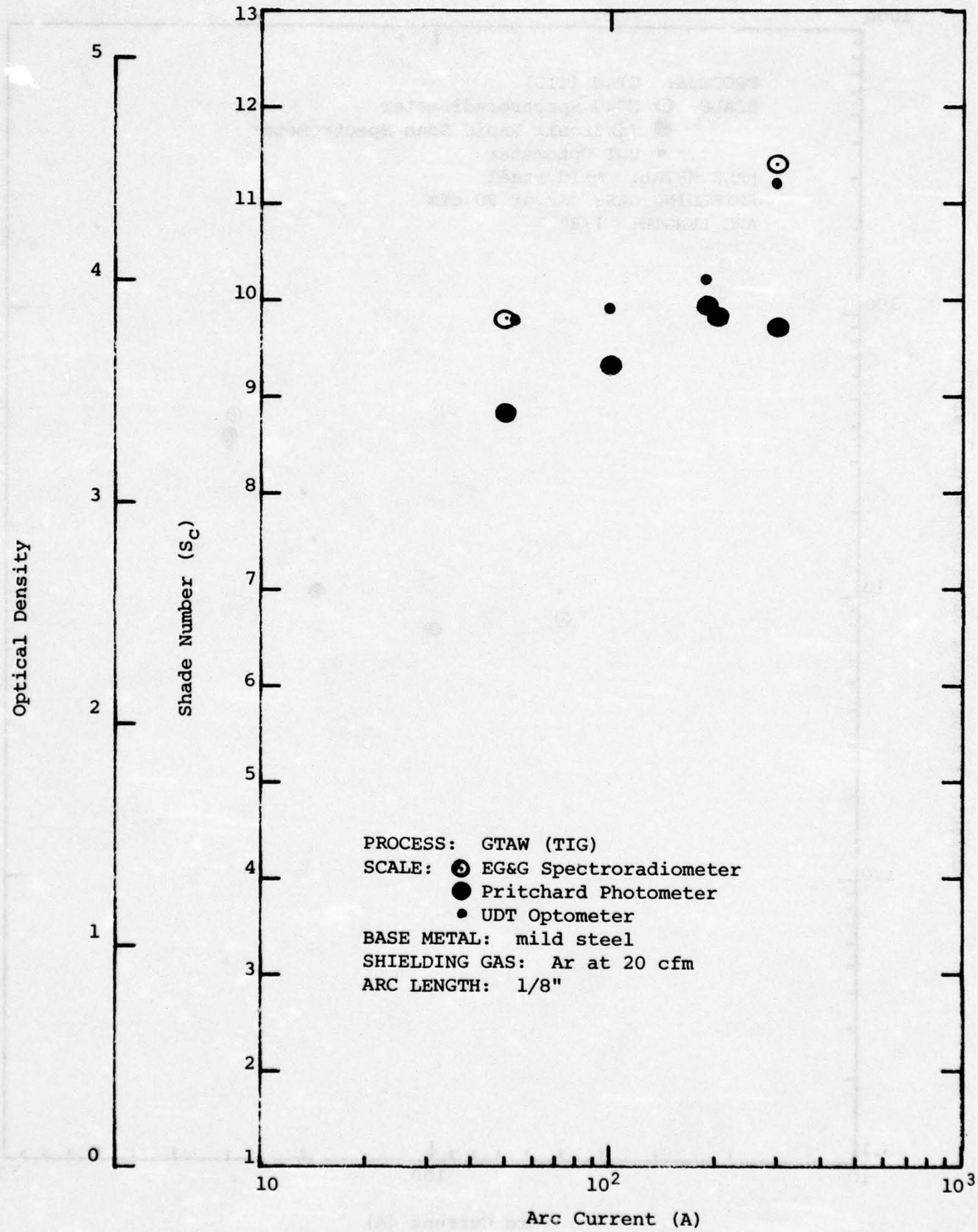


Figure 2d. Comfortable Shade Number (S_C) or Optical Density for Arc Viewing as a Function of Arc Current for Events 8 to 11 and 23.

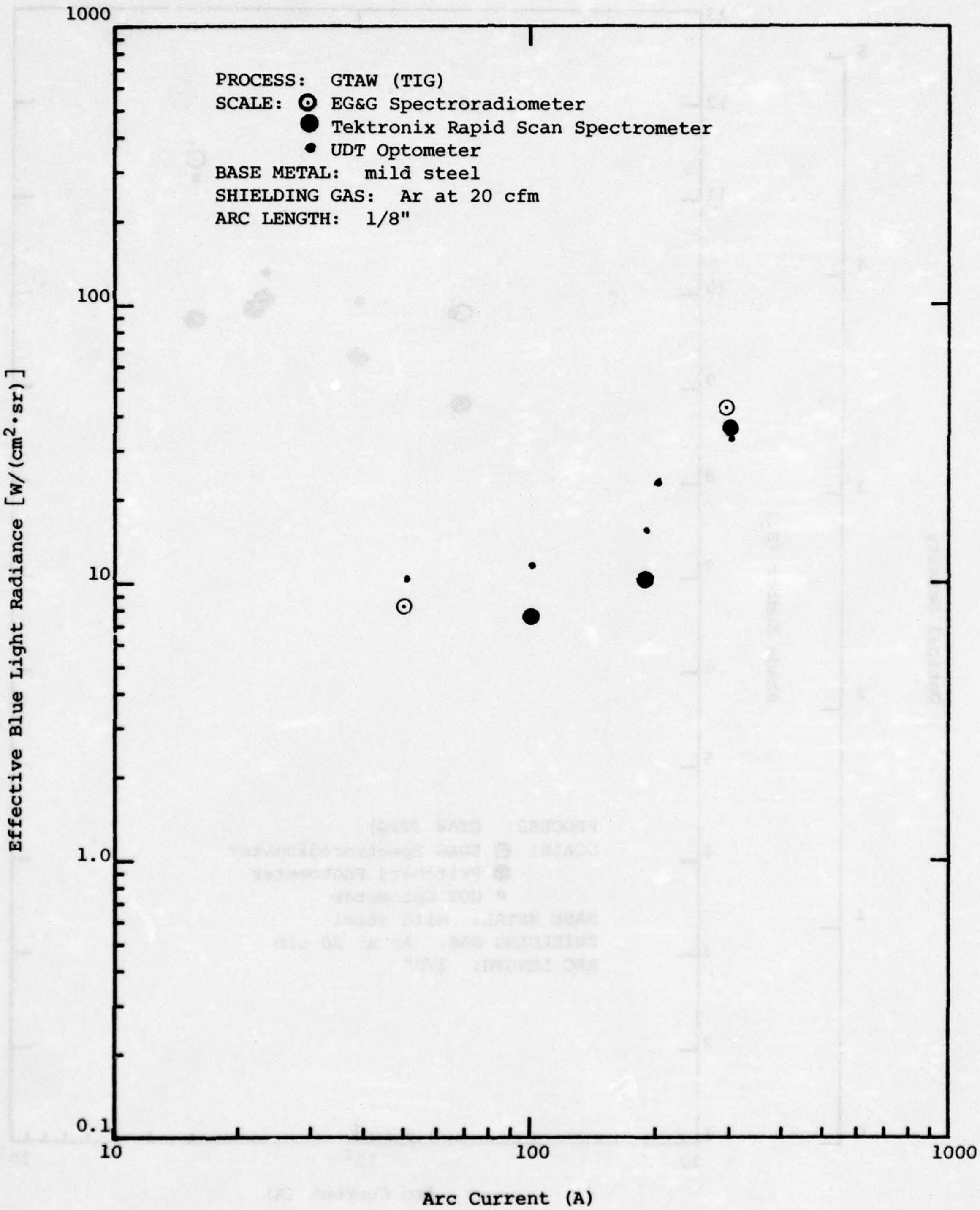


Figure 2e. Effective Blue Light Radiance as a Function of Arc Current for Events 8 to 11 and 23.

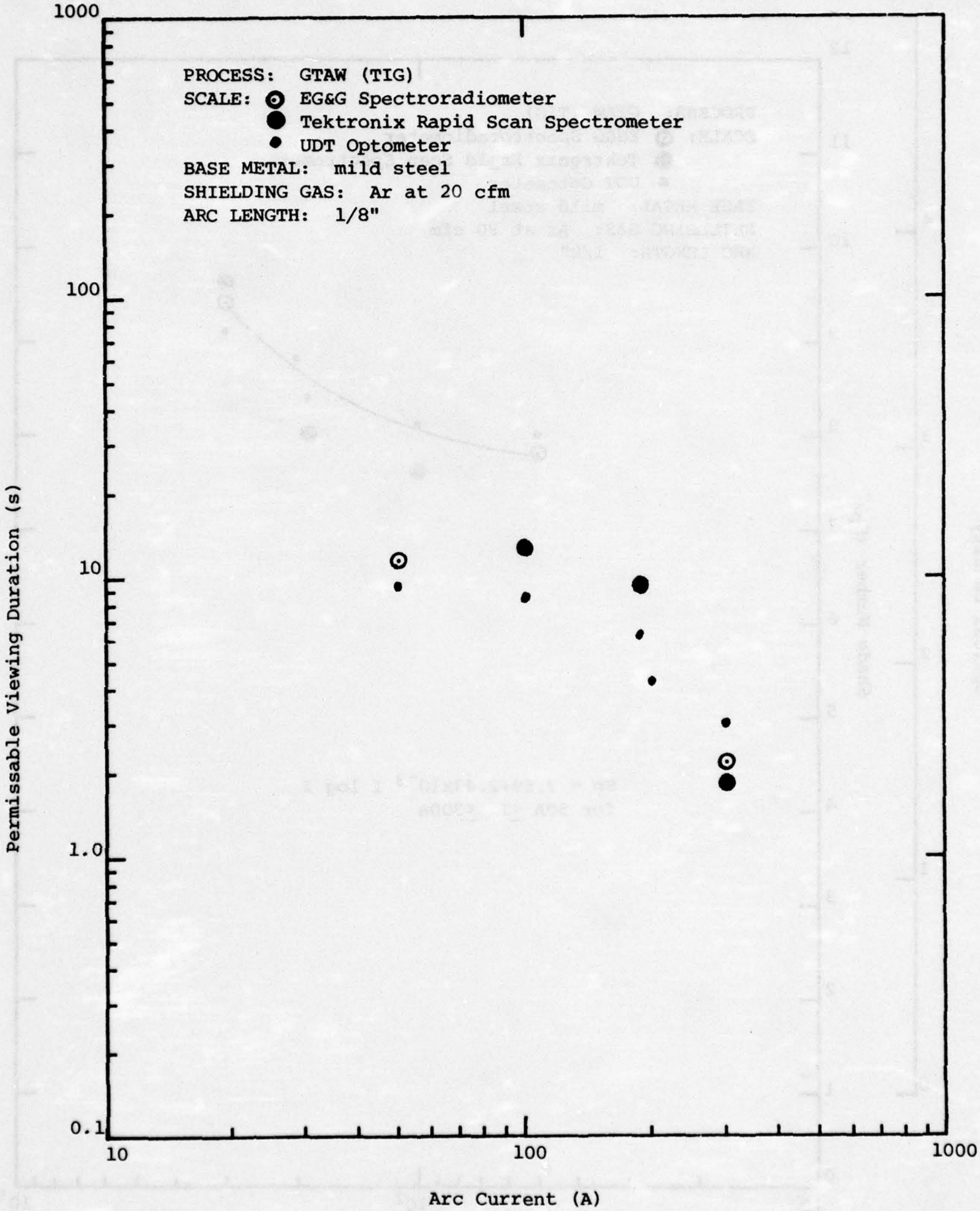


Figure 2f. Recommended Maximum Viewing Duration as a Function of Arc Current for Events 8 to 11 and 23 at Distances less than 1.0 m.

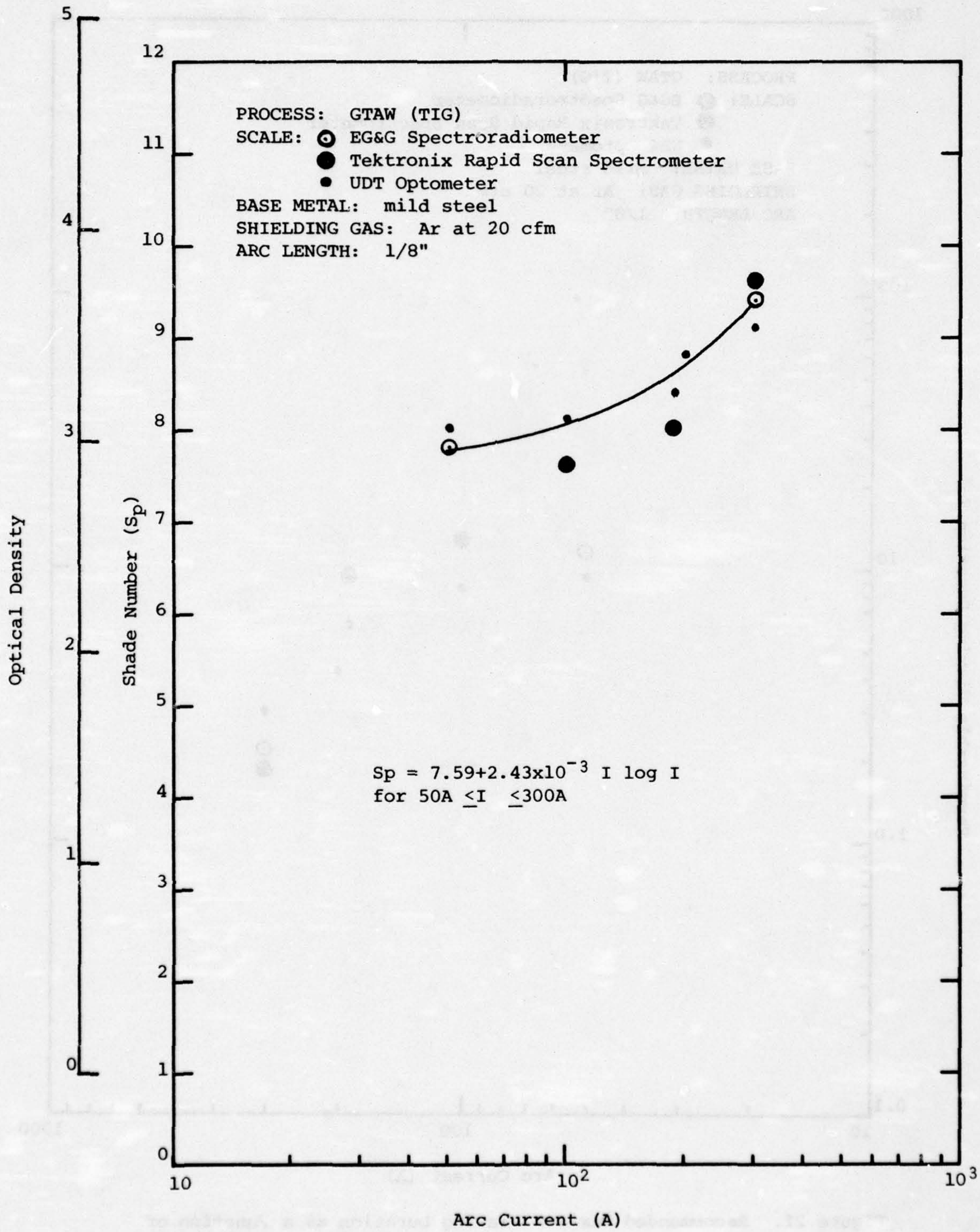


Figure 2g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 8 to 11 and 23.

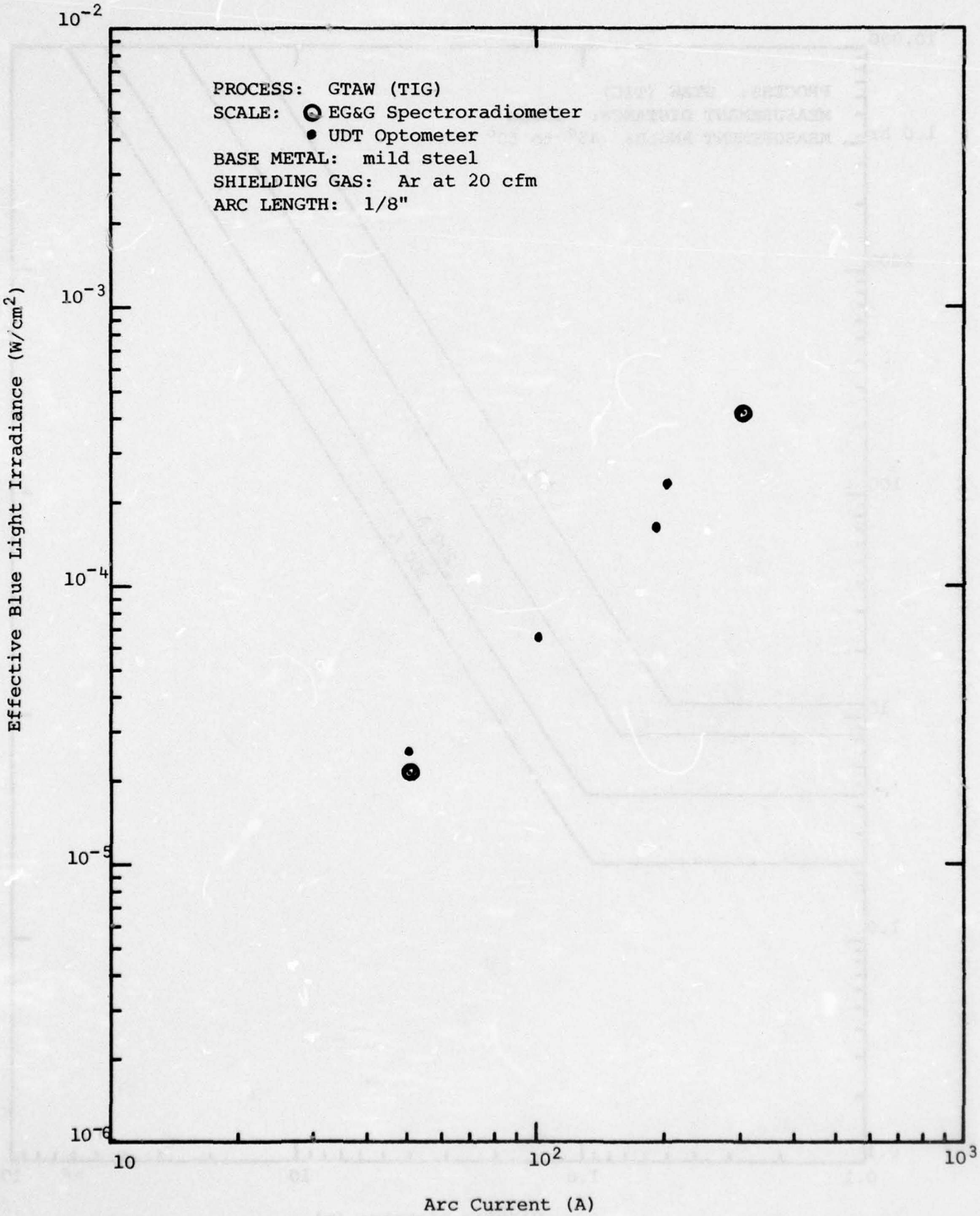


Figure 2h. Effective Blue Light Irradiance as a Function of Arc Current for Events 8 to 11 and 23.

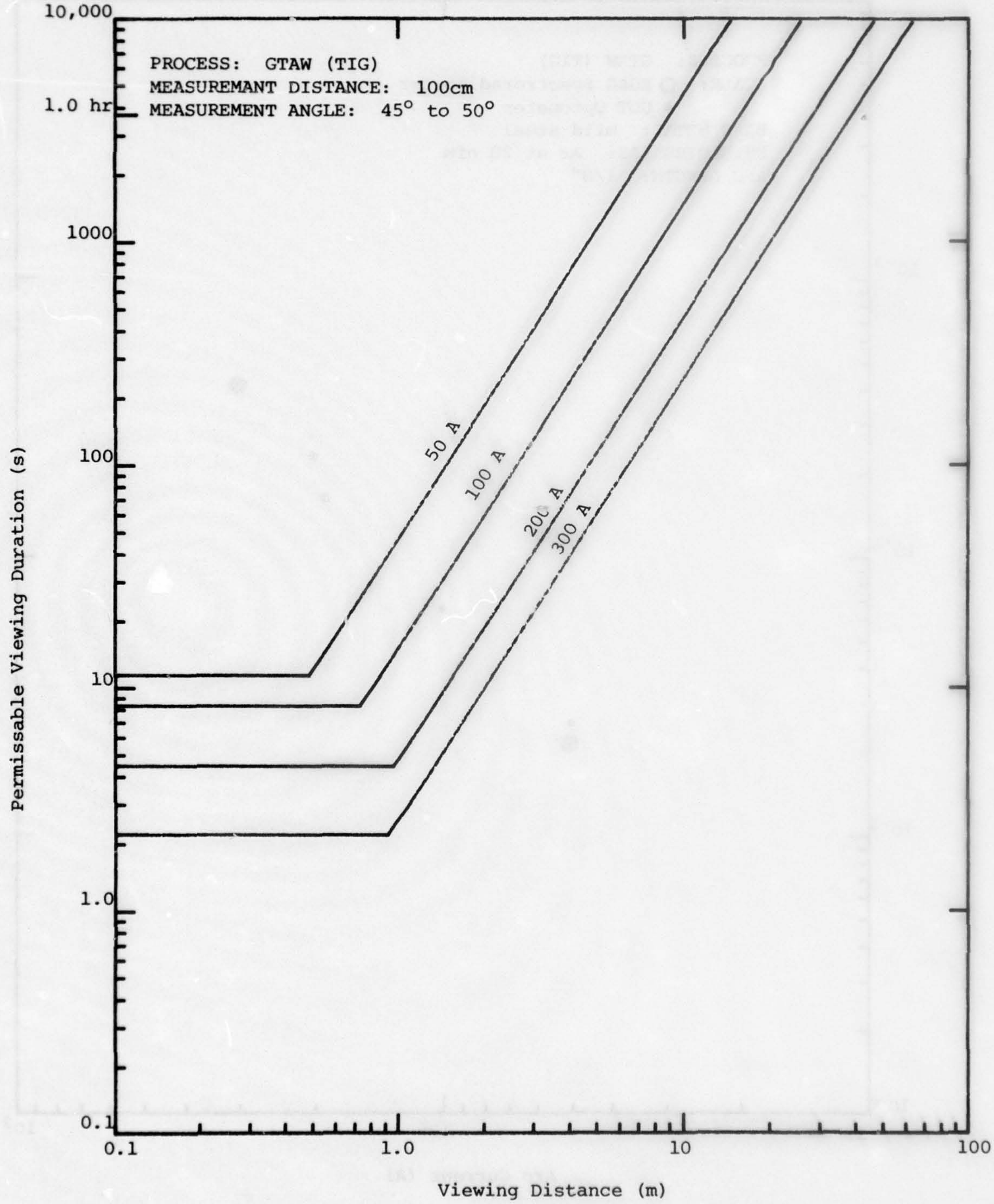


Figure 2i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 8 to 11 and 23.

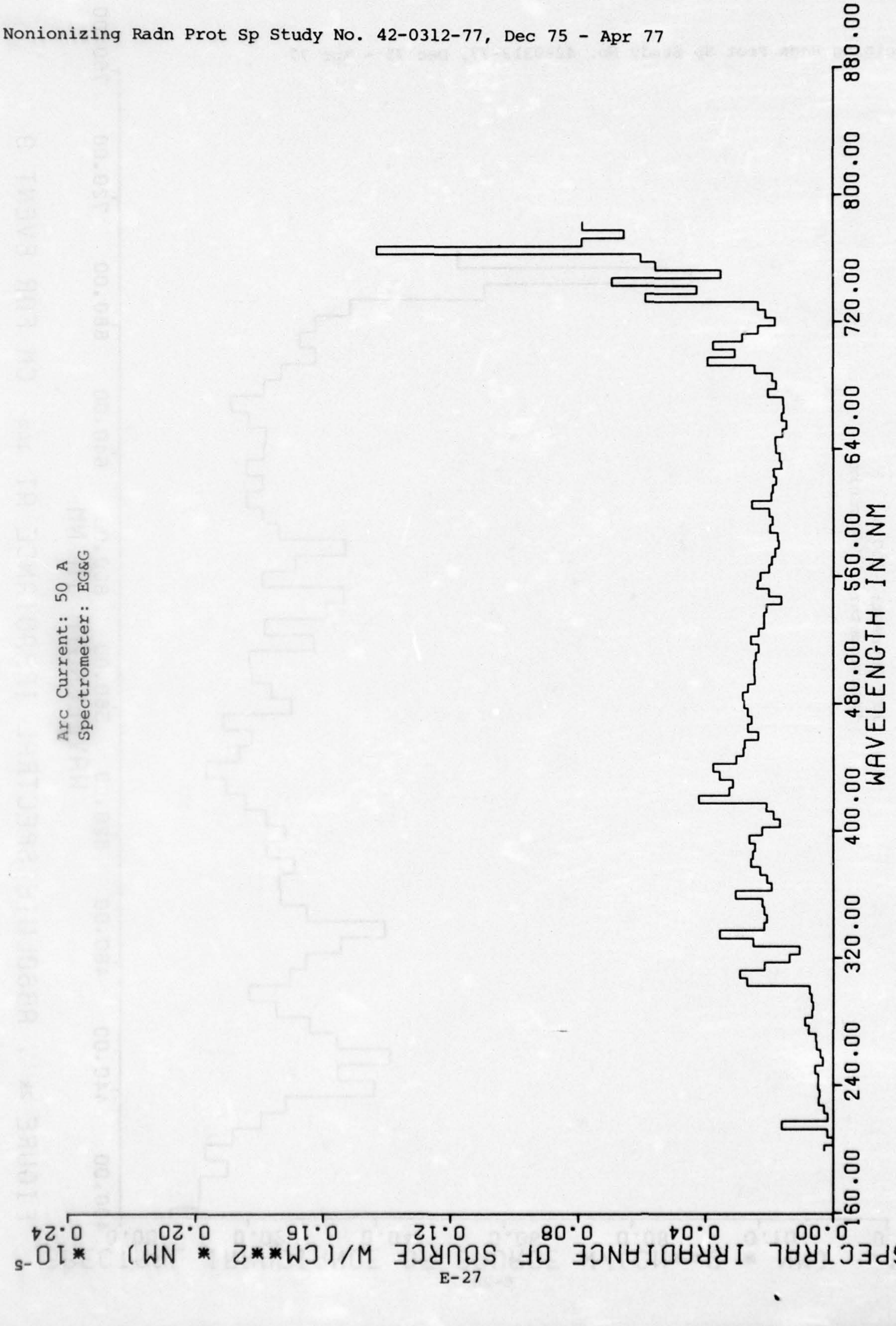


FIGURE 2j . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 8

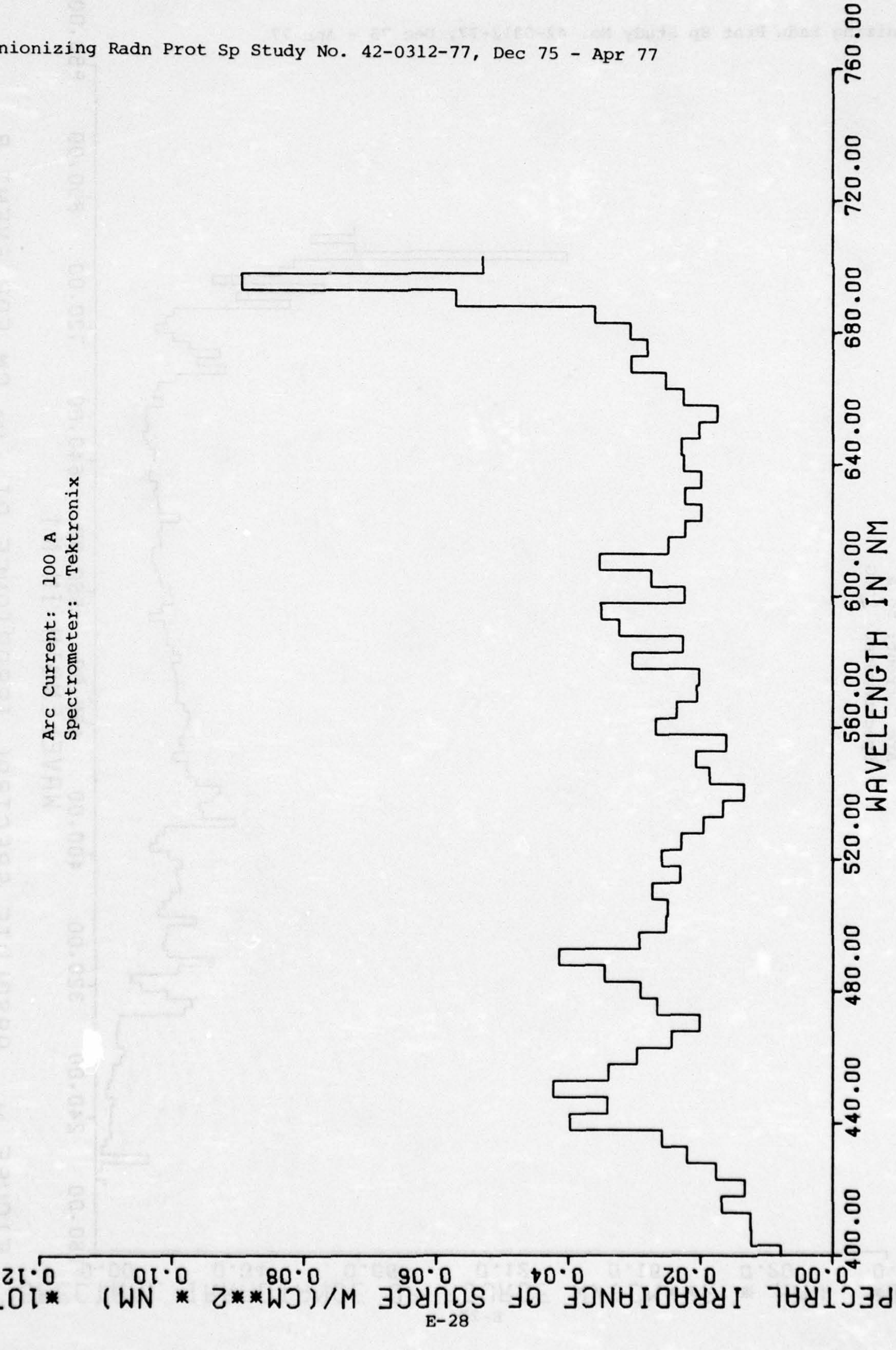


FIGURE 2k . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 9

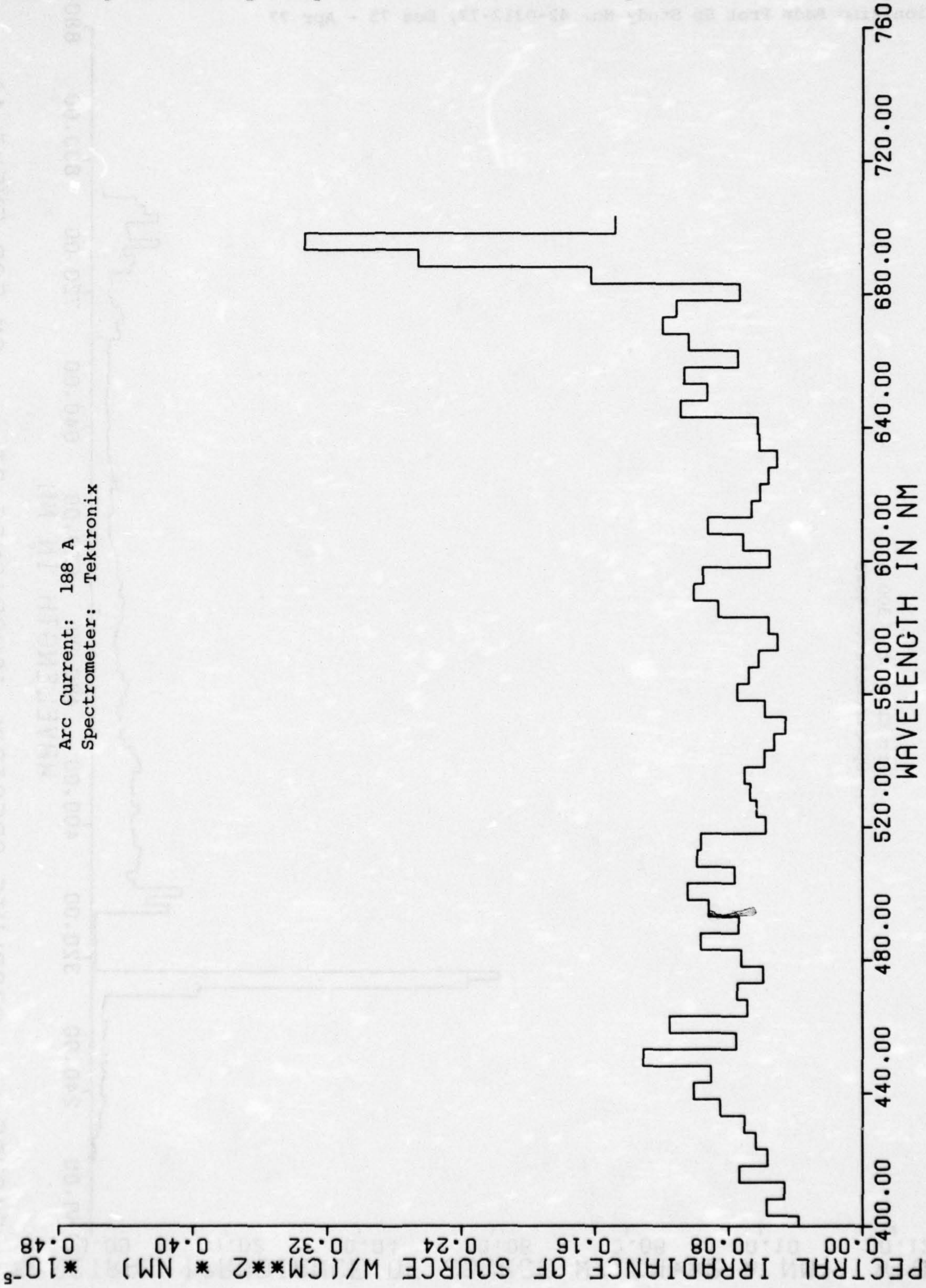


FIGURE 2l . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 10

Nonionizing Radn Prot Sp Study No. 42-0312-77, Dec 75 - Apr 77

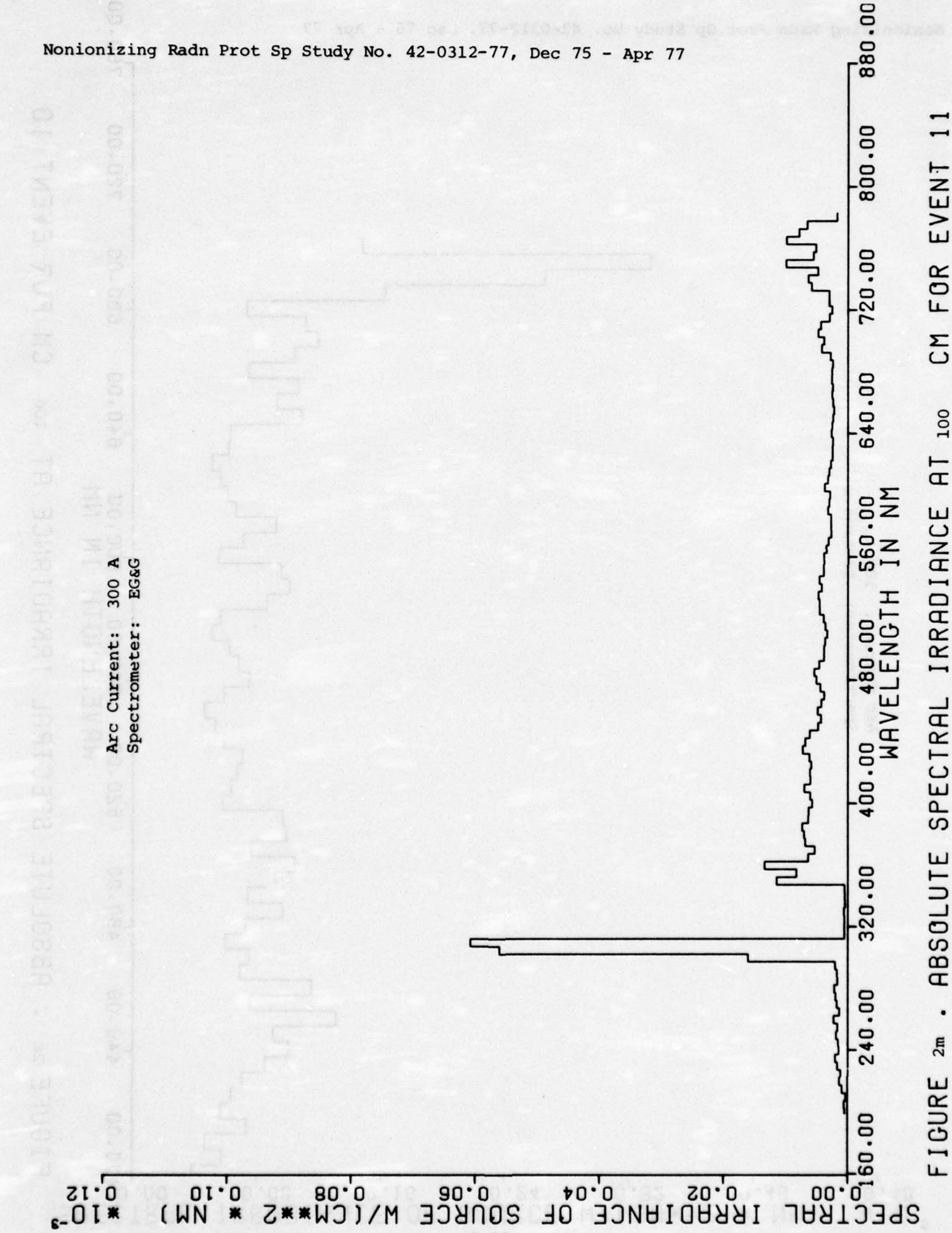


FIGURE 2m . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 11

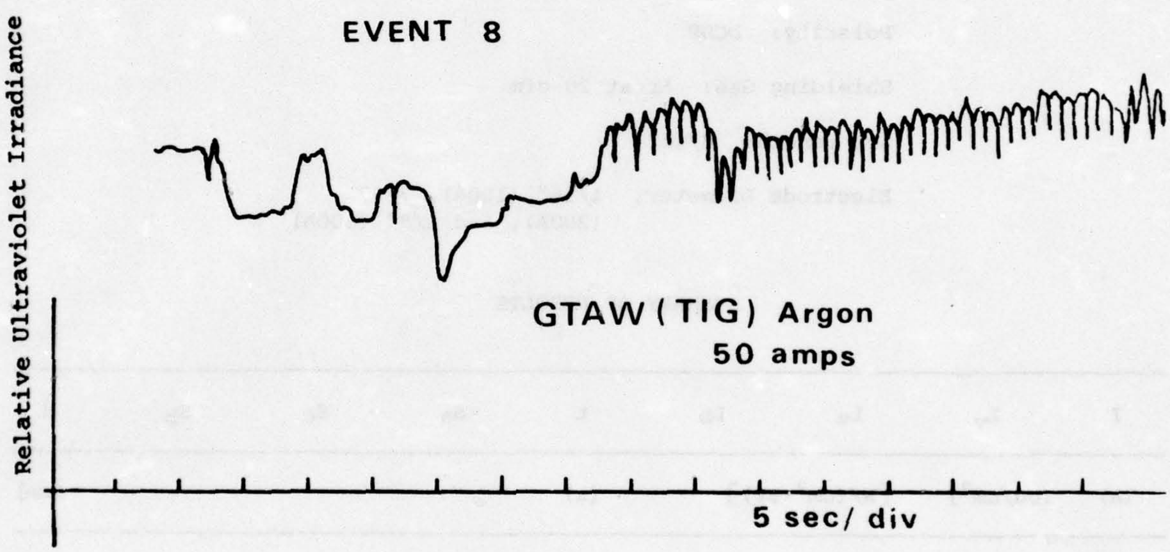


Figure 2n. Recording of Ultraviolet Irradiance from Event 8 (GTAW) vs Time which shows some Arc Oscillation at this low Current. The Recorder Plot used the Readout from the IL 730 Instrument.

TABLE 3. WELDING PARAMETERS FOR EVENTS 20 TO 22.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 100 to 300 A

Polarity: DCSP

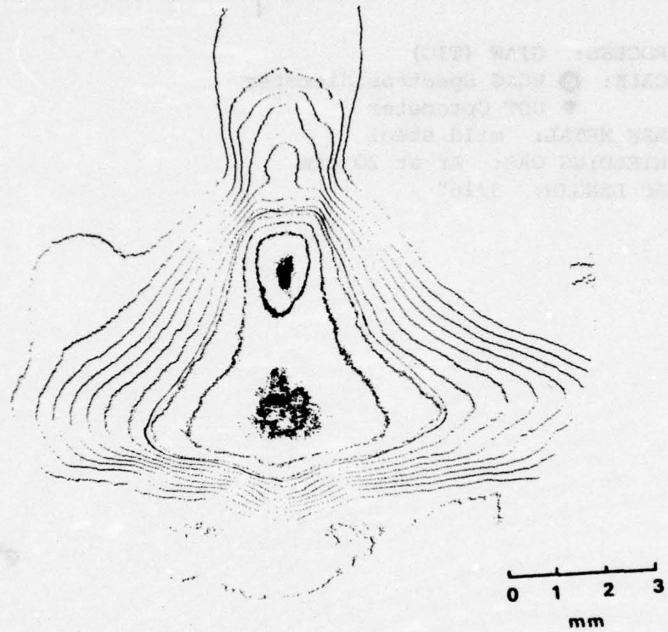
Shielding Gas: Ar at 20 cfm

Arc Length: 3/16"

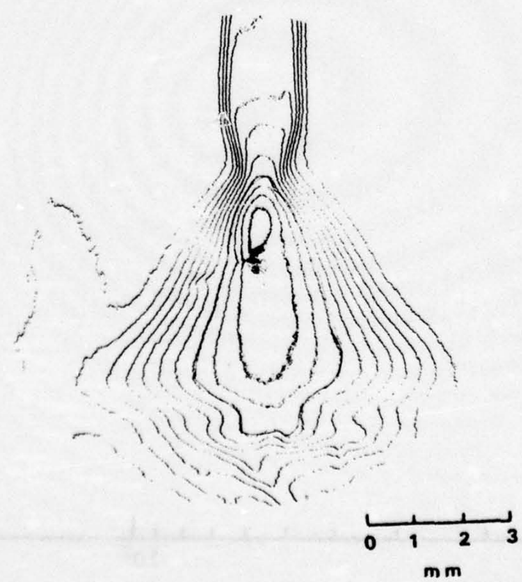
Electrode Diameter: 1/16" (100A), 3/32" (200A), and 1/8" (300A)

SUMMARY OF RESULTS

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[W/(cm^2·sr)]		(s)	-	-	-	(cm)
100	4600	54.2	9.6	10.4	12	9.4	7.9	100
200	7500	-	-	-	12	9.9	-	
300	9000	183	28.9	3.5	12	10.1	9.0	140



Event 20, 300 A, CI=0.13



Event 22, 100 A, CI=0.12

Figure 3a. Microdensitometer Scans of 35mm Processed Negatives Exposed 4 m from the Welding Arcs for Events 20-22.

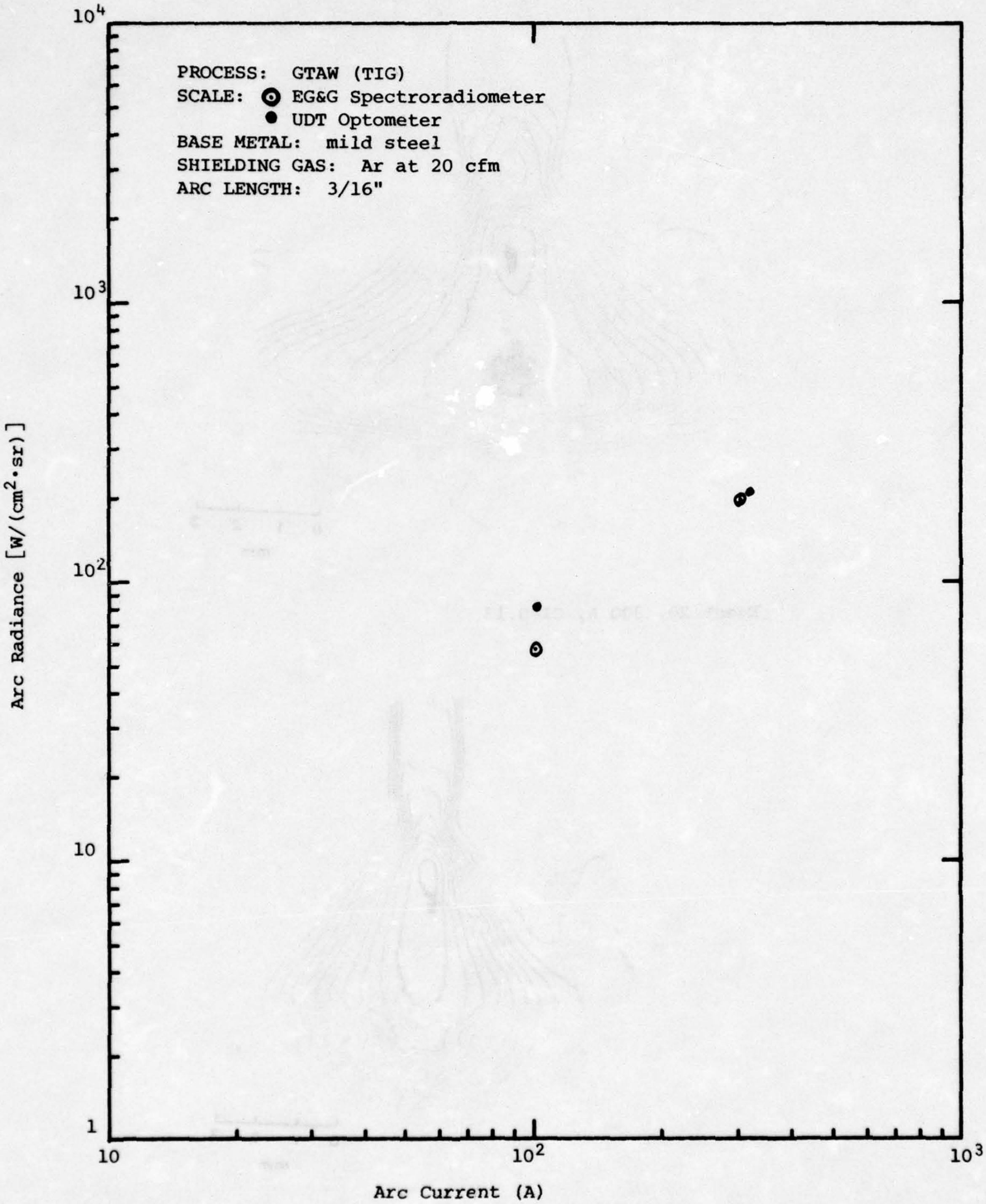


Figure 3b. Arc Radiance as a Function of Arc Current for Events 20 to 22.

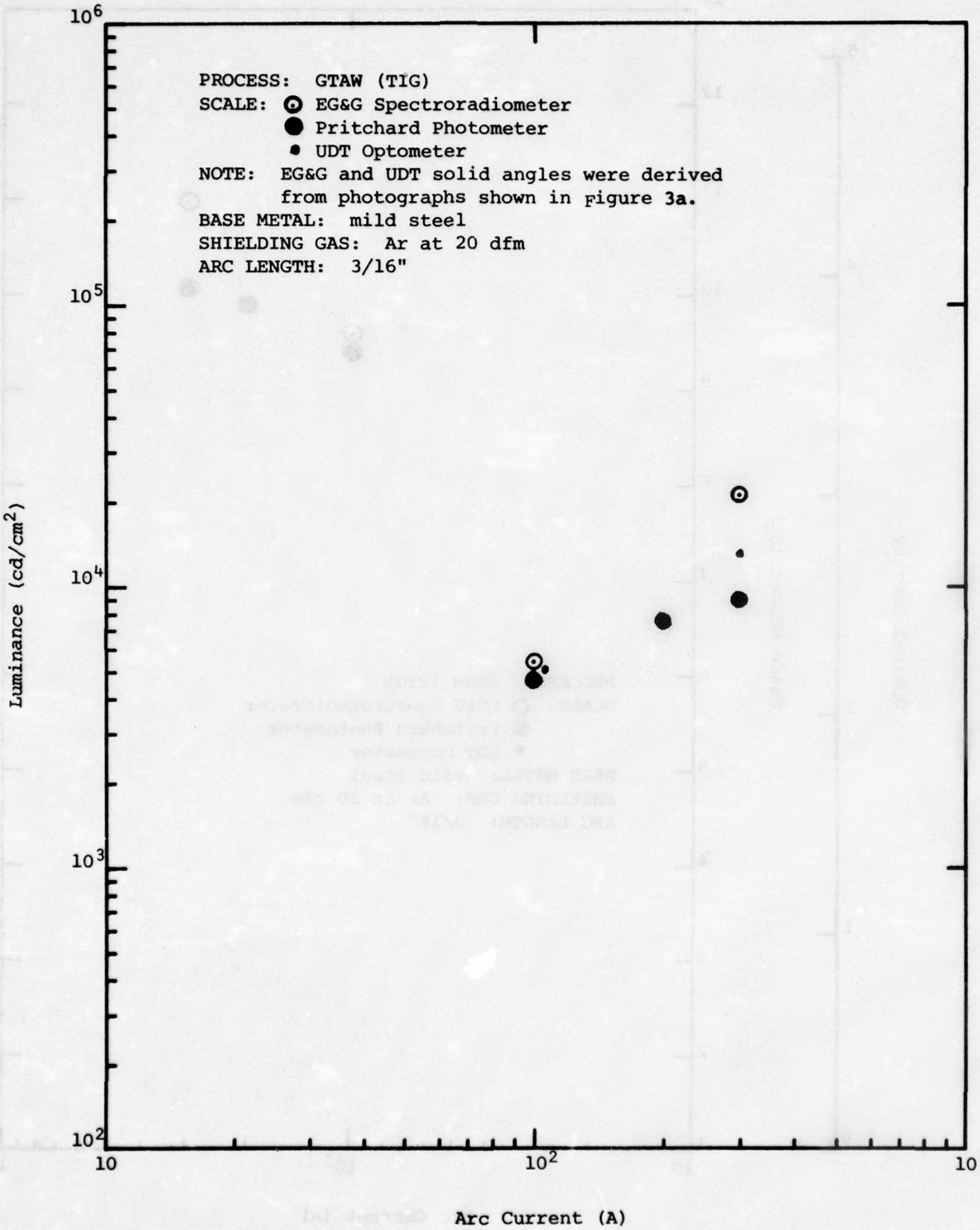


Figure 3c. Arc Luminance as a Function of Arc Current for Events 20 to 22.

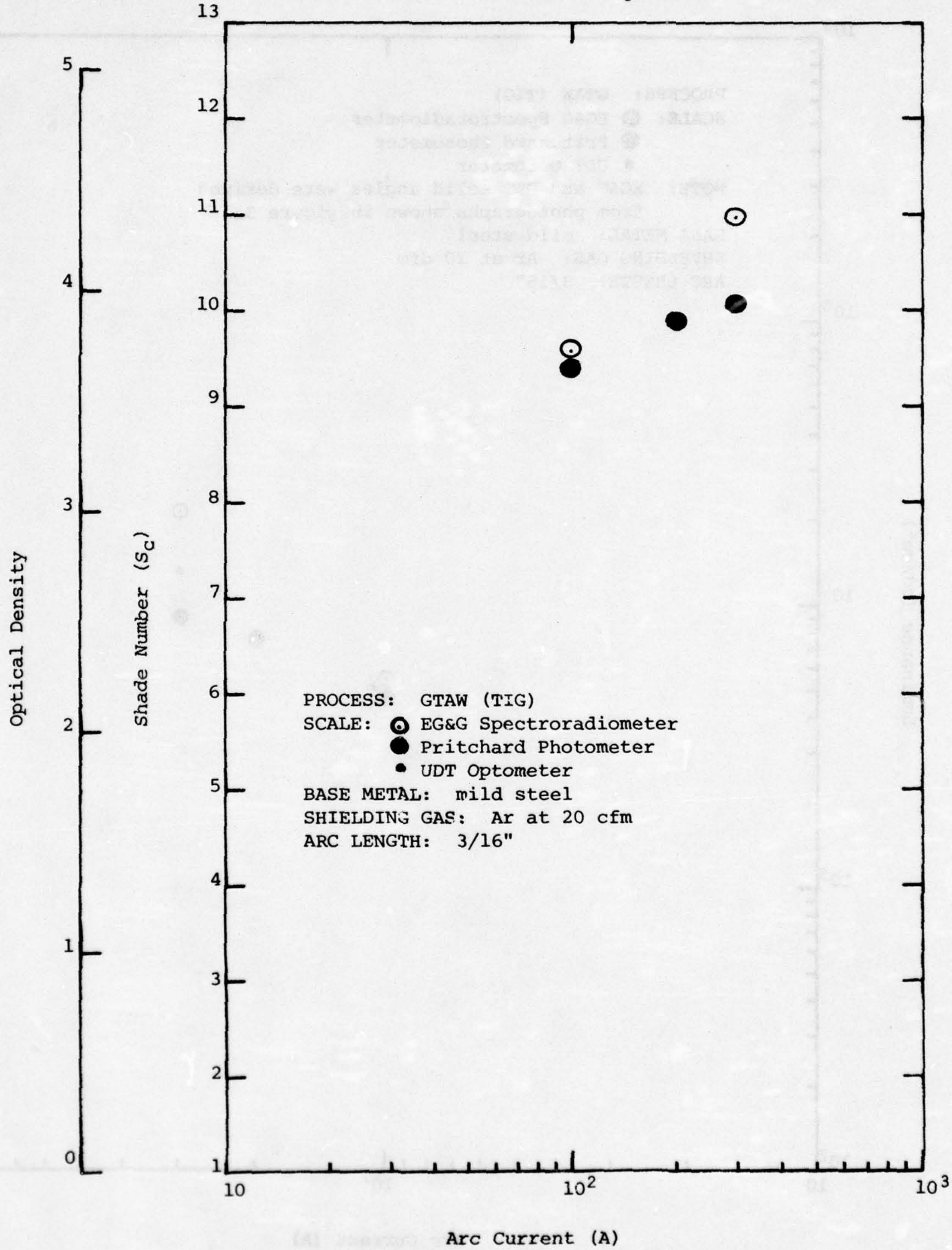


Figure 3d. Comfortable Shade Number (S_C) or Optical Density for Arc Viewing as a Function of Arc Current for Events 20 to 22.

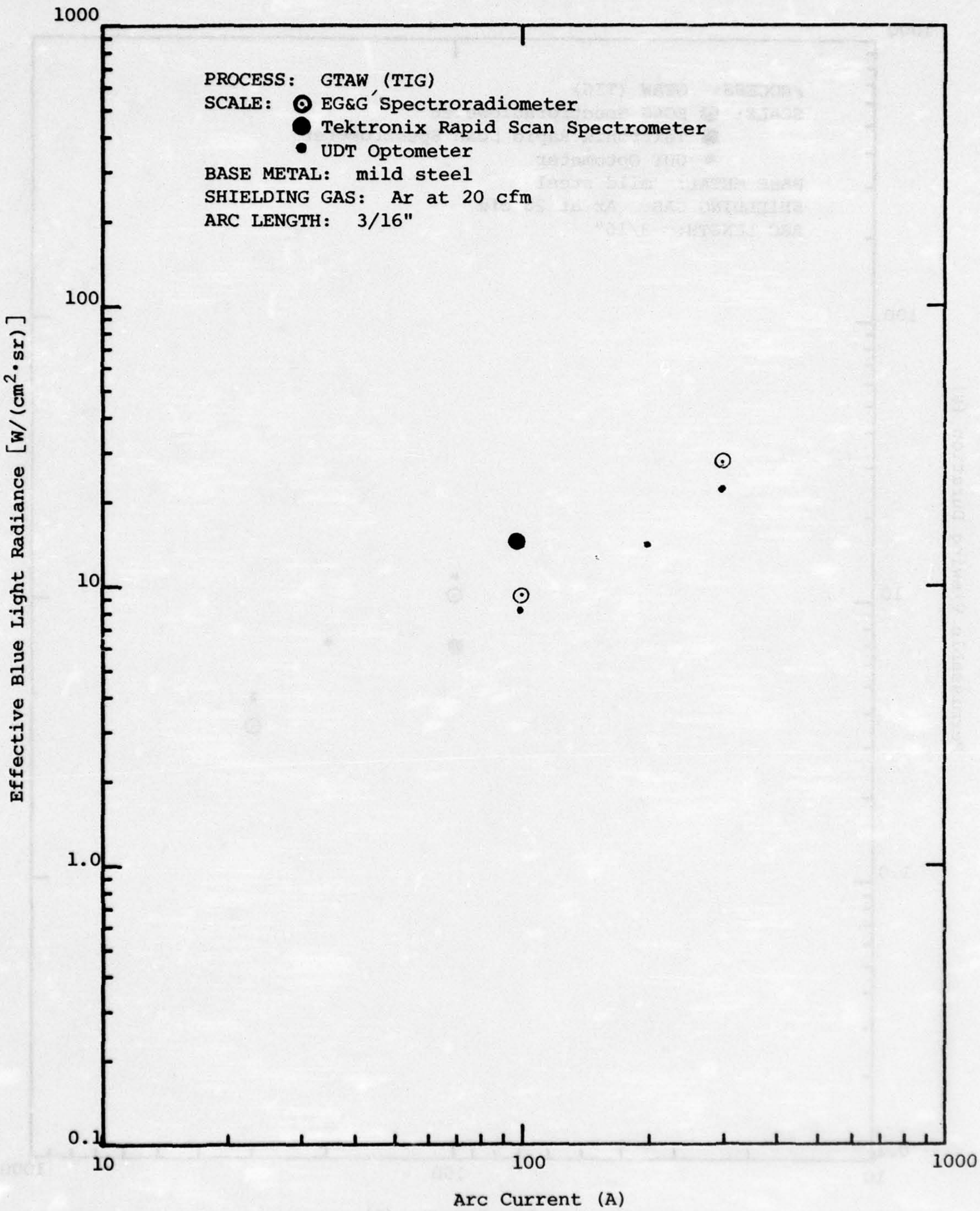


Figure 3e. Effective Blue Light Radiance as a Function of Arc Current for Events 20 to 22.

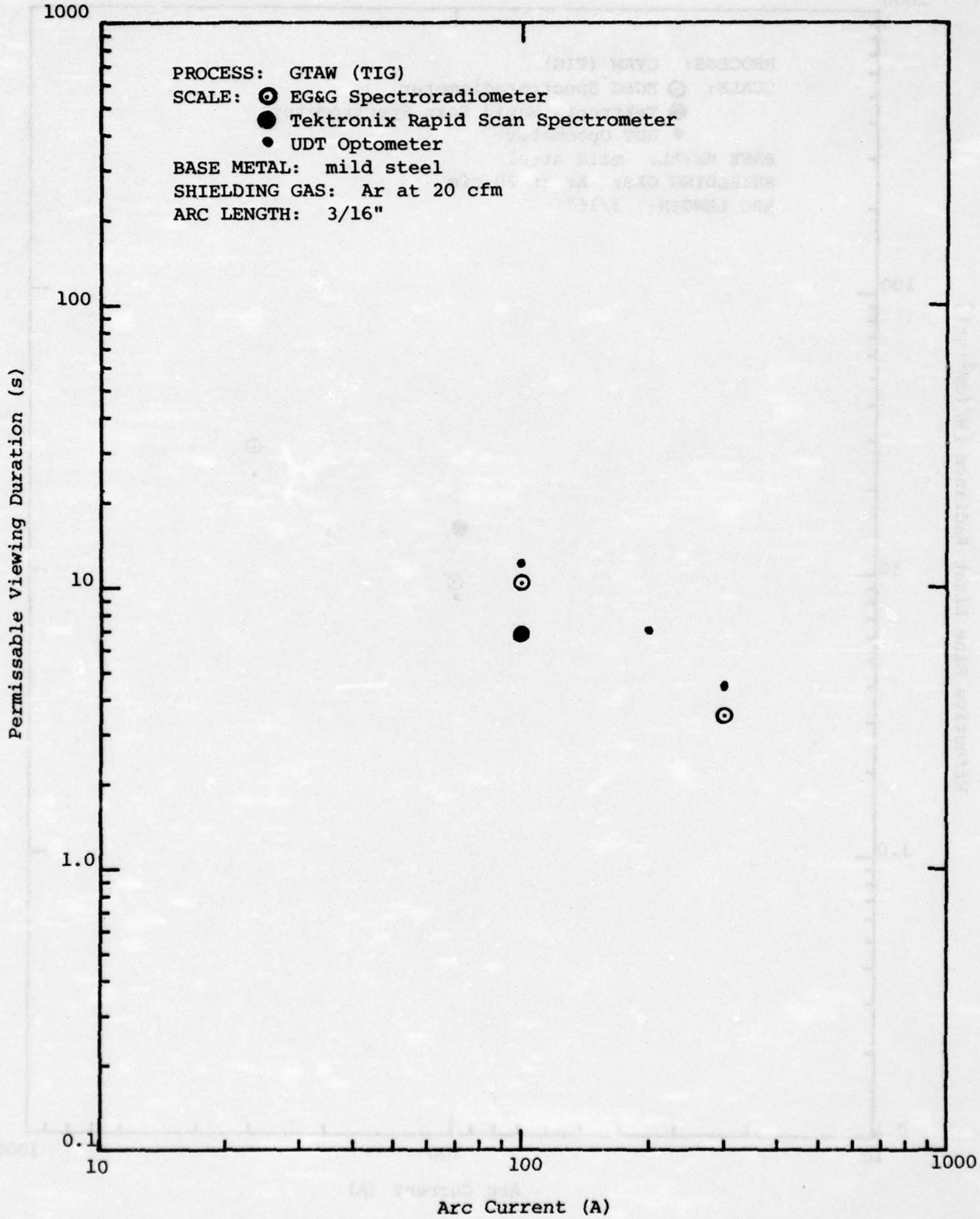


Figure 3f. Recommended Maximum Viewing Duration as a Function of Arc Current for Events 20 to 22 at Distances less than 1.2 m.

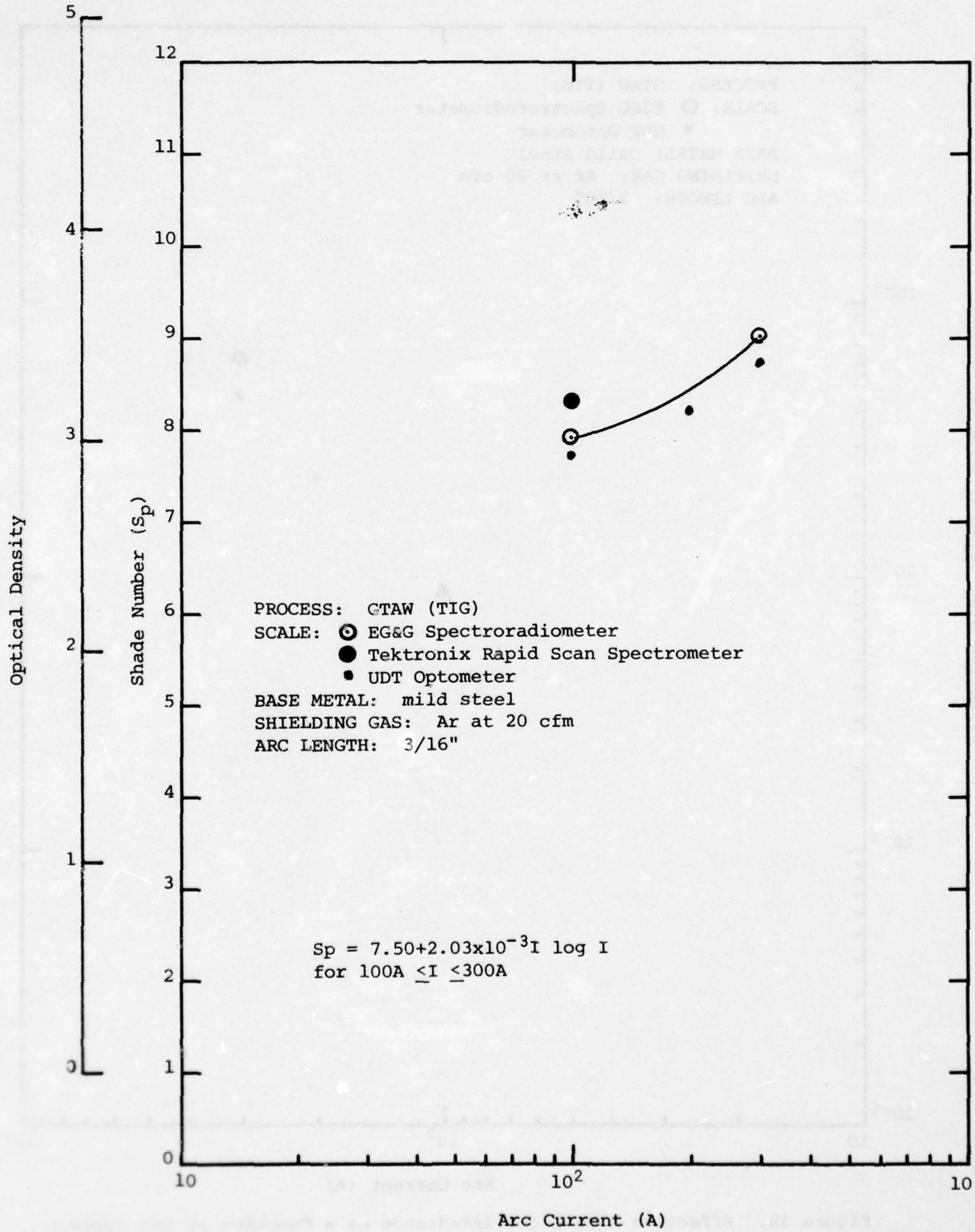


Figure 3g. **Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 20 to 22.**

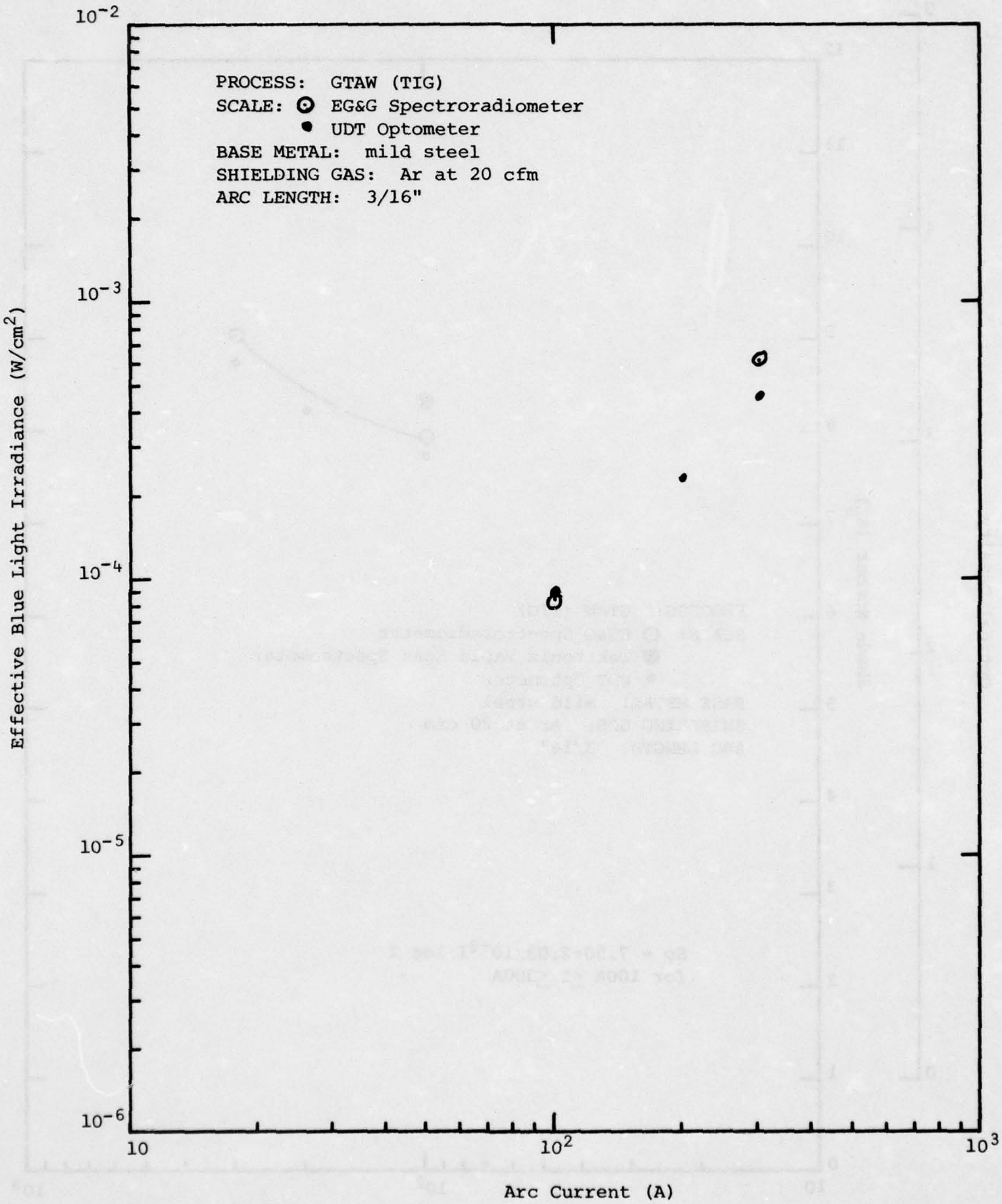


Figure 3h. Effective Blue Light Irradiance as a Function of Arc Current for Events 20 to 22.

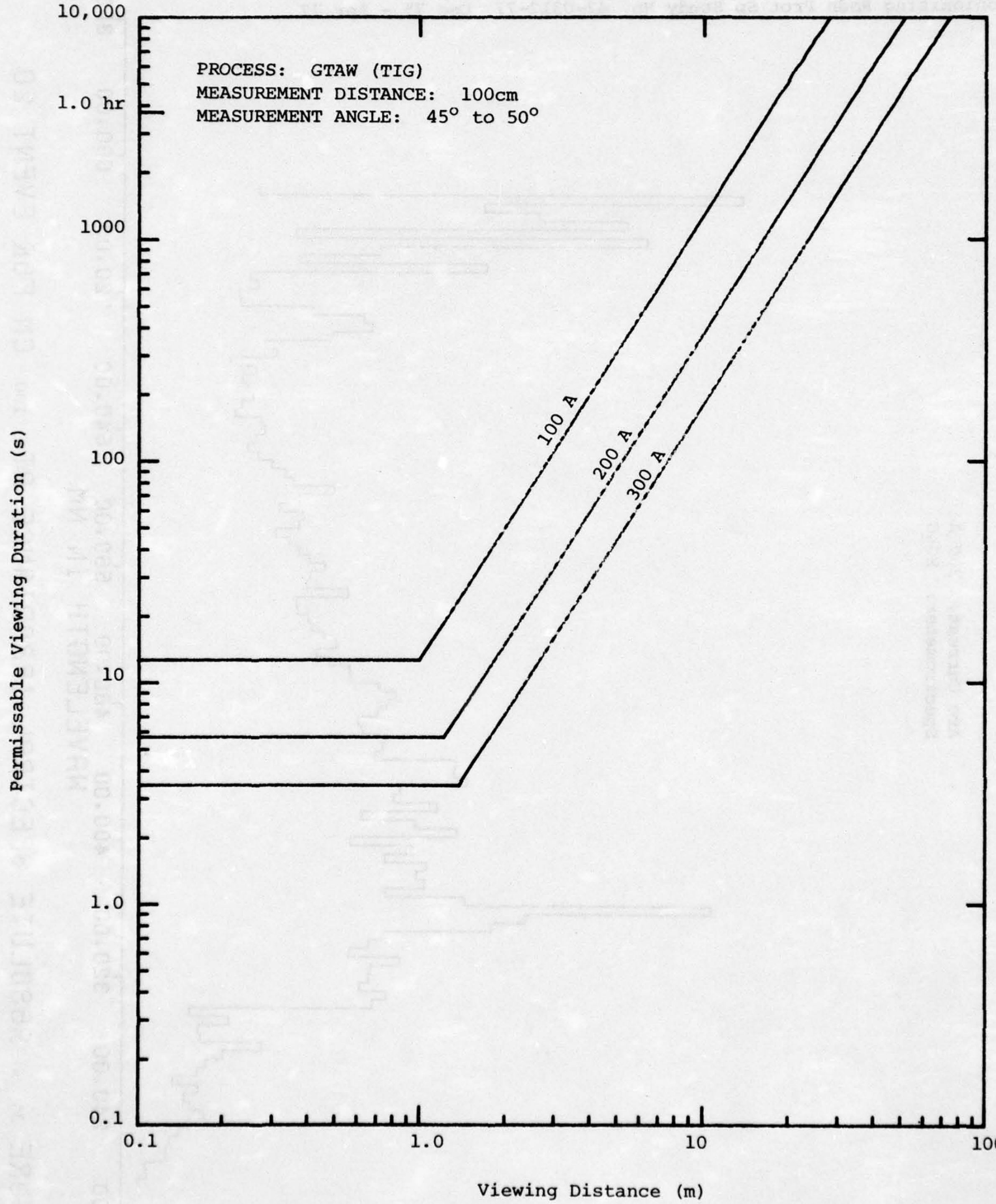


Figure 3i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 20 to 22.

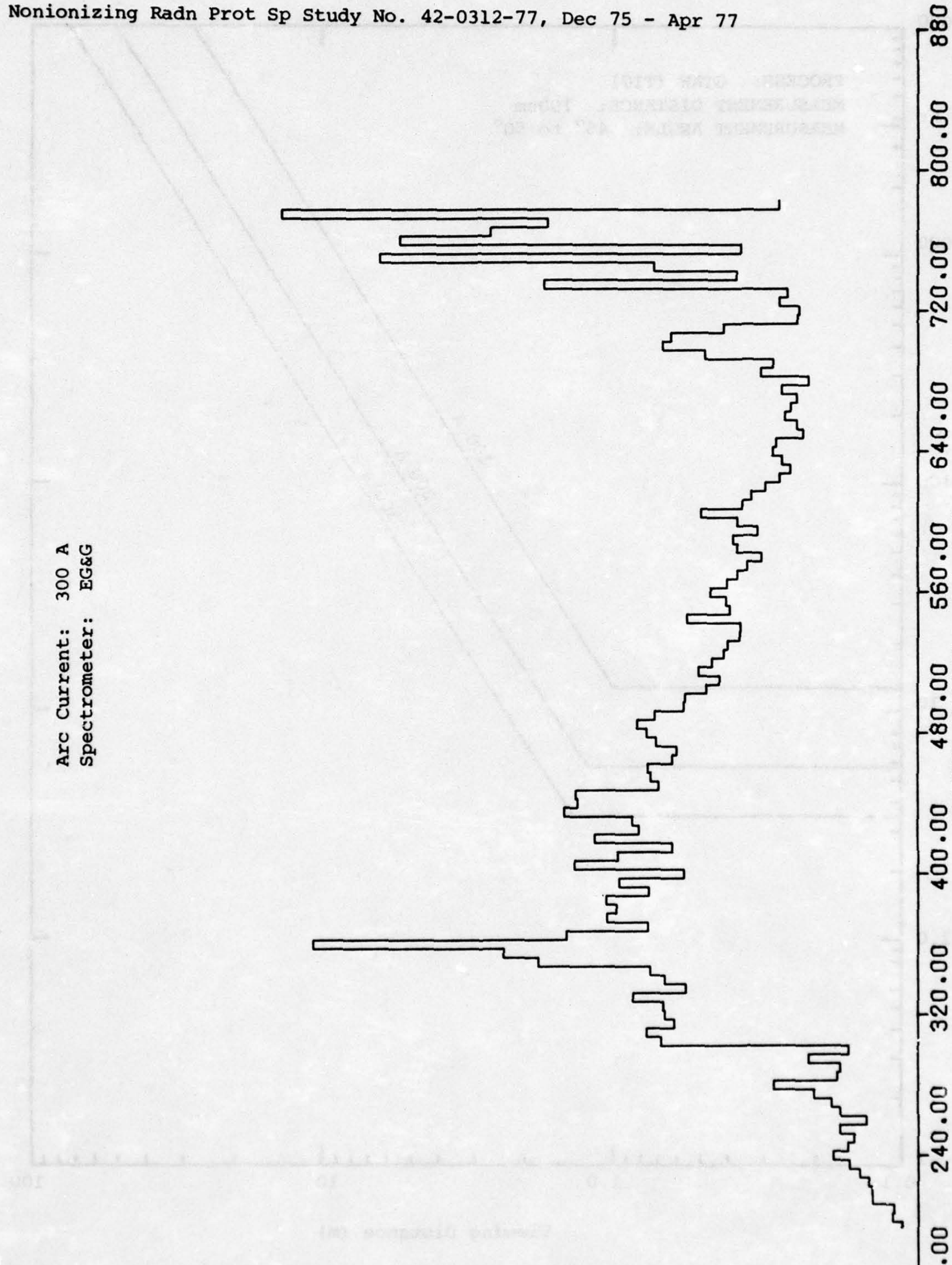


FIGURE 3j . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 20

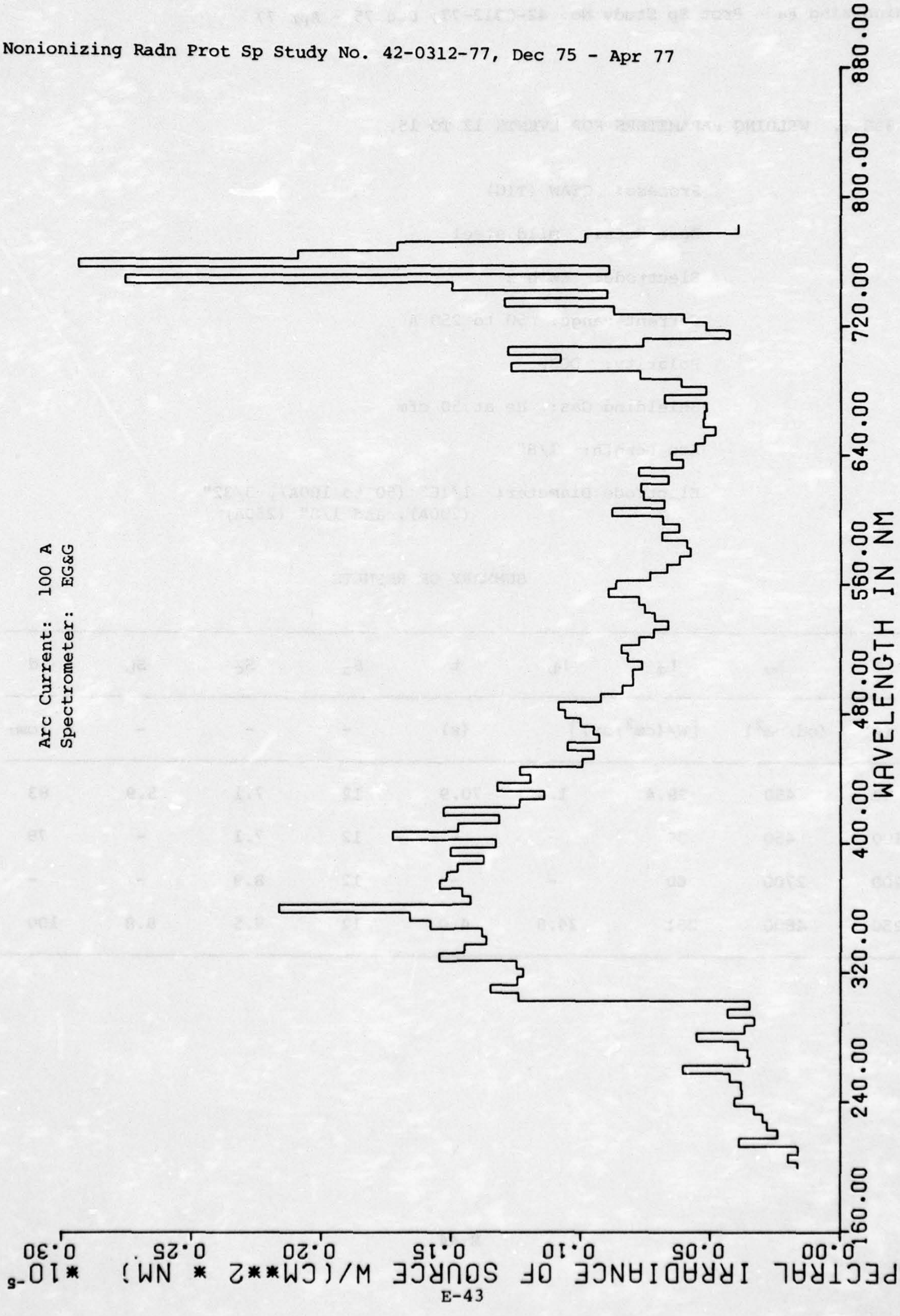


FIGURE 3k . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 22

TABLE 4. WELDING PARAMETERS FOR EVENTS 12 TO 15.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 250 A

Polarity: DCSP

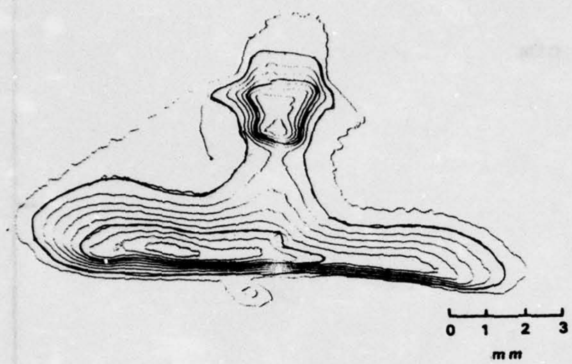
Shielding Gas: He at 50 cfm

Arc Length: 1/8"

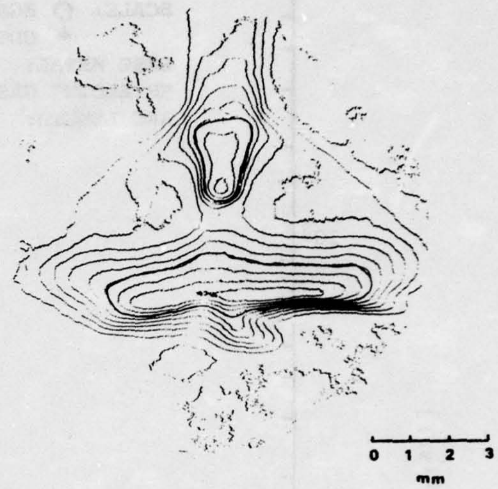
Electrode Diameter: 1/16" (50 to 100A), 3/32" (200A), and 1/8" (250A)

SUMMARY OF RESULTS

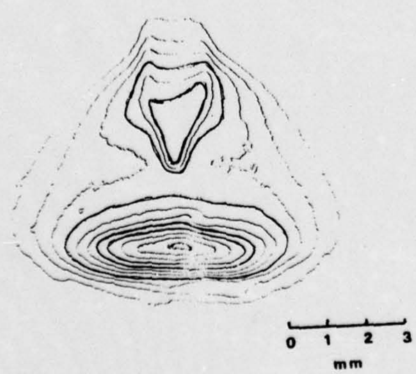
I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[$W/(cm^2 \cdot sr)$]		(s)	-	-	-	(cm)
50	450	28.4	1.4	70.9	12	7.1	5.9	83
100	450	39	-	-	12	7.1	-	78
200	2700	60	-	-	12	8.9	-	-
250	4800	281	24.8	4.0	12	9.5	8.8	100



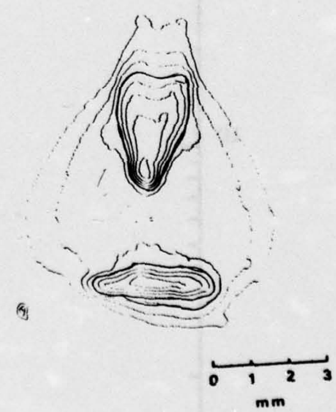
Event 12, 250 A, CI=0.11



Event 13, 200 A, CI=0.125



Event 14, 100 A, CI=0.12



Event 15, 50 A, CI=0.13

Figure 4a. Microdensitometer Scans of 35mm Processed Negatives Exposed 4 m from the Welding Arcs for Events 12-15.

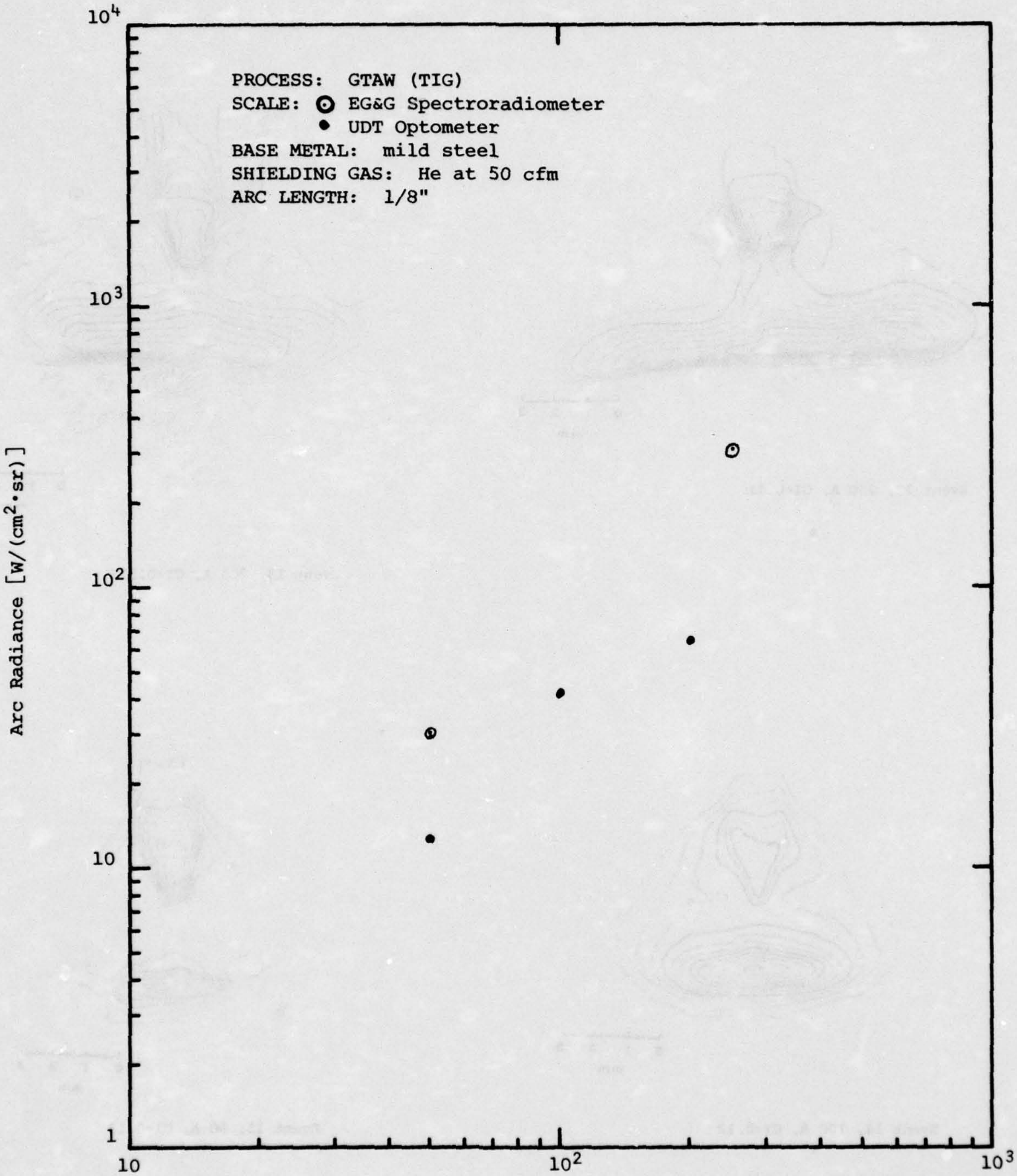


Figure 4b. Arc Radiance as a Function of Arc Current for Events 12 to 15.

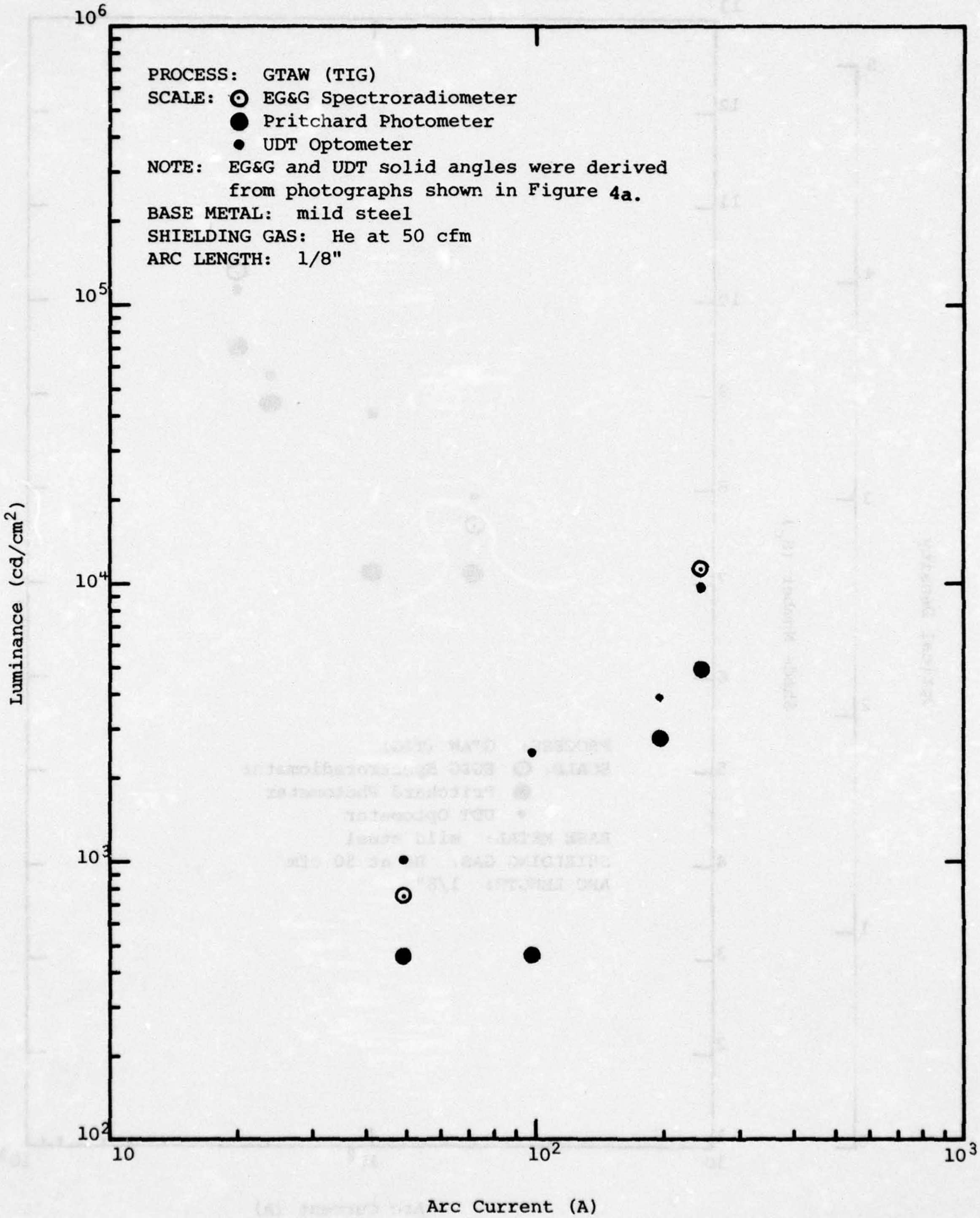


Figure 4c. Arc Luminance as a Function of Arc Current for Events 12 to 15.

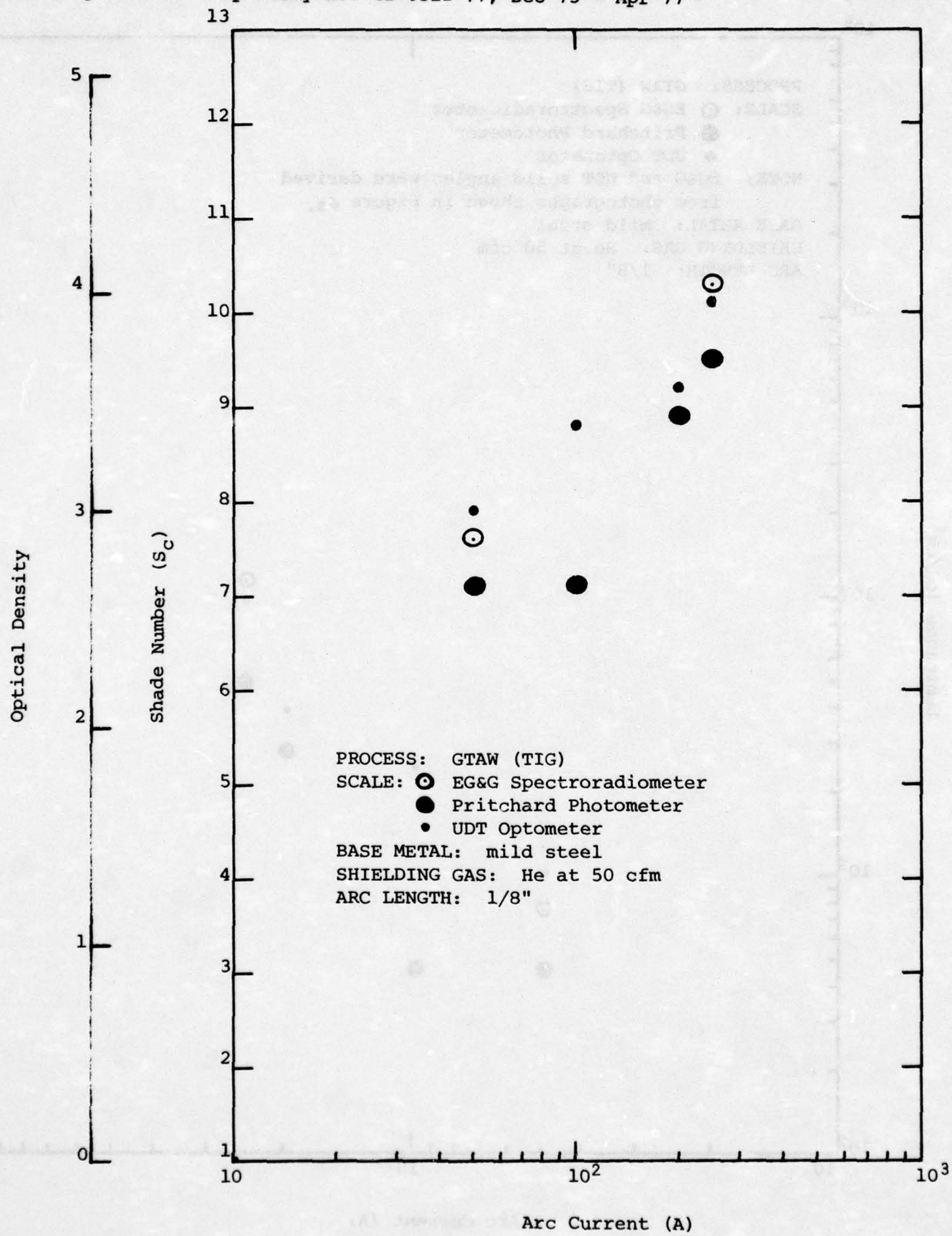


Figure 4d. Comfortable Shade Number (S_C) or Optical Density for Arc Viewing as a Function of Arc Current for Events 12 to 15.

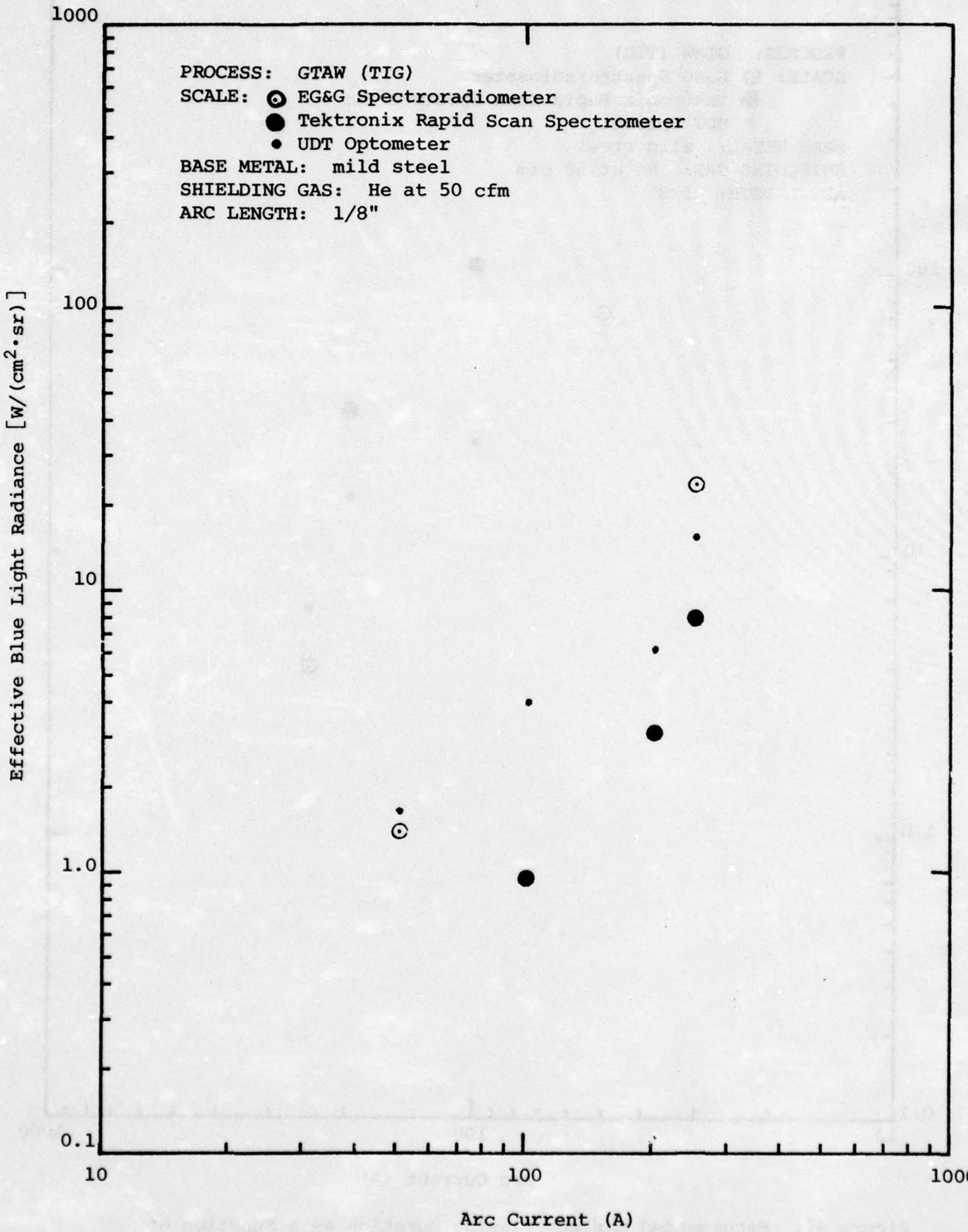


Figure 4e. Effective Blue Light Radiance as a Function of Arc Current for Events 12 to 15.

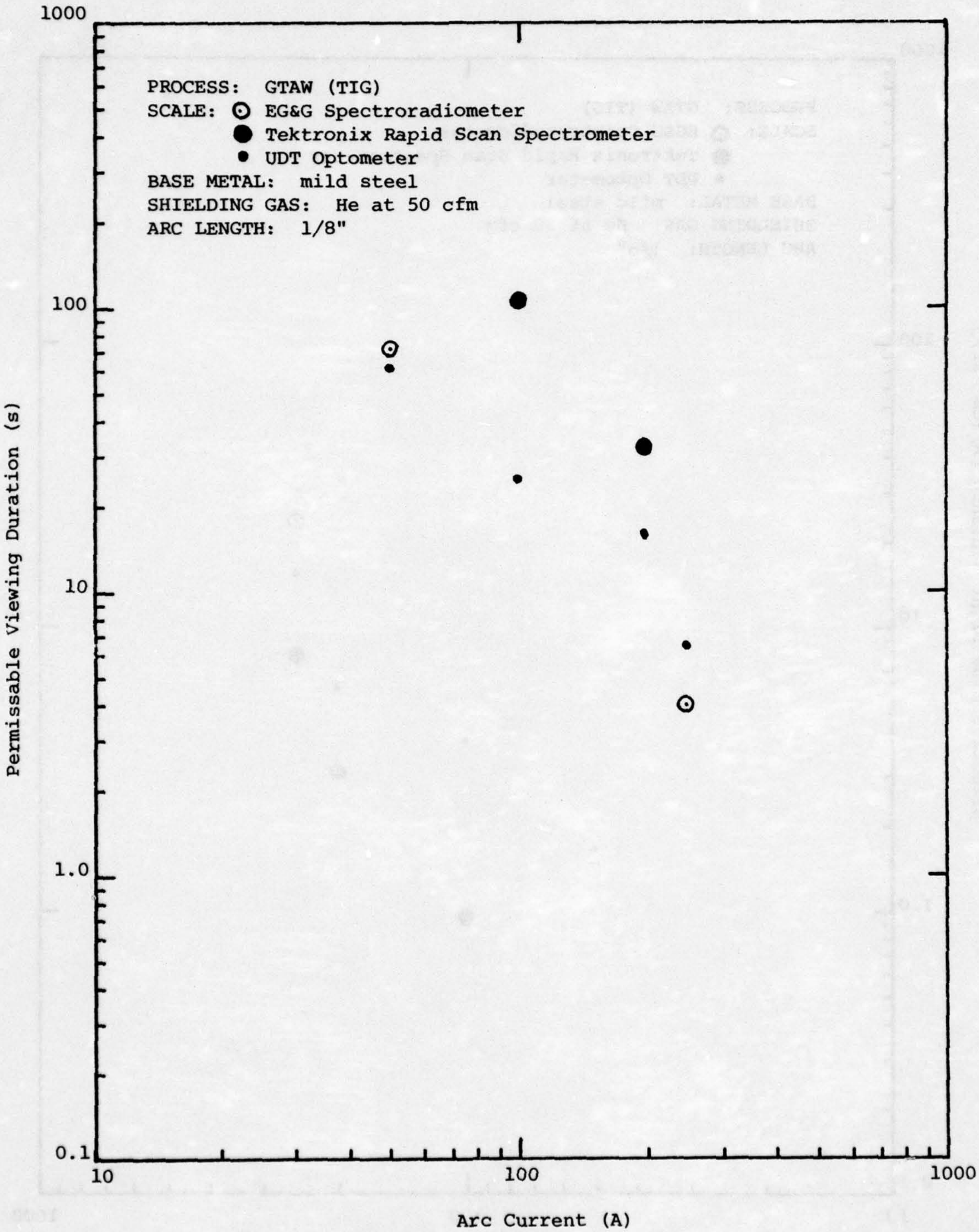


Figure 4f. Recommended maximum Viewing Duration as a Function of Arc Current for Events 12 to 15 at Distances less that 1.0 m.

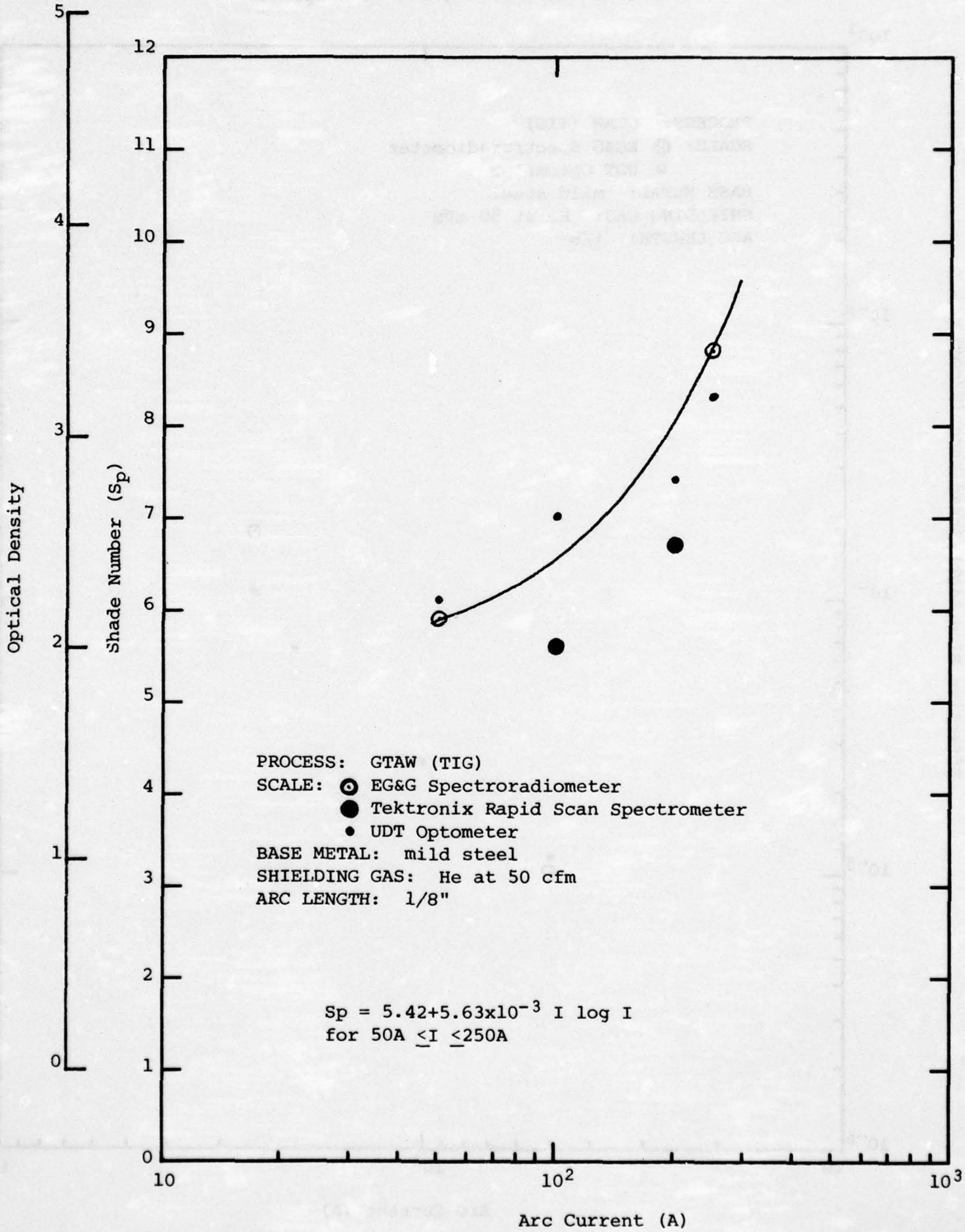


Figure 4g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 12 to 15.

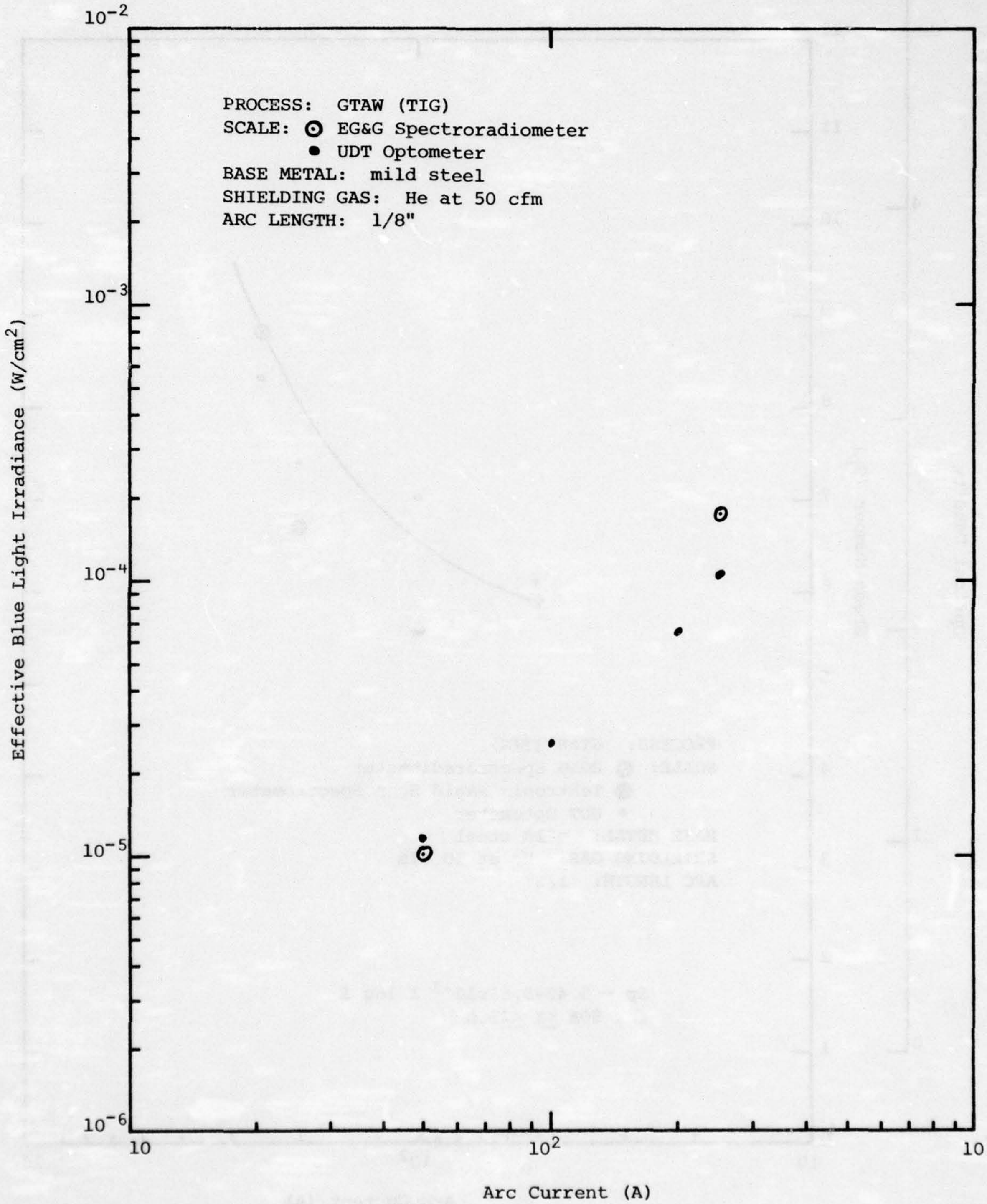
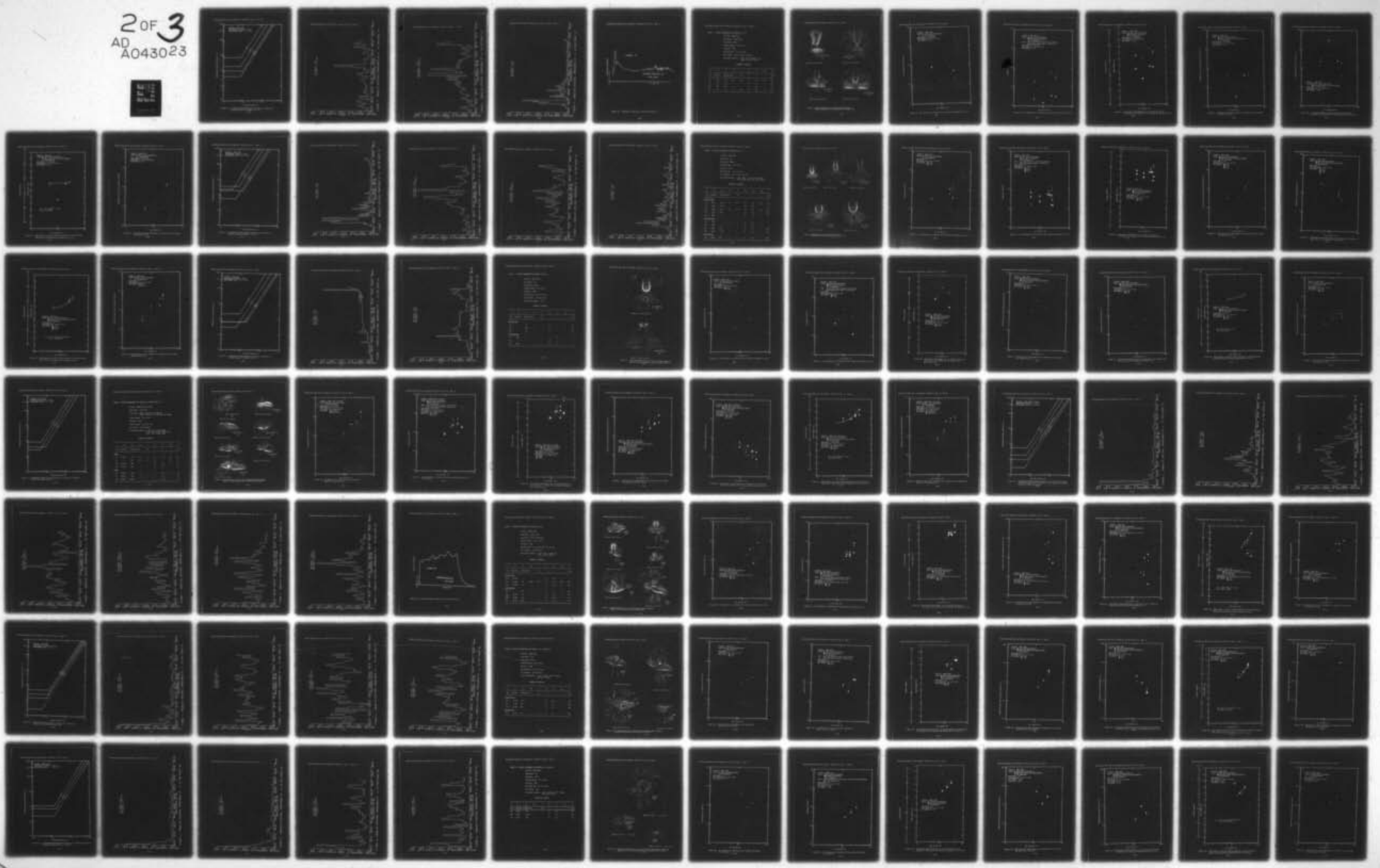


Figure 4h. Effective Blue Light Irradiance as a Function of Arc Current for Events 12 to 15.

AD-A043 023 ARMY ENVIRONMENTAL HYGIENE AGENCY ABERDEEN PROVING GR--ETC F/G 6/18
EVALUATION OF THE POTENTIAL RETINAL HAZARDS FROM OPTICAL RADIAT--ETC(U)
AUG 77 W J MARSHALL , D H SLINEY, T L LYON

UNCLASSIFIED USAEHA-42-0312-77 NL

2 OF 3
AD A043023



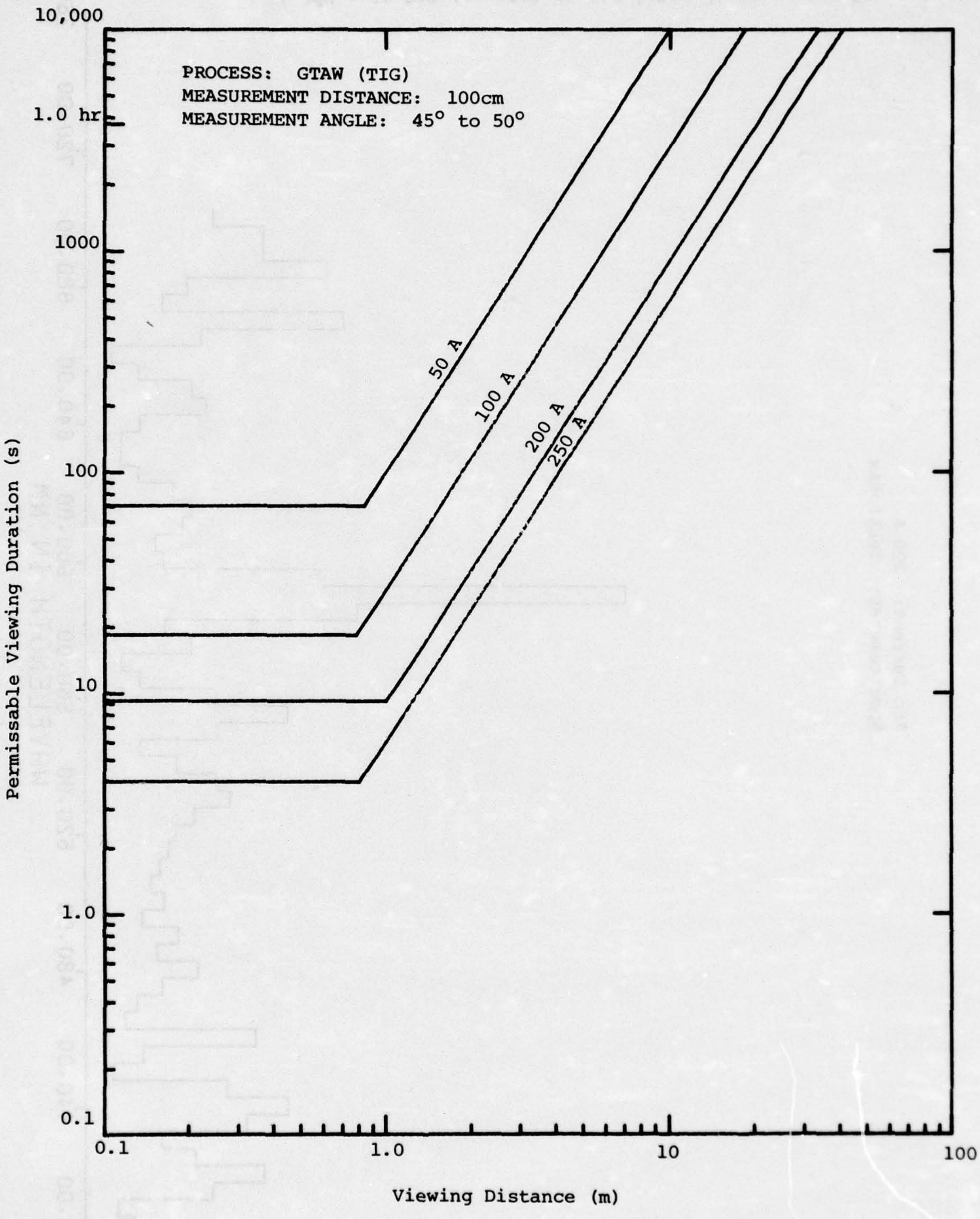


Figure 4i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 12 to 15.

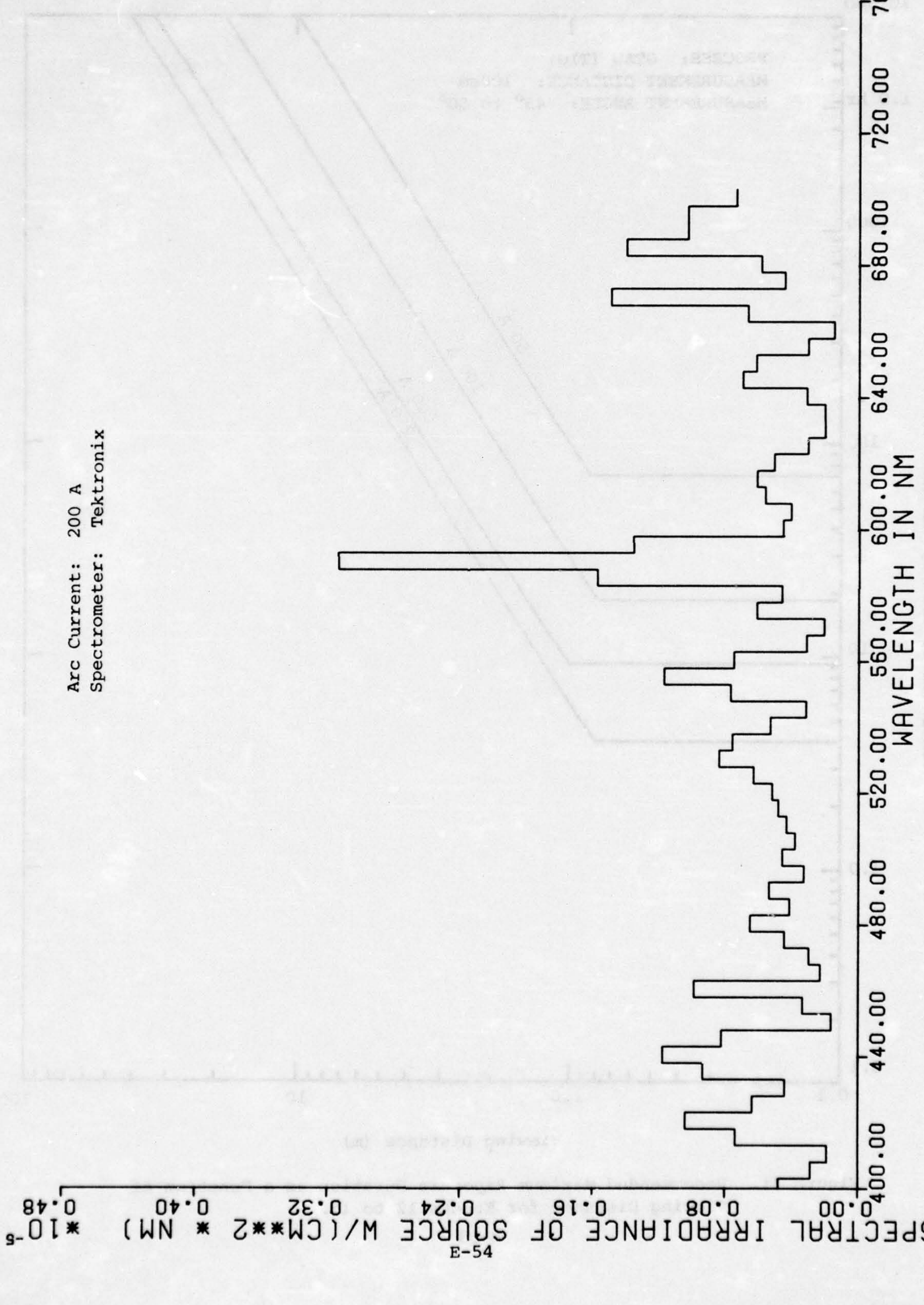


FIGURE 4j . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 13

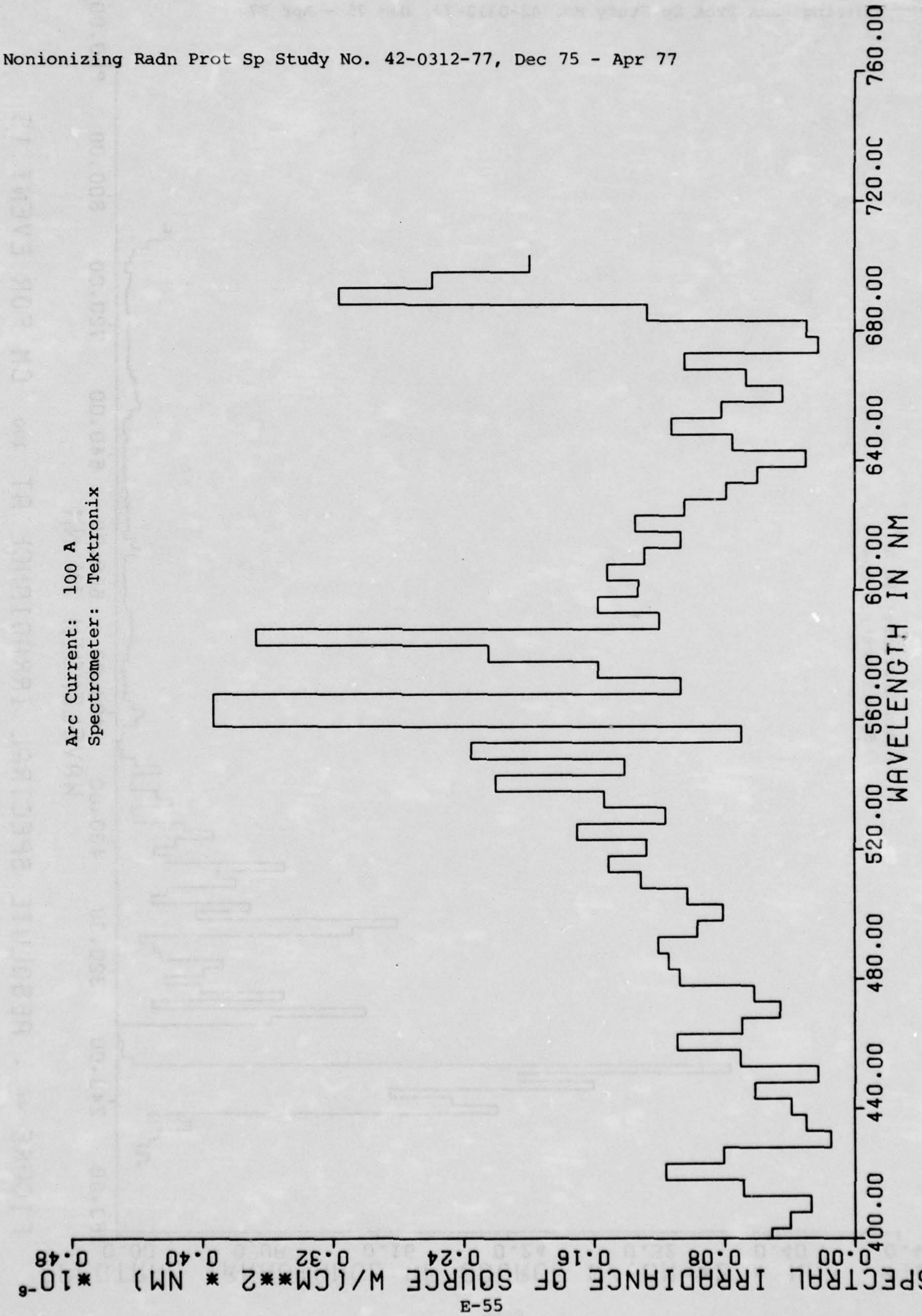


FIGURE 4k . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 14

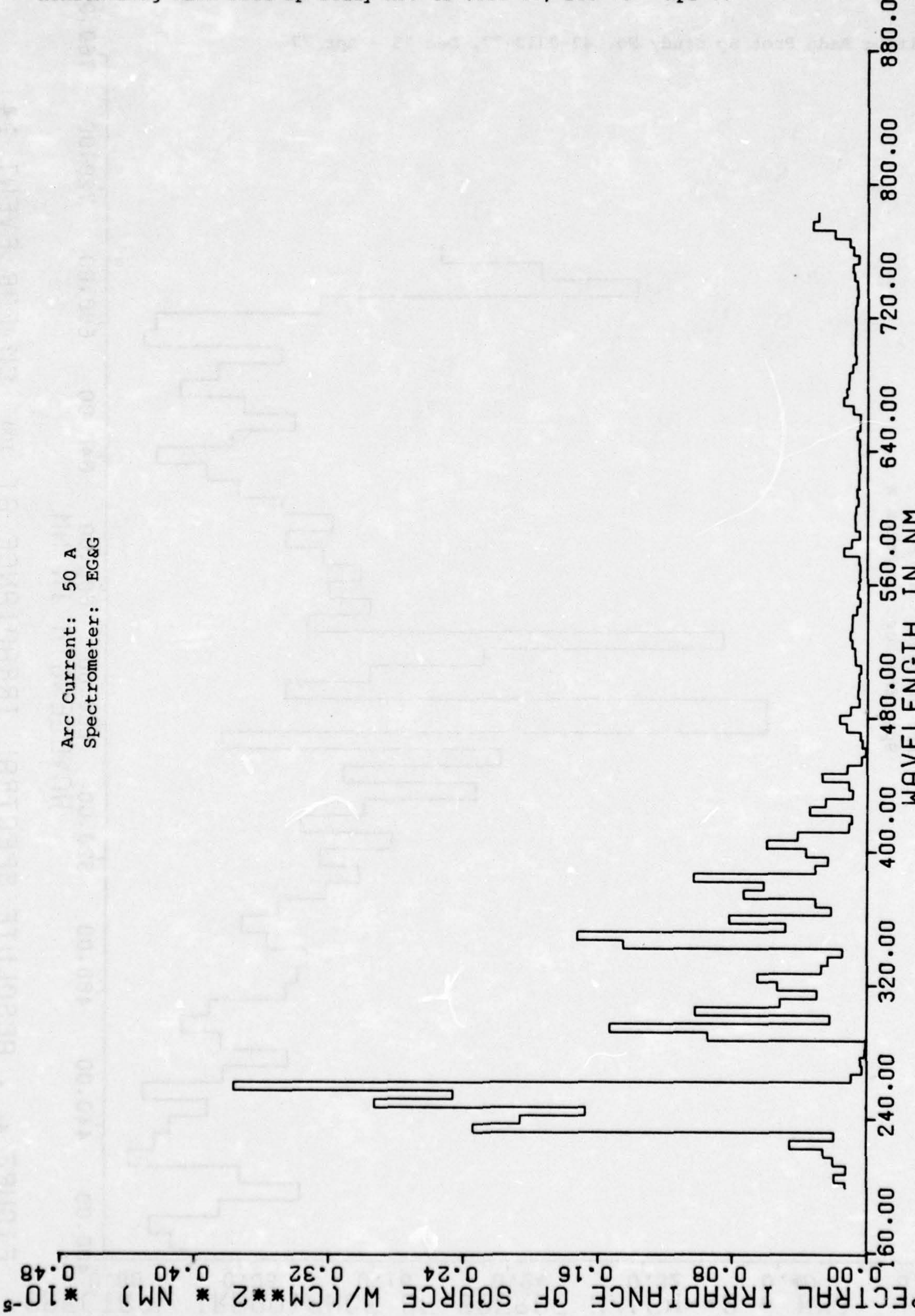


FIGURE 4ℓ . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 15

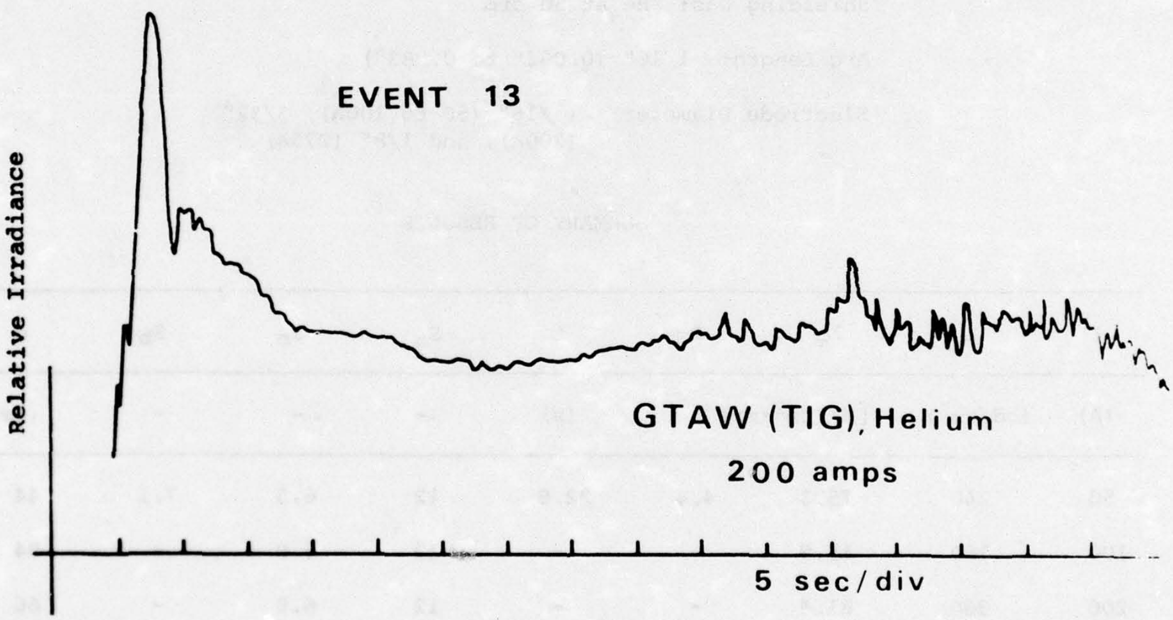


Figure 4m. Irradiance (UDT 40x) vs Time for Event 13.

TABLE 5. WELDING PARAMETERS FOR EVENTS 16 TO 19.

Process: GTAW (TIG)

Base Metal: mild steel

Electrode: EWTh-2

Current Range: 50 to 275 A

Polarity: DCSP

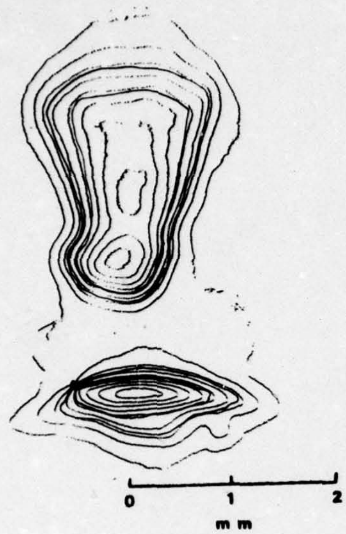
Shielding Gas: He at 50 cfm

Arc Length: 1/16" (0.062" to 0.083")

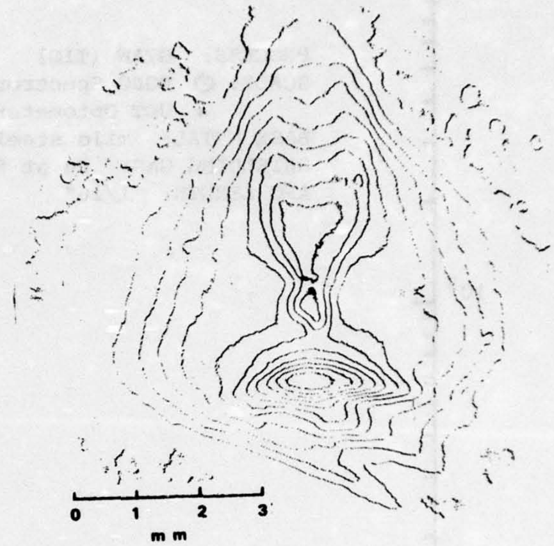
Electrode Diameter: (1/16" (50 to 100A), 3/32" (200A), and 1/8" (275A)

SUMMARY OF RESULTS

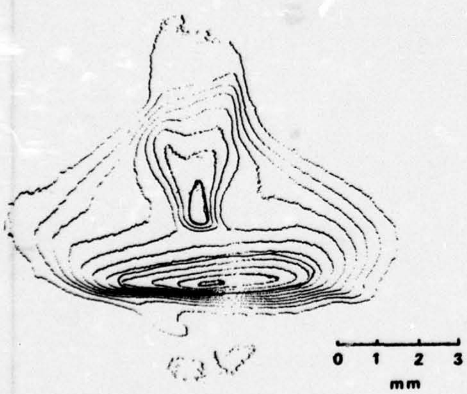
I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[W/(cm^2·sr)]		(s)	-	-	-	(cm)
50	240	75.3	4.4	22.8	12	6.5	7.1	44
100	150	15.9	-	-	12	5.0	-	94
200	360	81.4	-	-	12	6.9	-	66
275	330	47.2	5.2	19.2	12	6.8	7.3	160



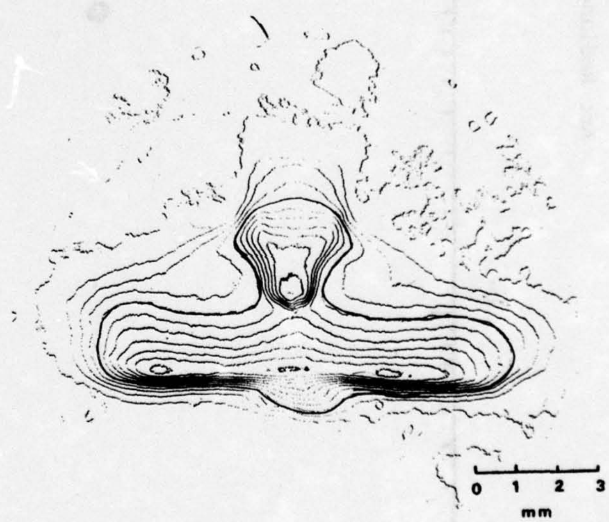
Event 16, 50 A, CI=0.09



Event 17, 100 A, CI=0.06



Event 18, 200 A, CI=0.115



Event 19, 275 A, CI=0.06

Figure 5a. Microdensitometer Scans of 35mm Processed Photographic Negatives Exposed 4 m from the Welding Arcs for Events 16-19.

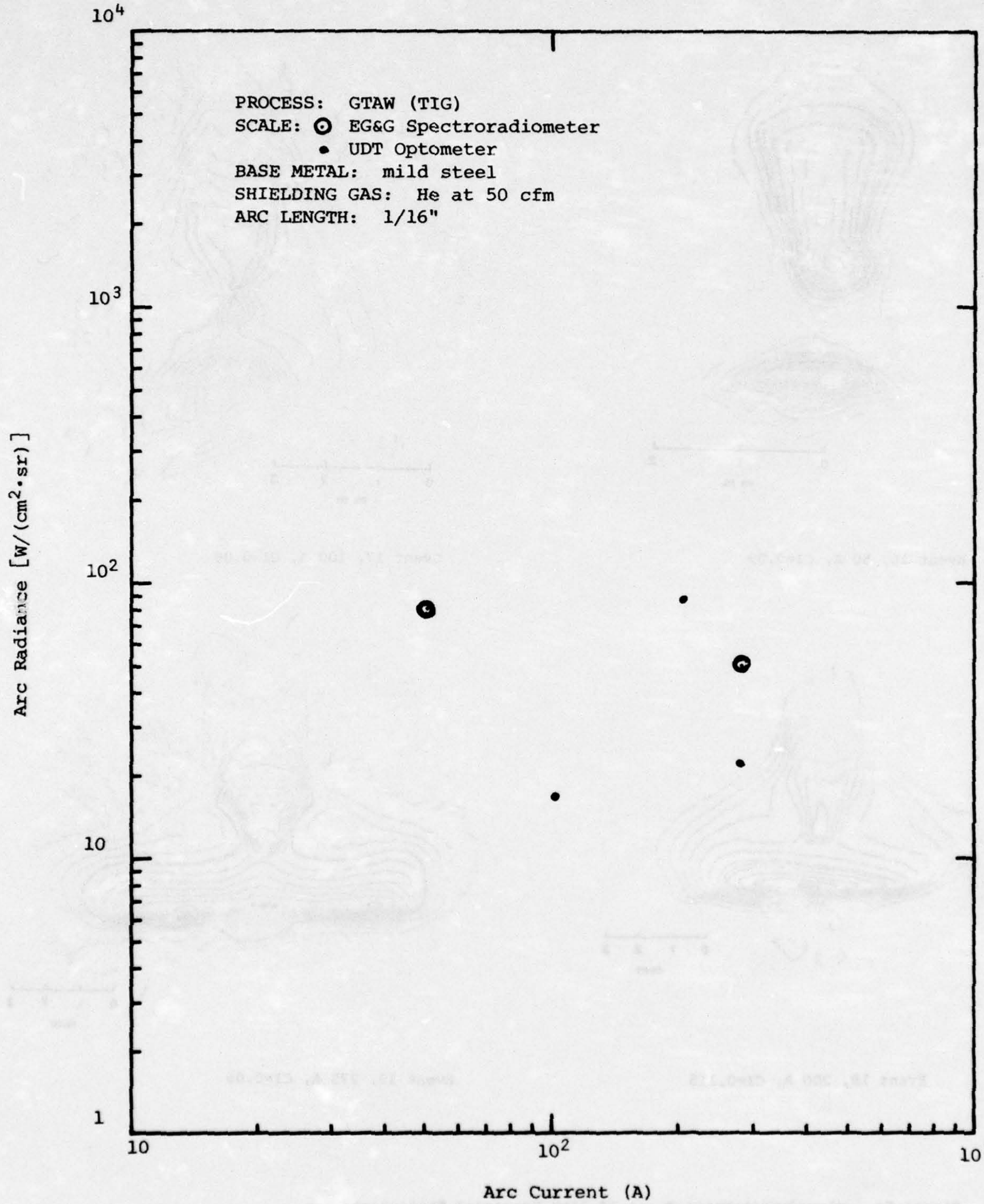


Figure 5b. Arc Radiance as a Function of Arc Current for Events 16 to 19.

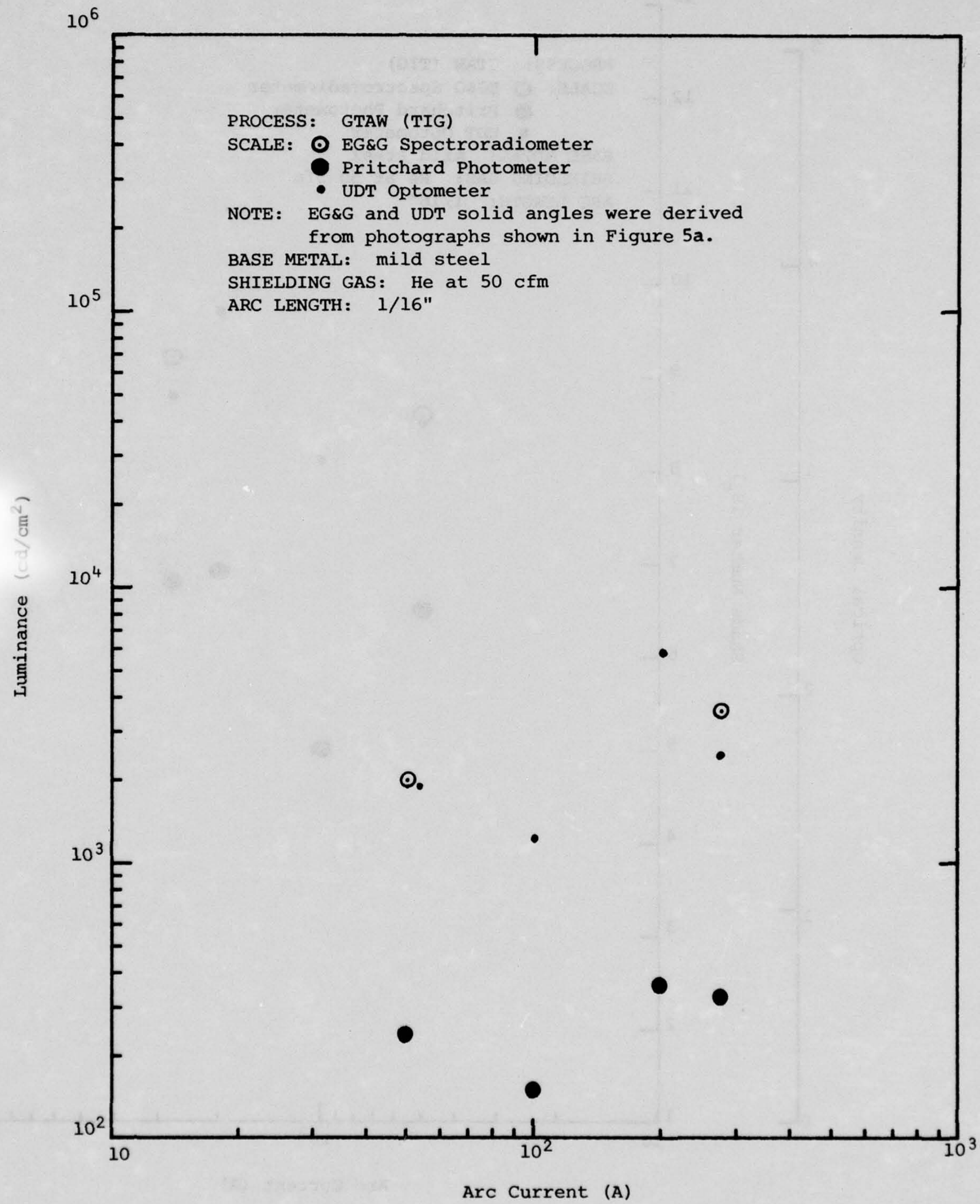


Figure 5c. Arc Luminance as a Function of Arc Current for Events 16 to 19.

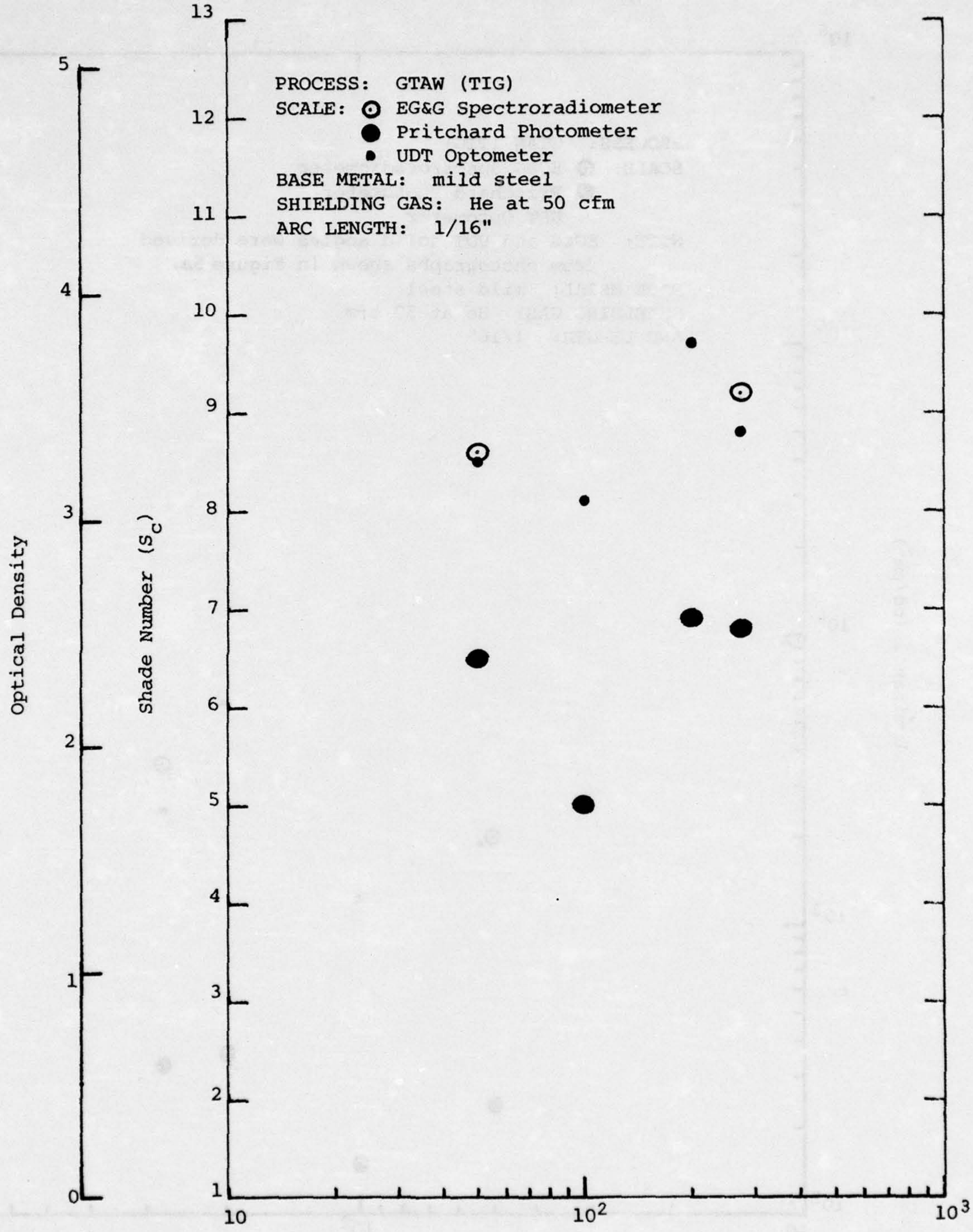


Figure 5d. Comfortable Shade Number (S_c) or Optical Density for Arc Viewing as a Function of Arc Current for Events 16 to 19.

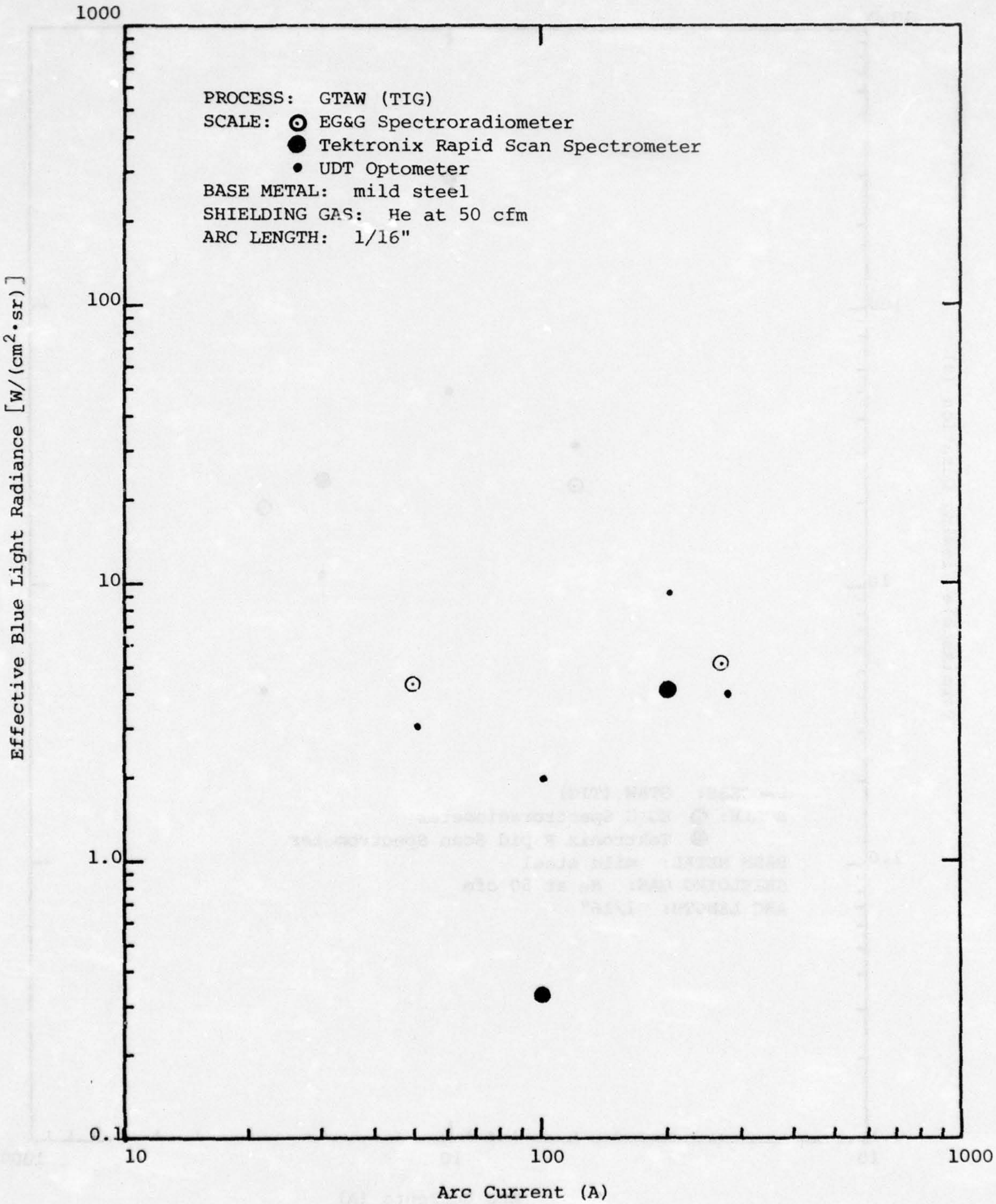


Figure 5e. Effective Blue Light Radiance as a Function of Arc Current for Events 16 to 19.

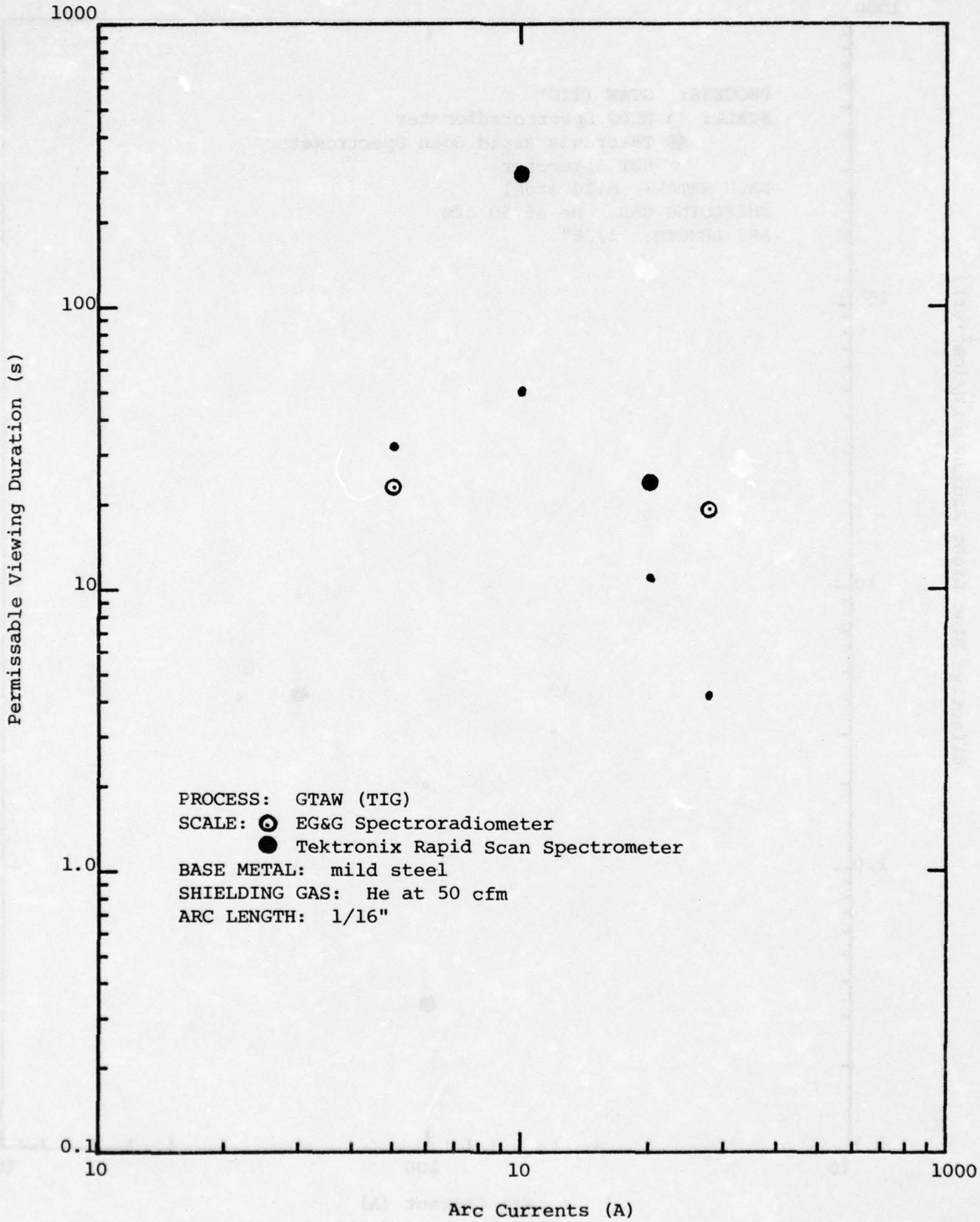


Figure 5f. Recommended Maximum Viewing Duration as a Function of Arc Current for Events 16 to 19 at Distances less than 1.5 m.

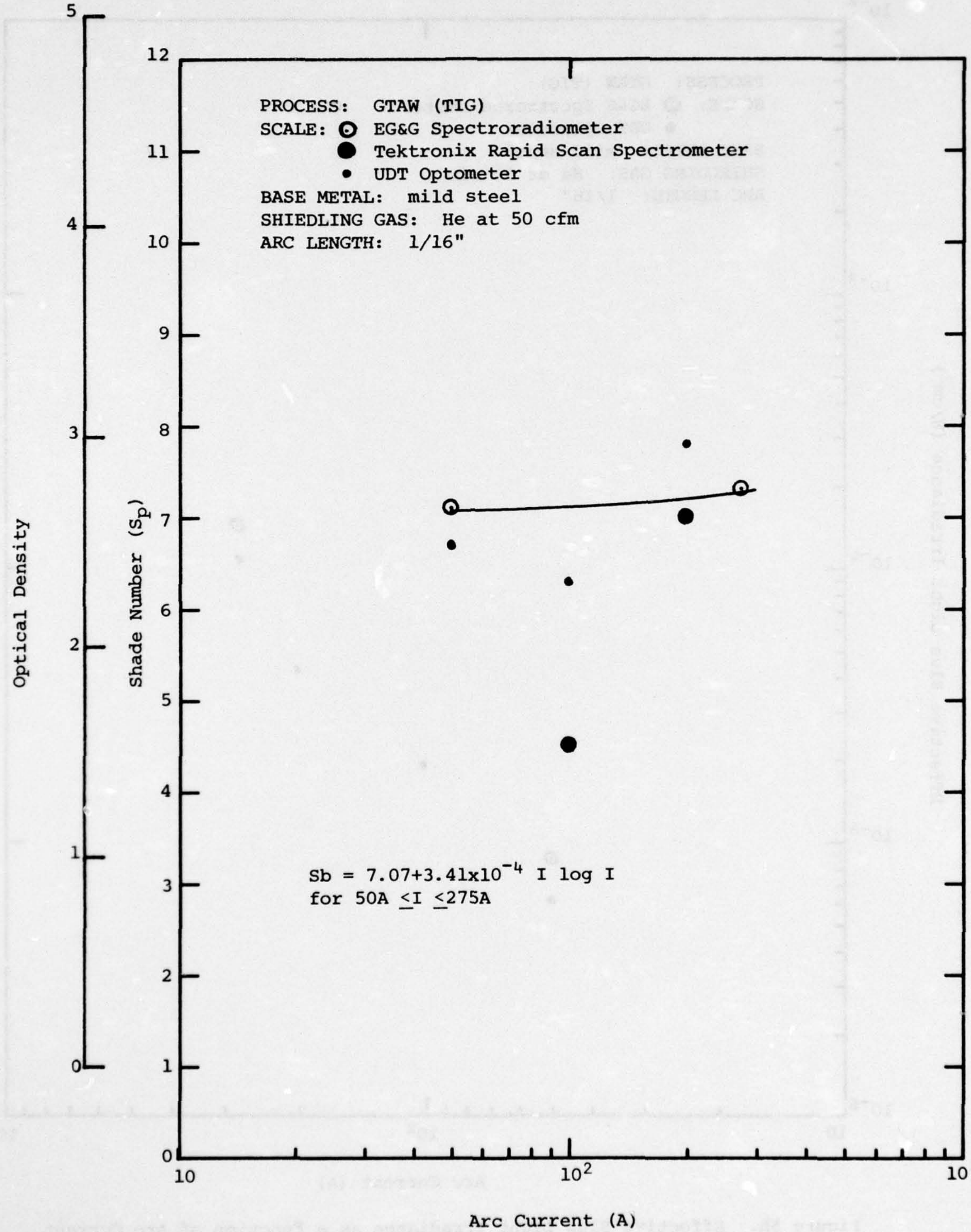


Figure 5g. Shade Number of Optical Density Necessary for Eye Protection against Blue Light Emitted During Events 16 to 19.

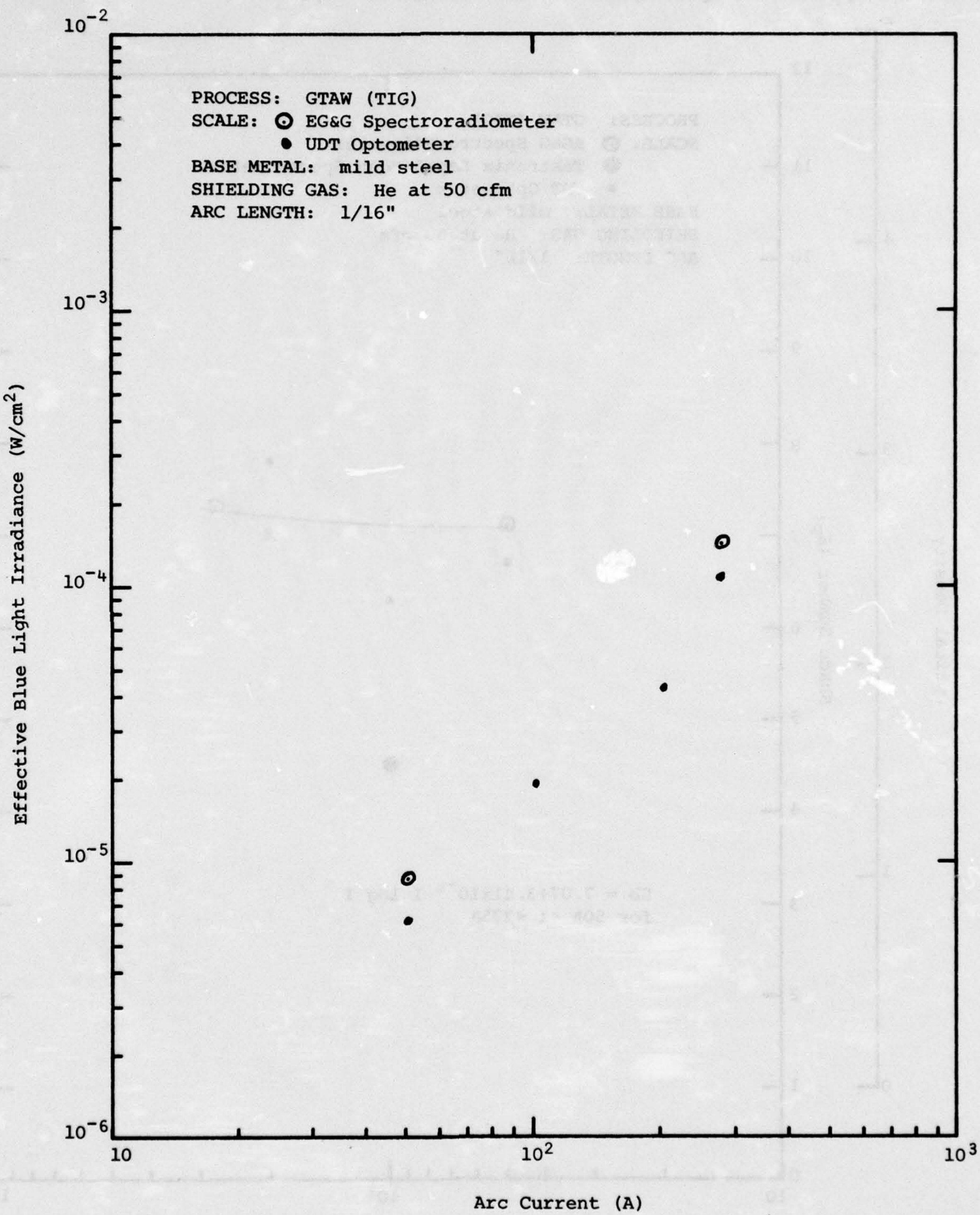


Figure 5h. Effective Blue Light Irradiance as a Function of Arc Current for Events 16 to 19.

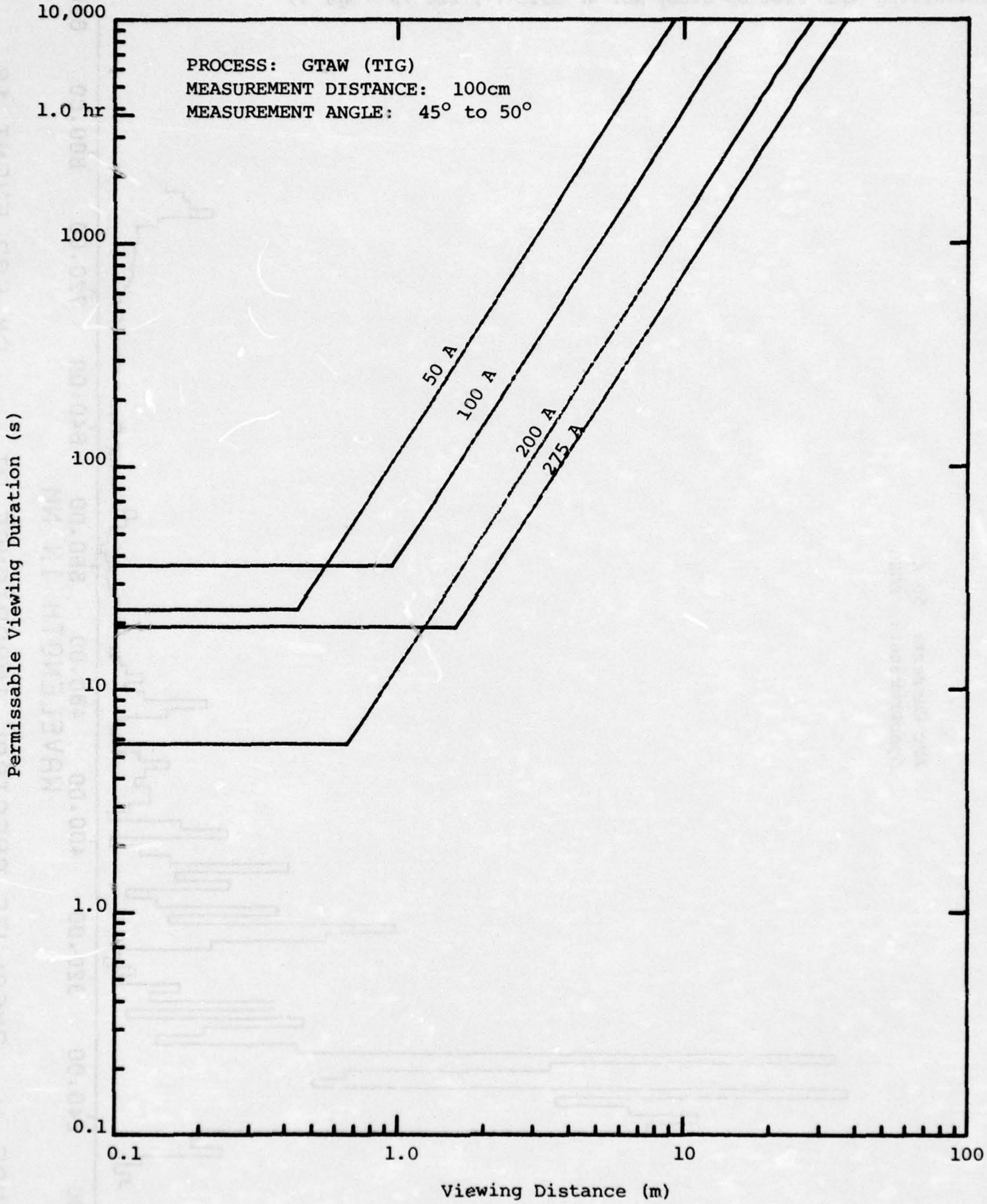


Figure 5i. Recommended maximum Exposure Duration as a Function of Viewing Distance for Events 16 to 19.

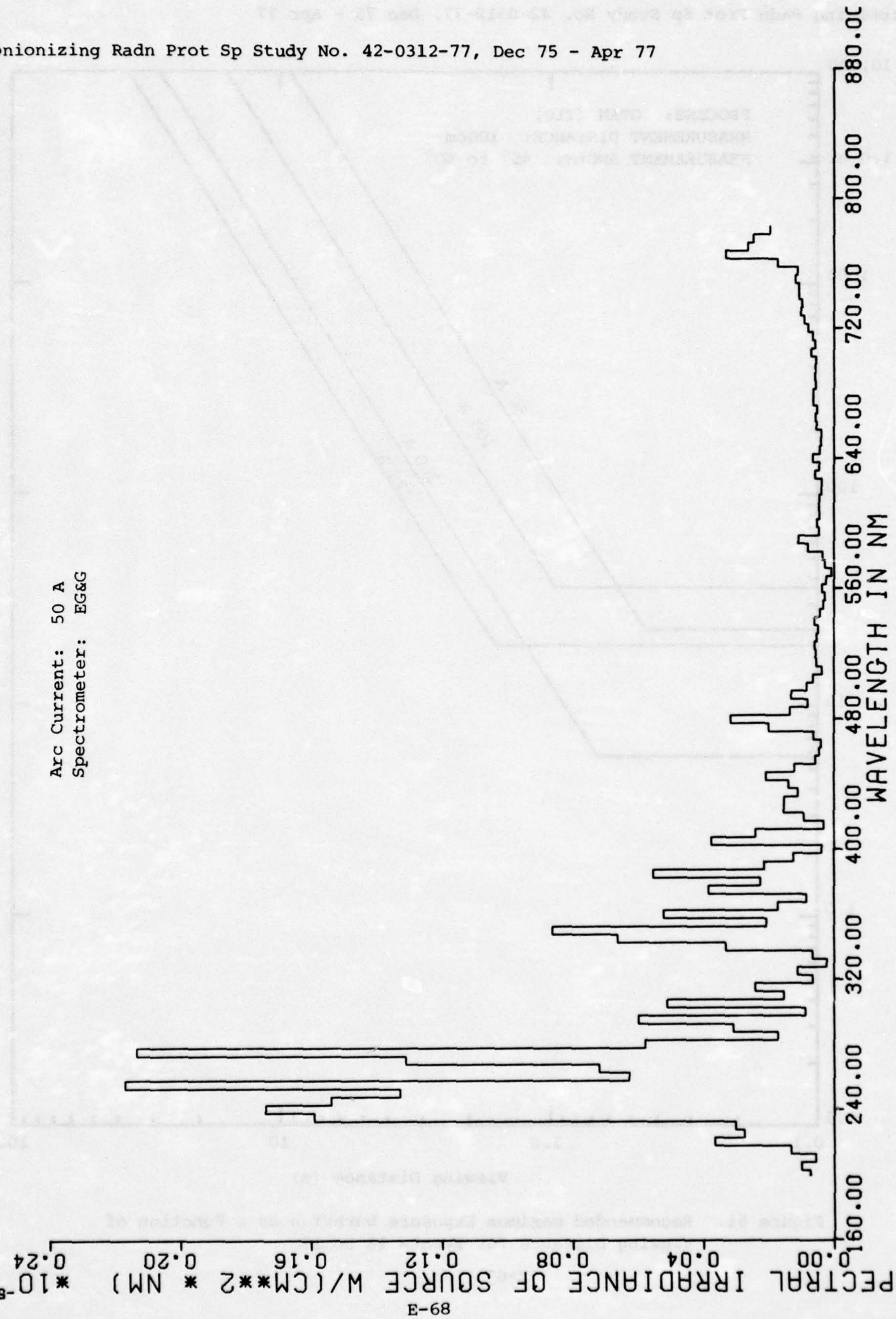


FIGURE 5j . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 16

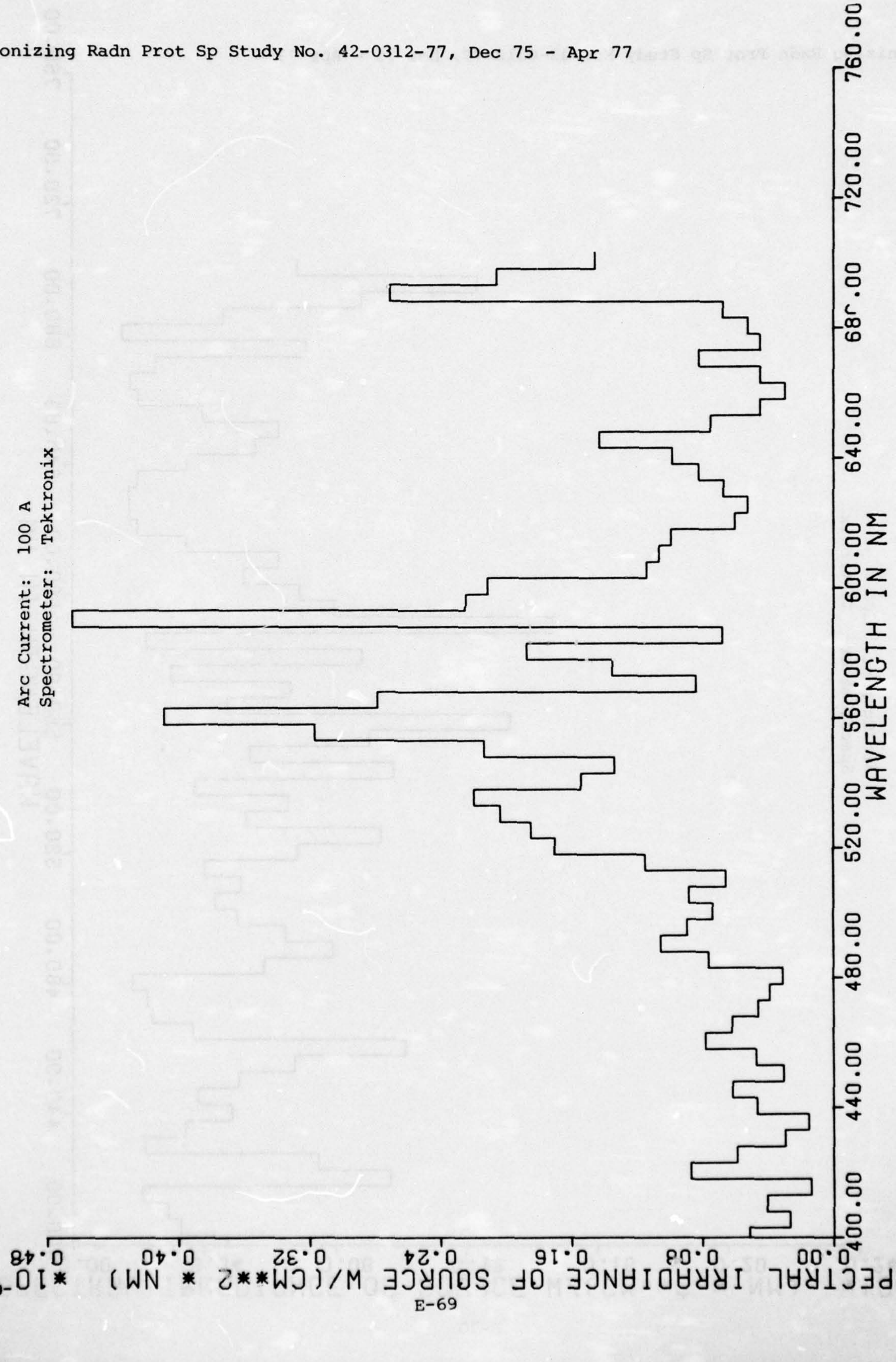


FIGURE 5k . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 17

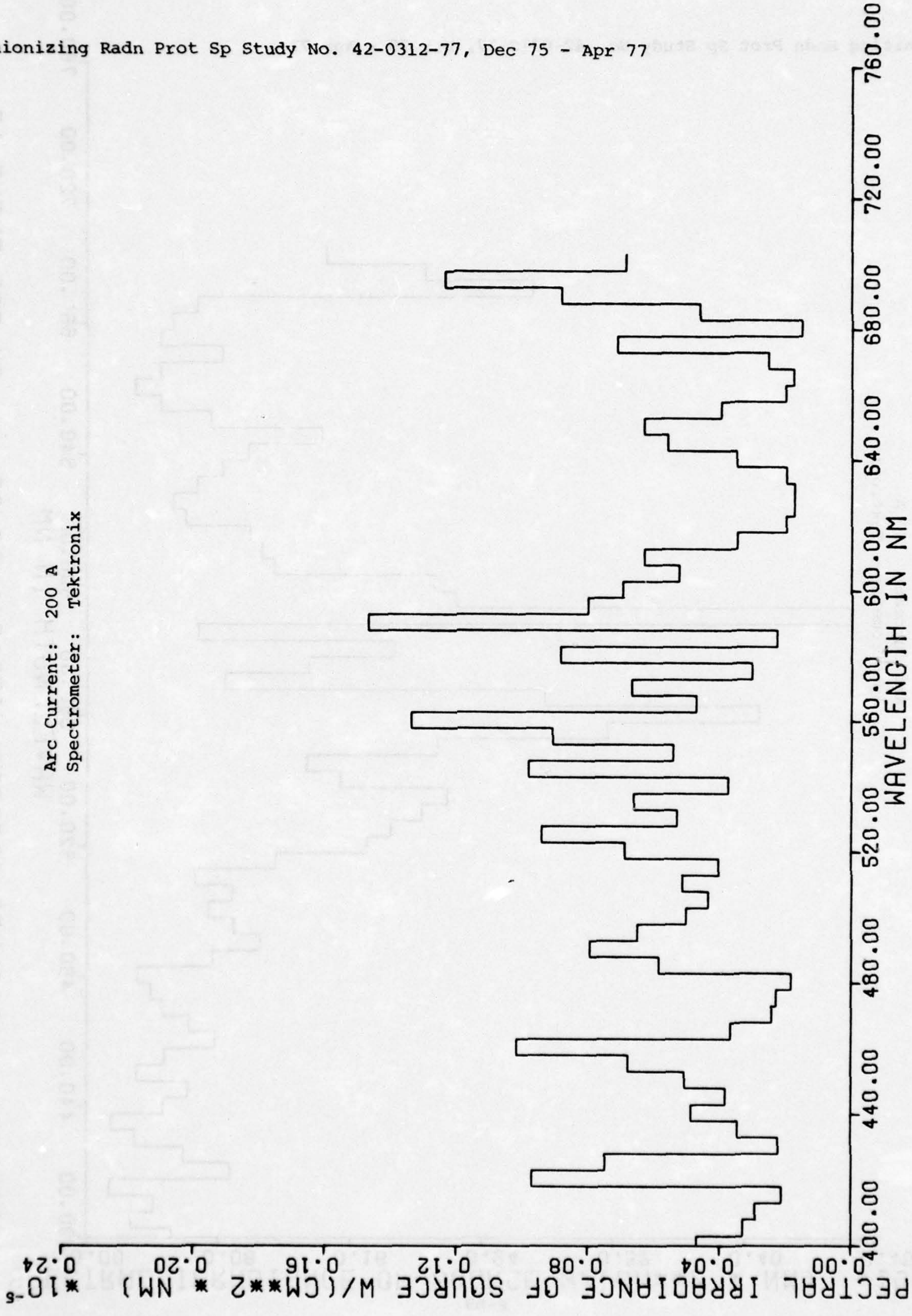


FIGURE 5ℓ . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 18

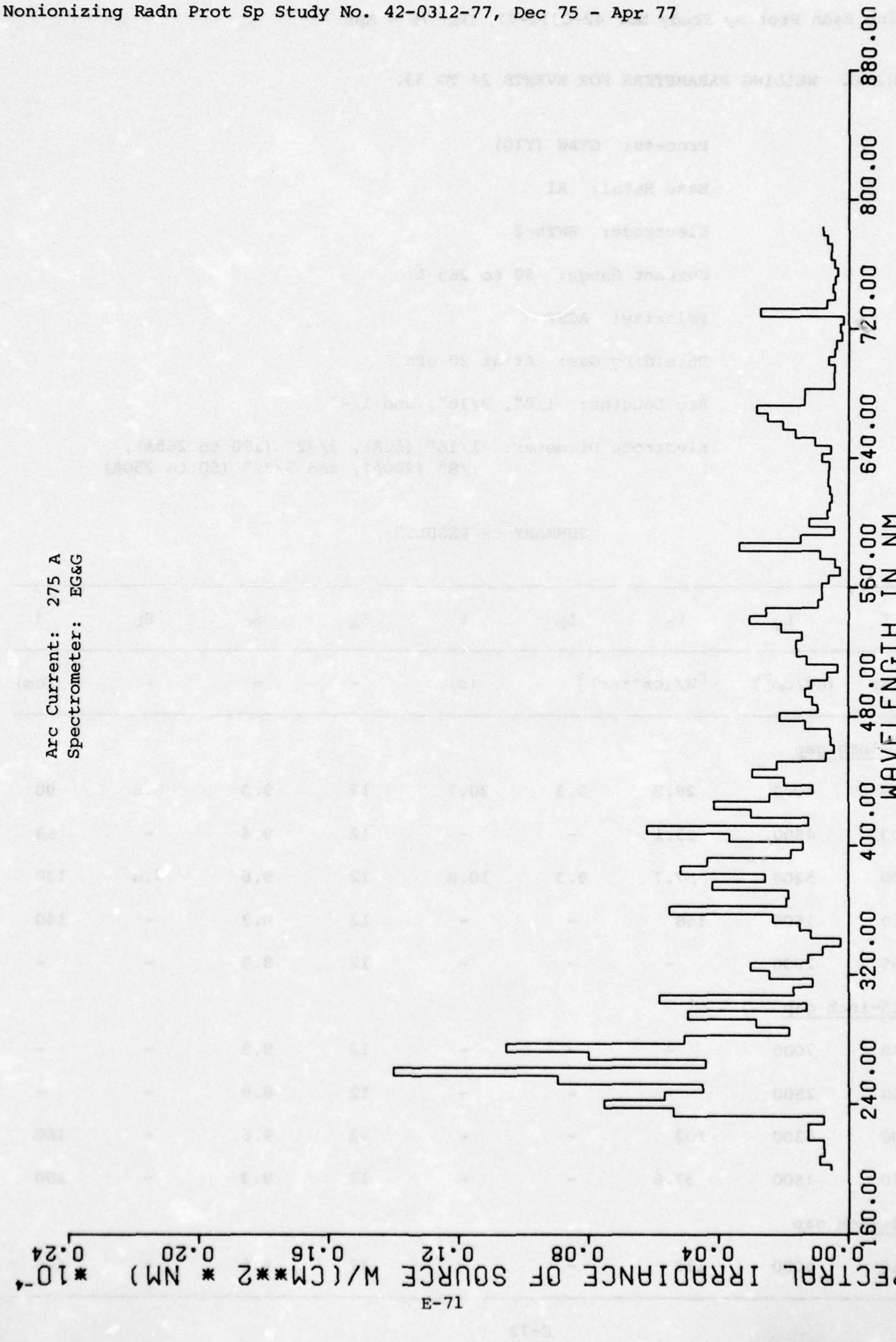


FIGURE 5m. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 19

TABLE 6. WELDING PARAMETERS FOR EVENTS 24 TO 33.

Process: GTAW (TIG)

Base Metal: Al

Electrode: EWTh-2

Current Range: 50 to 265 A

Polarity: ACHF

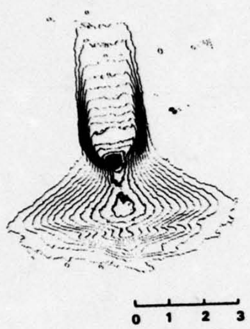
Shielding Gas: Ar at 20 cfm

Arc Lengths: 1/8", 3/16", and 1/4"

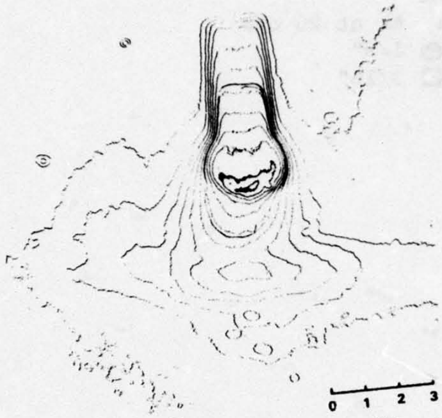
Electrode Diameter: 1/16" (50A), 3/32" (100 to 265A), 1/8" (200A), and 5/32" (50 to 250A)

SUMMARY OF RESULTS

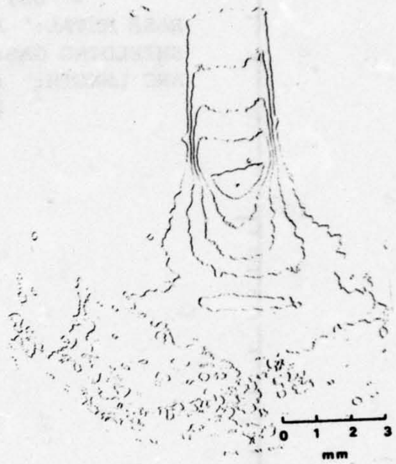
I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[$W/(cm^2 \cdot sr)$]		(s)	-	-	-	(cm)
1/8-inch gap								
50	4200	29.8	3.3	30.7	12	9.3	6.8	90
100	4500	25.1	-	-	12	9.4	-	59
200	5200	57.7	9.3	10.8	12	9.6	7.8	130
250	1500	158	-	-	12	8.3	-	140
265	2800	-	-	-	12	8.9	-	-
3/16-inch gap								
50	7000	-	-	-	12	9.8	-	-
100	2500	-	-	-	12	8.8	-	-
200	5300	102	-	-	12	9.6	-	160
250	1500	37.6	-	-	12	8.3	-	290
1/4-inch gap								
250	5000	112	-	-	12	9.5	-	200



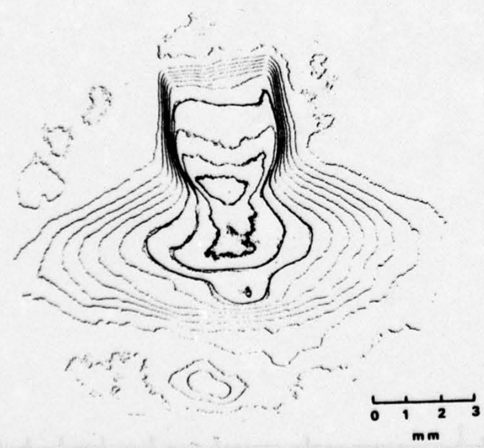
Event 31, 200 A, CI=0.06



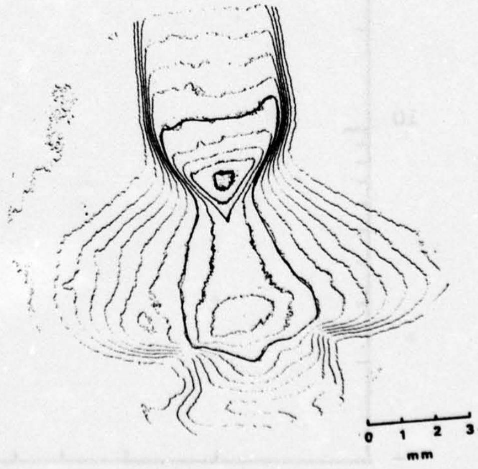
Event 24, 50 A, CI=0.07



Event 25, 100 A, CI=0.08



Event 26, 100 A, CI=0.11



Event 28, 250 A, CI=0.10

Figure 6a. Microdensitometer Scans of 35mm Processed Photographic Negatives Exposed at 4 m from the Welding Arcs for Events 24-33.

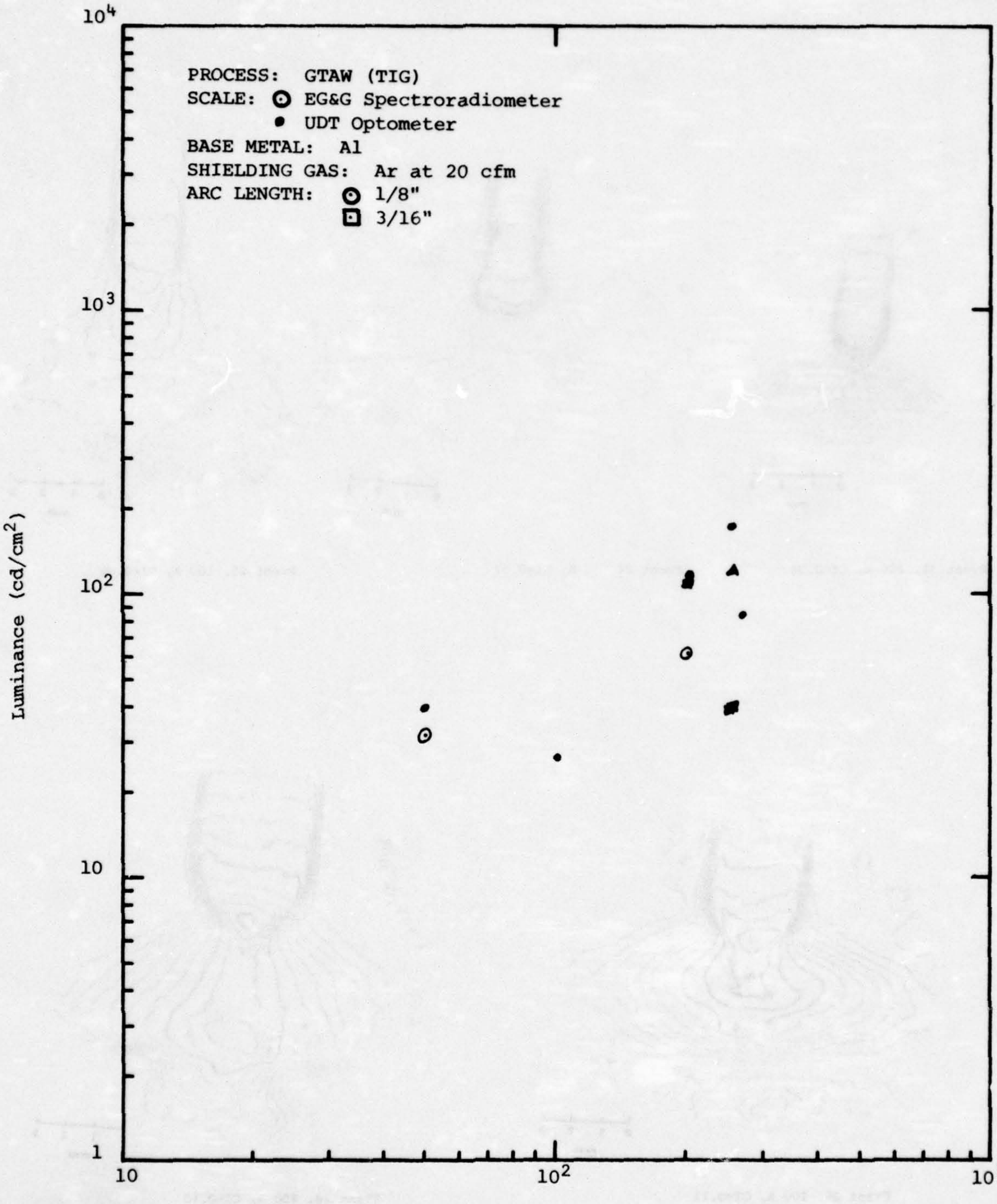


Figure 6b. Arc Radiance as a Function of Arc Current for Events 24 to 33.

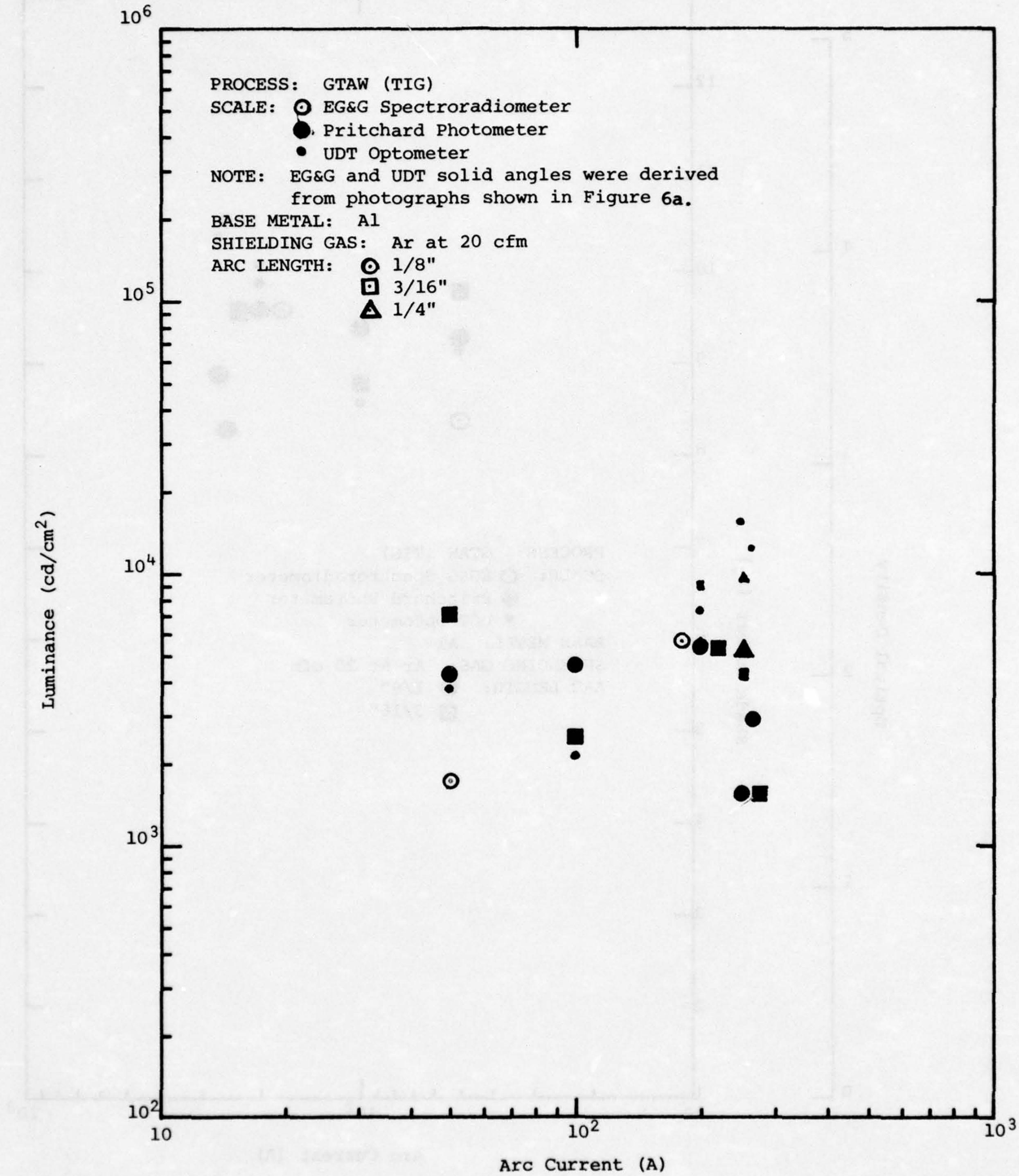


Figure 6c. Arc Luminance as a Function of Arc Current for Events 24 to 33.

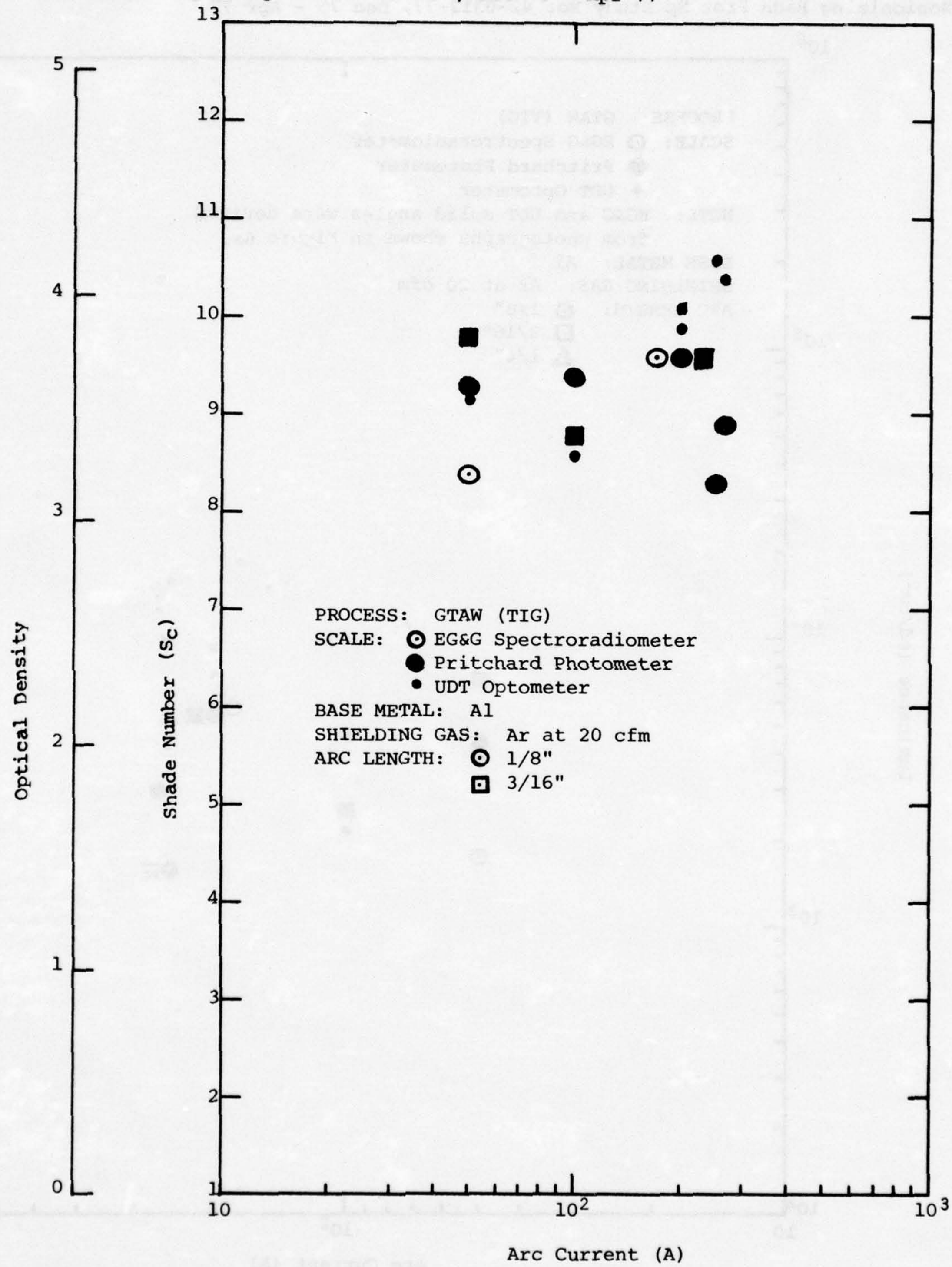
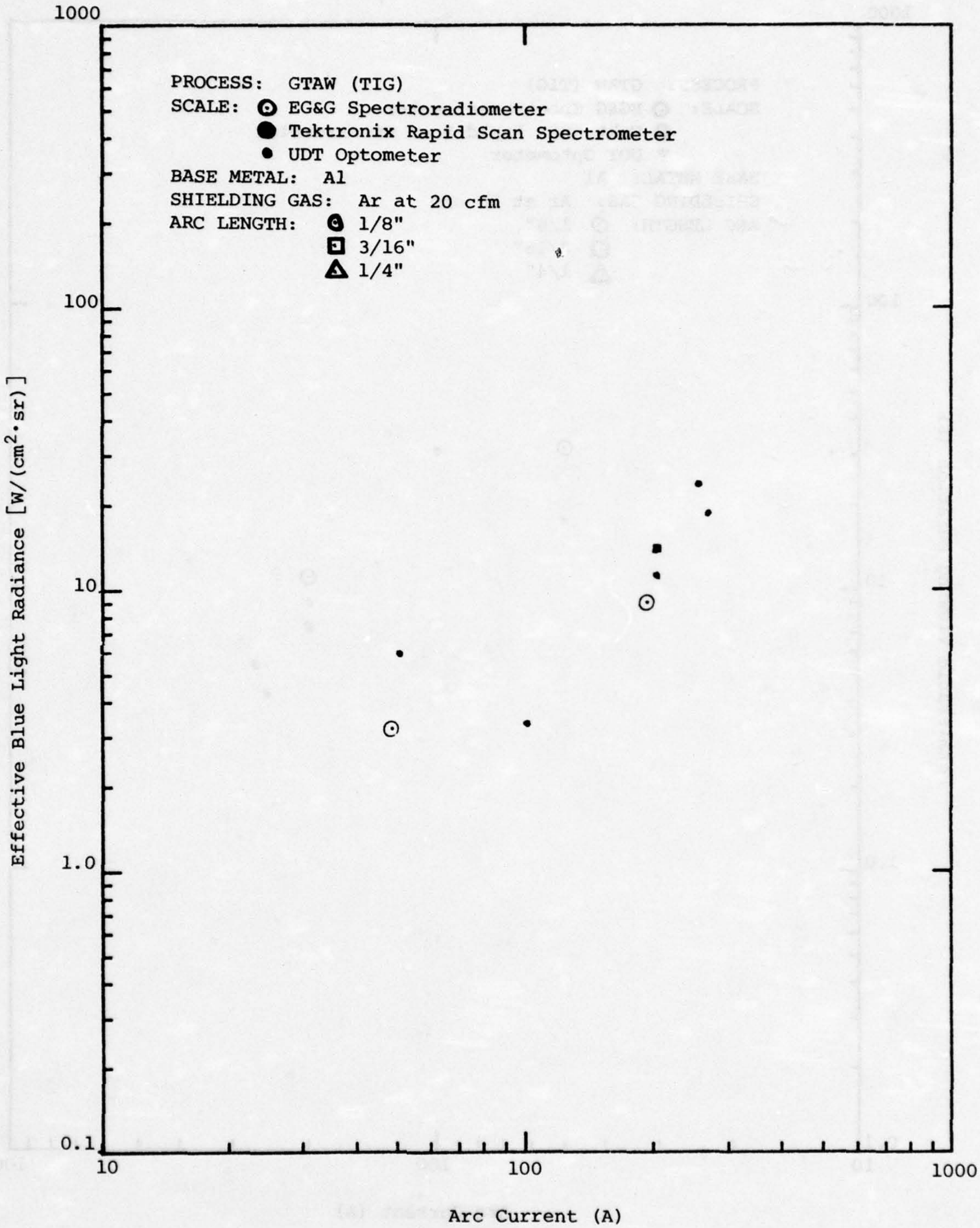


Figure 6d. Comfortable Shade Number (S_c) or Optical Density for Arc Viewing as a Function of Arc Current for Events 24 to 33.



Figures 6e. Effective Blue Light Radiance as a Function of Arc Current for Events 24 to 33.

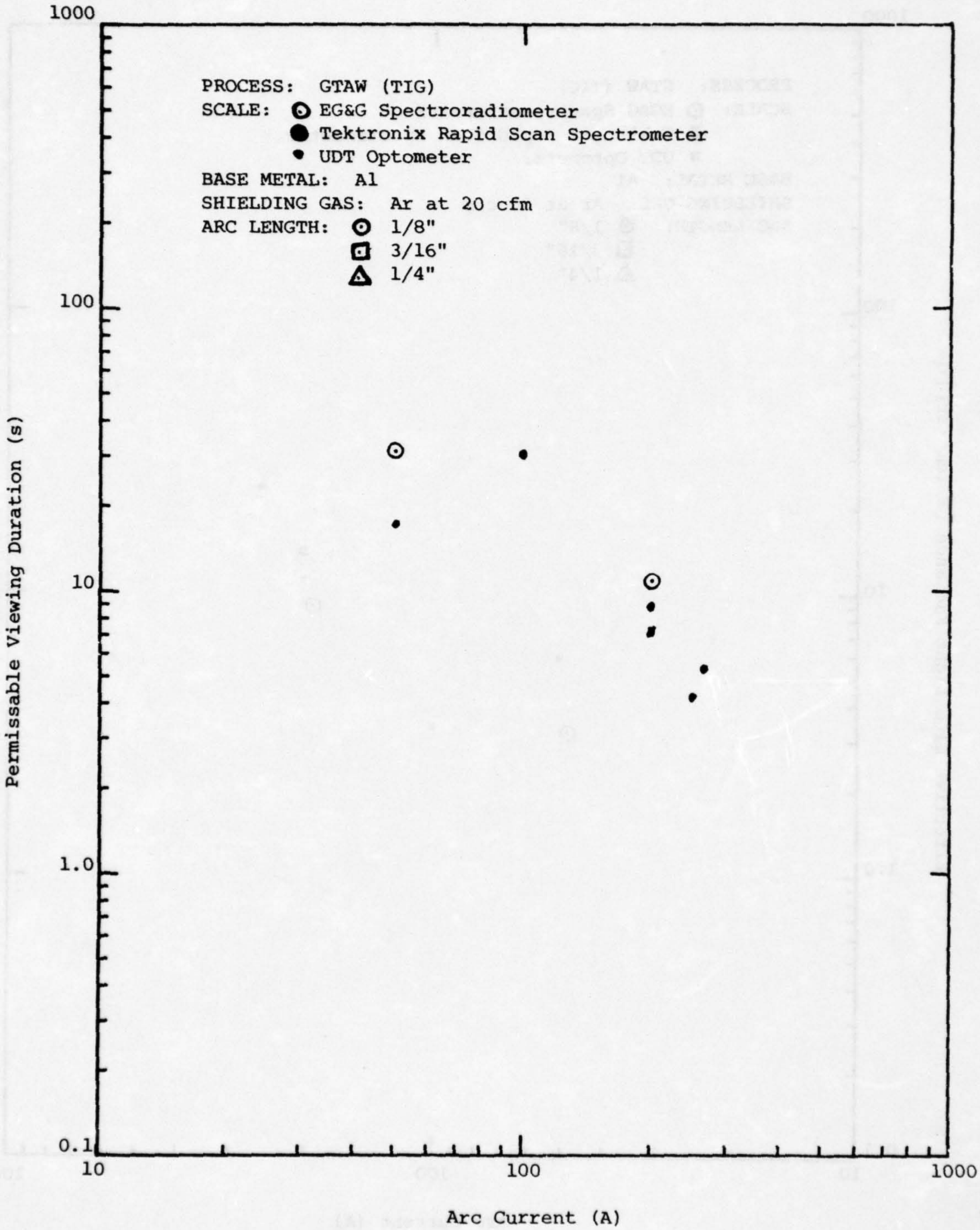


Figure 6f. Permissable Viewing Duration as a Function of Arc Current for Events 24 to 33 at Distances less than 2.0 m.

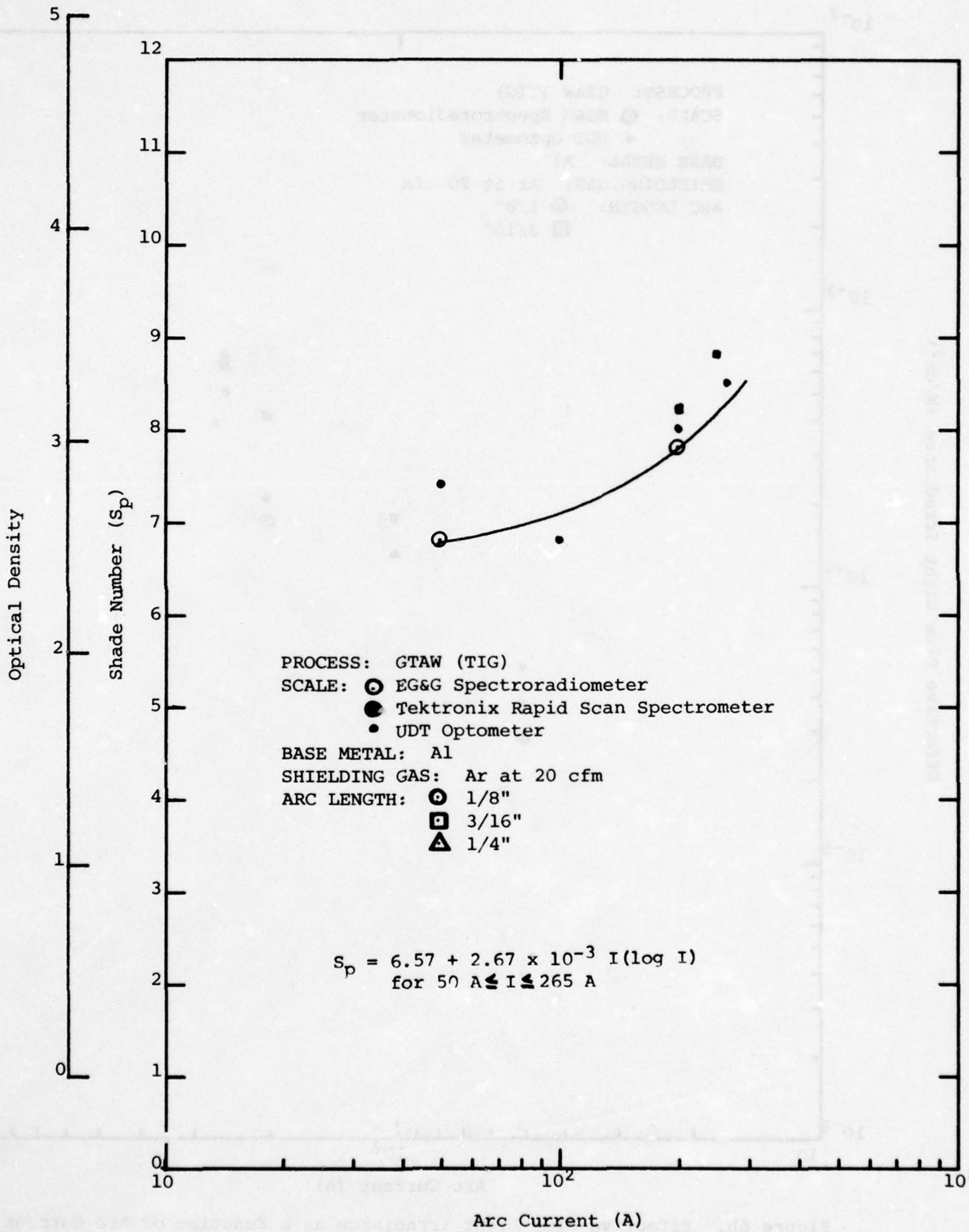


Figure 6g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted During Events 24 to 33.

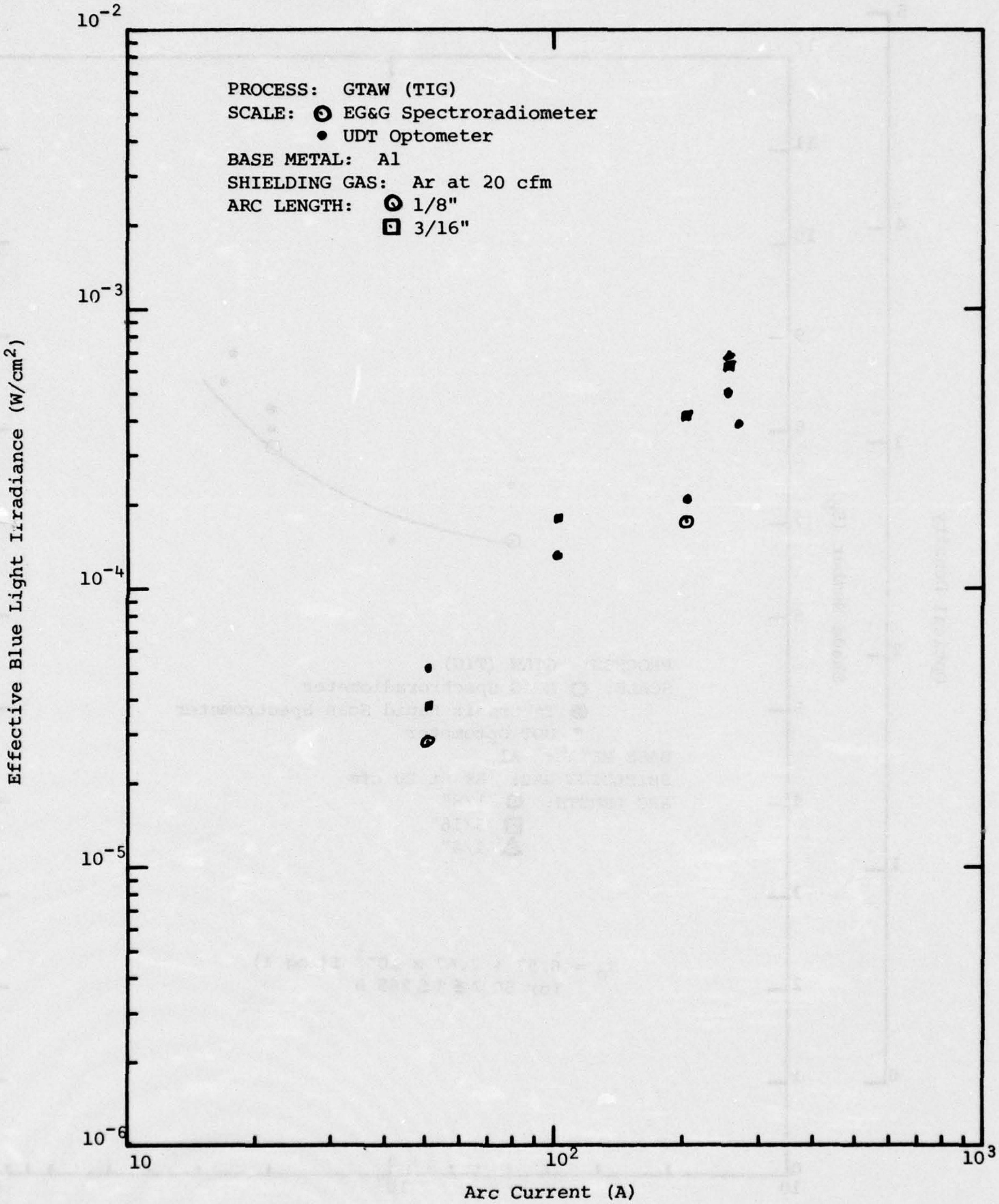


Figure 6h. Effective Blue Light Irradiance as a Function of Arc Current for Events 24 to 33.

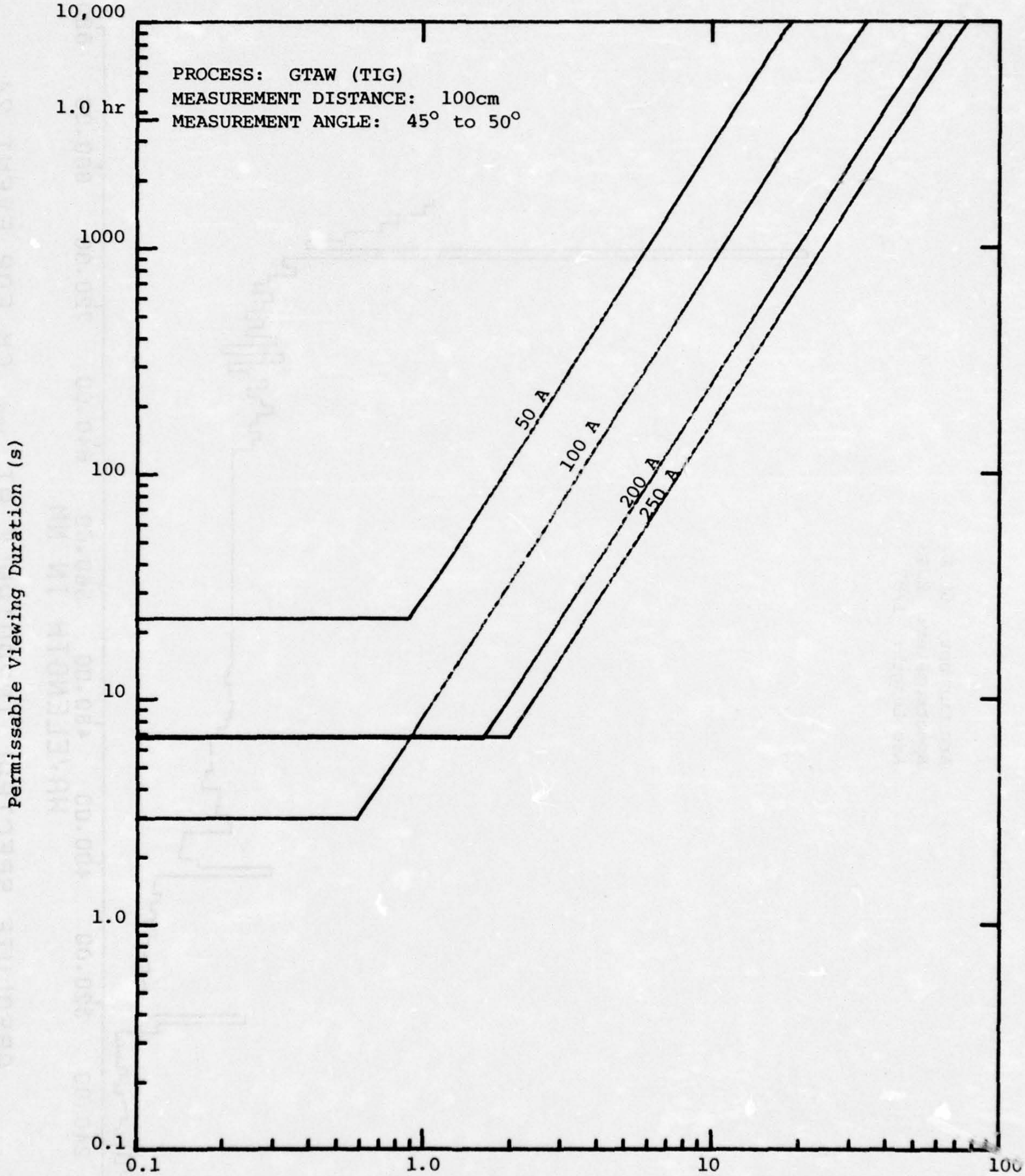


Figure 6i. Recommended maximum Exposure Duration as a Function of Viewing Distance for Events 24 to 33.

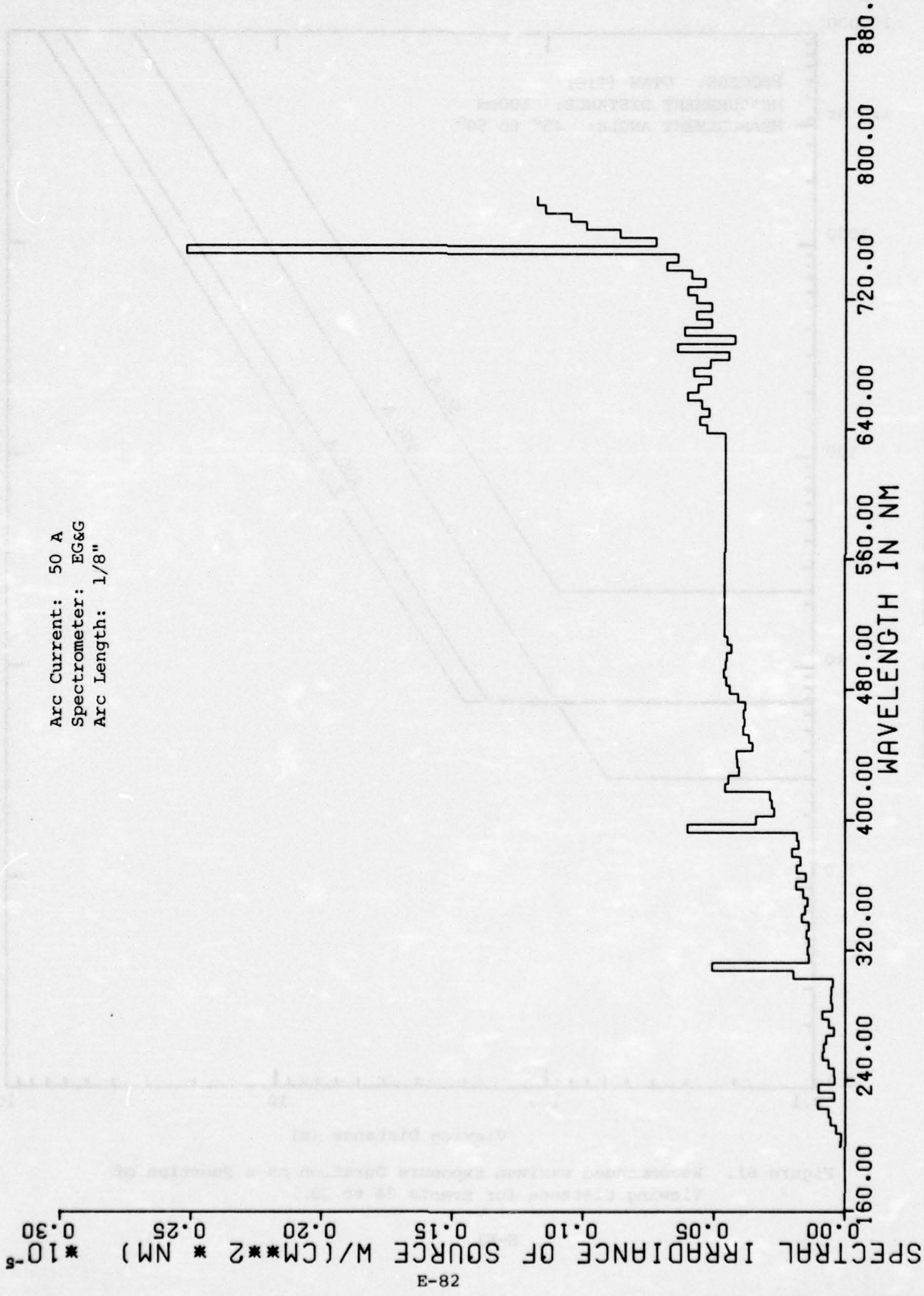


FIGURE 6j . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 24

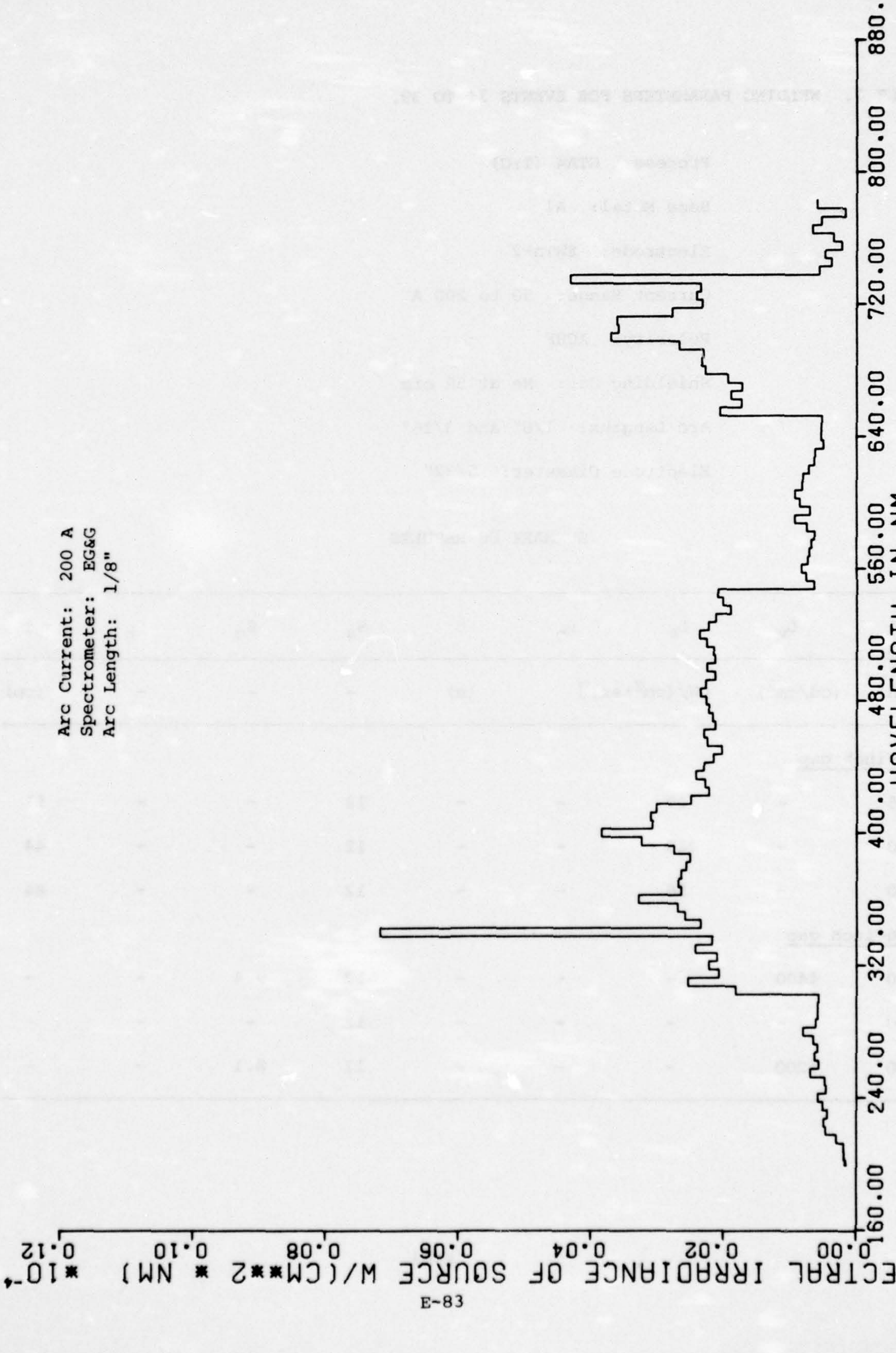


FIGURE 6k ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 26

TABLE 7. WELDING PARAMETERS FOR EVENTS 34 TO 39.

Process: GTAW (TIG)

Base Metal: Al

Electrode: EWTh-2

Current Range: 50 to 200 A

Polarity: ACHF

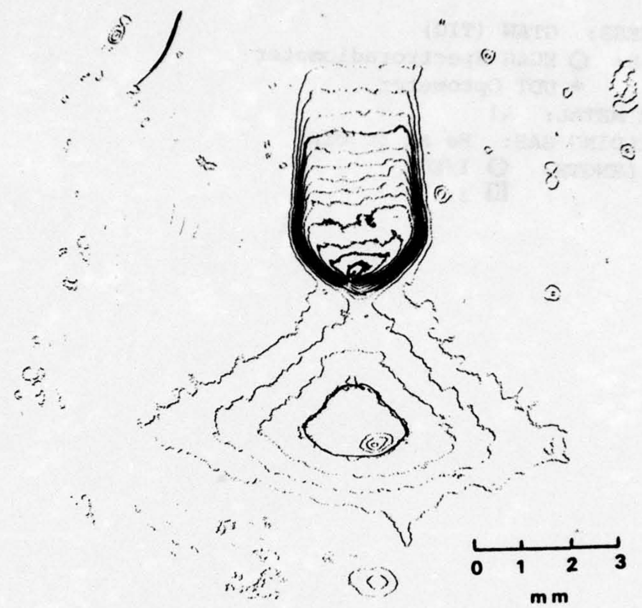
Shielding Gas: He at 50 cfm

Arc Lengths: 1/8" and 3/16"

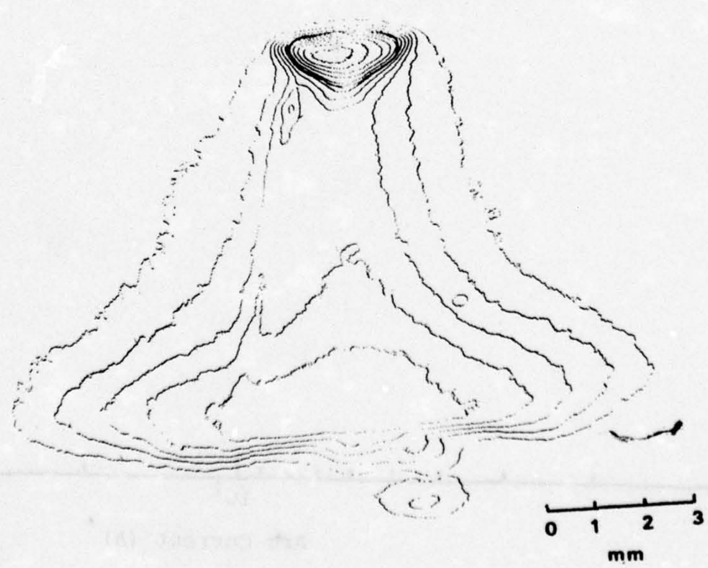
Electrode Diameter: 5/32"

SUMMARY OF RESULTS

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[$W/(cm^2 \cdot sr)$]		(s)	-	-	-	(cm)
1/8-inch gap								
65	-	19	-	-	12	-	-	51
100	-	245	-	-	12	-	-	44
200	-	56	-	-	12	-	-	84
3/16-inch gap								
50	4400	-	-	-	12	9.4	-	-
150	-	-	-	-	12	-	-	-
200	1200	-	-	-	12	8.1	-	-



Event 36, 100 A, CI=0.08



Event 37, 200 A, CI=0.04

Figure 7a. Microdensitometer Scans of 35 mm Processed Negatives Exposed 4 m from the Welding Arc for Events 34-39.

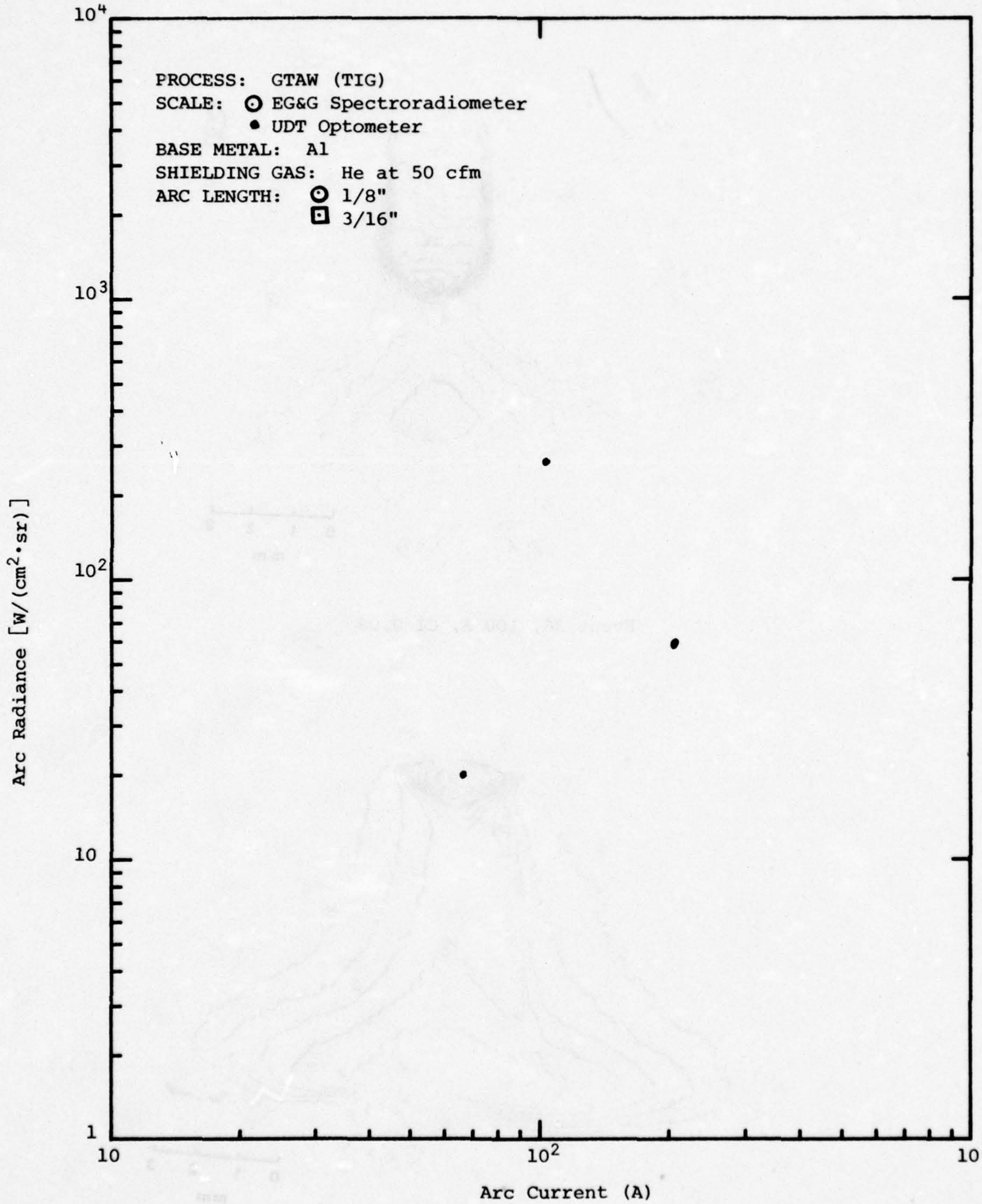


Figure 7b. Arc Radiance as a Function of Arc Current for Events 34 to 39.

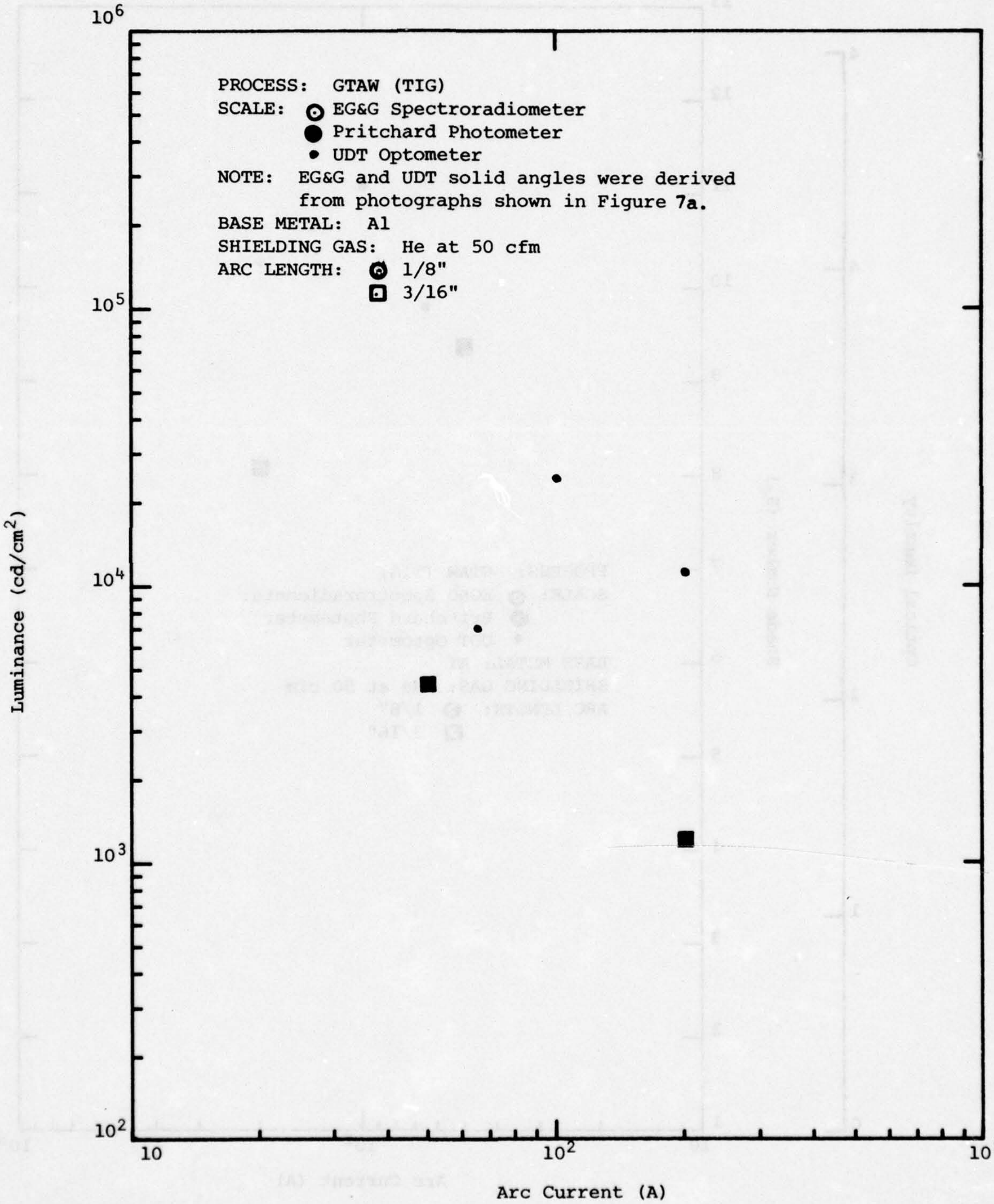


Figure 7c. Arc Luminance as a Function of Arc Current for Events 34 to 39.

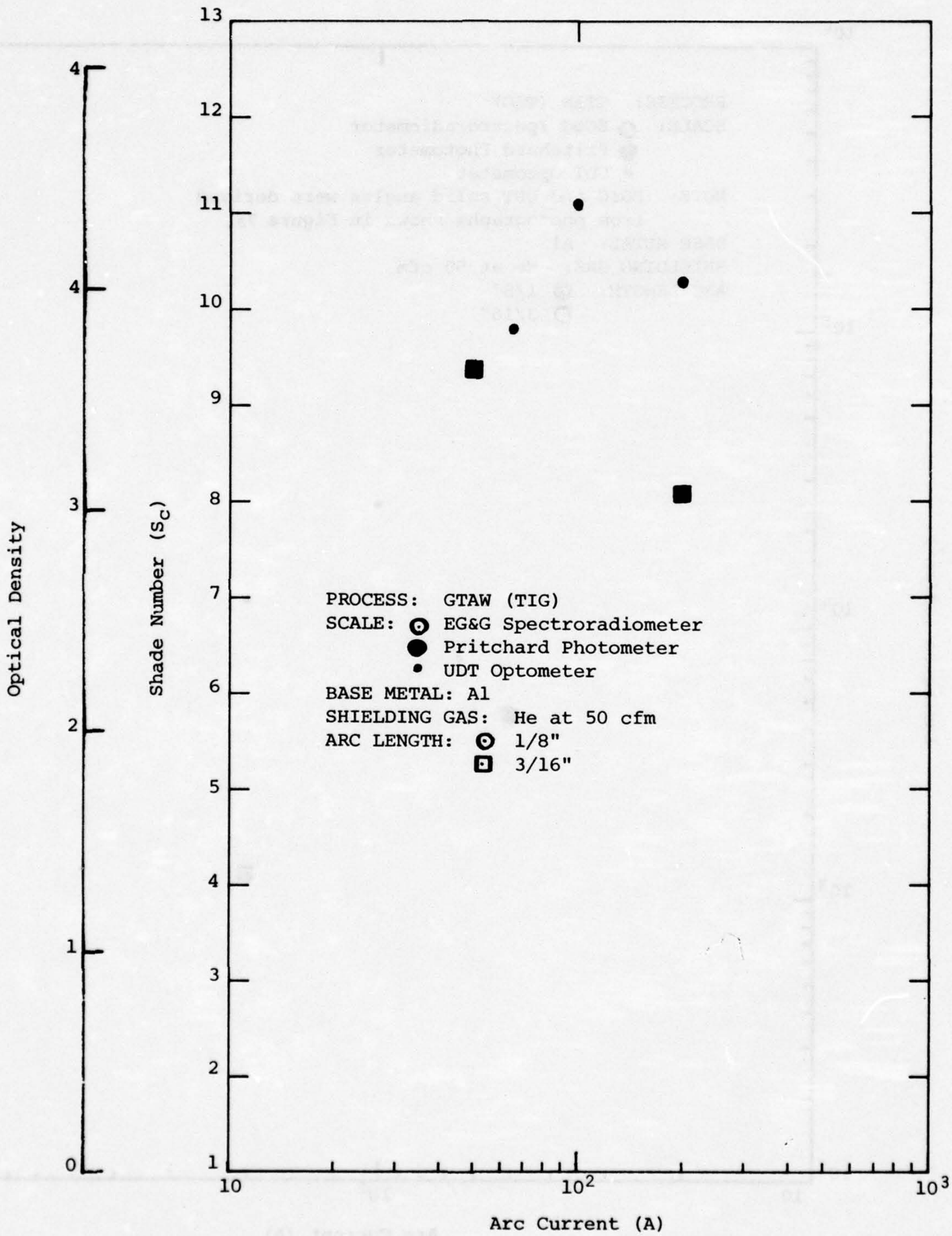


Figure 7d. Comfortable Shade Number (S_C) or Optical Density for Arc Viewing as a Function of Arc Currents for Events 34 to 39.

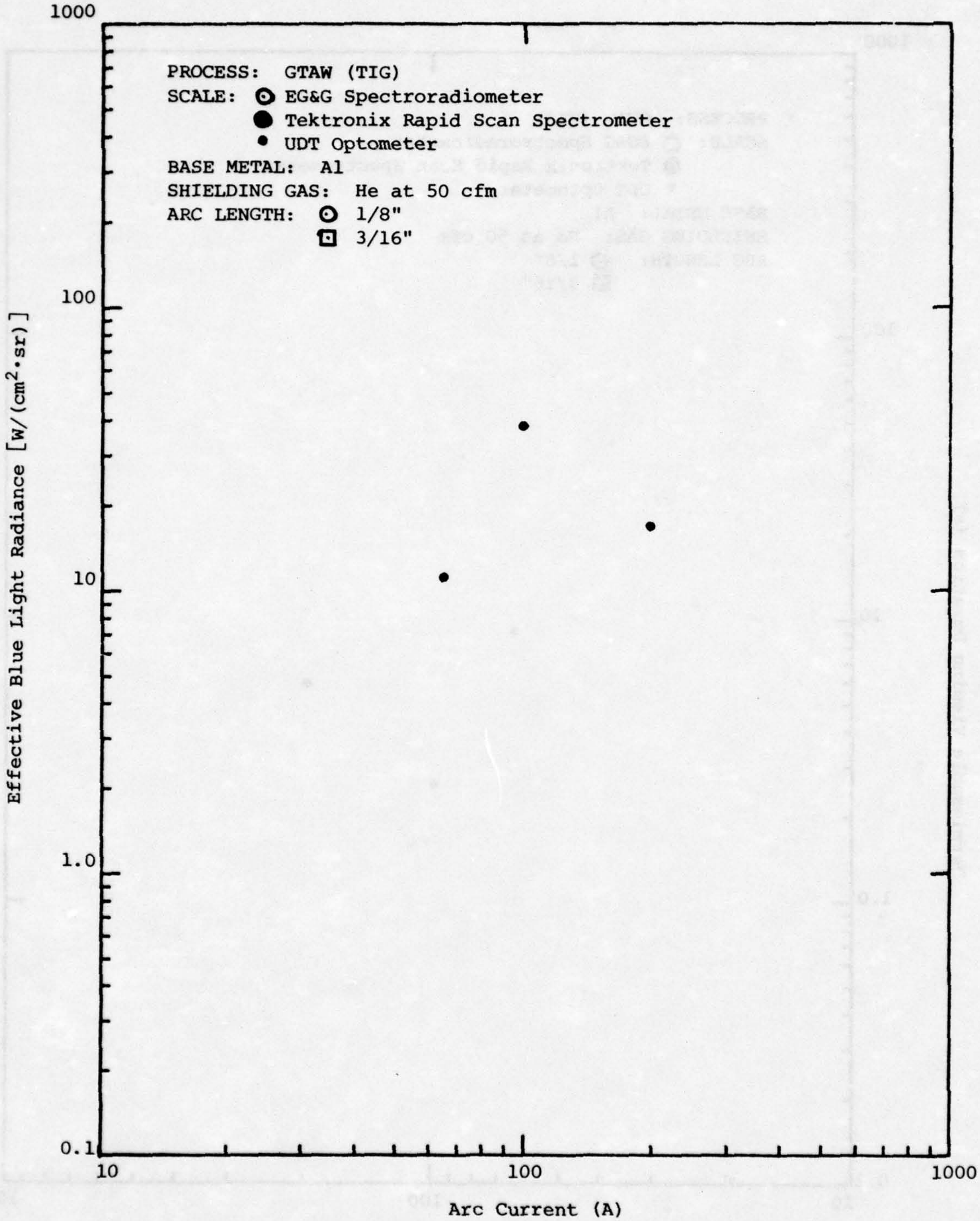


Figure 7e. Effective Blue Light Radiance as a Function of Arc Current for Events 34 to 39.

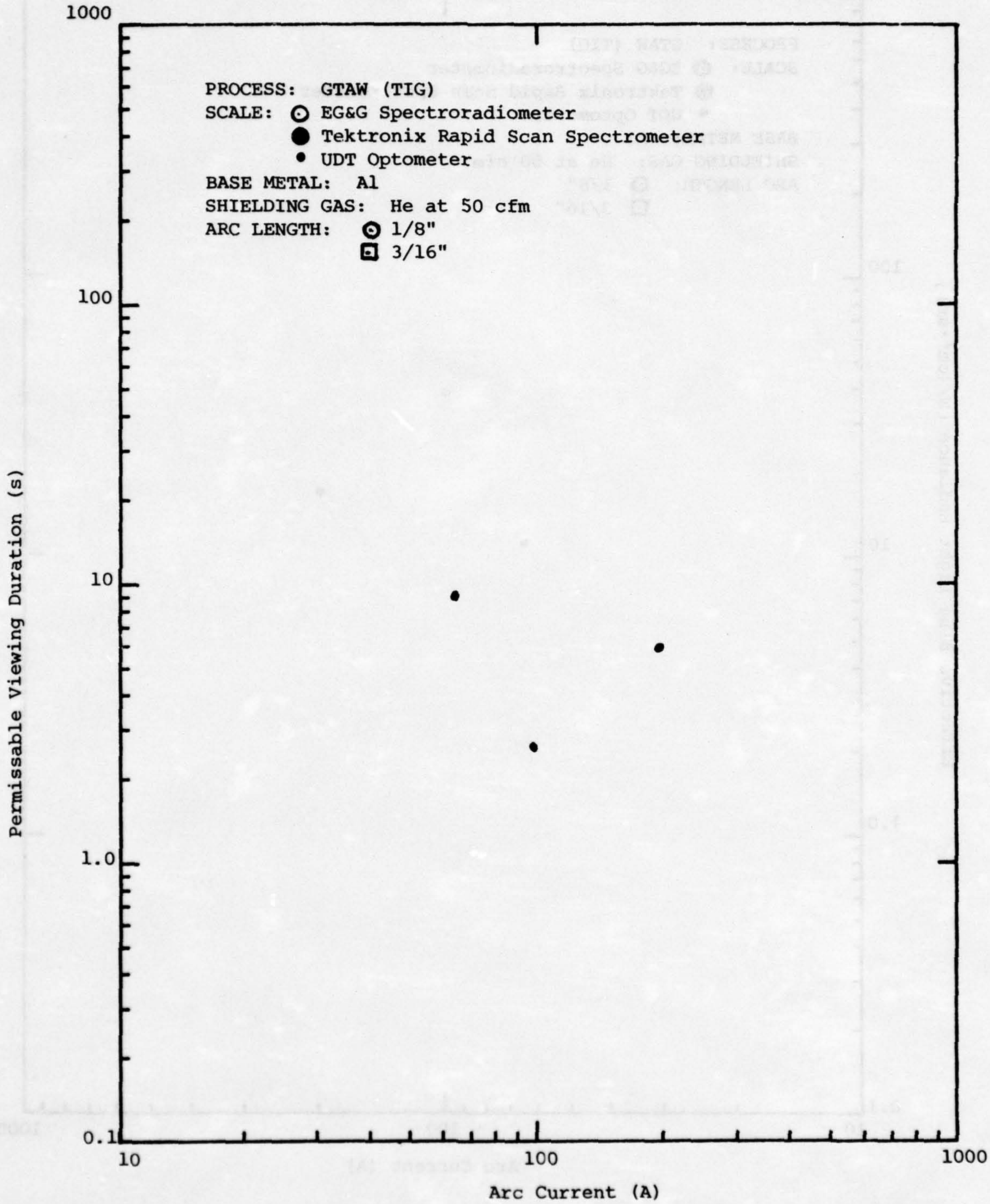


Figure 7f. Permissable Viewing Duration as a Function of Arc Current for Events 34 to 39 at Distances less than 1.0 m.

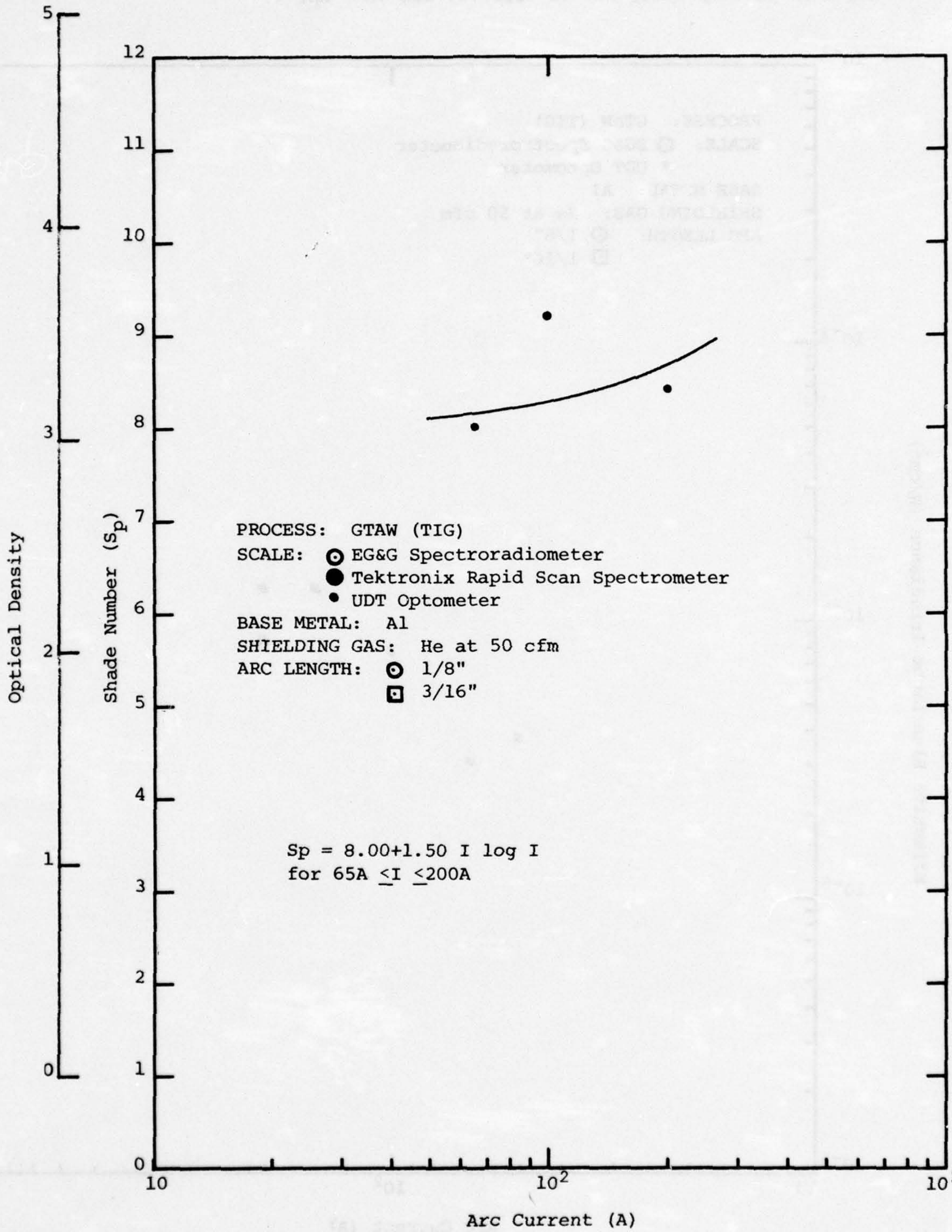


Figure 7g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 34 to 39.

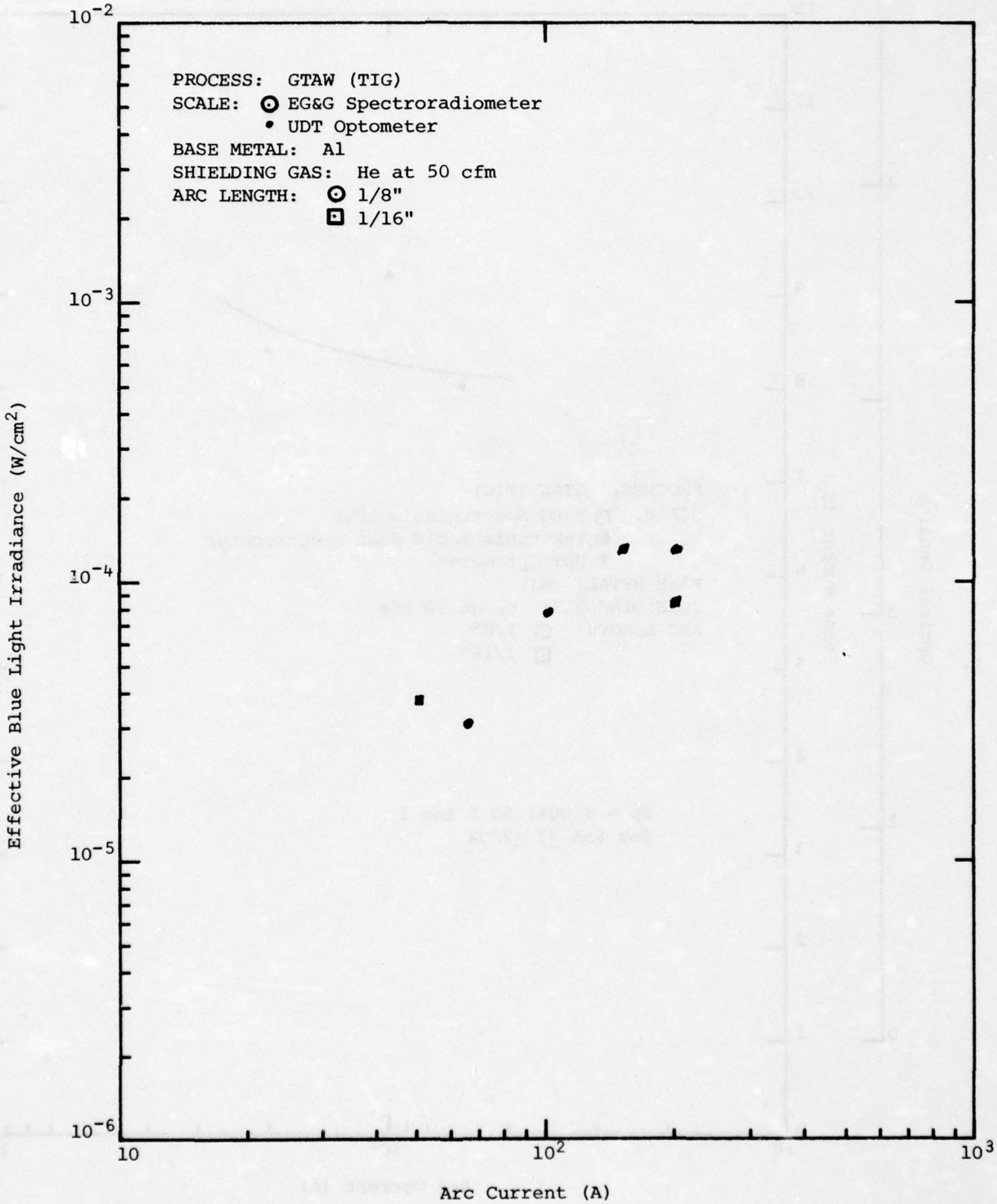


Figure 7h. Effective Blue Light Irradiance as a Function of Arc Current for Events 34 to 39.

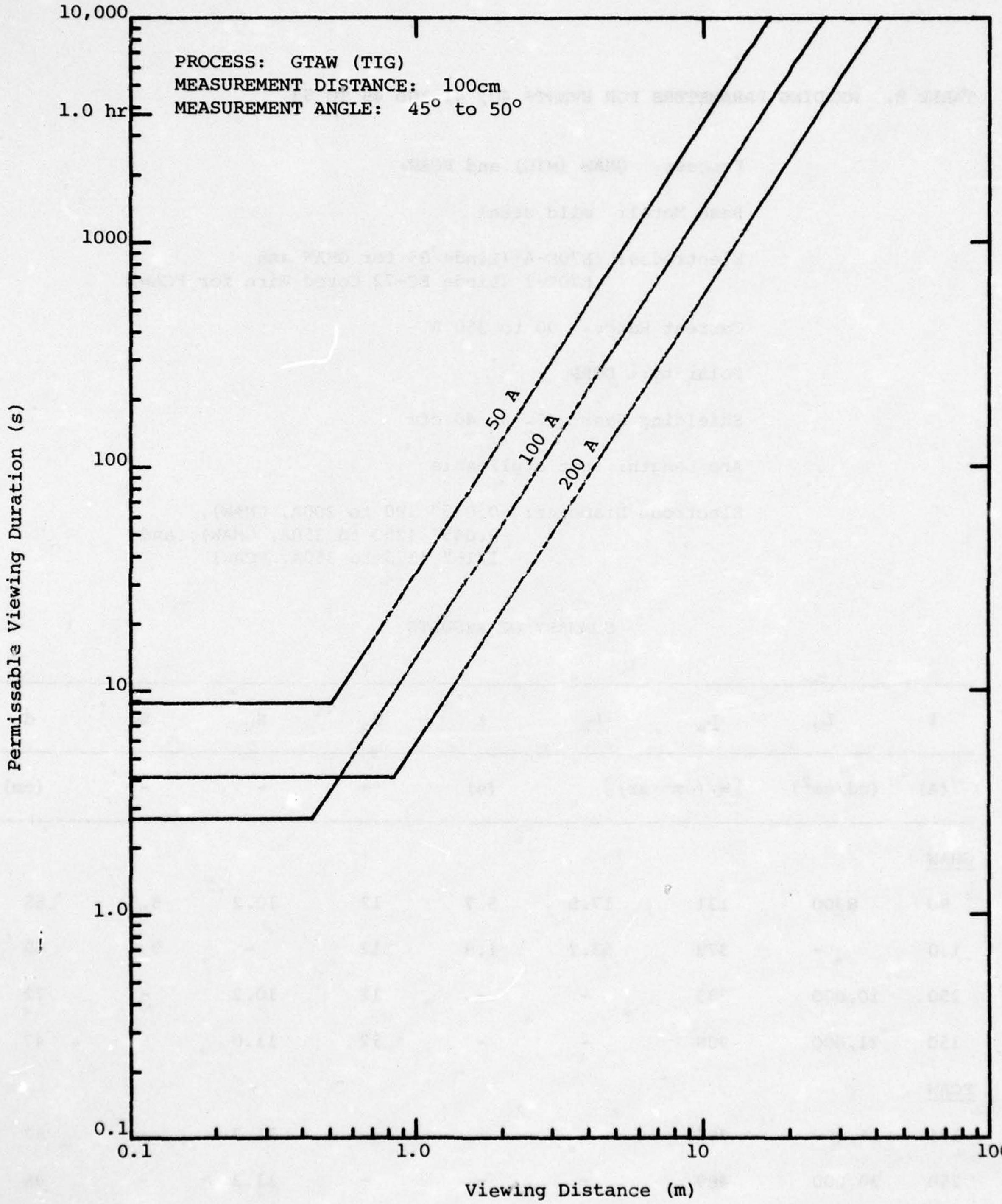


Figure 7i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 34 to 39.

TABLE 8. WELDING PARAMETERS FOR EVENTS 40, 41 AND 49 TO 53.

Process: GMAW (MIG) and FCAW

Base Metal: mild steel

Electrodes: E70S-4 (Linde 85 for GMAW and
E70T-1 (Linde FC-72 Cored Wire for FCAW)

Current Range: 90 to 350 A

Polarity: DCRP

Shielding Gas: CO_2 at 40 cfm

Arc Length: not applicable

Electrode Diameter: 0.035" (90 to 200A, GMAW),
0.045" (250 to 350A, GMAW), and
1/16" (175 to 350A, FCAW)

SUMMARY OF RESULTS

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[W/(cm^2·sr)]		(s)	-	-	-	(cm)
GMAW								
90	8300	131	17.5	5.7	12	10.2	8.5	65
150	-	379	53.7	1.9	12	-	9.6	59
250	10,000	385	-	-	12	10.2	-	72
350	21,000	909	-	-	12	11.0	-	47
FCAW								
175	26,000	362	-	-	-	11.2	-	83
250	30,000	489	-	-	-	11.3	-	96
350	20,000	1540	-	-	-	10.9	-	51

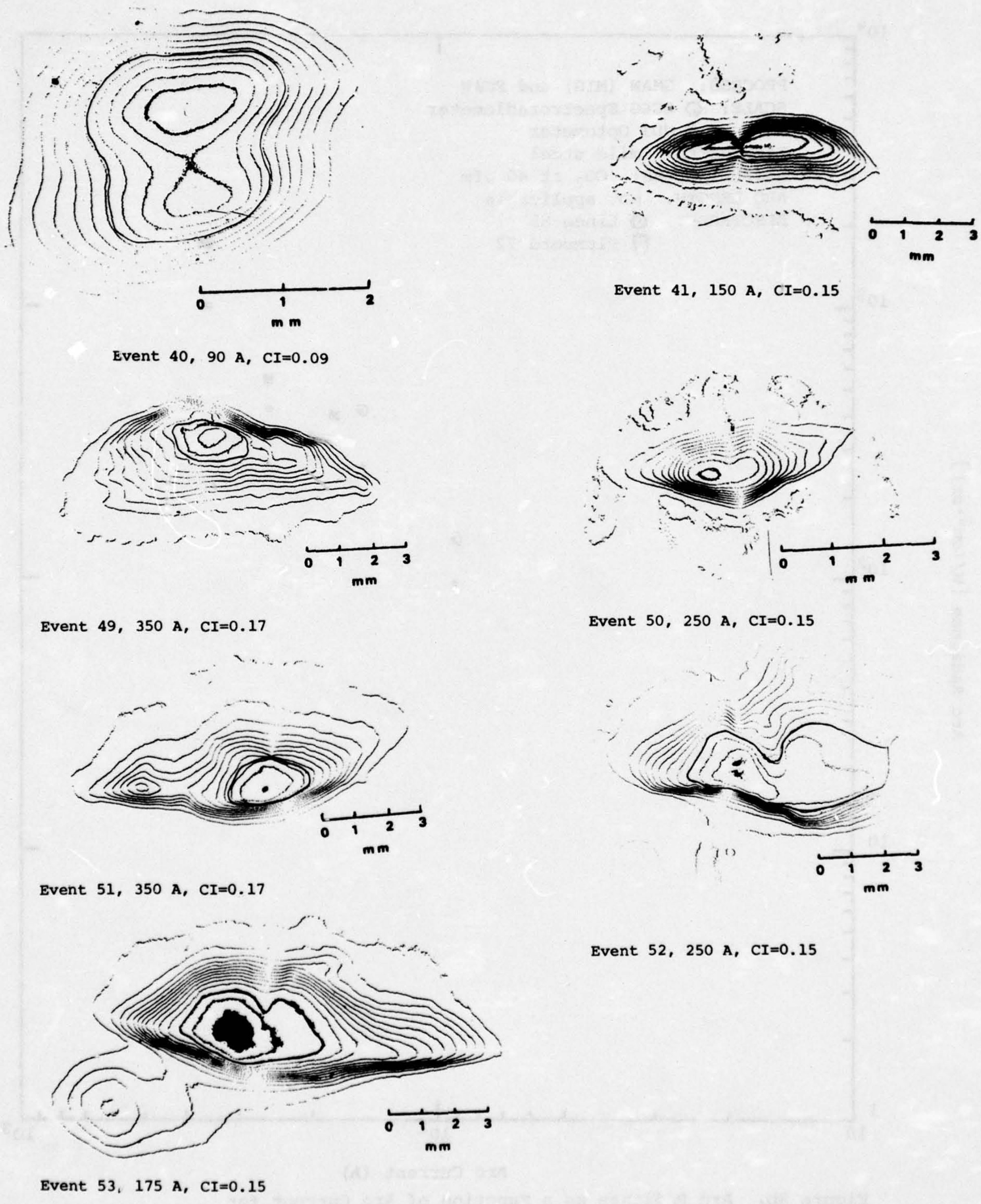


Figure 8a. Microdensitometer Scans of 35 mm Processed Photographic Negatives Exposed 4 m from the Welding Arcs for Events 40-41 and 49-53.

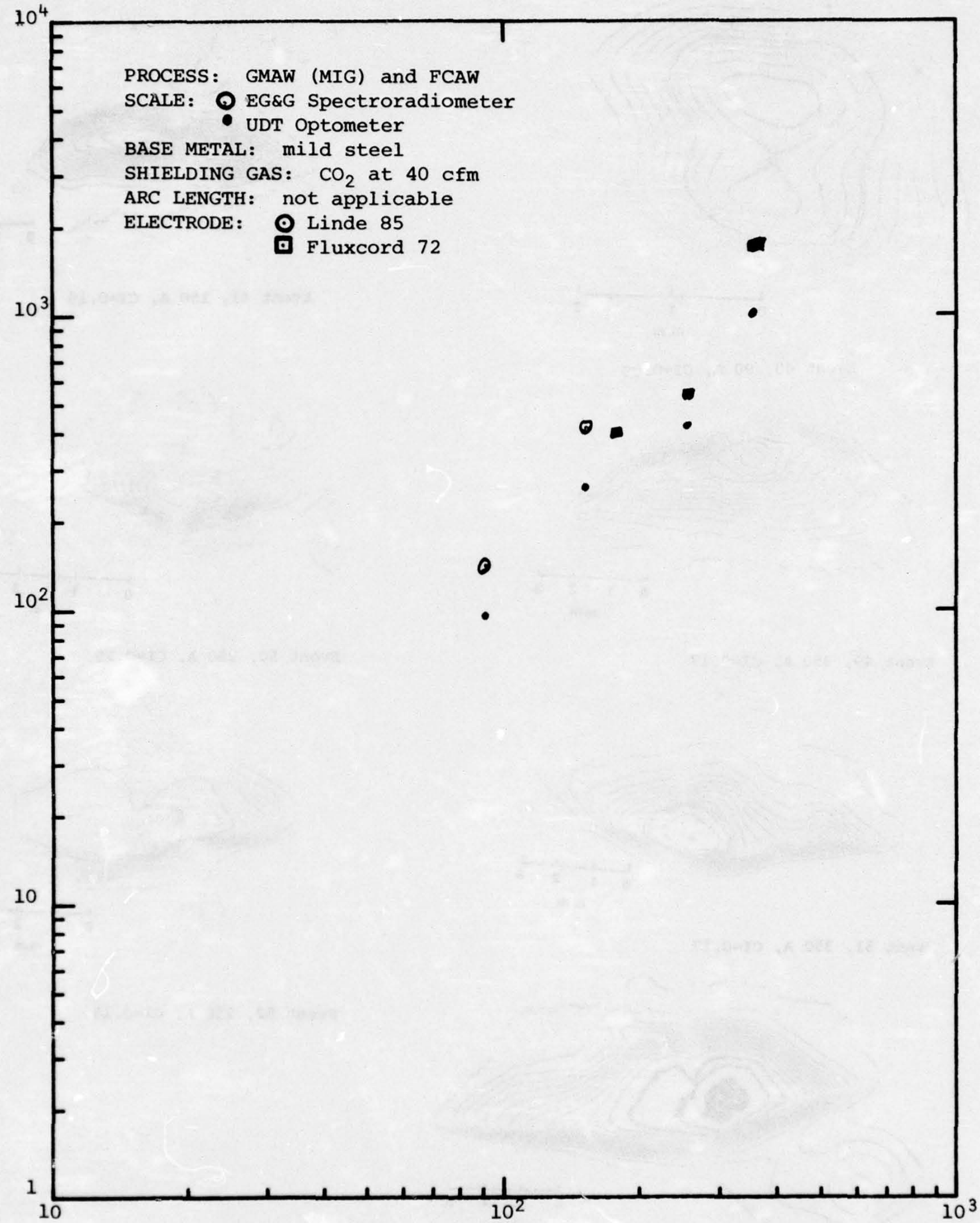


Figure 8b. Arc Radiance as a Function of Arc Current for Events 40, 41 and 49 to 53.

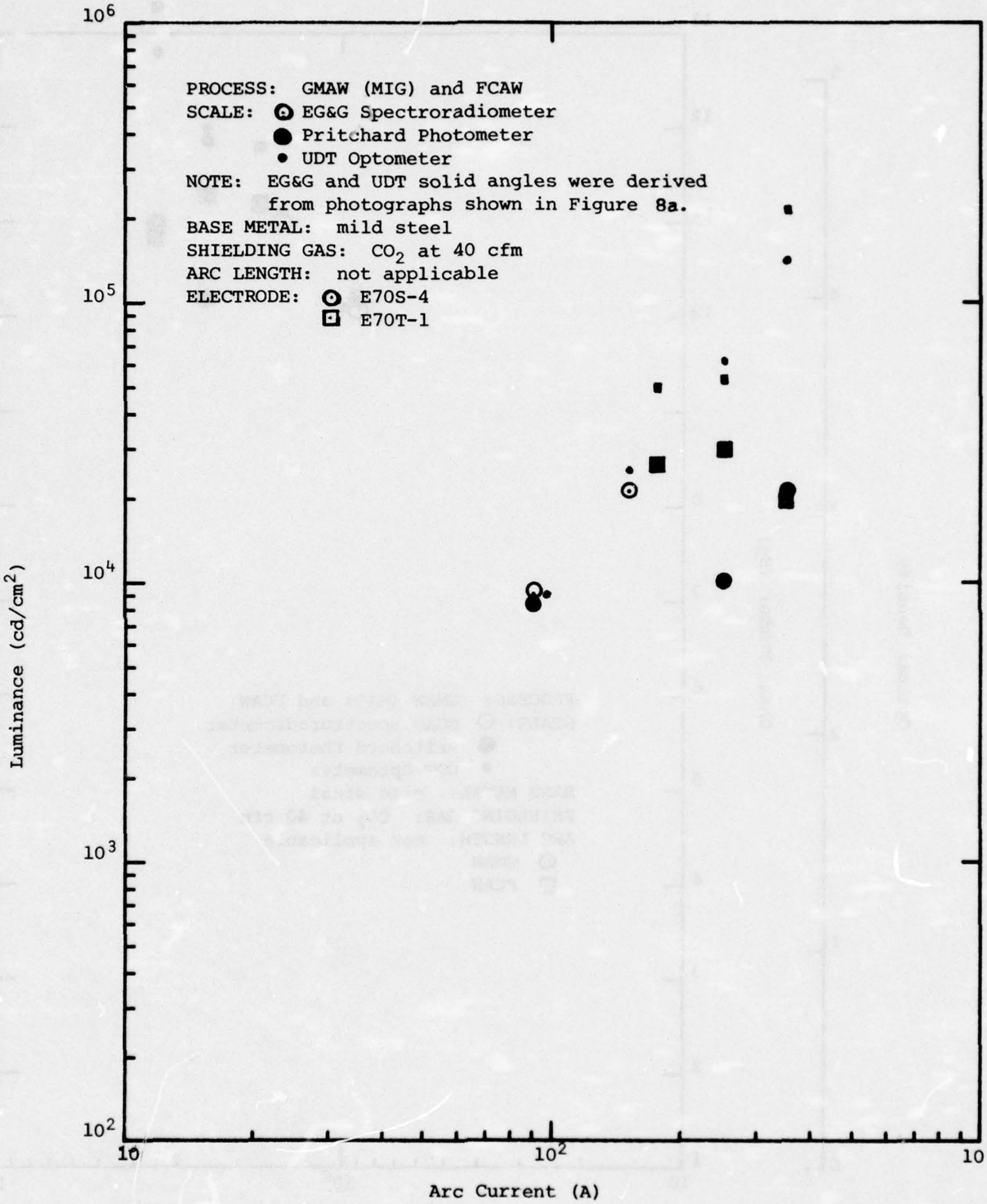


Figure 8c. Arc Luminance as a Function of Arc Current for Events 40, 41 and 49 to 53.

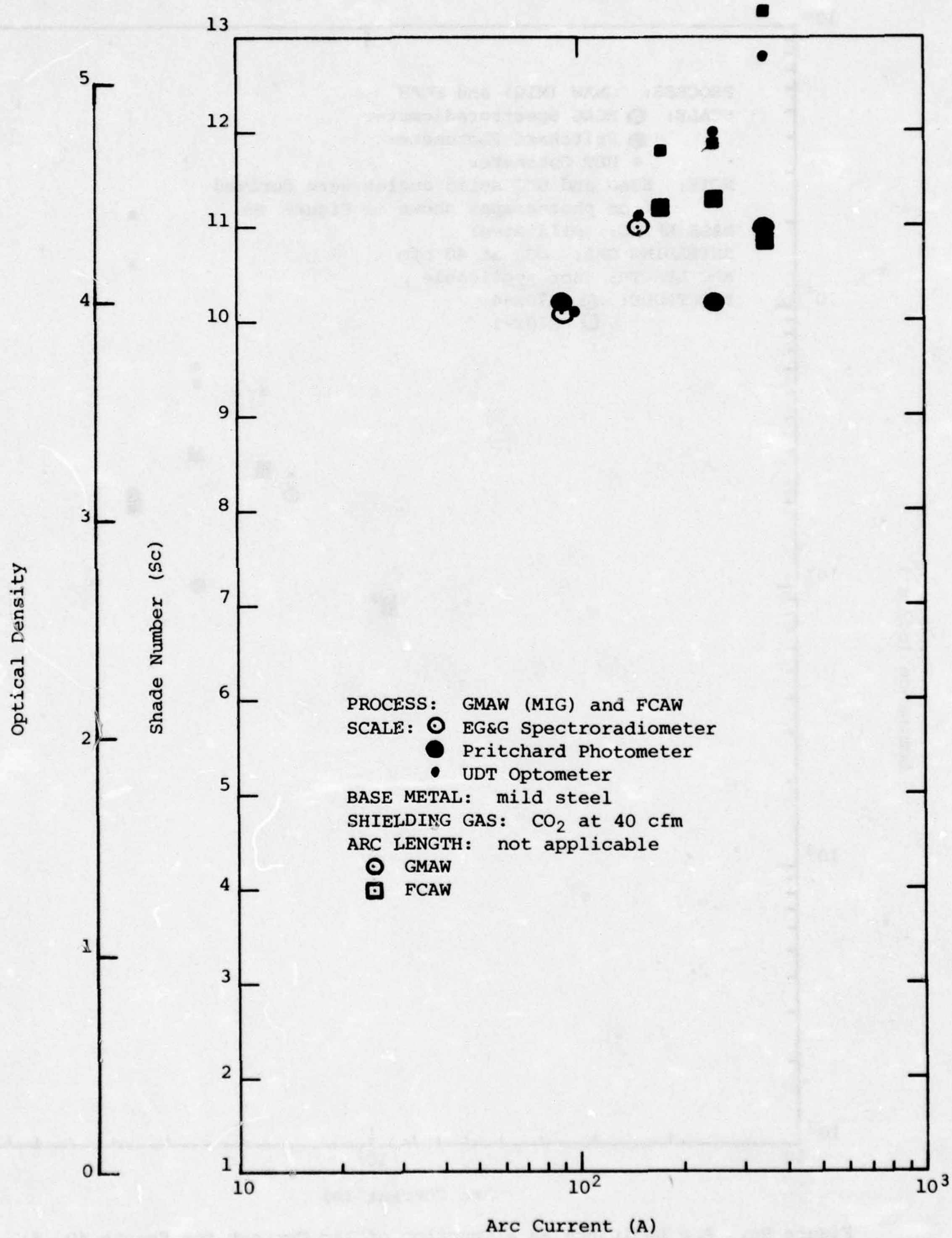


Figure 8d. Comfortable Shade Number (Sc) or Optical Density for Arc Viewing as a Function of Arc Current for Events 40, 41 and 49 to 53.

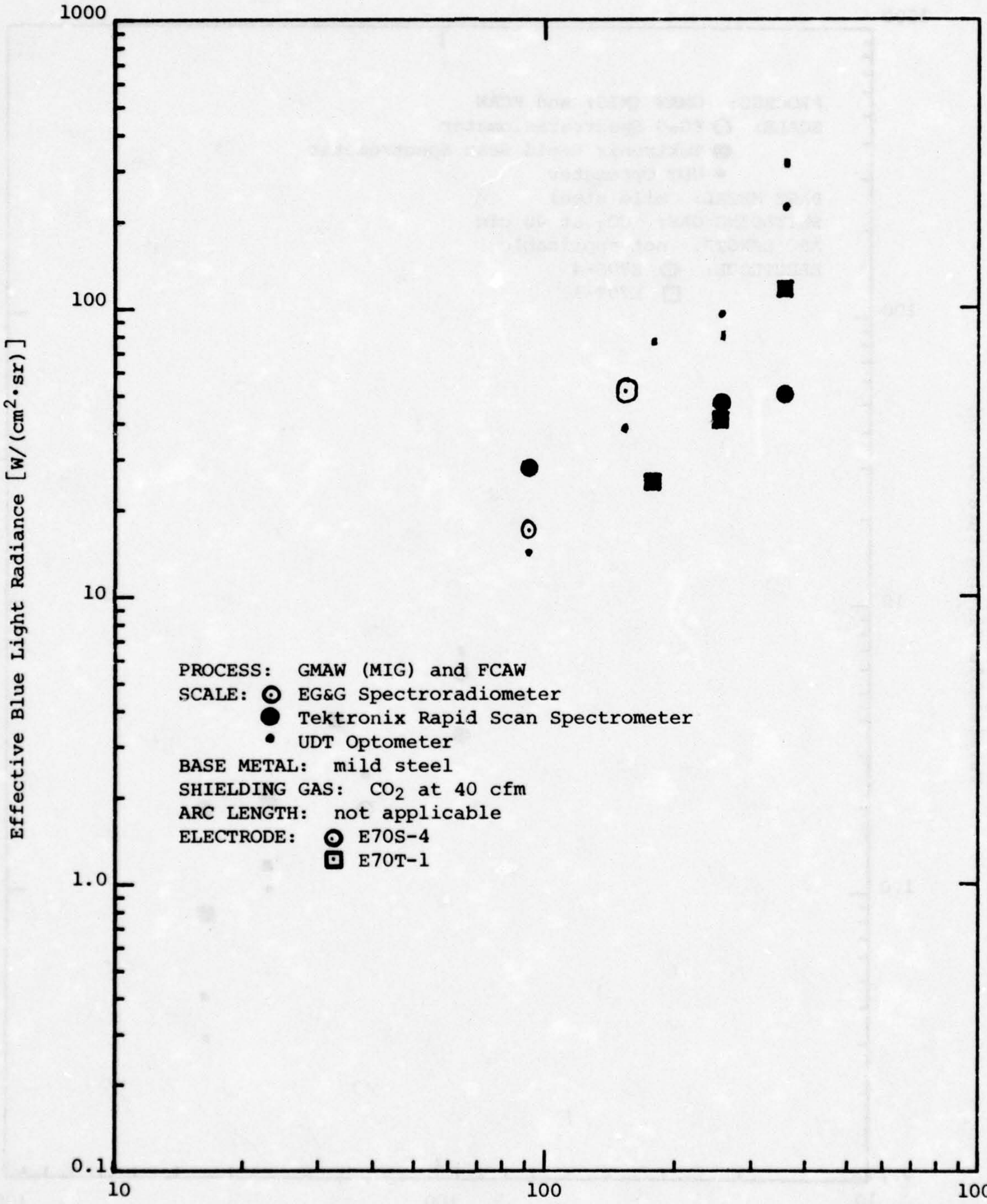


Figure 8e. Effective Blue Light Radiance as a Function of Arc Current for Events 40, 41 and 49 to 53.

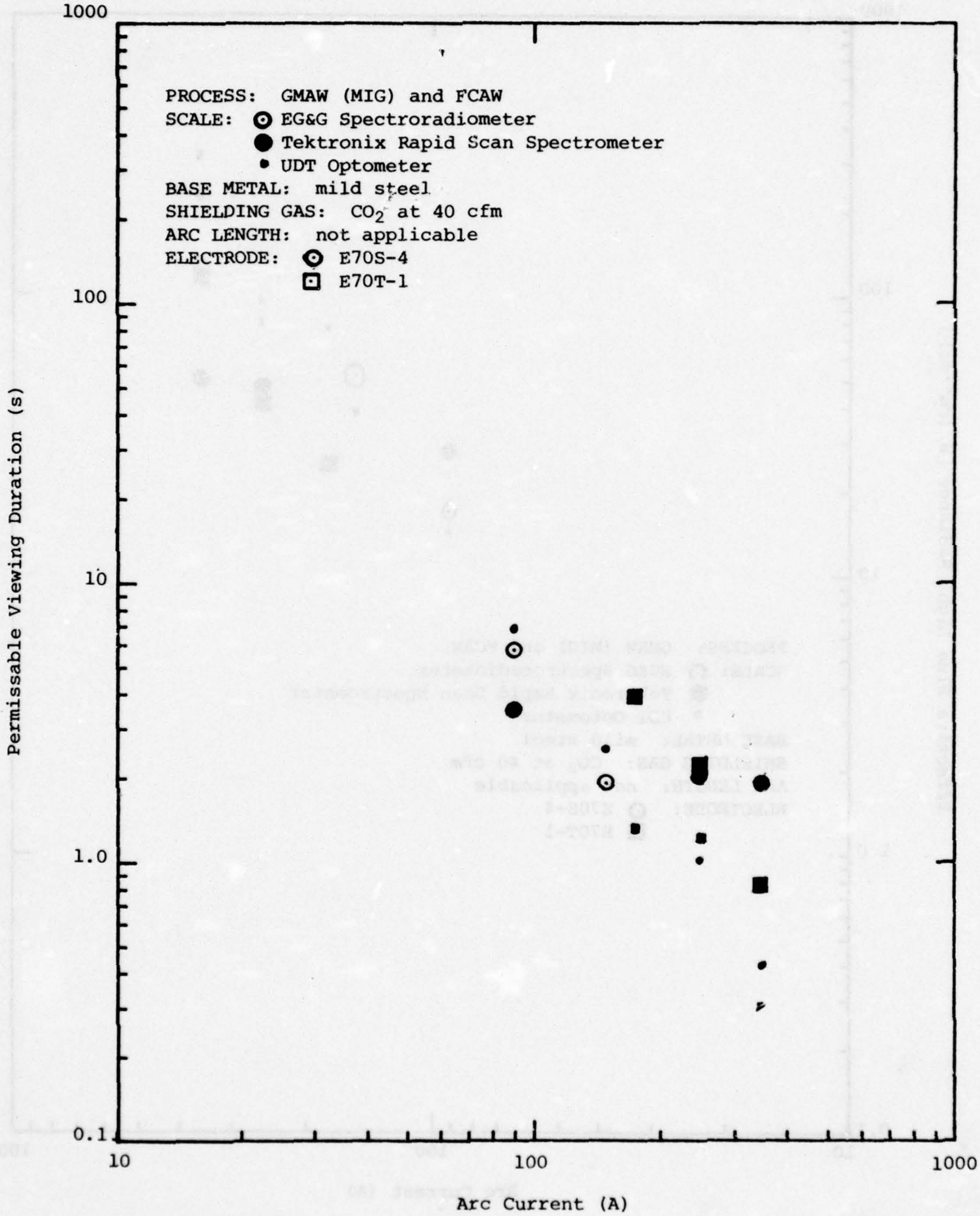


Figure 8f. Permissable Viewing Duration as a Function of Arc Current for Events 40, 41 and 49 to 53 at Distances Less than 0.7 m.

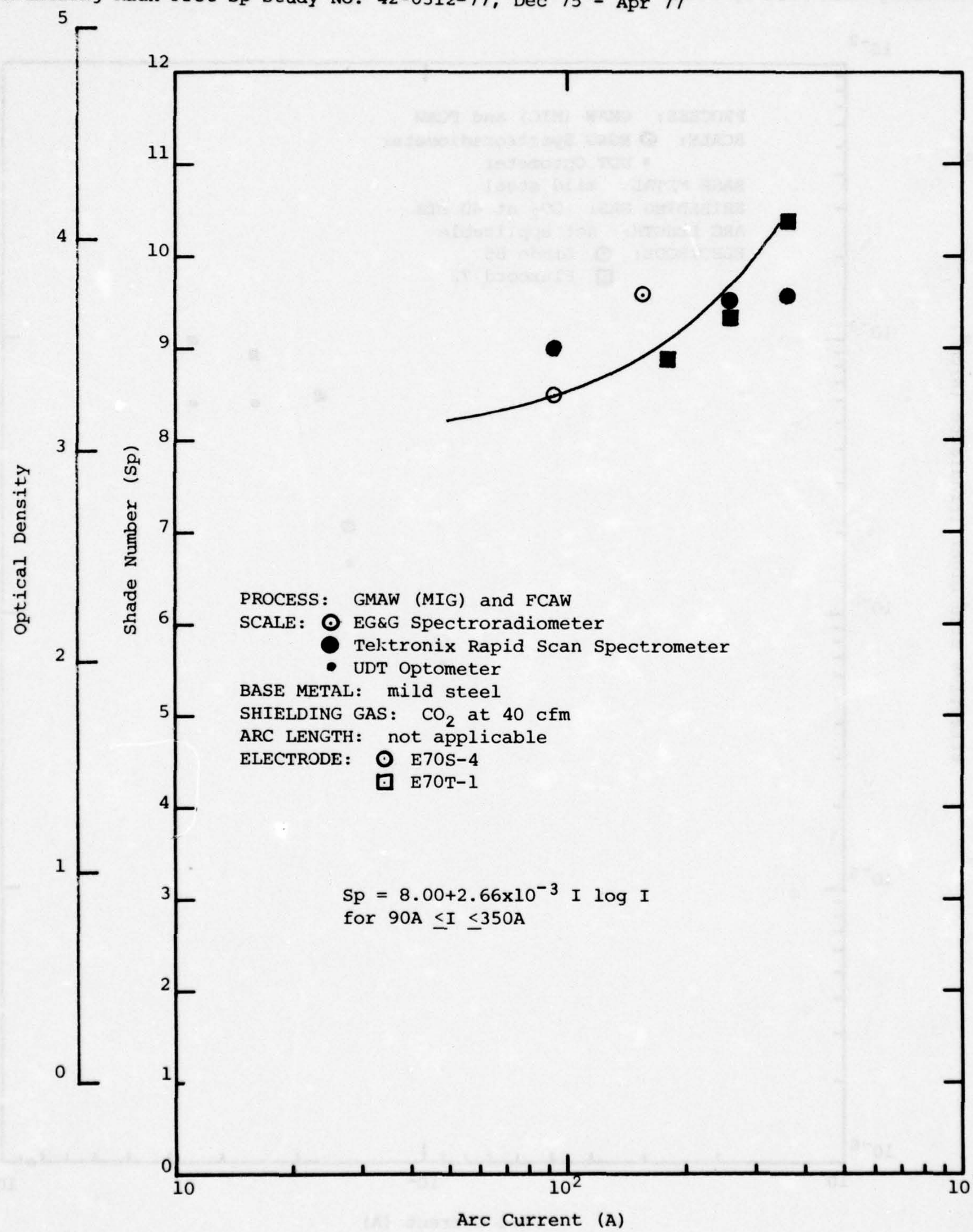


Figure 8g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 40, 41 and 49 to 53.

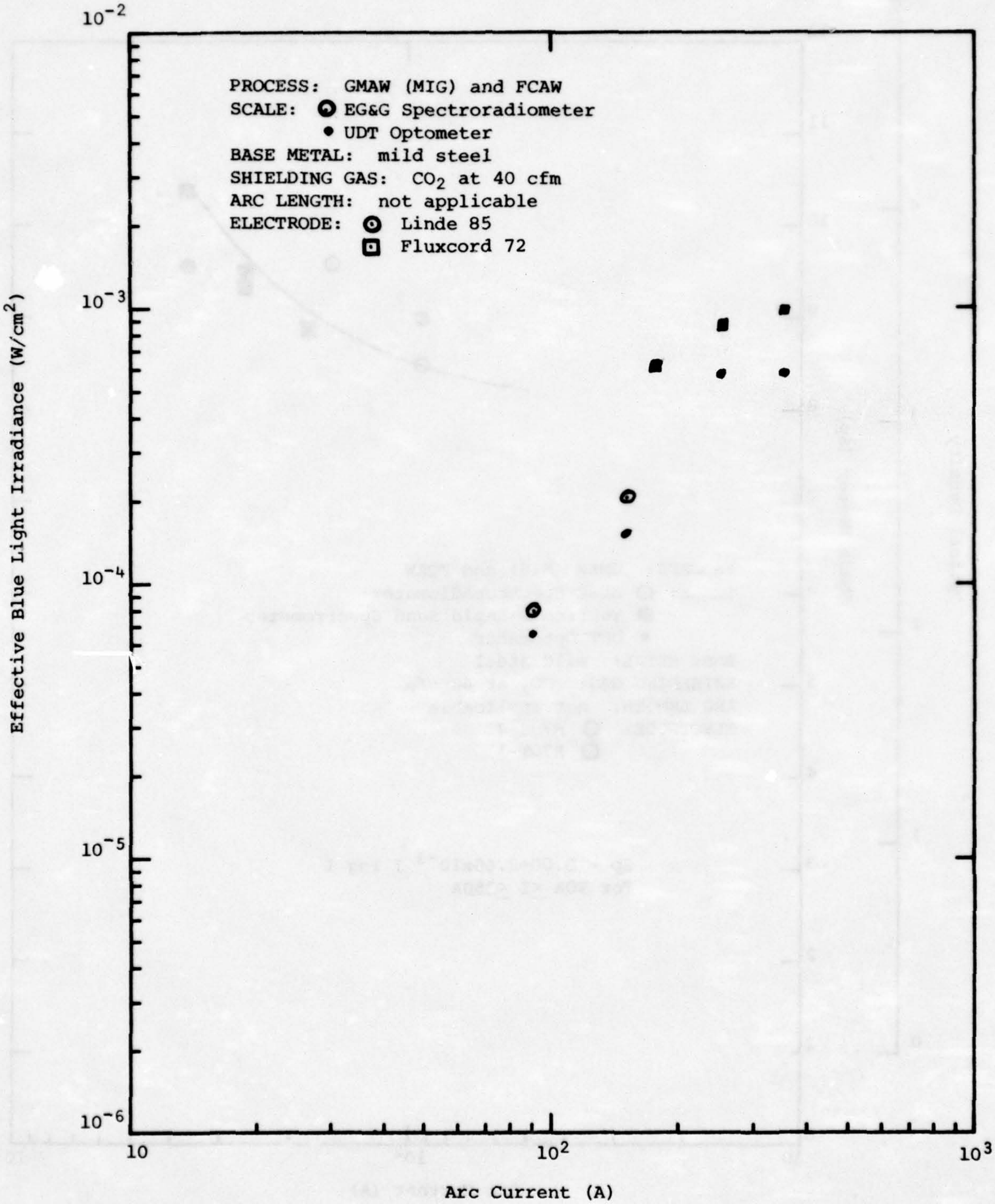


Figure 8h. Effective Blue Light Irradiance as a Function of Arc Current for Events 40, 41 and 49 to 53.

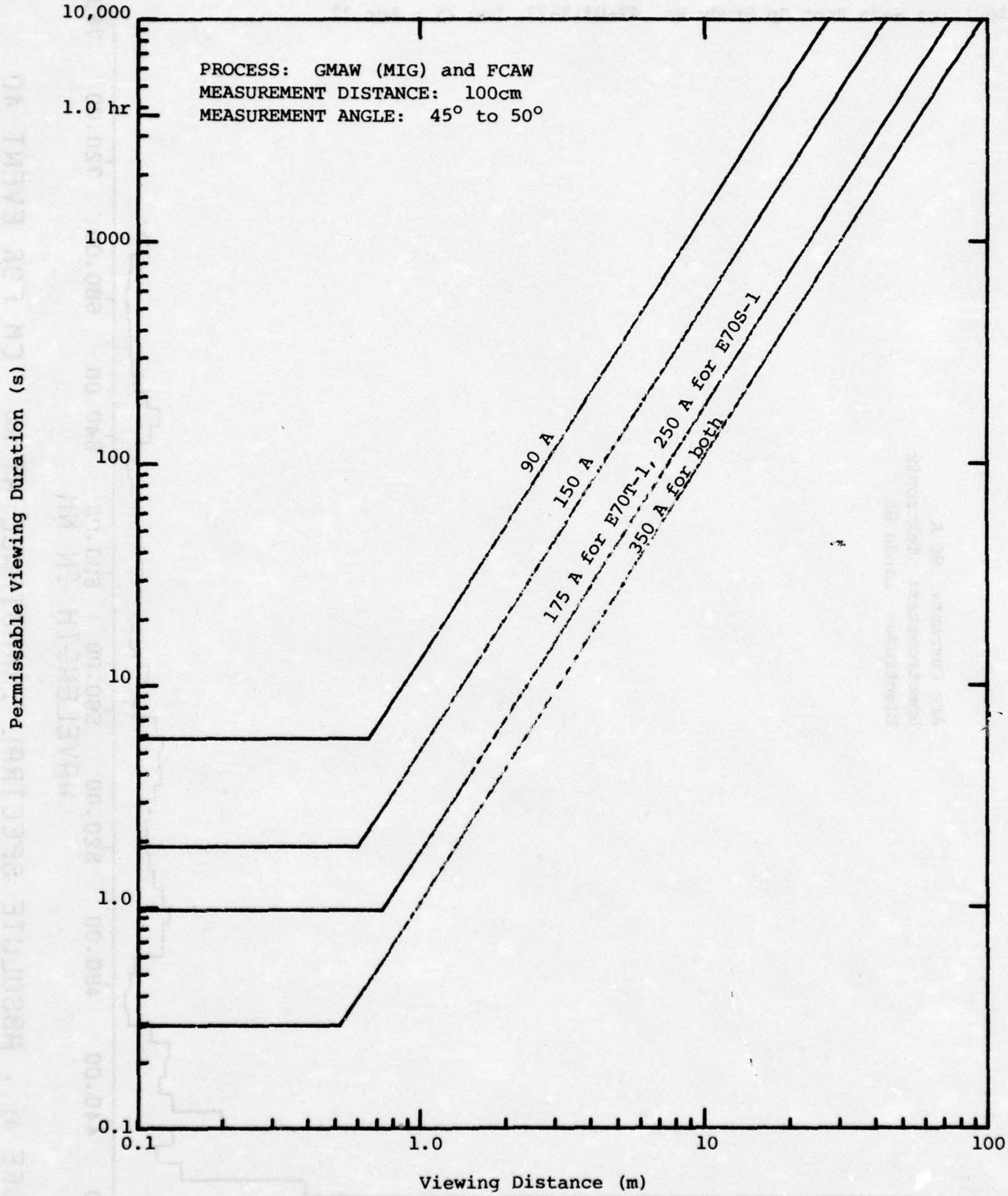


Figure 8i. Recommended maximum exposure duration as a Function of Viewing Distance for Events 40, 41 and 49-53. Two types of Electrodes were used (E70T-1 and E70S-1).

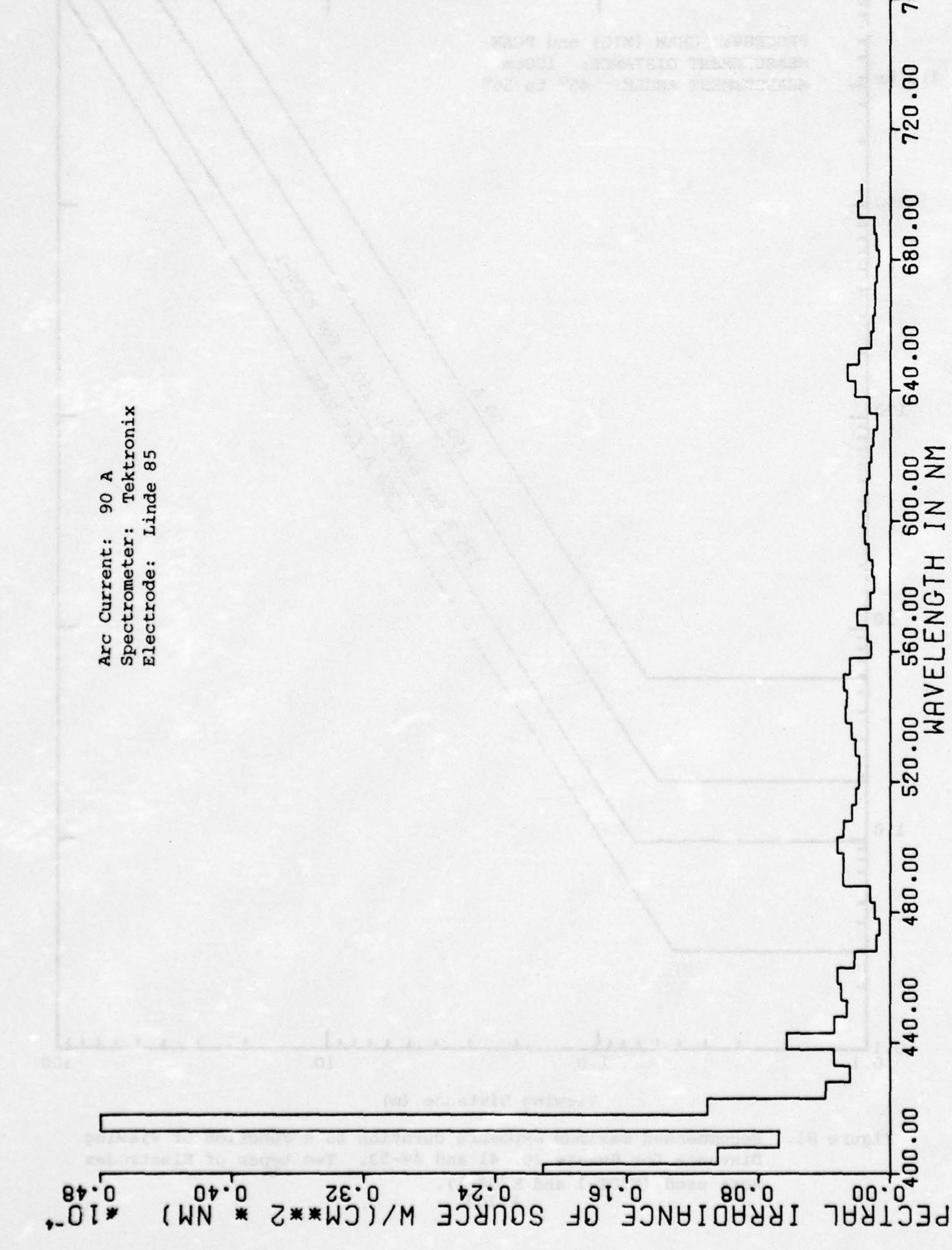


FIGURE 8j . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 40

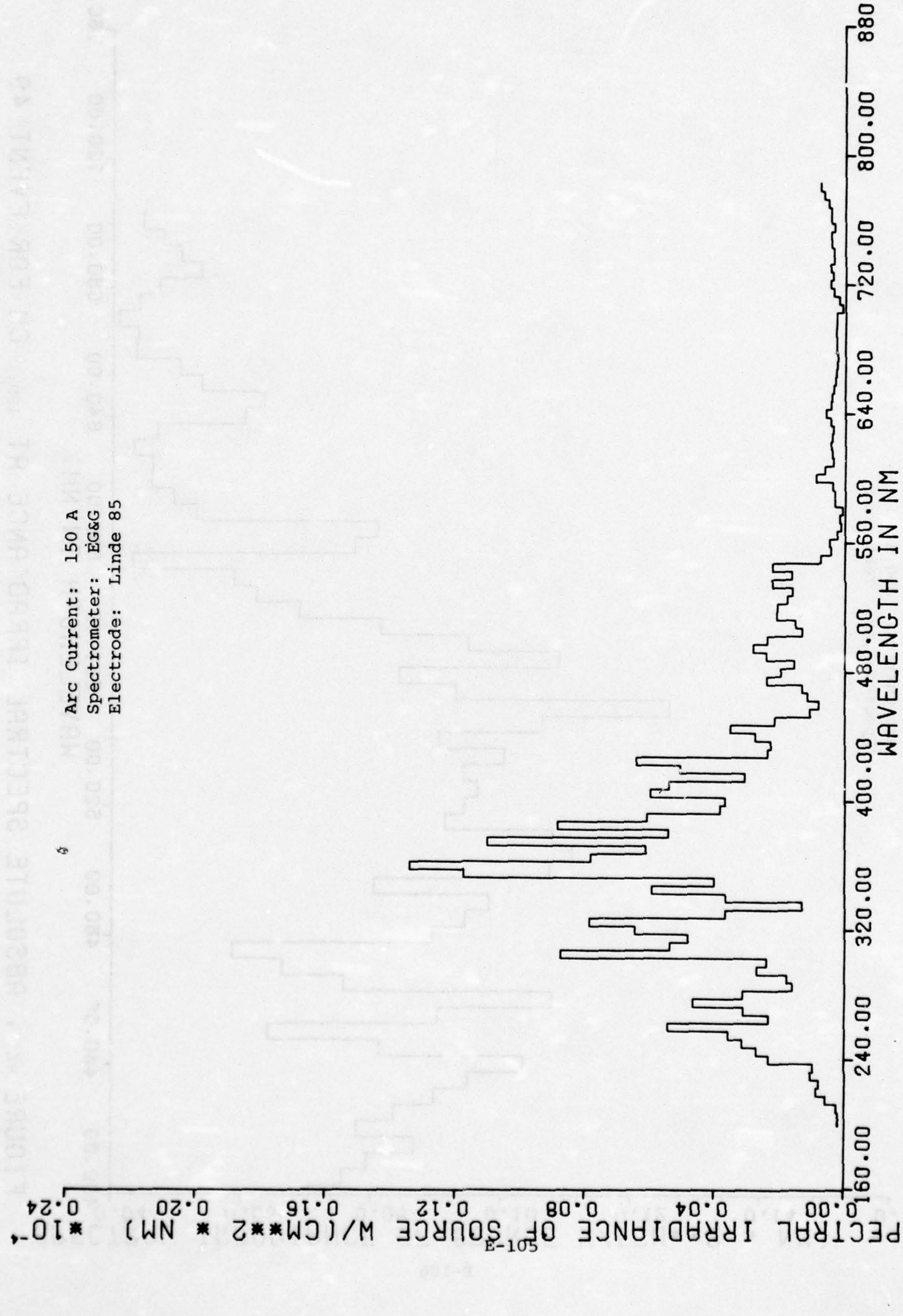


FIGURE 8k ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 41

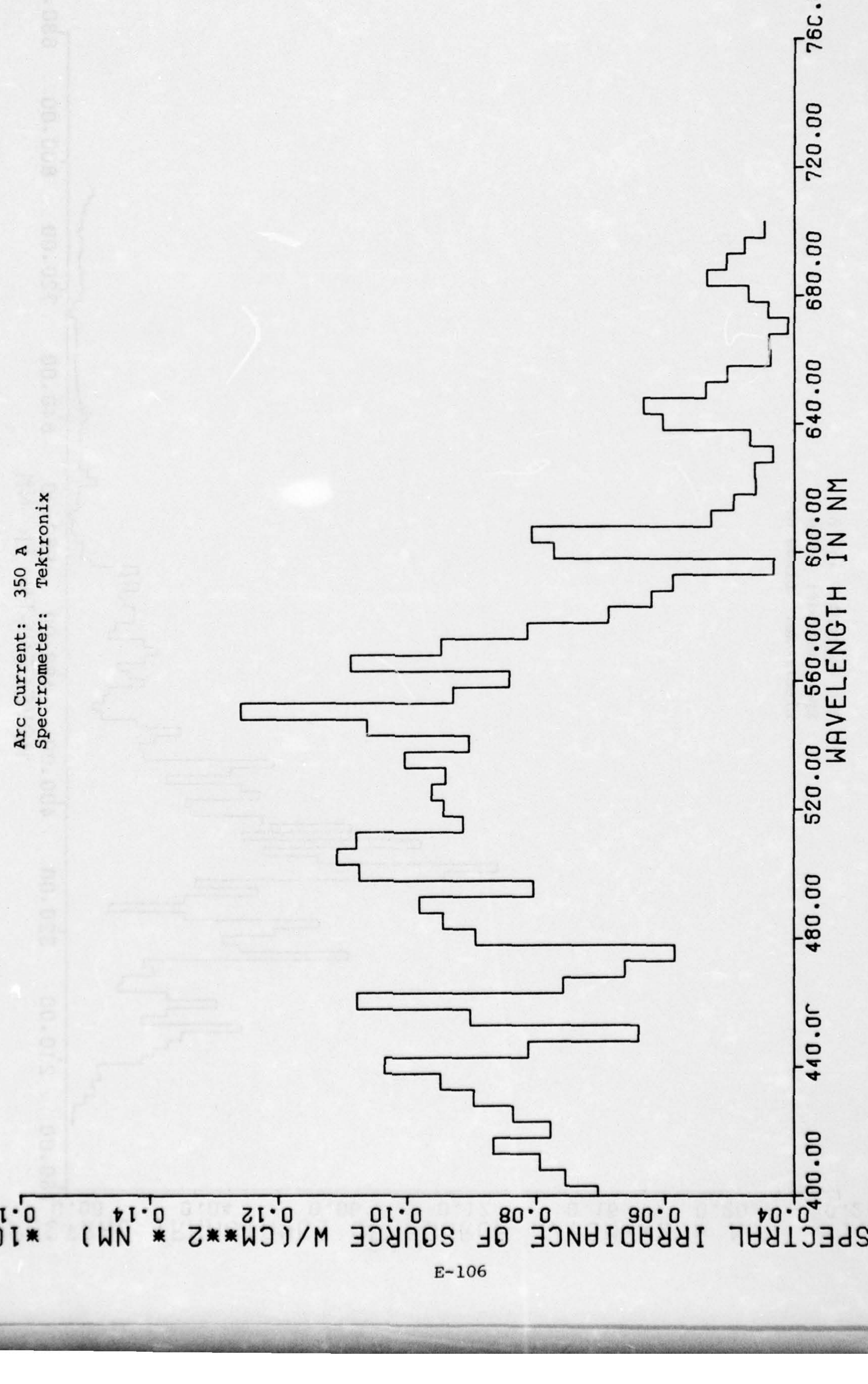


FIGURE 8l . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 49

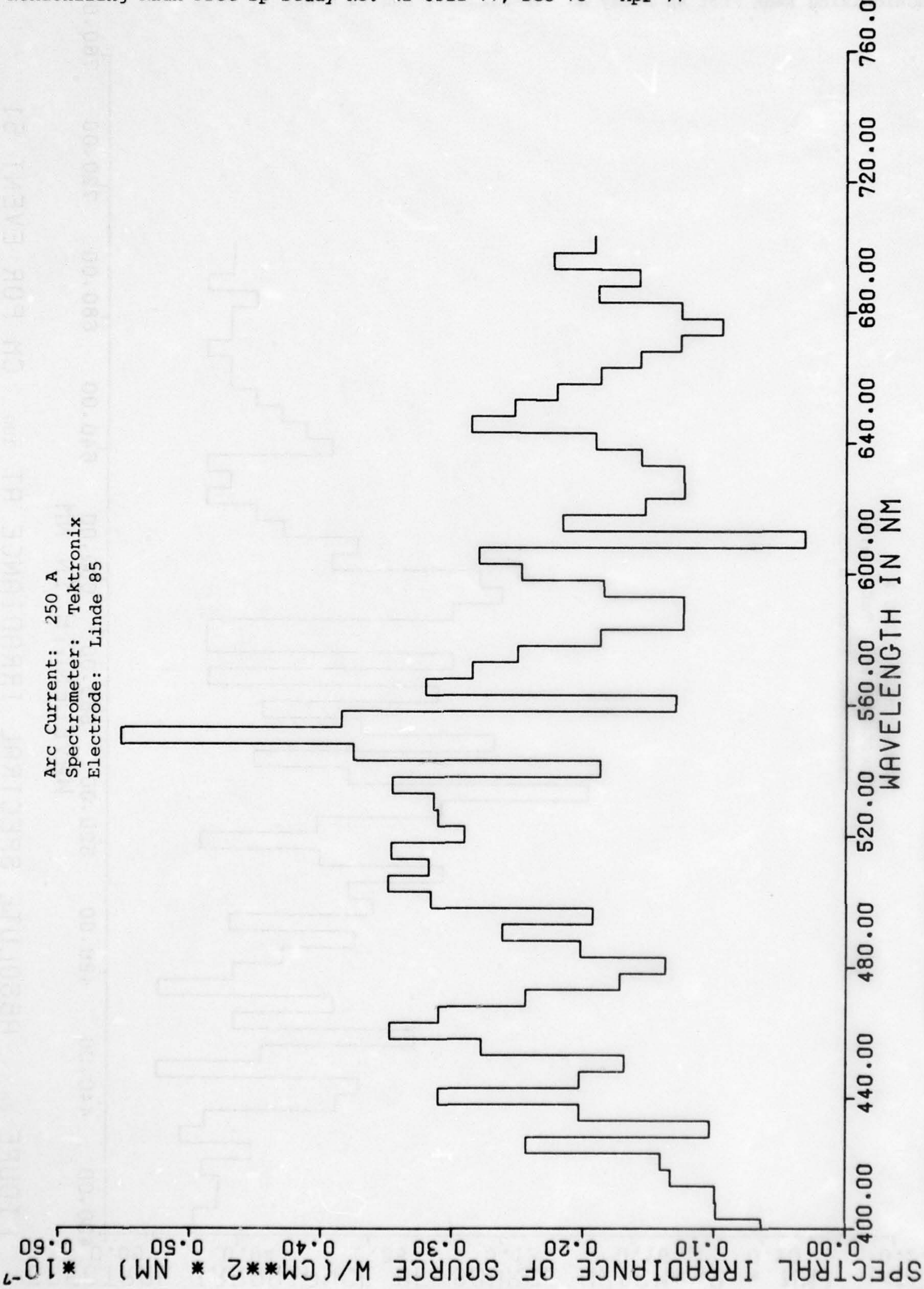


FIGURE 8m. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 50

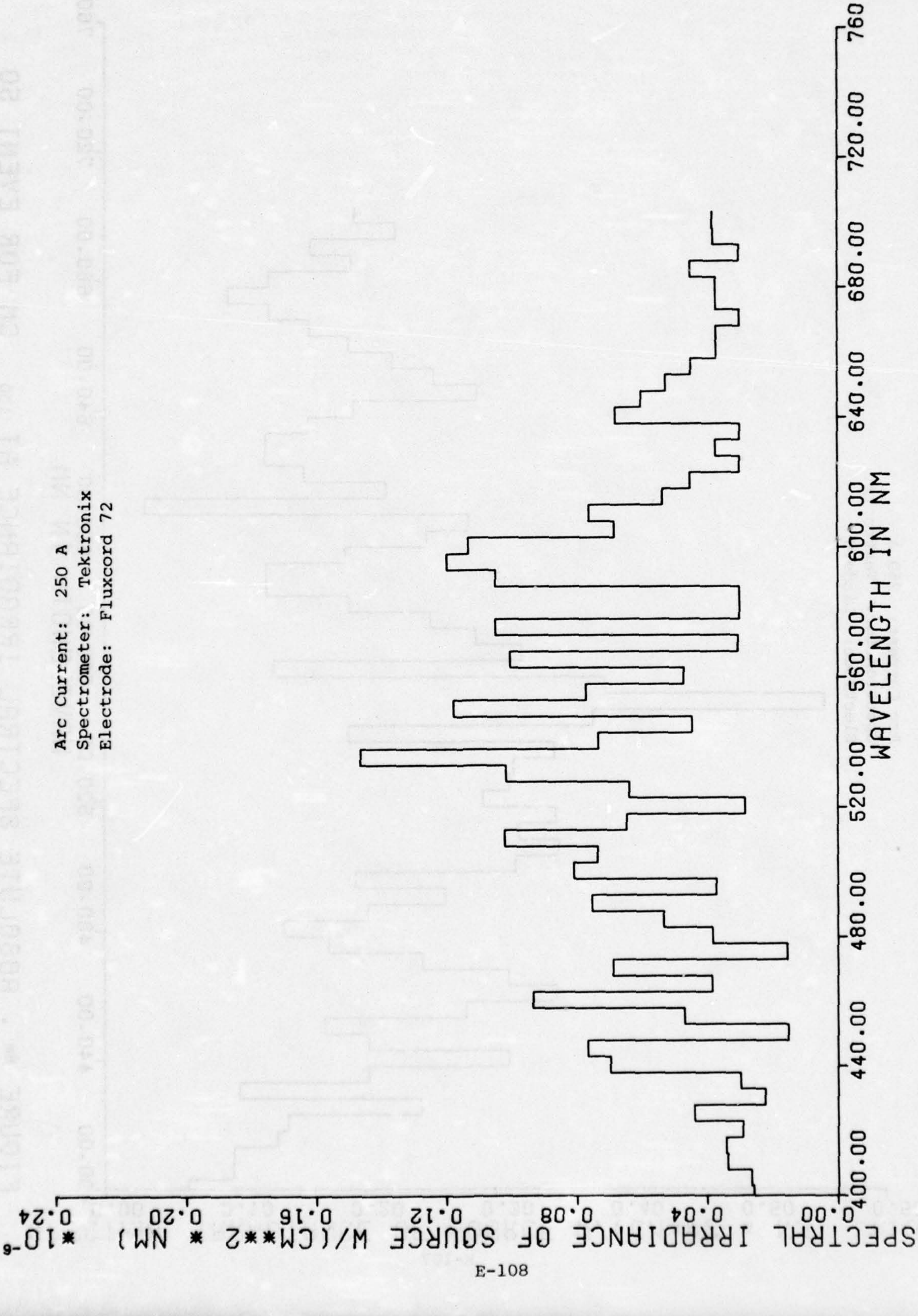


FIGURE 8n . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 51

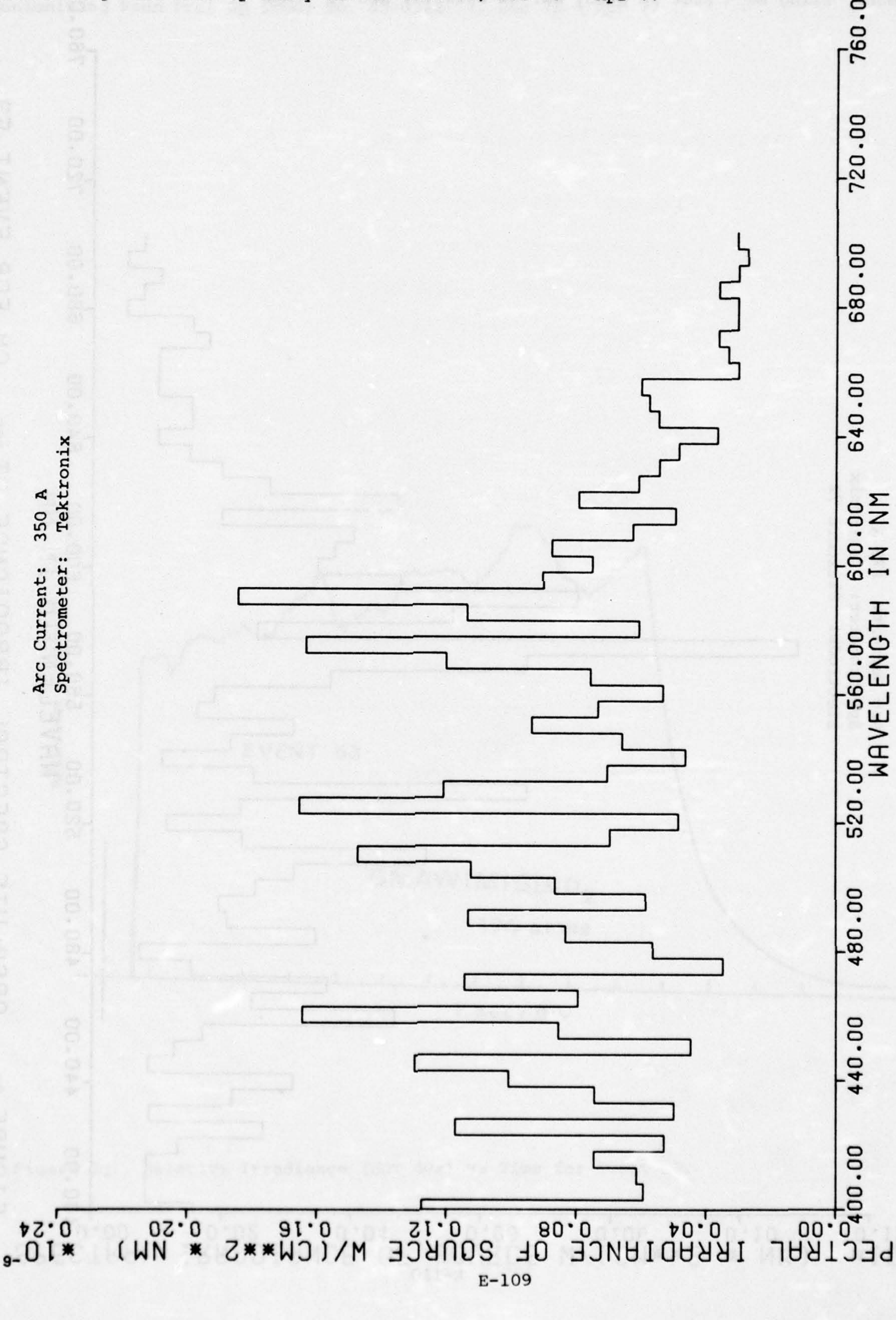


FIGURE 80 . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 52

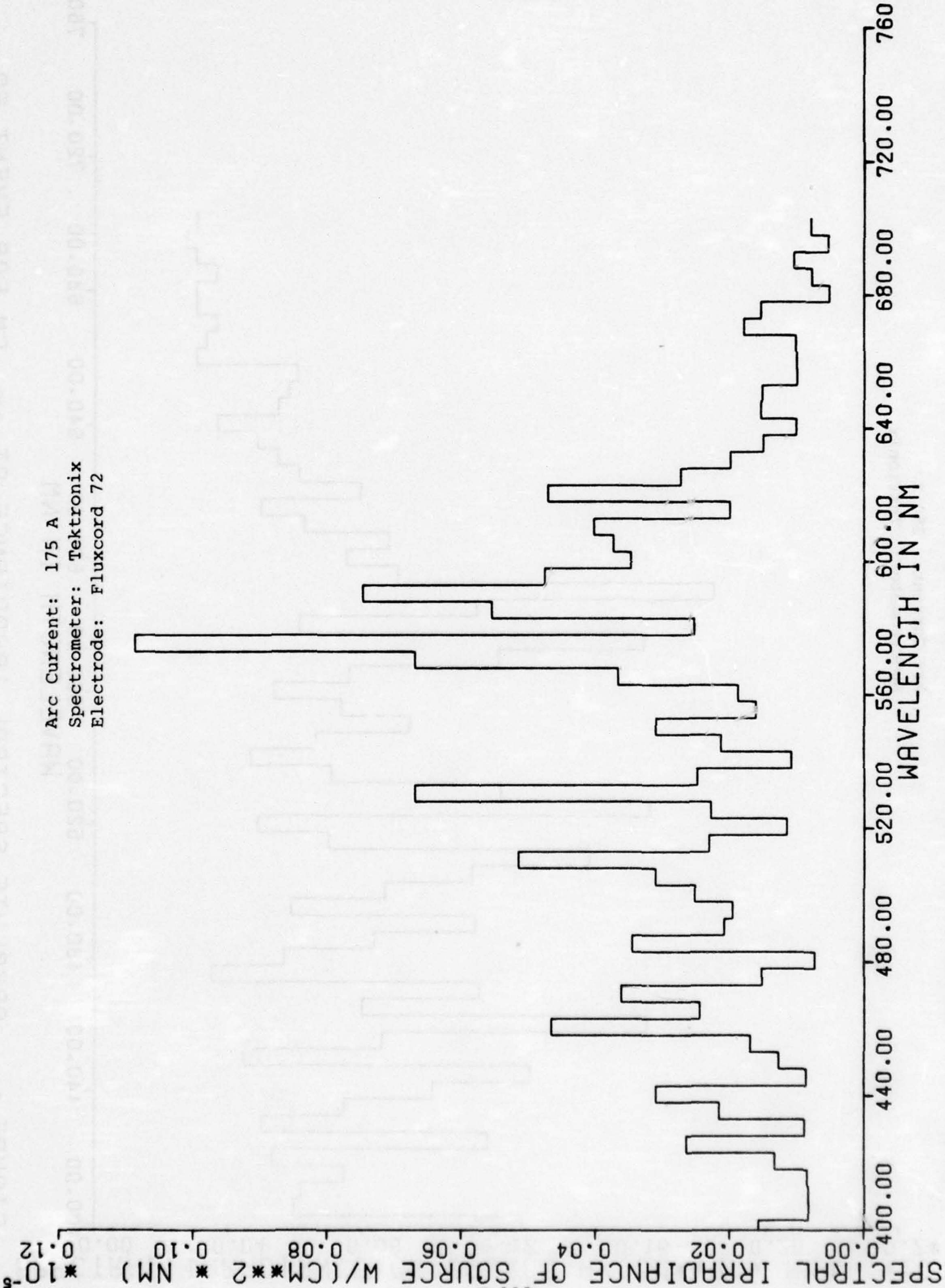


FIGURE 8p . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 53

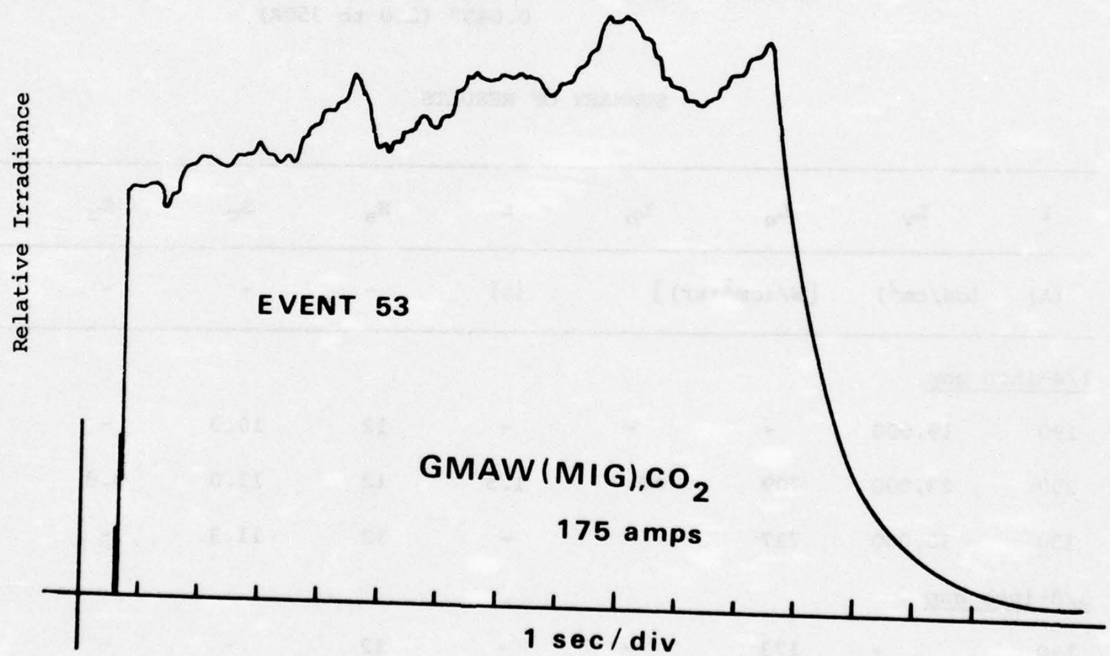


Figure 8q. Relative Irradiance (UDT 40x) vs Time for Event 53.

TABLE 9. WELDING PARAMETERS FOR EVENTS 42 TO 48.

Process: GMAW (MIG)

Base Metal: mild steel

Electrode: E70S-4 (Linde 85)

Current Range: 150 to 350 A

Polarity: DCRP

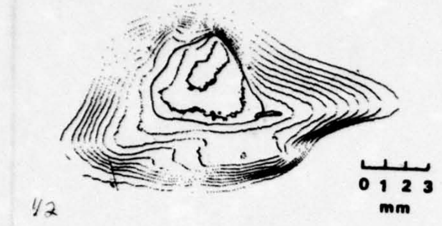
Shielding Gas: 5% O_2 and 95% Ar at 50 cfm

Arc Lengths: 1/4" and 3/8"

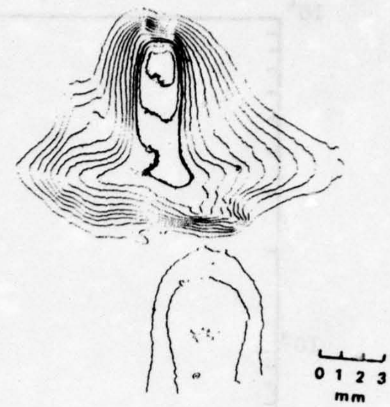
Electrode Diameter: 0.035" (150 to 200A) and
0.045" (250 to 350A)

SUMMARY OF RESULTS

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	$[W/(cm^2 \cdot sr)]$		(s)	-	-	-	(cm)
1/4-inch gap								
190	19,000	-	-	-	12	10.9	-	-
250	23,000	709	64.5	1.5	12	11.0	9.8	102
350	30,000	737	-	-	12	11.3	-	97
3/8-inch gap								
150	-	173	-	-	12	-	-	132
200	24,000	321	-	-	12	11.1	-	118
260	19,000	116	-	-	12	10.9	-	132
350	90,000	2890	-	-	12	12.4	-	59

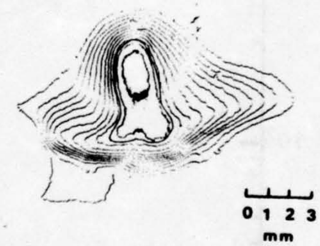


Event 42, 150 A, CI-0.17

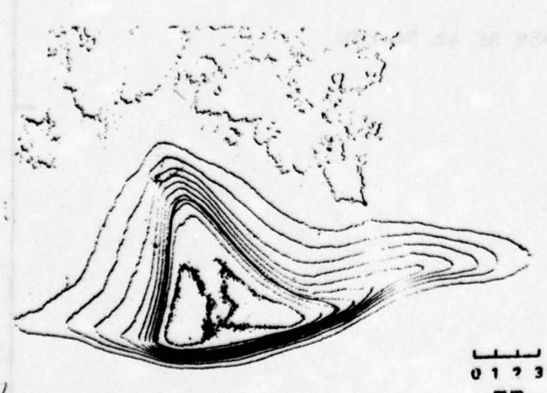


Event 44, 200 A, CI=0.16

Event 46, 260 A, CI=0.15



Event 45, 250 A, CI=0.17



Event 47, 350 A, CI=0.16

Event 48, 350 A, CI=0.17

Figure 9a. Microdensitometer Scans of 35 mm Processed Photographic Negatives Exposed 4 m from the Welding Arcs for Events 42-48.

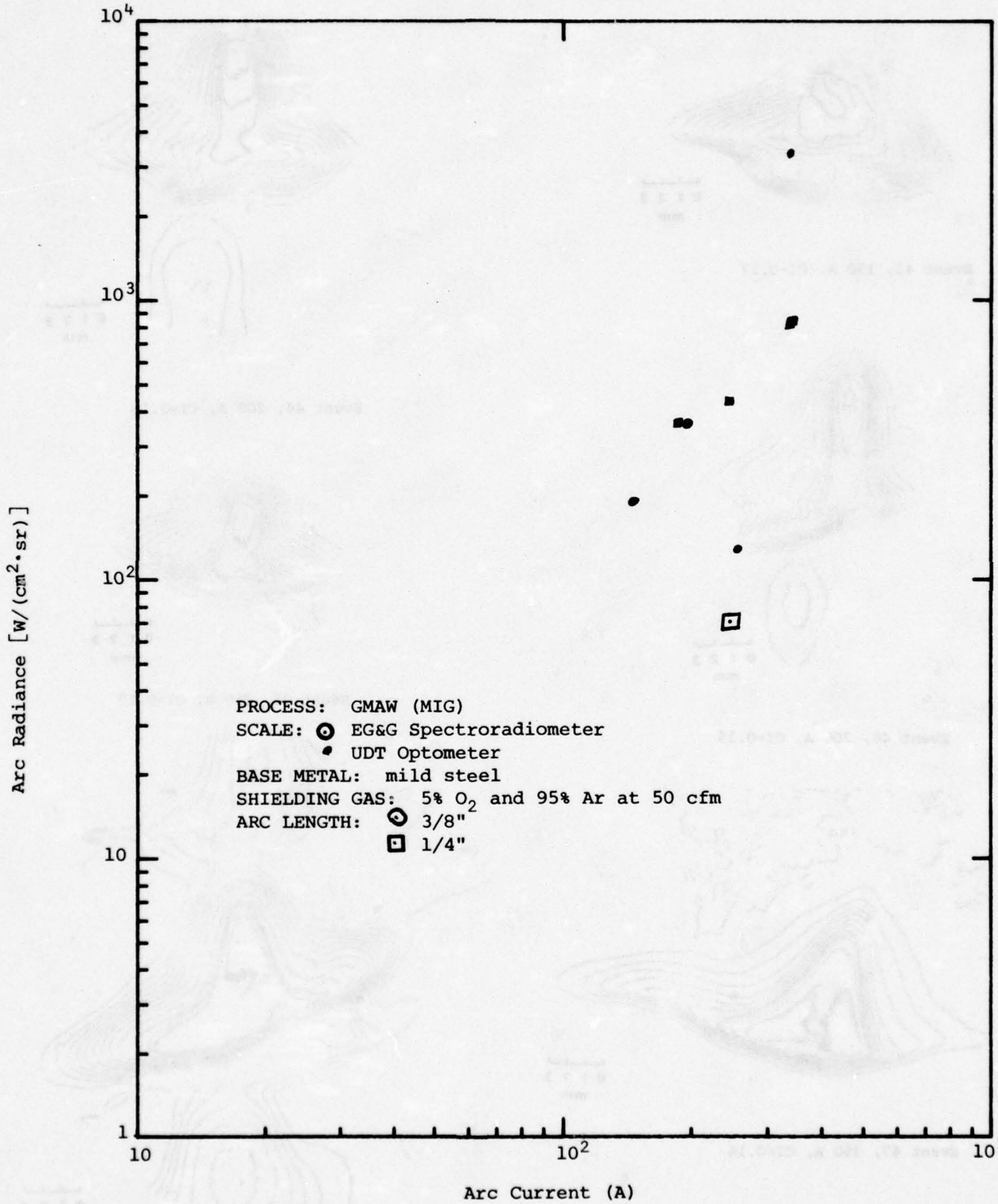


Figure 9b. Arc Radiance as a Function of Arc Current for Events 42 to 48.

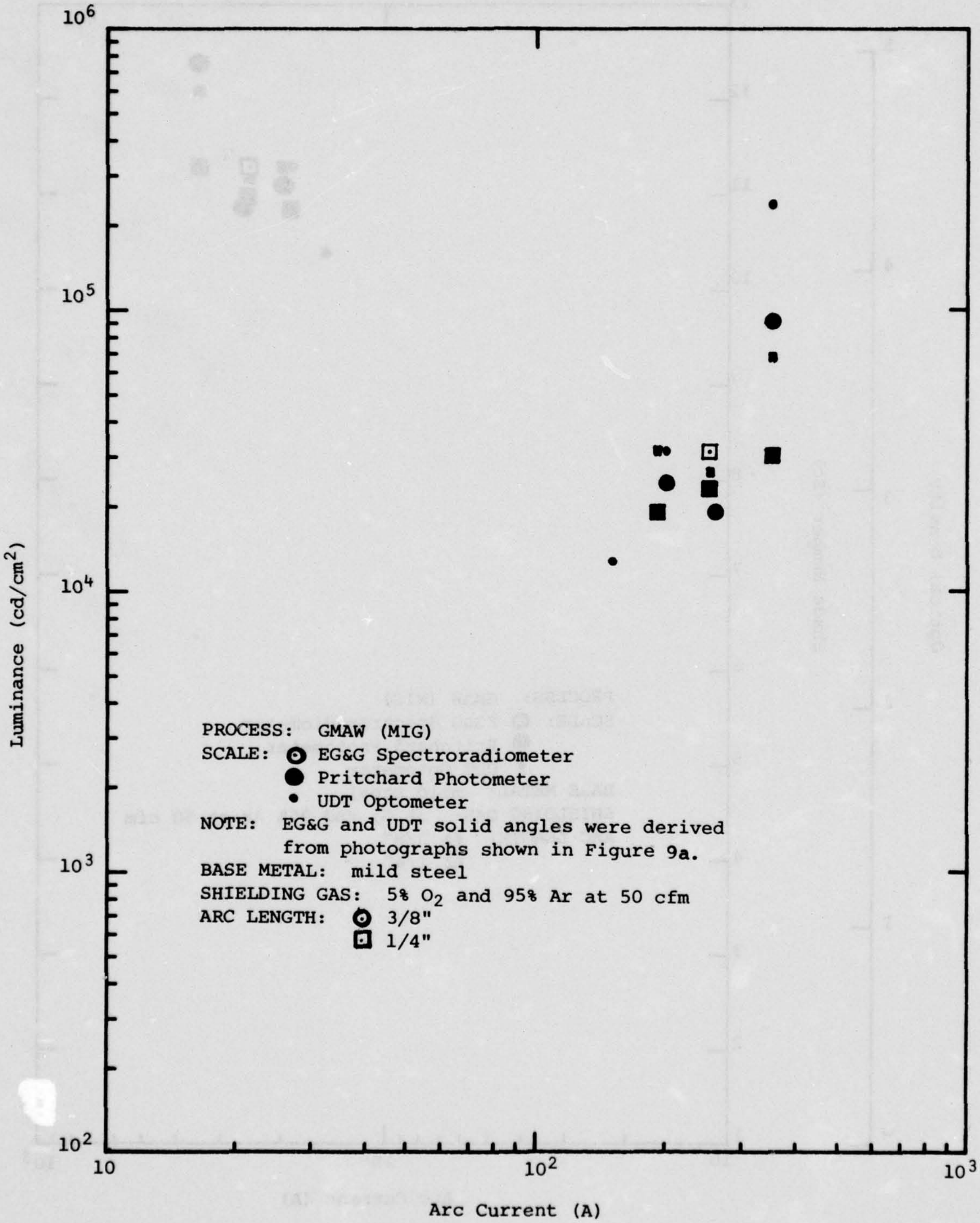


Figure 9c. Arc Luminance as a Function of Arc Current for Events 42 to 48.

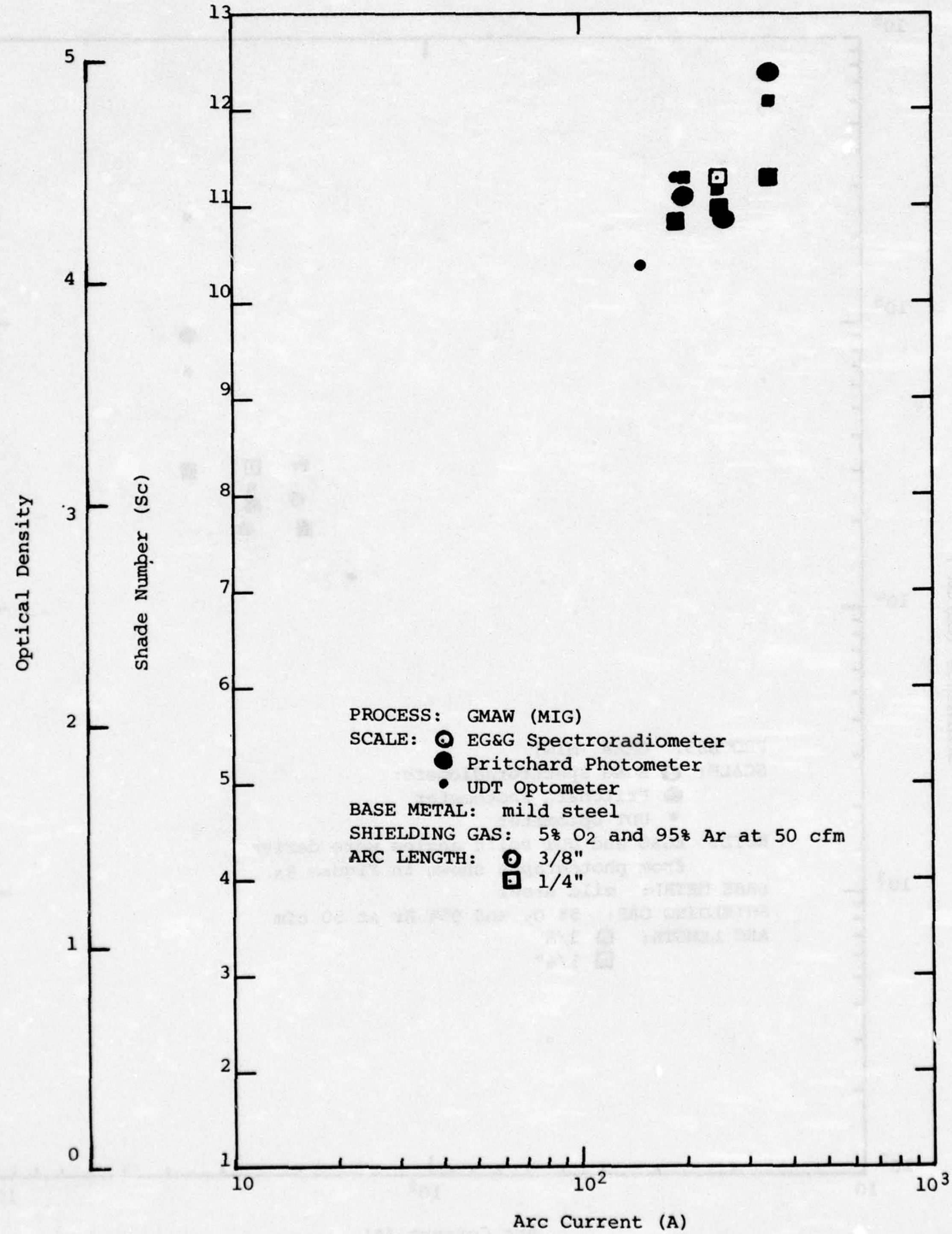


Figure 9d. Comfortable Shade Number (Sc) or Optical Density for Arc Viewing as a Function of Arc Current for Events 42 to 48.

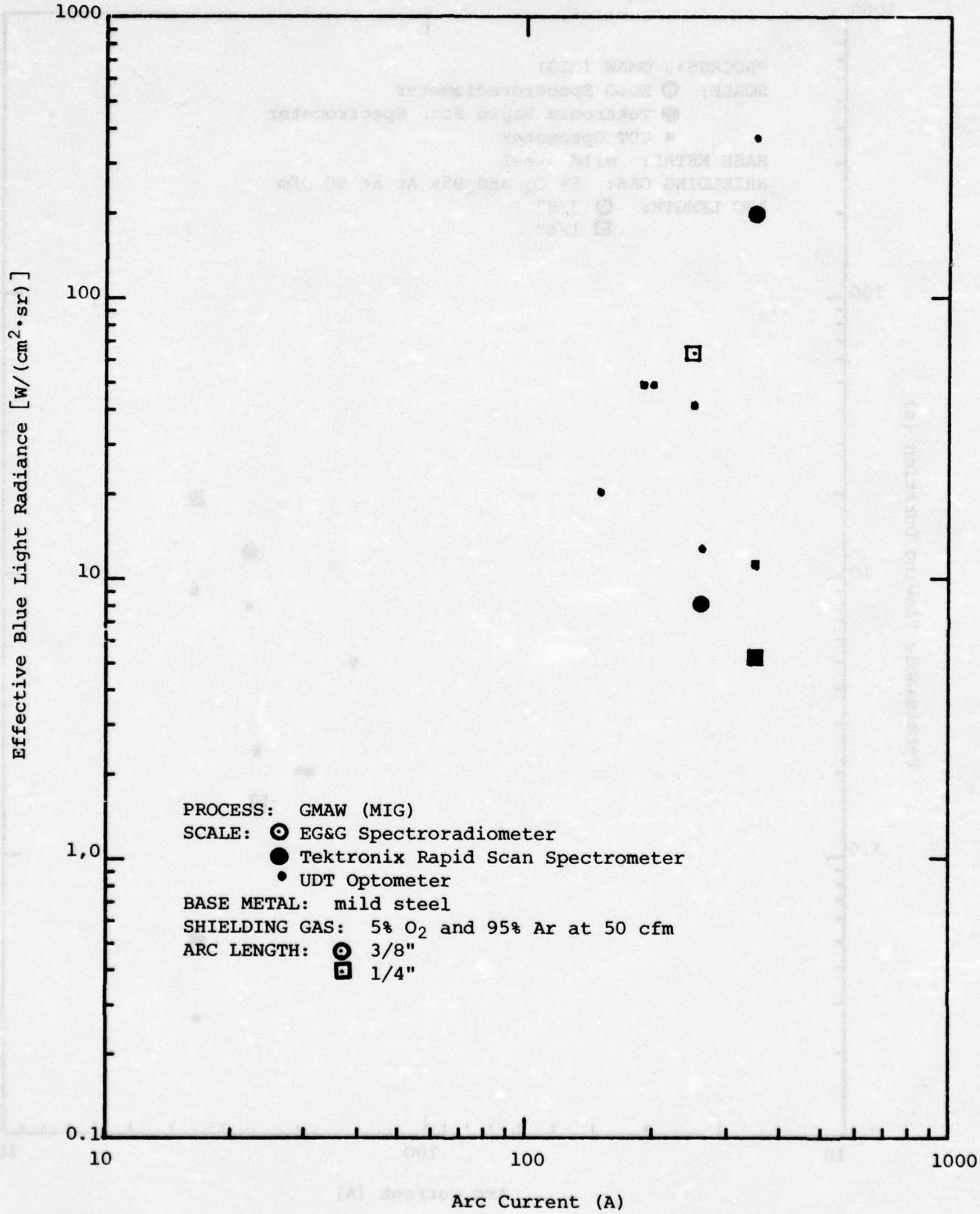


Figure 9e. Effective Blue Light Radiance as a Function of Arc Current for Events 42 to 48.

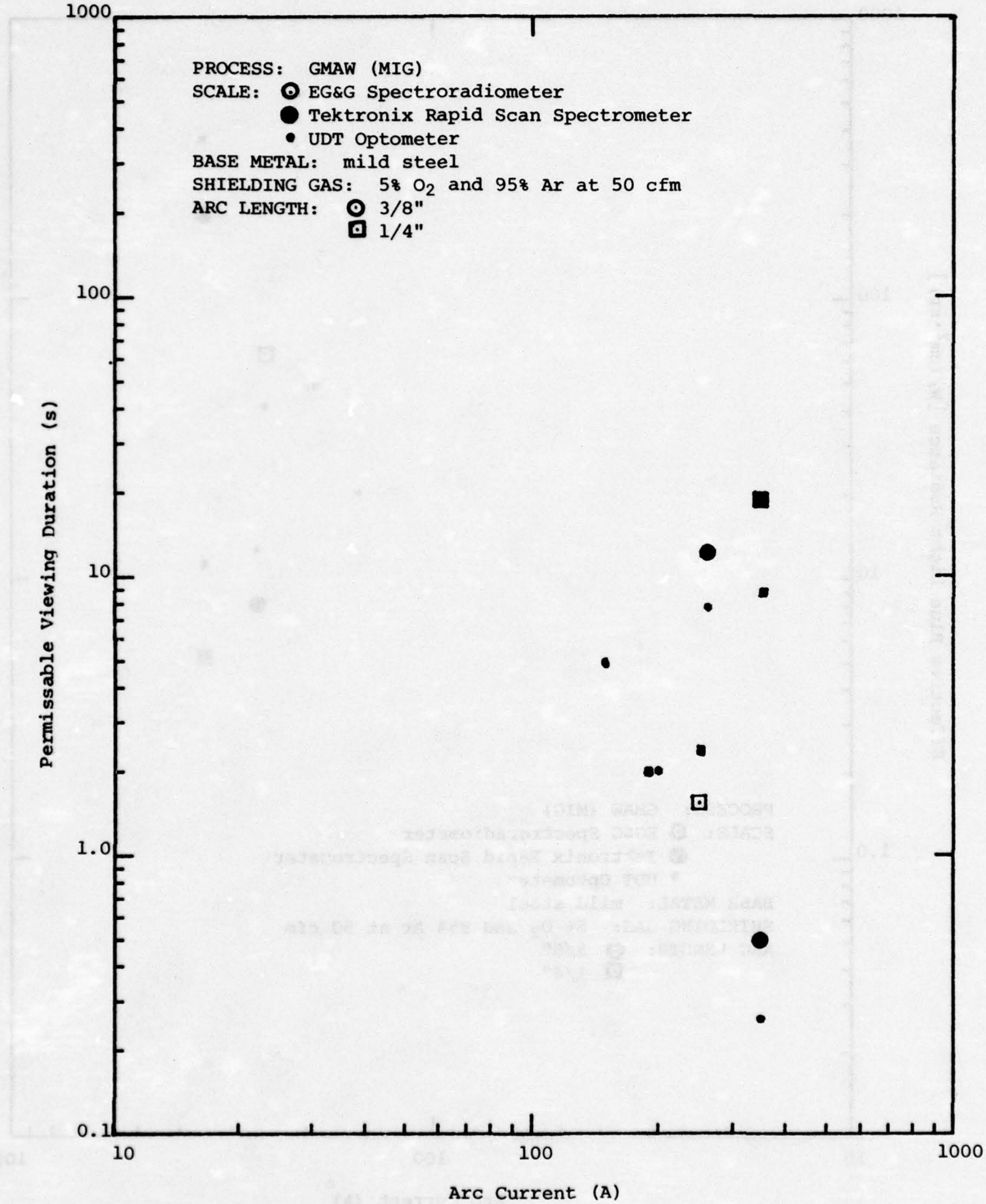


Figure 9f. Permissable Viewing Duration as a Function of Arc Current for Events 42 to 48 at Distances Less Than 1.0 m.

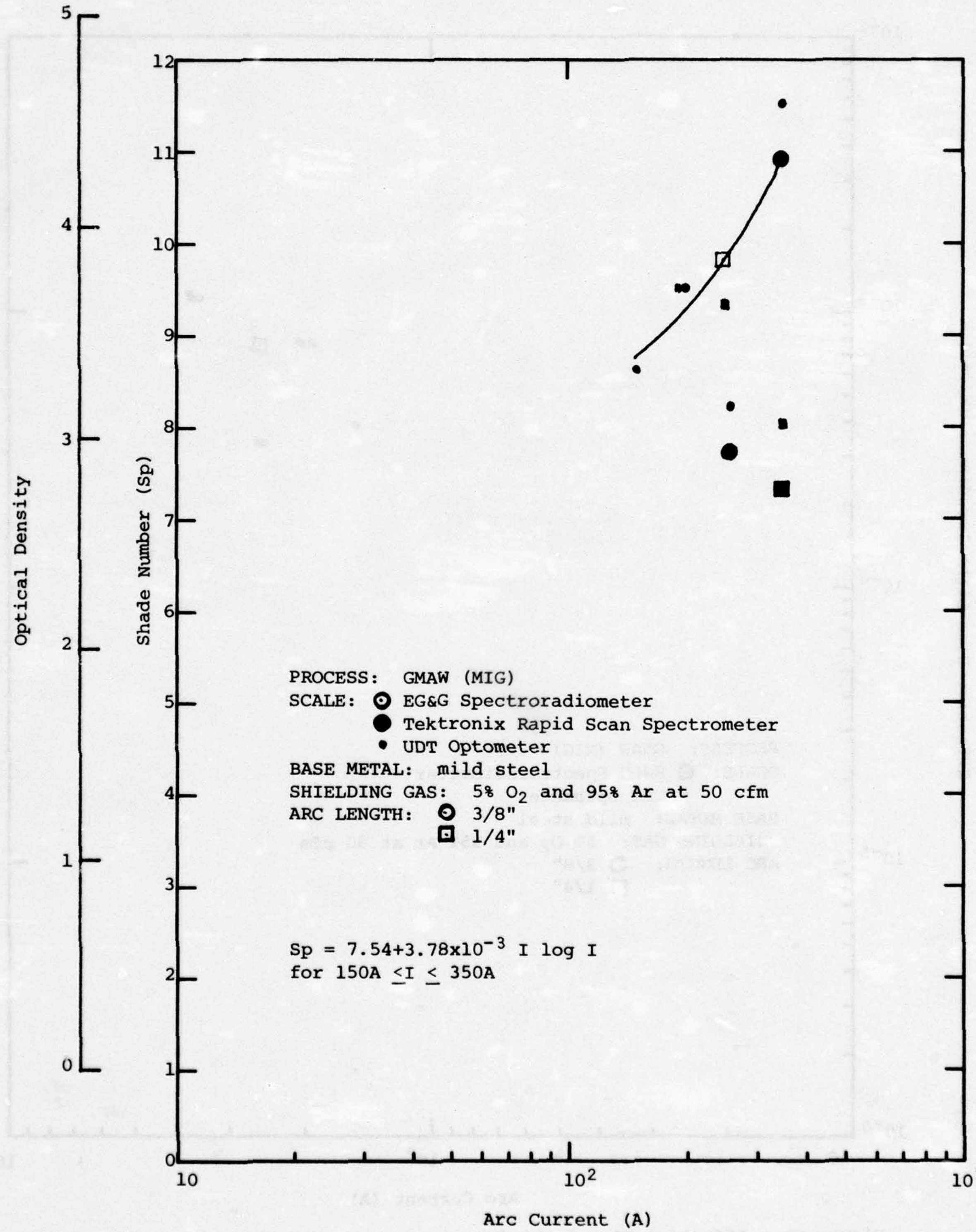


Figure 9g. Shade Number or Optical Density Necessary for Eye Protection Against Blue Light Emitted During Events 42 to 48.

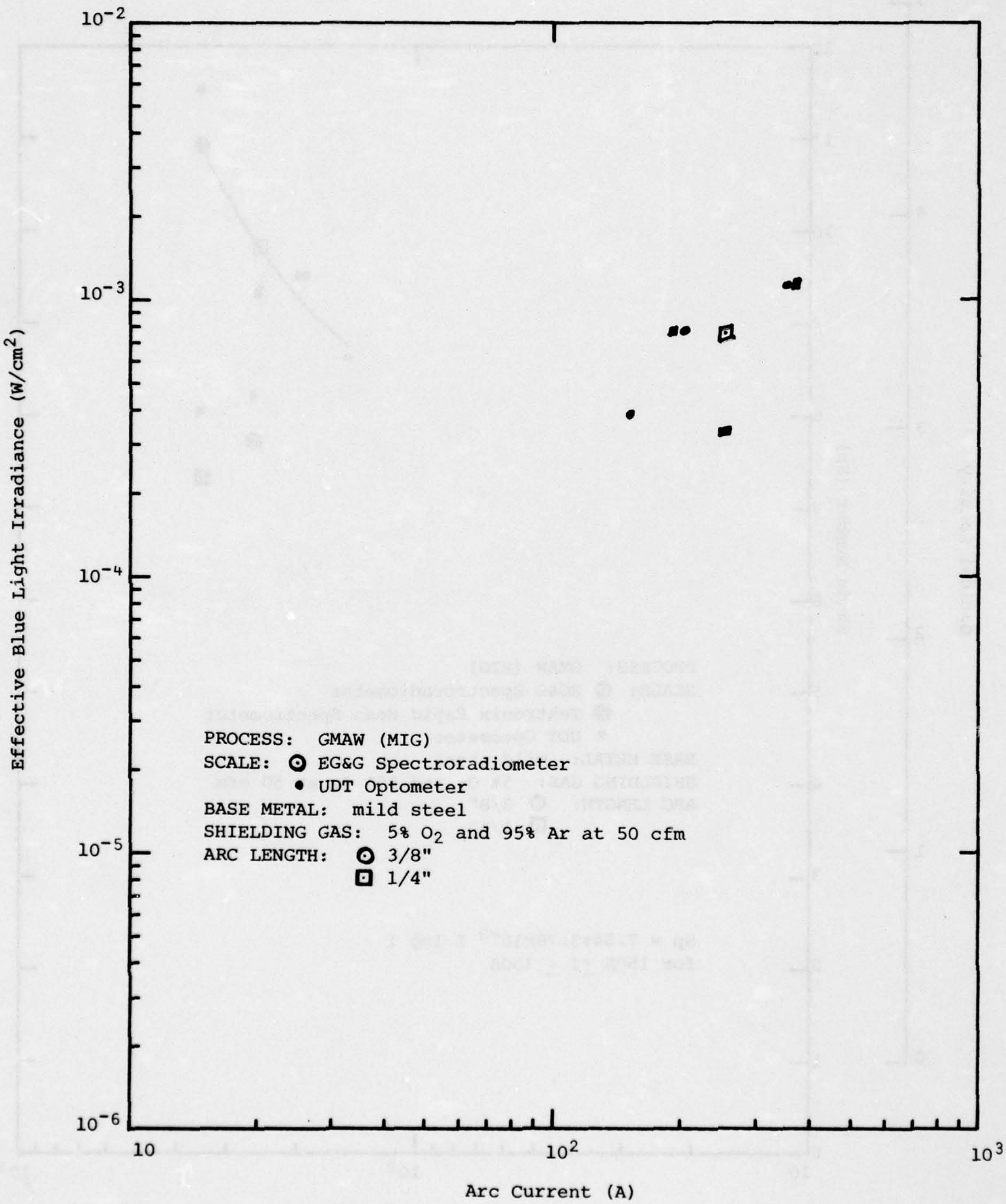


Figure 9h. Effective Blue Light Irradiance as a Function of Arc Current for Events 42 to 48.

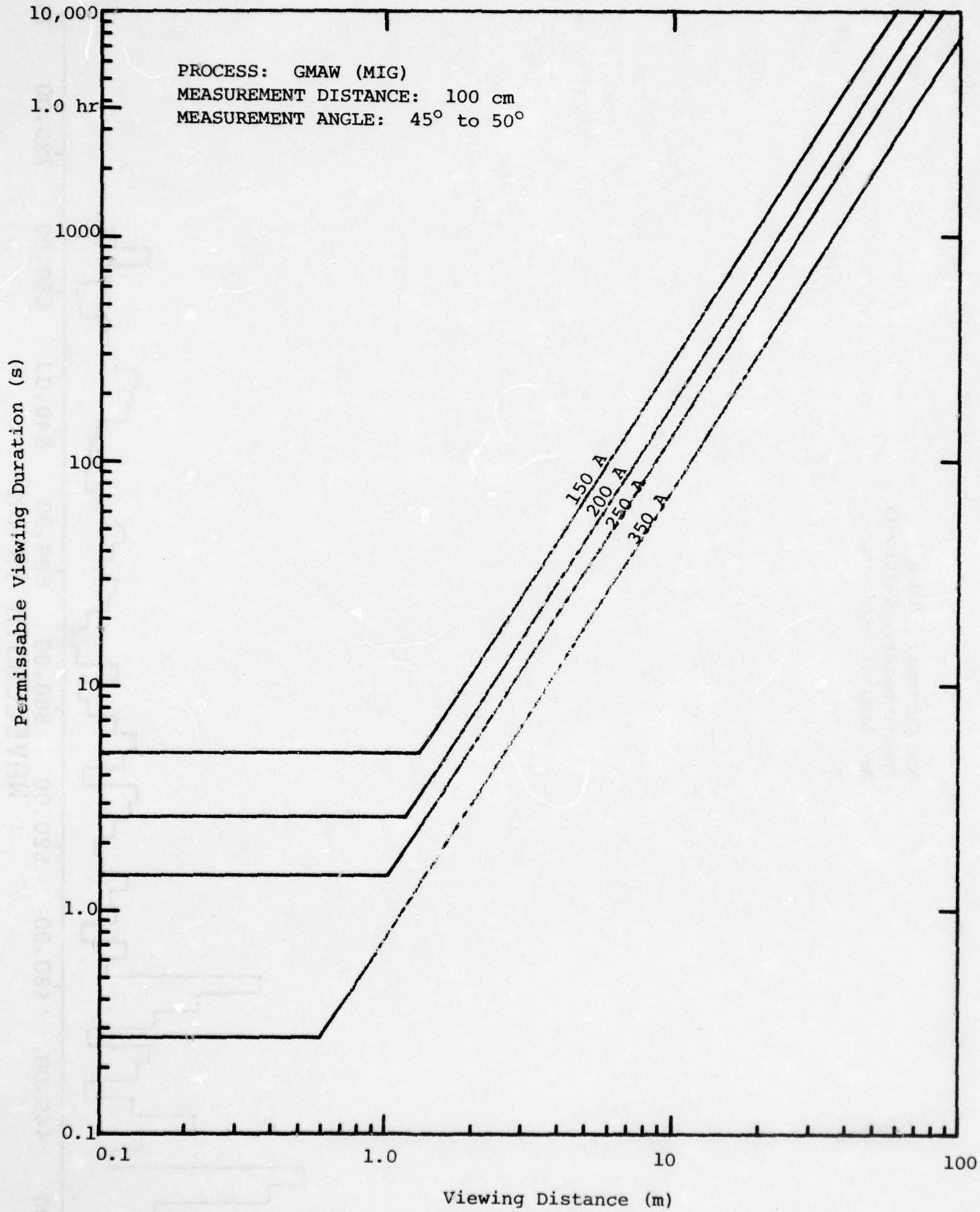


Figure 9i. Recommentded Maximum Exposure Duration as a Function of Viewing Distance for Events 42 to 48.

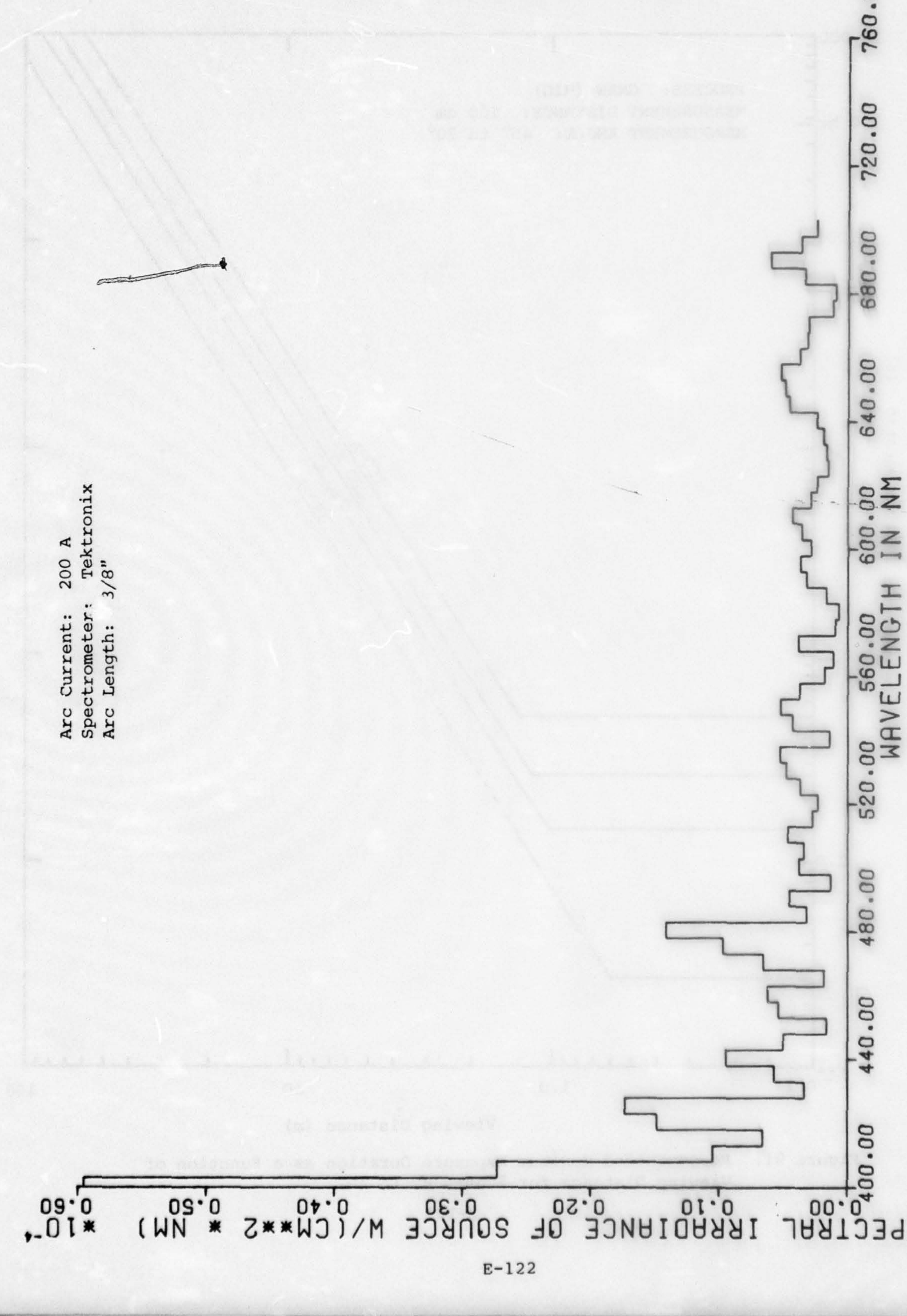


FIGURE 9j ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 44

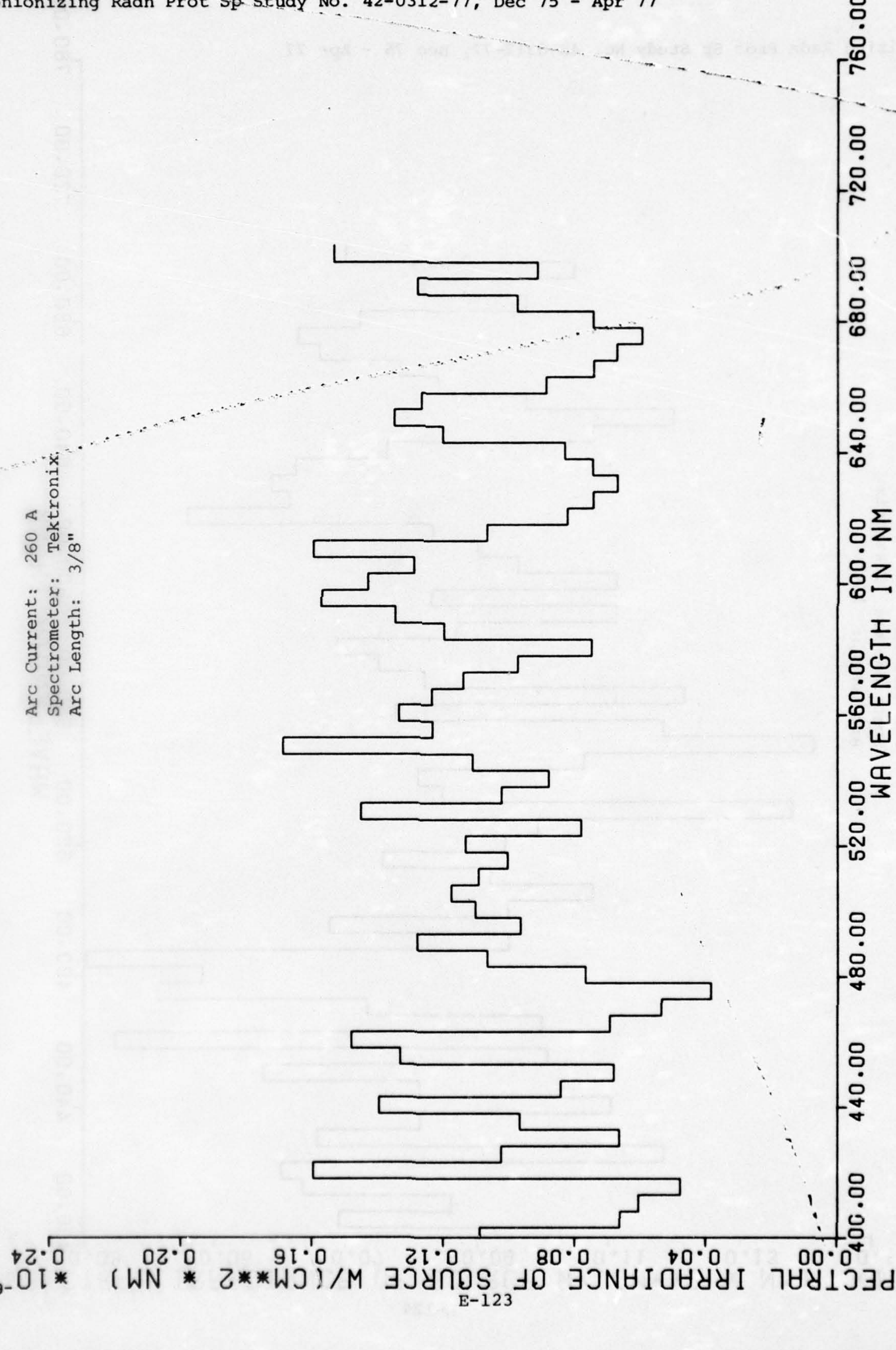


FIGURE 9k · ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 46

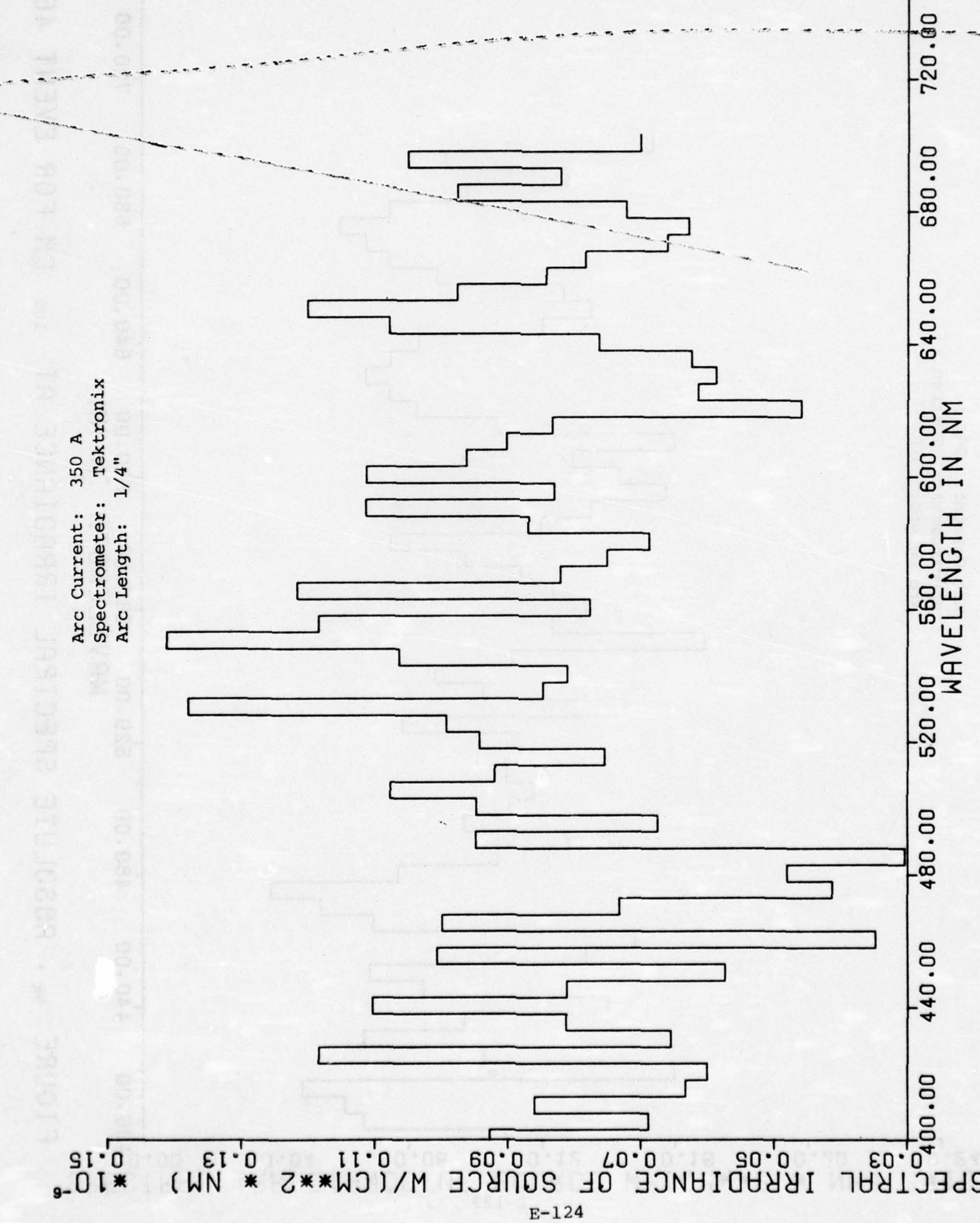


FIGURE 9l . ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 47

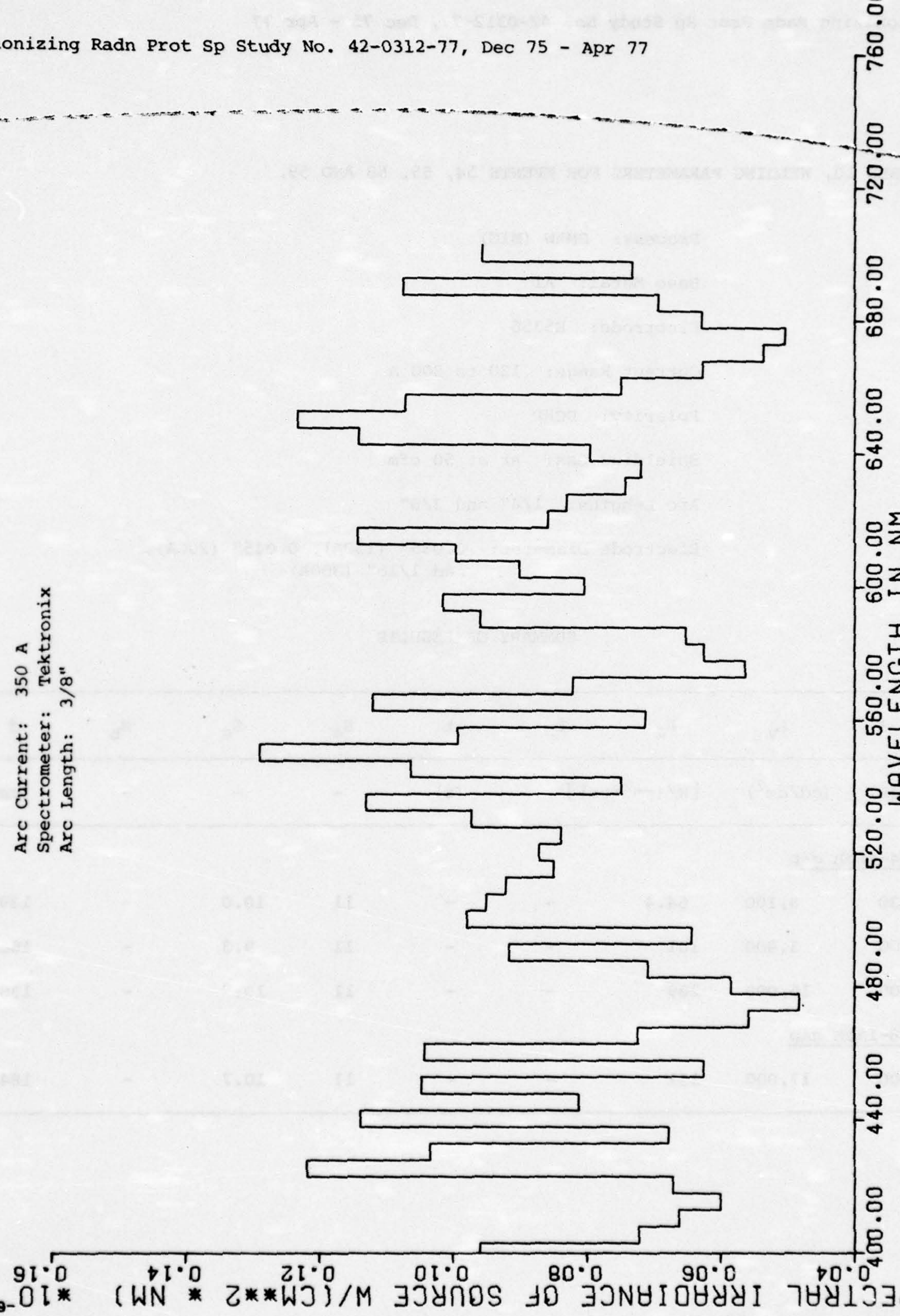


FIGURE 9m · ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 48

TABLE 10, WELDING PARAMETERS FOR EVENTS 54, 55, 58 AND 59.

Process: GMAW (MIG)

Base Metal: Al

Electrode: E5356

Current Range: 130 to 300 A

Polarity: DCRP

Shielding Gas: Ar at 50 cfm

Arc Lengths: 1/4" and 3/8"

Electrode Diameter: 0.035" (130A), 0.045" (200A), and 1/16" (300A)

SUMMARY OF RESULTS

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[W/(cm^2·sr)]		(s)	-	-	-	(cm)
1/4-inch gap								
130	8,100	64.4	-	-	11	10.0	-	139
200	3,900	101	-	-	11	9.3	-	166
300	16,000	289	-	-	11	10.7	-	138
3/8-inch gap								
300	17,000	131	-	-	11	10.7	-	184

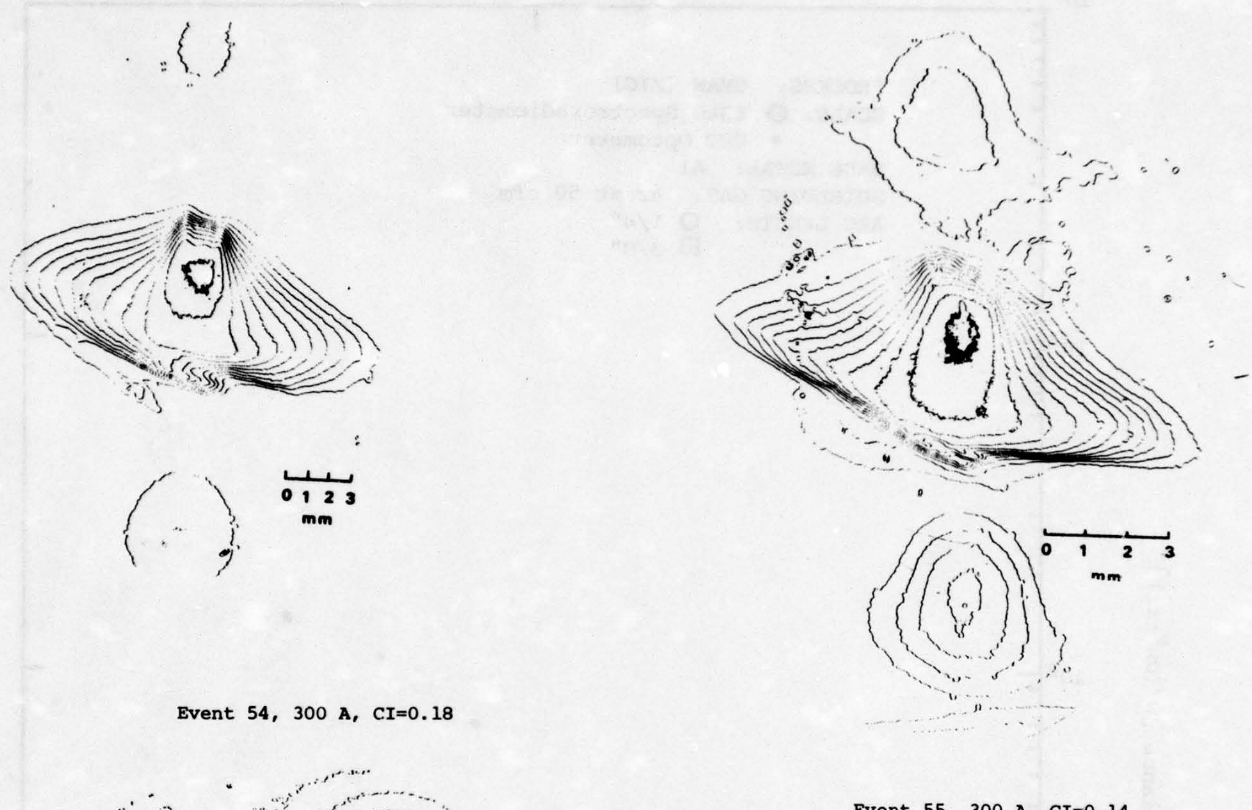


Figure 10a. Microdensitometer Scans of 35mm Processed Photographic Negatives Exposed at [illegible] from the Welding Arcs for Events 54-55 and 58-59.

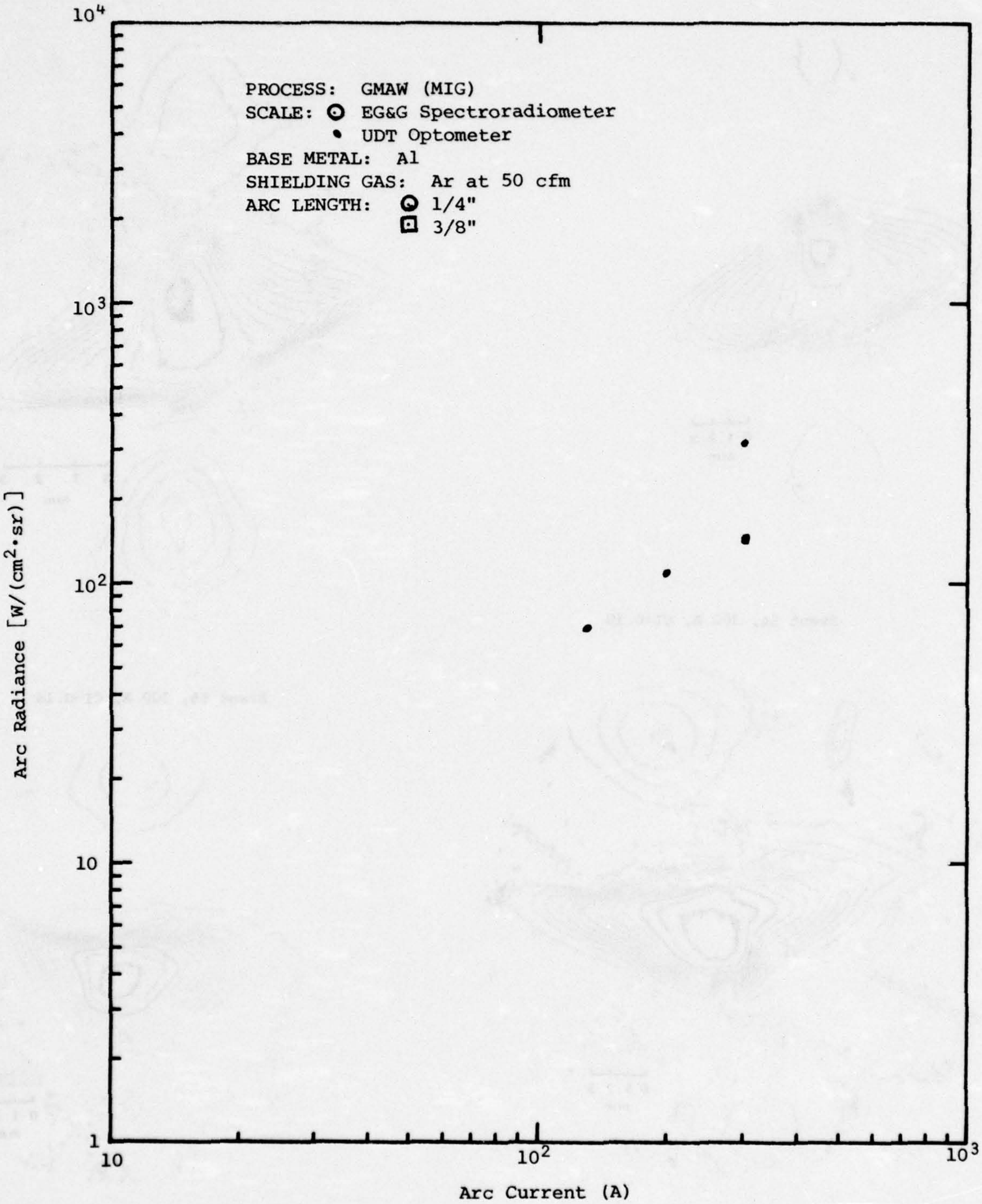


Figure 10b. Arc Radiance as a Function of Arc Current for Events 54, 55, 58 and 59.

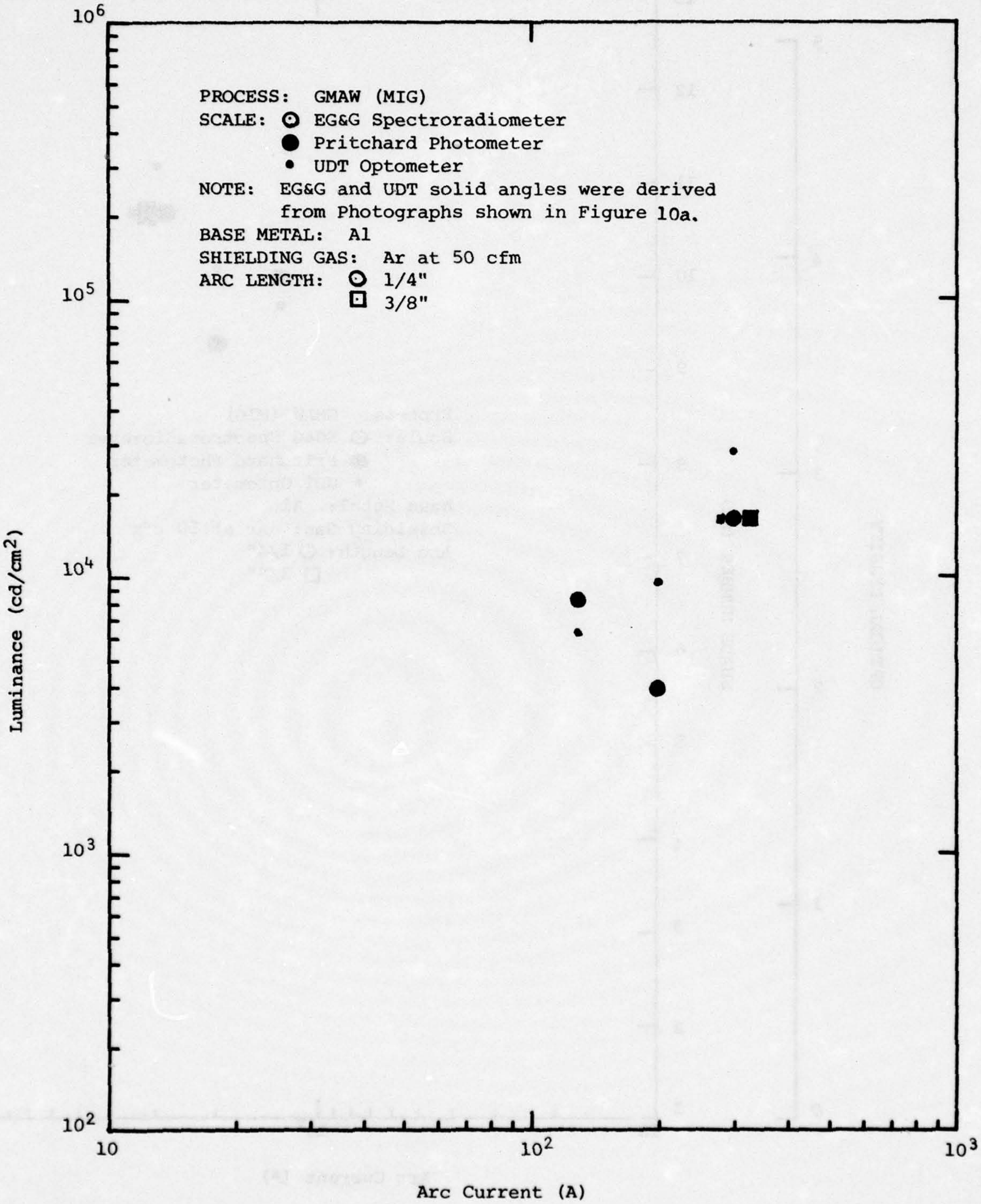


Figure 10c. Arc Luminance as a Function of Arc Current for Events 54, 55, 58 and 59.

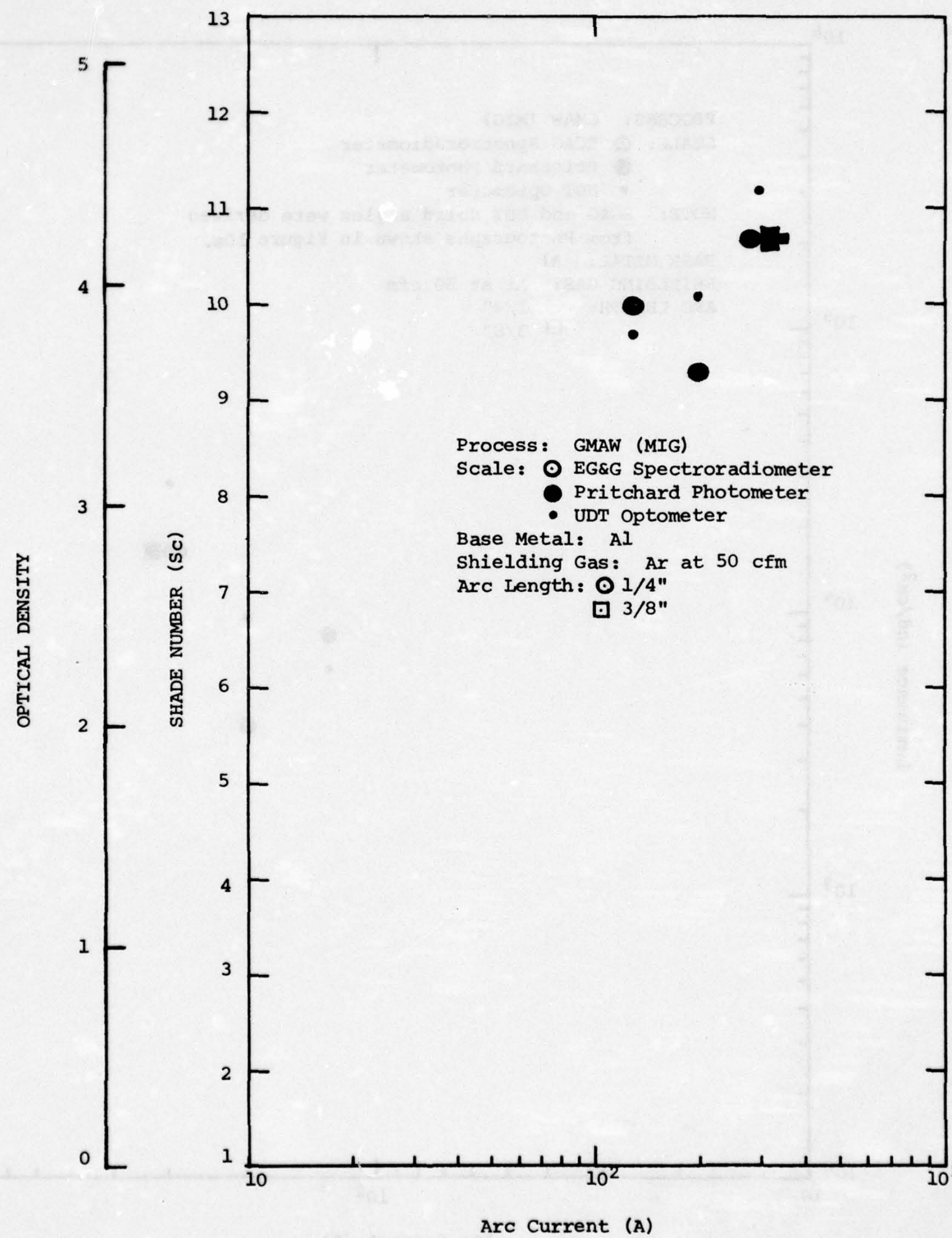


Figure 10d. Comfortable Shade Number (Sc) or Optical Density for Arc Viewing as a Function of Arc Current for Events 54, 55, 58 and 59.

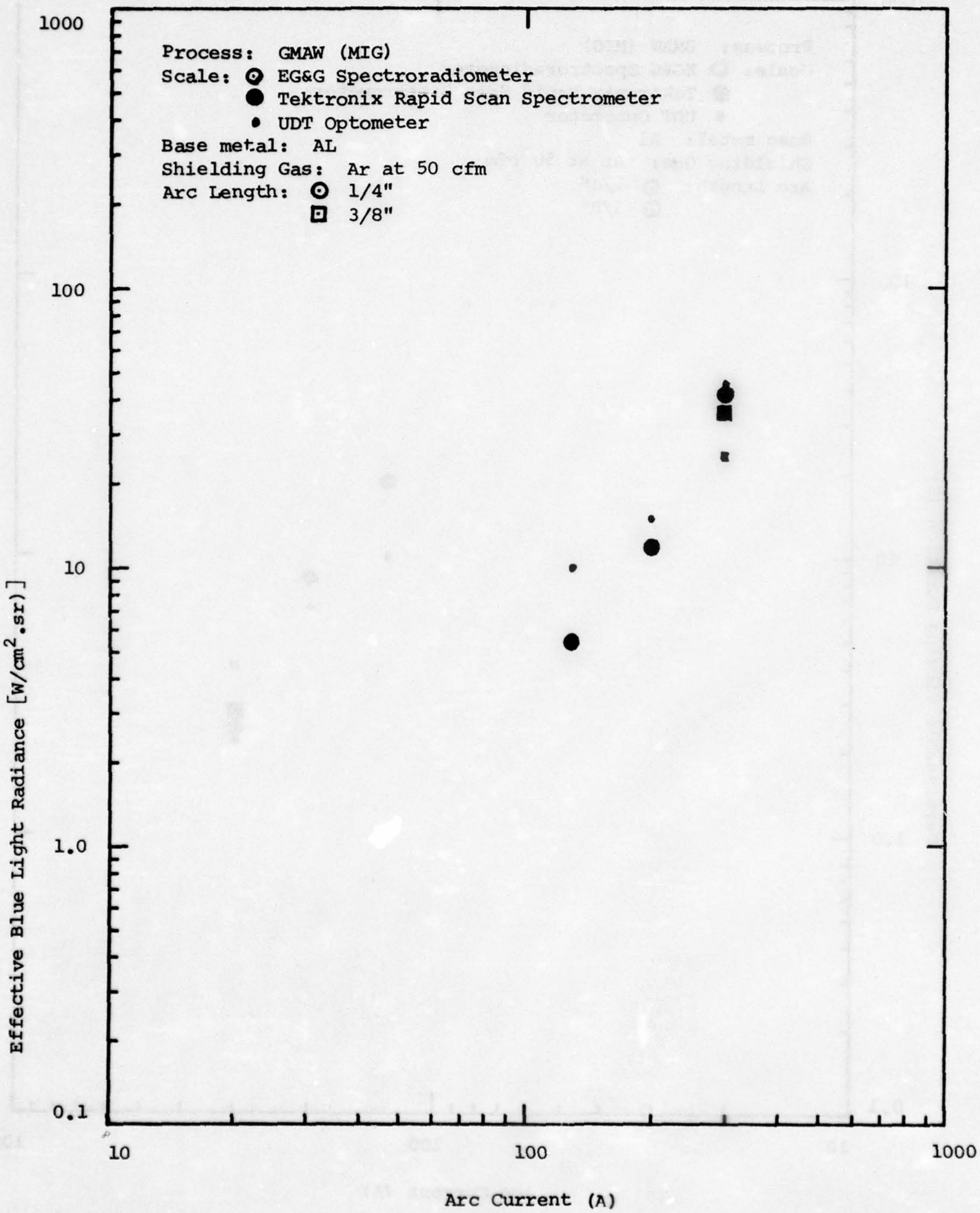


Figure 10e. Effective Blue Light Radiance as a Function of Arc Current for Events 54, 55, 58 and 59.

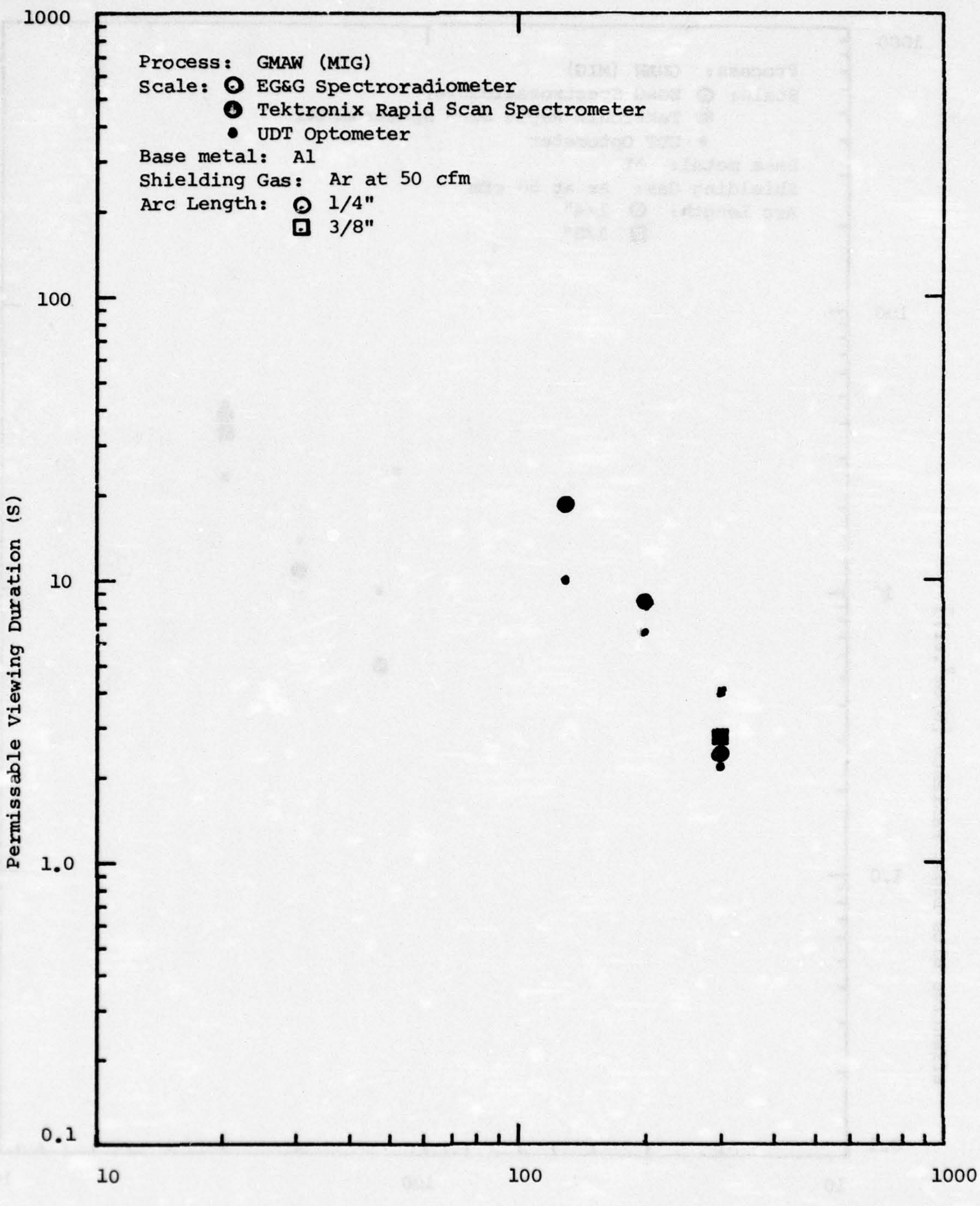


Figure 10f. Permissable Viewing Duration as a Function of Arc Current for Events 54, 55, 58 and 59 at Distances less than 1.5 m.

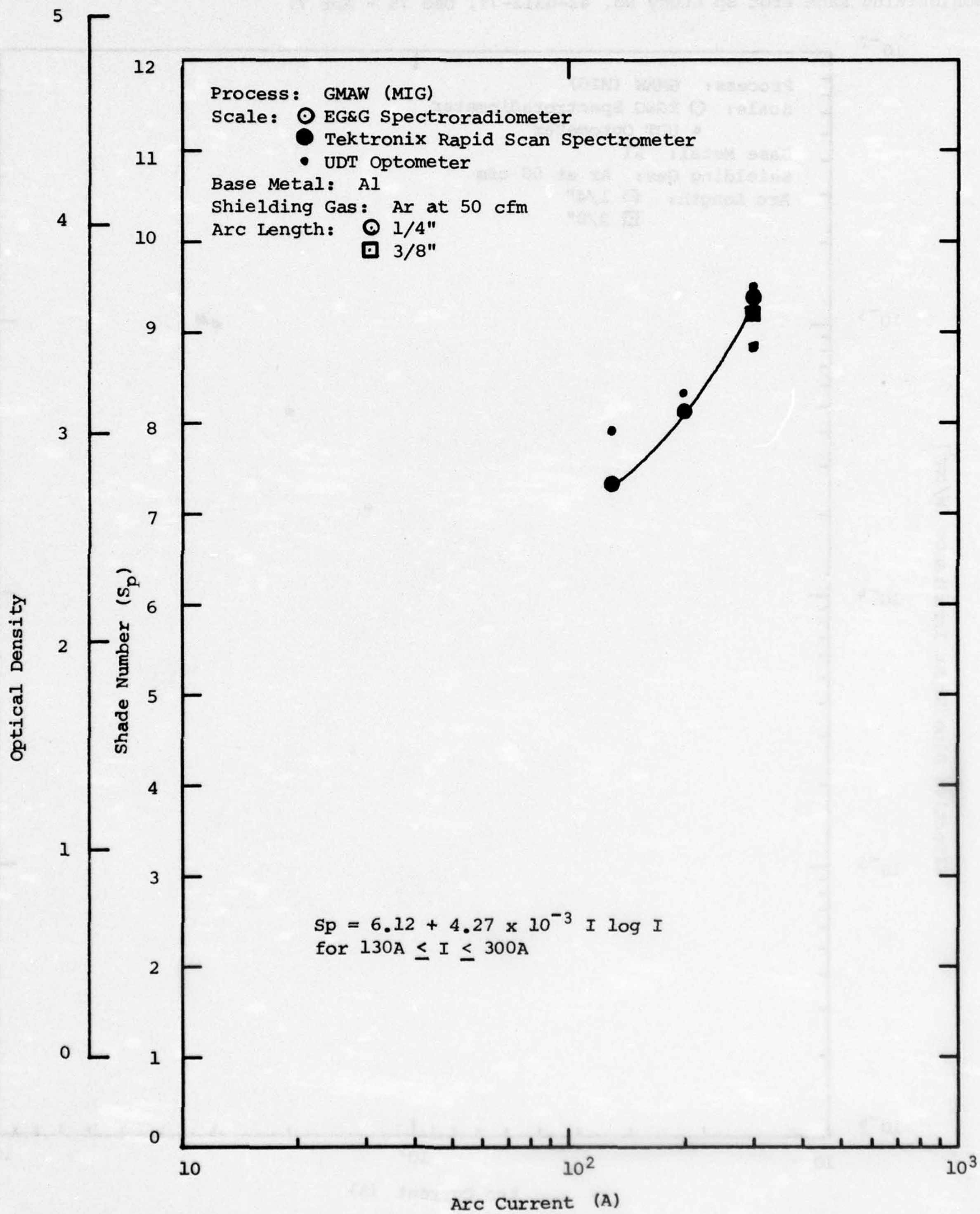


Figure 10g. Shade Number or Optical Density Necessary for Protection against Blue Light emitted during Events 54, 55, 58 and 59.

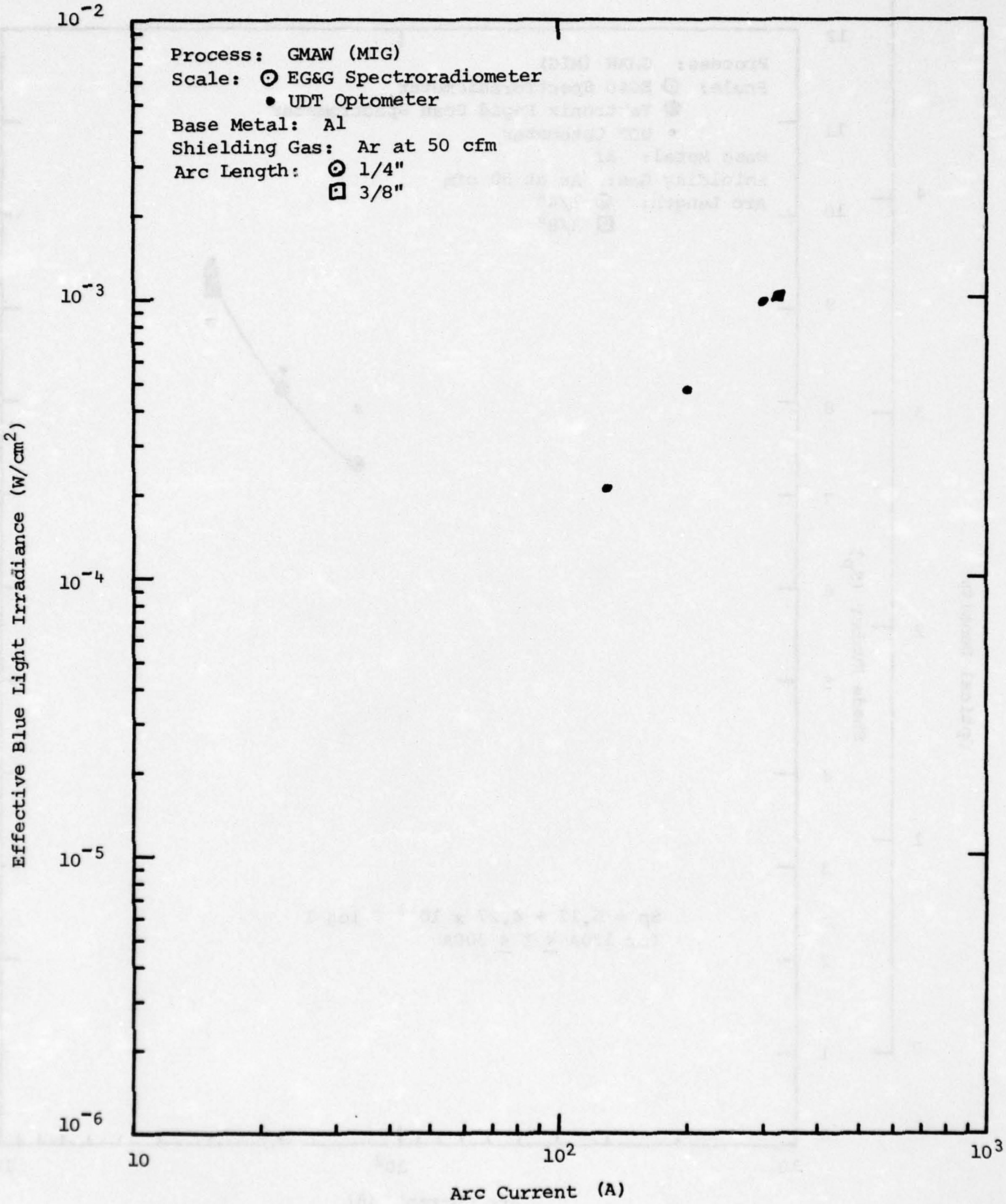


Figure 10h. Effective Blue Light Irradiance as a Function of Arc Current for Events 54, 55, 58 and 59.

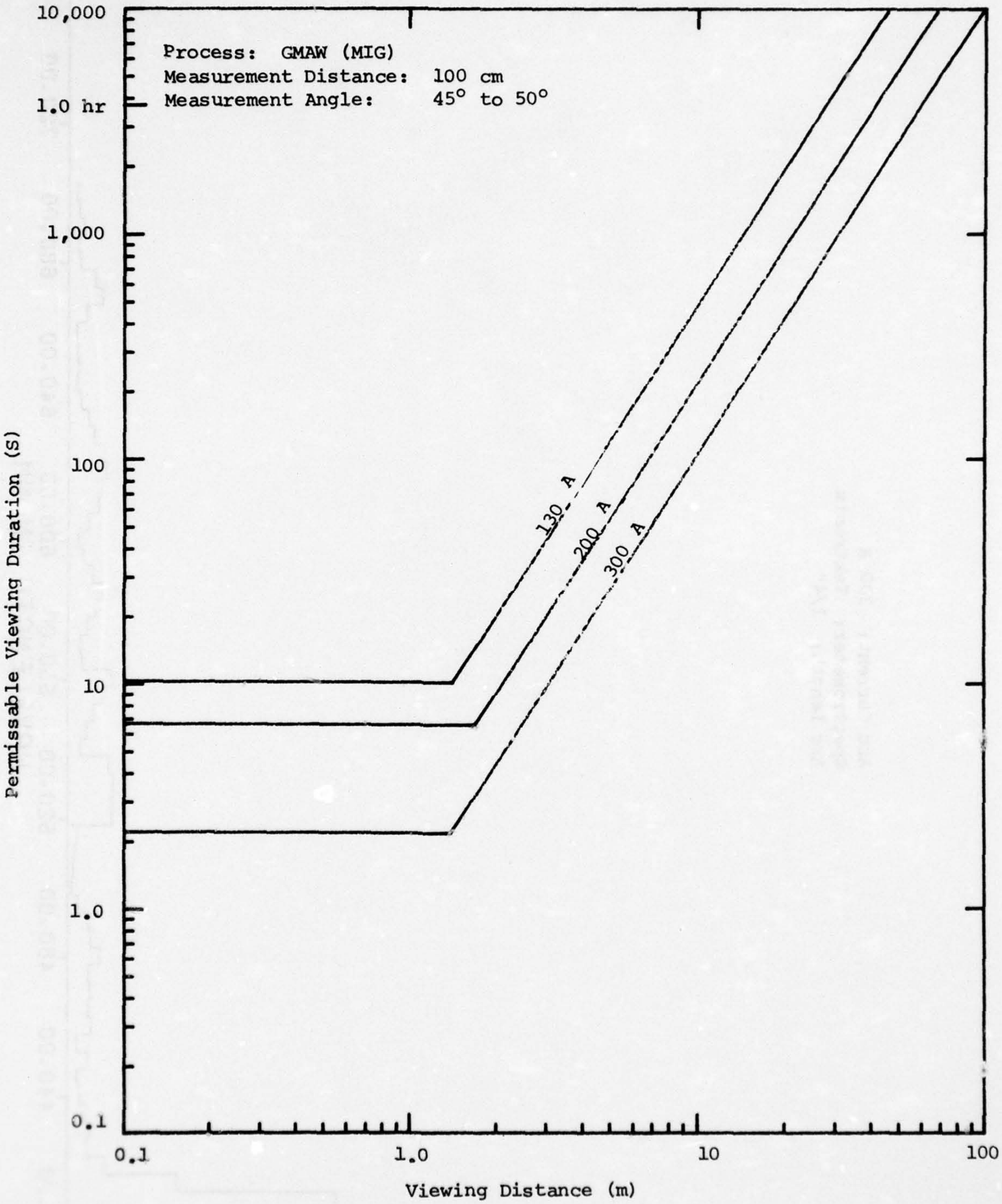


Figure 10i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 54, 55, 58 and 59.

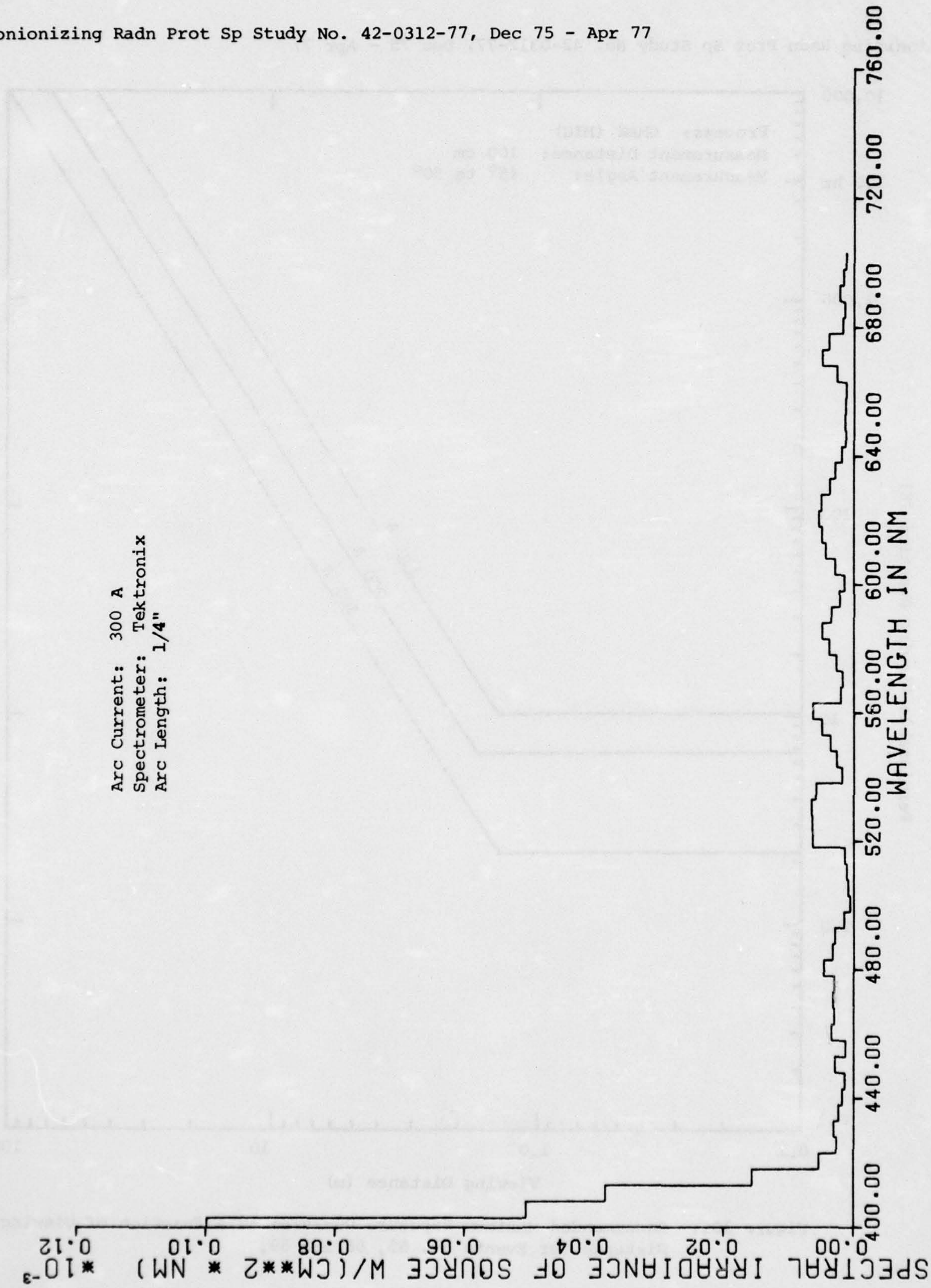


FIGURE 10j. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 54

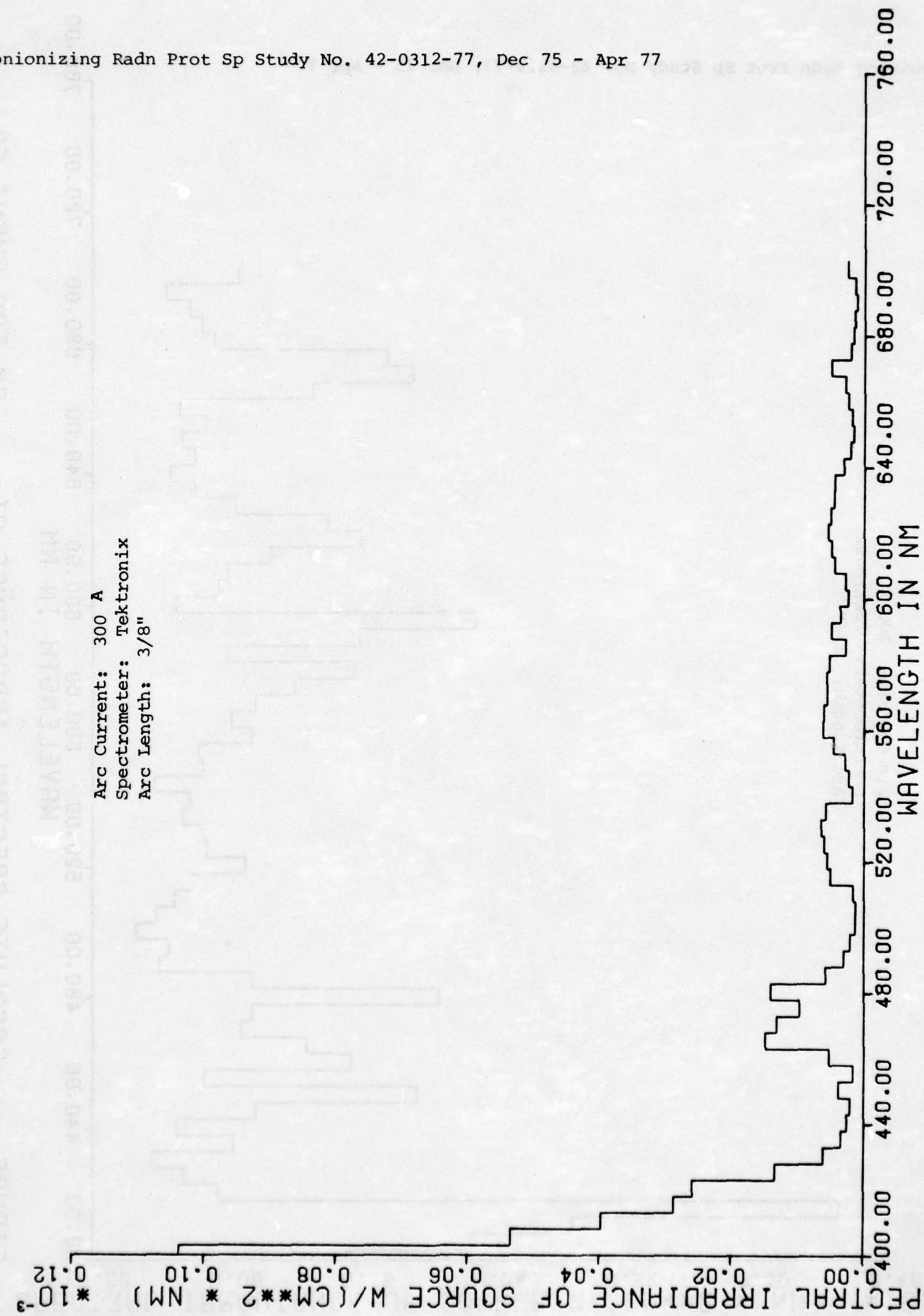


FIGURE 10k. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 55

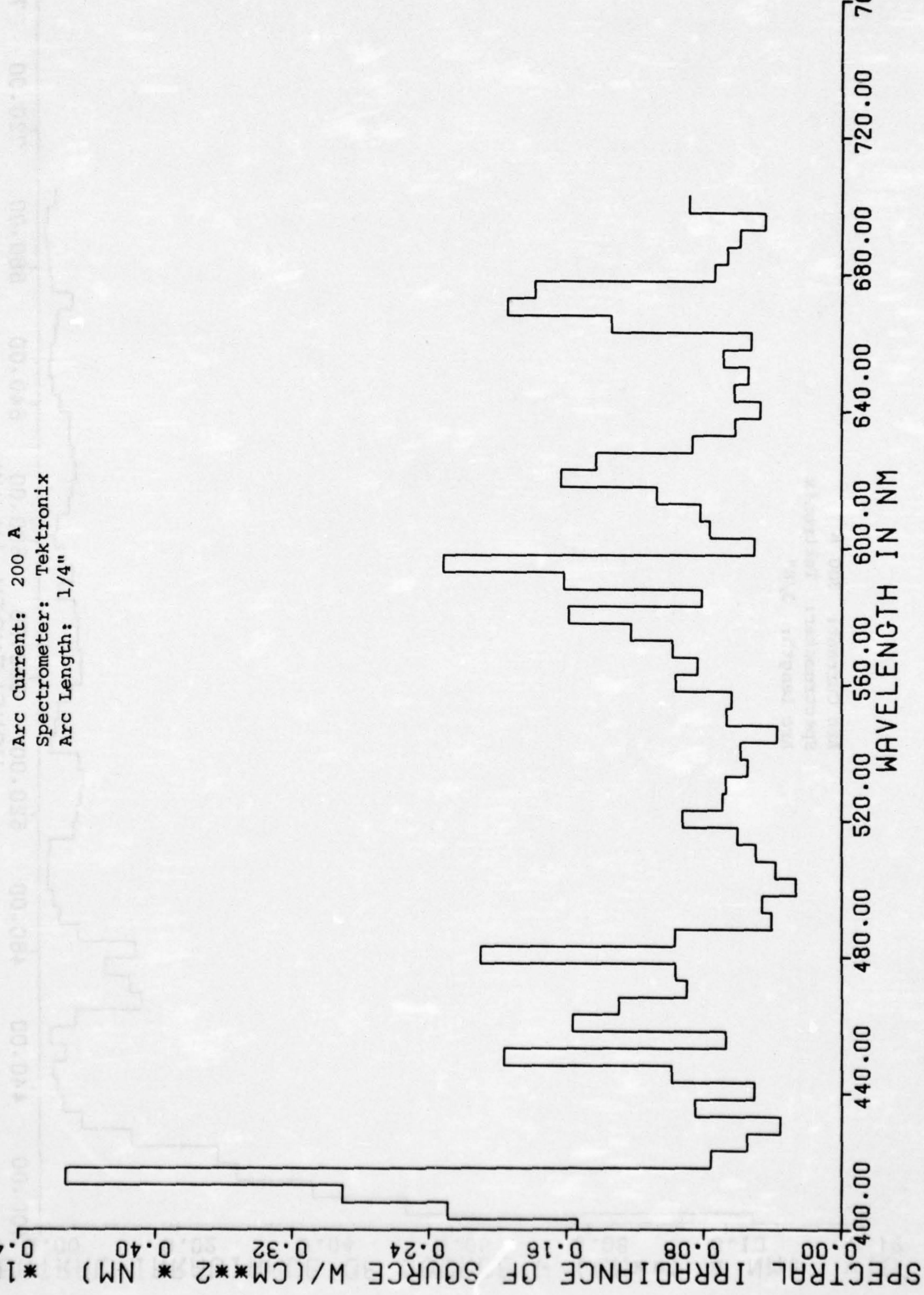


FIGURE 10l. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 58

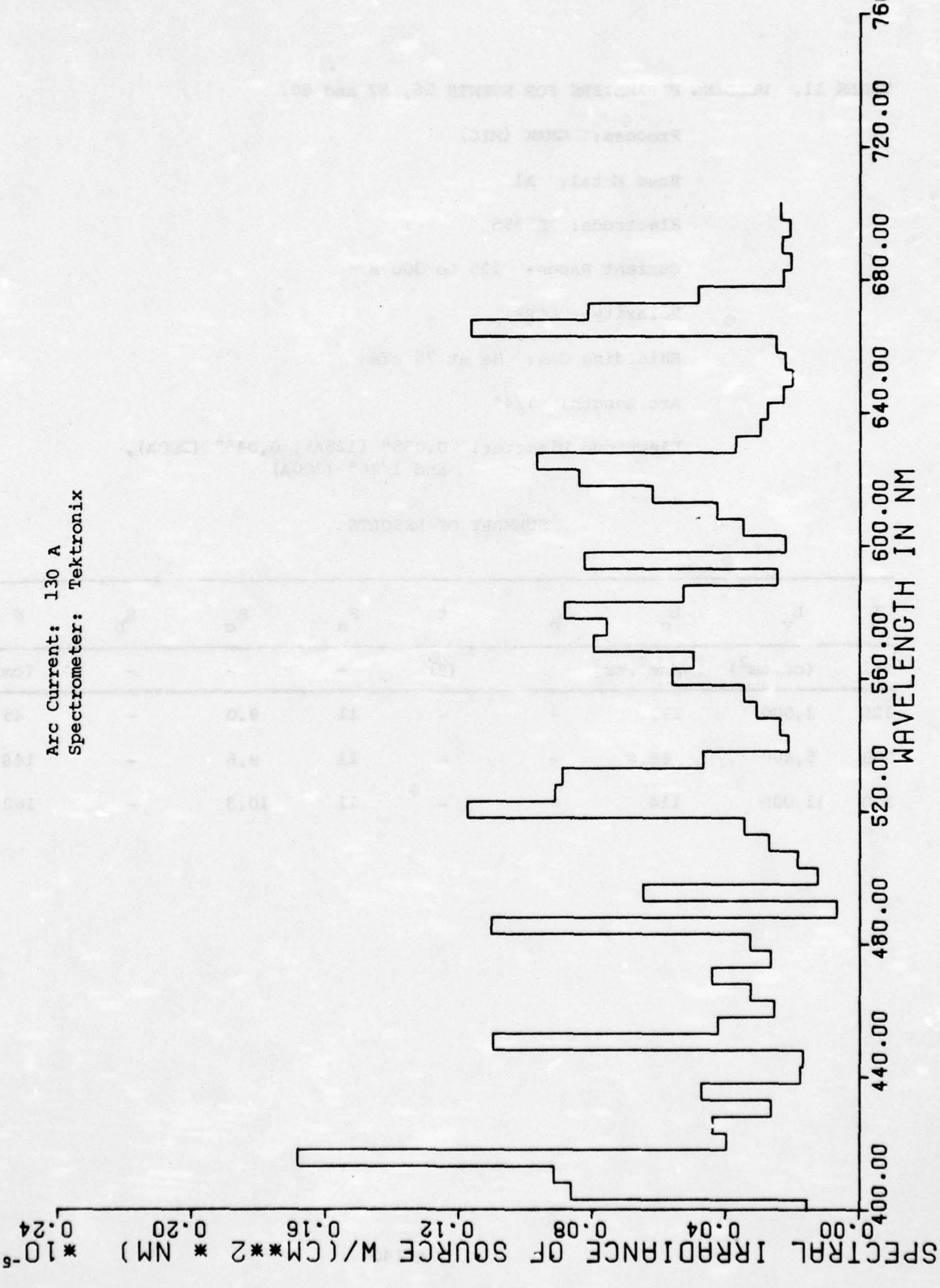


FIGURE 10m. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 59

TABLE 11. WELDING PARAMETERS FOR EVENTS 56, 57 and 60.

Process: GMAW (MIG)

Base Metal: Al

Electrode: E5356

Current Range: 125 to 300 A

Polarity: DCRP

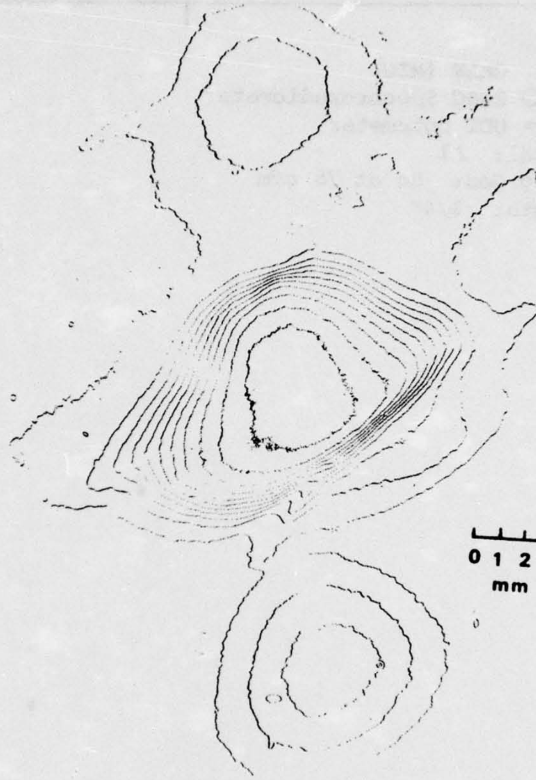
Shielding Gas: He at 75 cfm

Arc Length: 1/4"

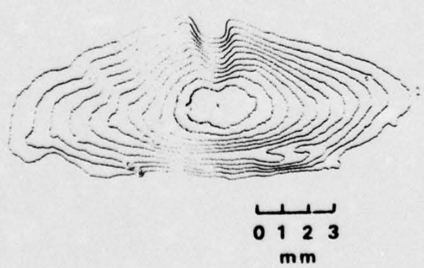
Electrode Diameter: 0.035" (125A), 0.045" (200A), and 1/16" (300A)

SUMMARY OF RESULTS

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(cd/cm^2)	[W/cm^2.sr]		(S)	-	-	-	(cm)
125	3,000	299	-	-	11	9.0	-	45
200	5,400	68.8	-	-	11	9.6	-	148
300	11,000	114	-	-	11	10.3	-	162



Event 56, 300 A, CI = 0.17



Event 57, 200 A, CI = 0.17

Event 60, 125 A, CI = 0.17

Figure 11a. Microdensitometer Scans of 35 mm Processed Photographic Negatives Exposed at 4 m from the Welding Arcs for Events 56, 57 and 60.

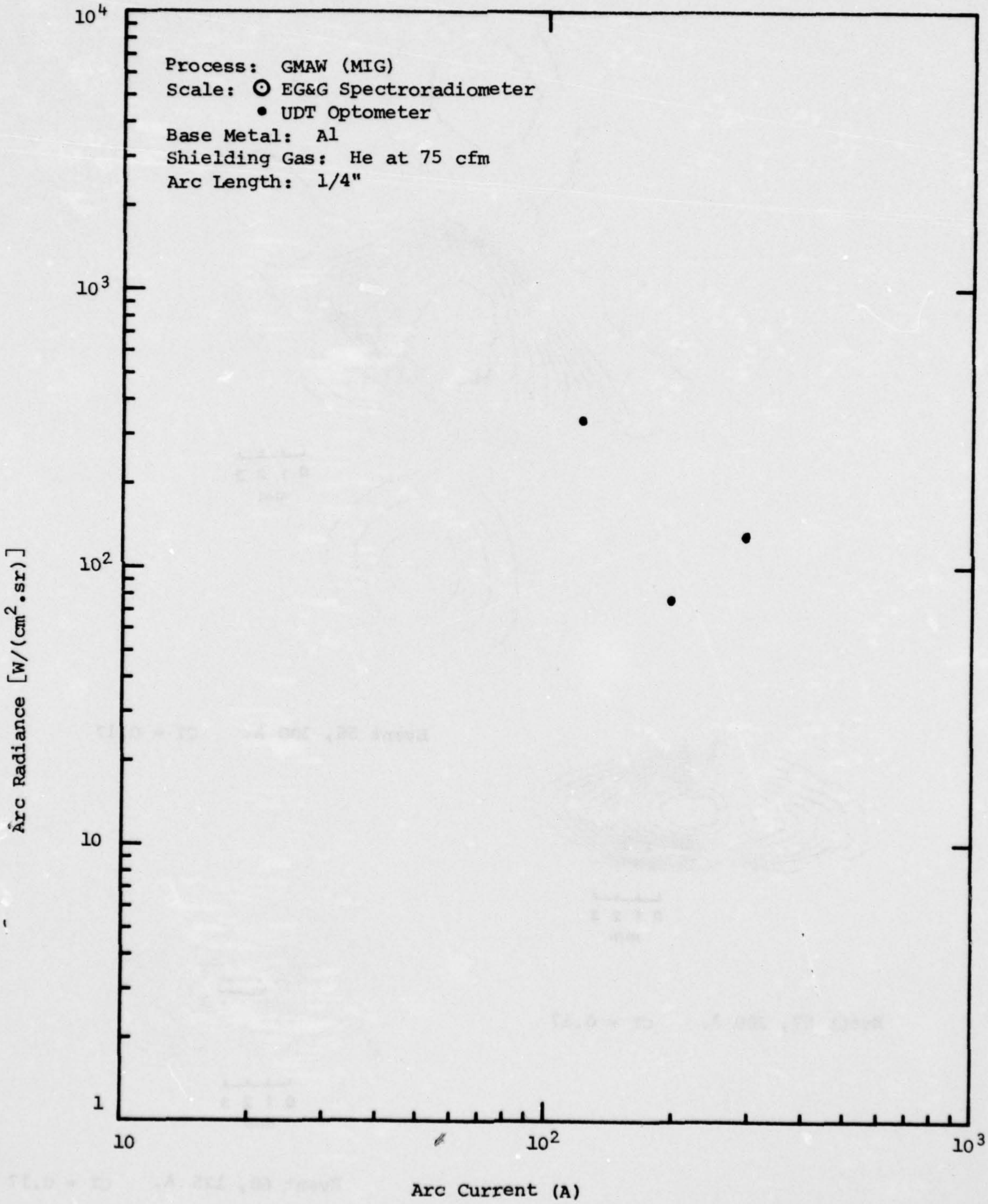


Figure 11b. Arc Radiance as a Function of Arc Current for Events 56, 57 and 60.

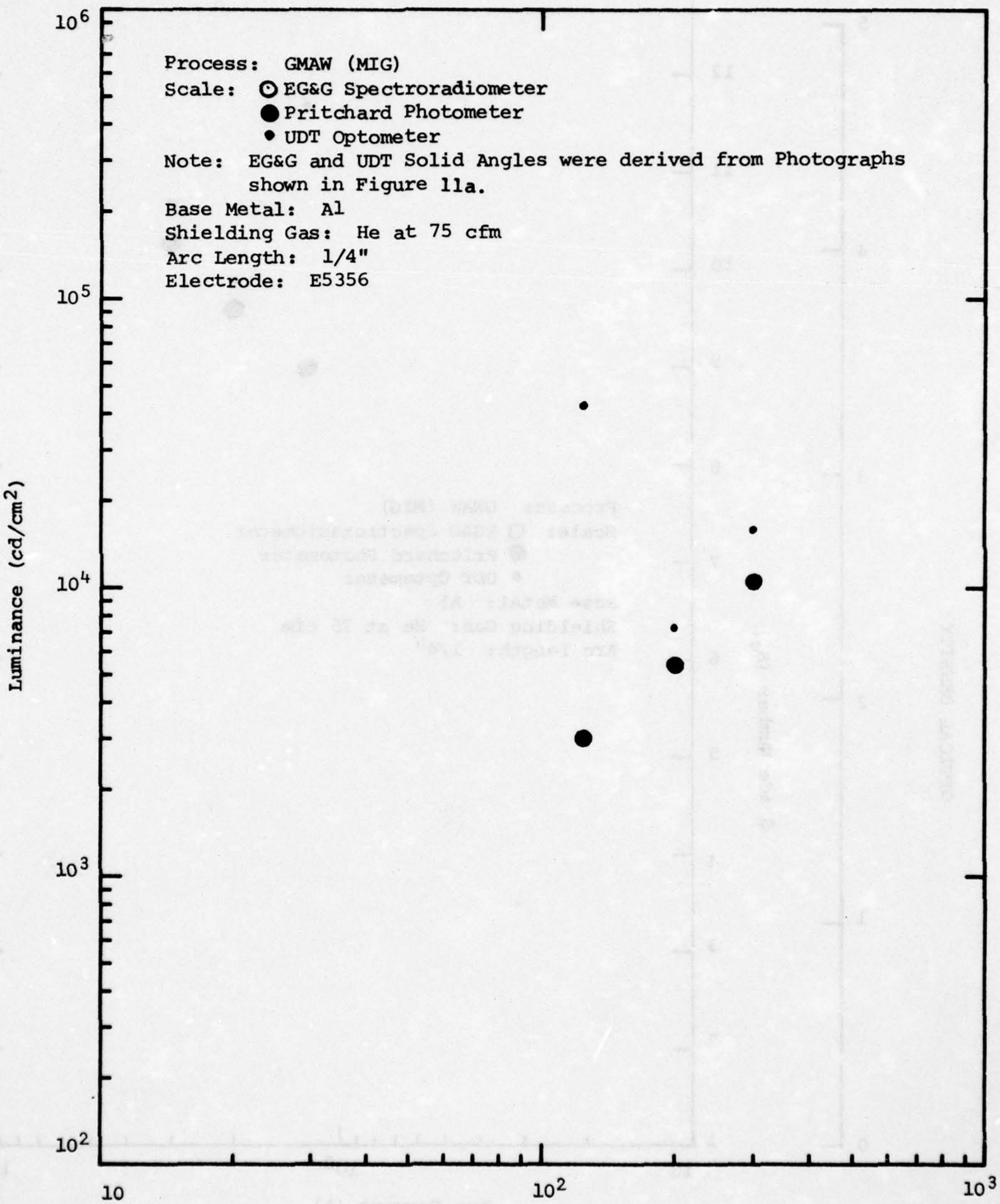


Figure 11c. Arc Luminance as a Function of Arc Current for Events 56, 57 and 60.

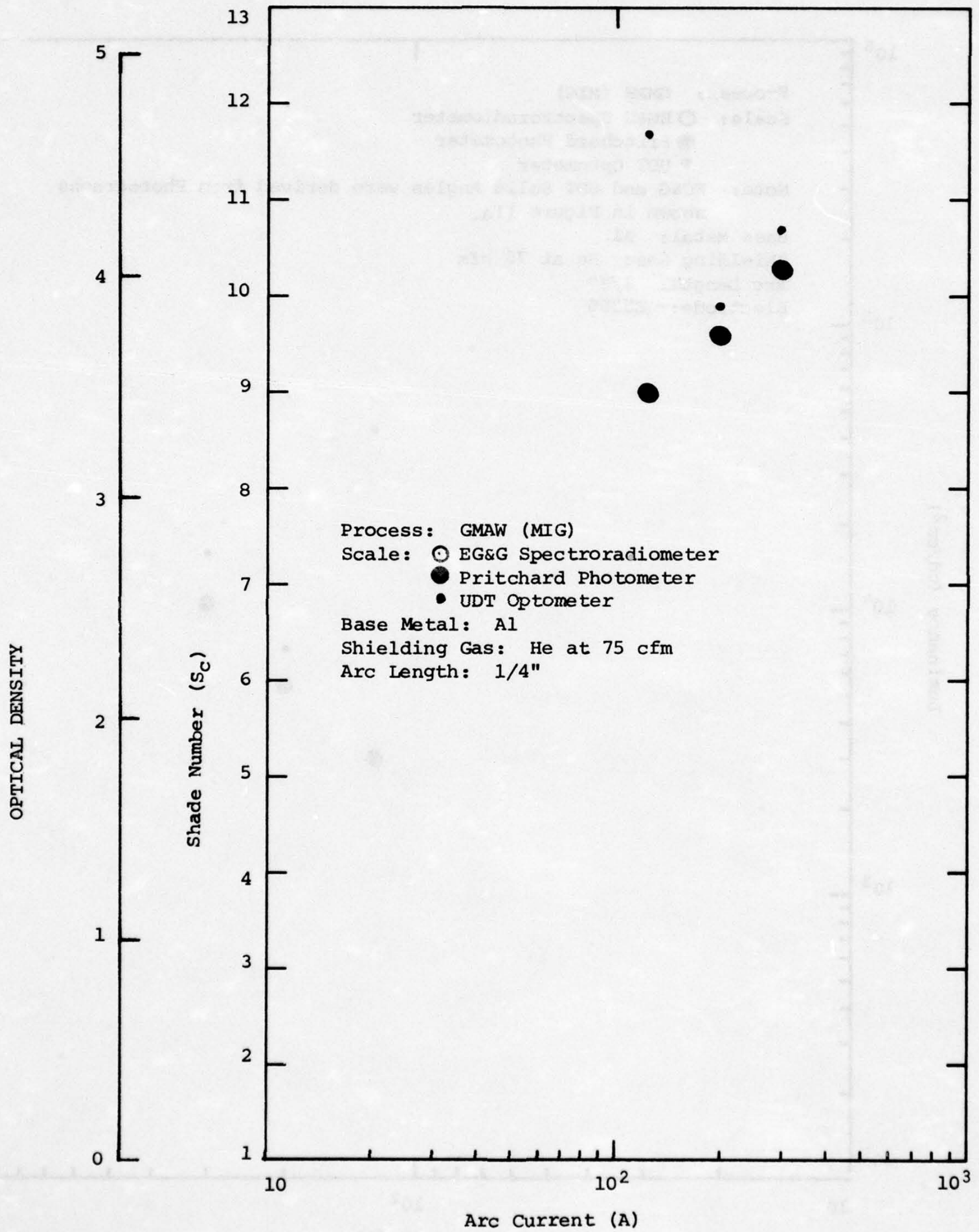


Figure 11d. Comfortable Shade Number (S_c) or Optical Density for Arc Viewing as a Function of Arc Current for Events 56, 57 and 60.

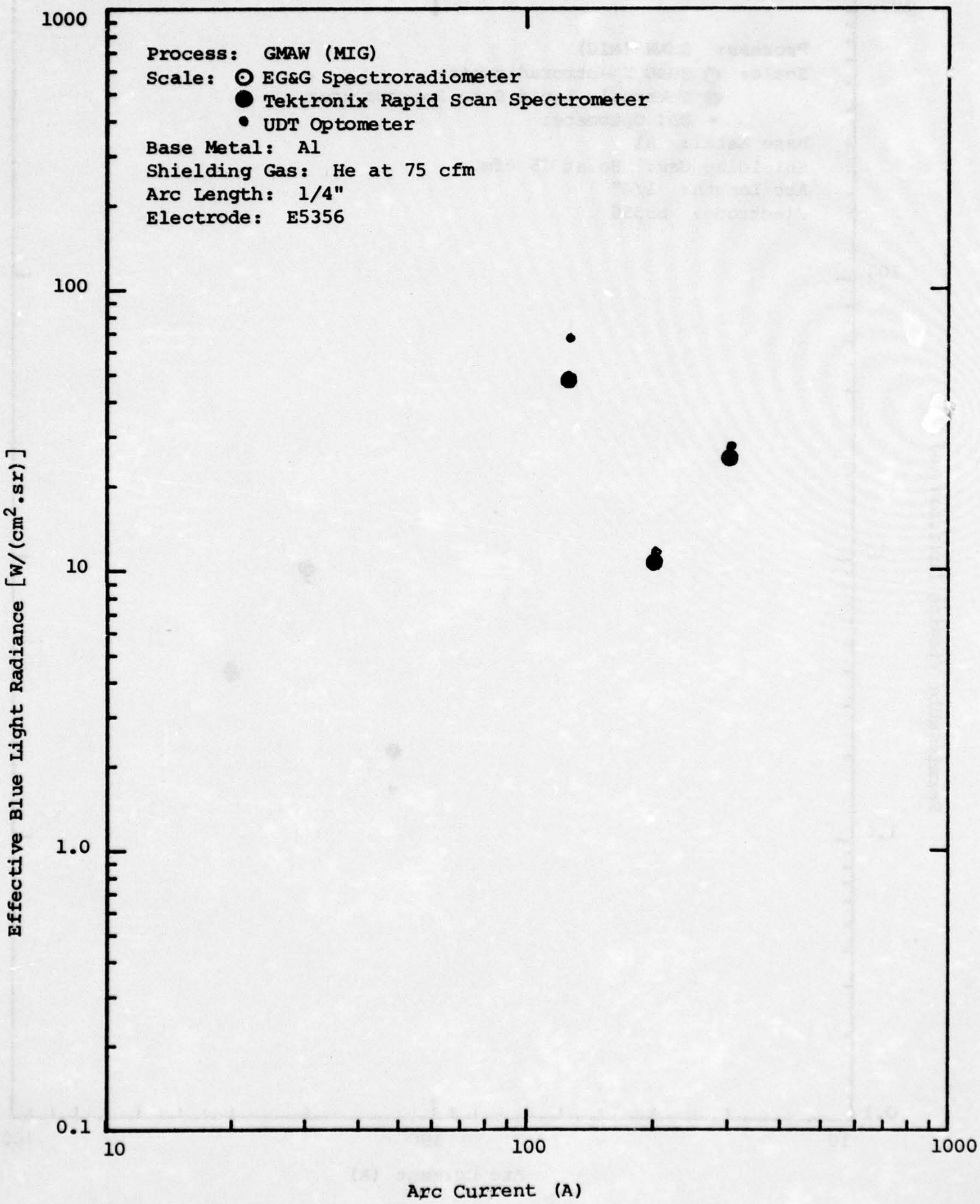


Figure 11e. Effective Blue Light Radiance as a Function of Arc Current for Events 56, 57 and 60.

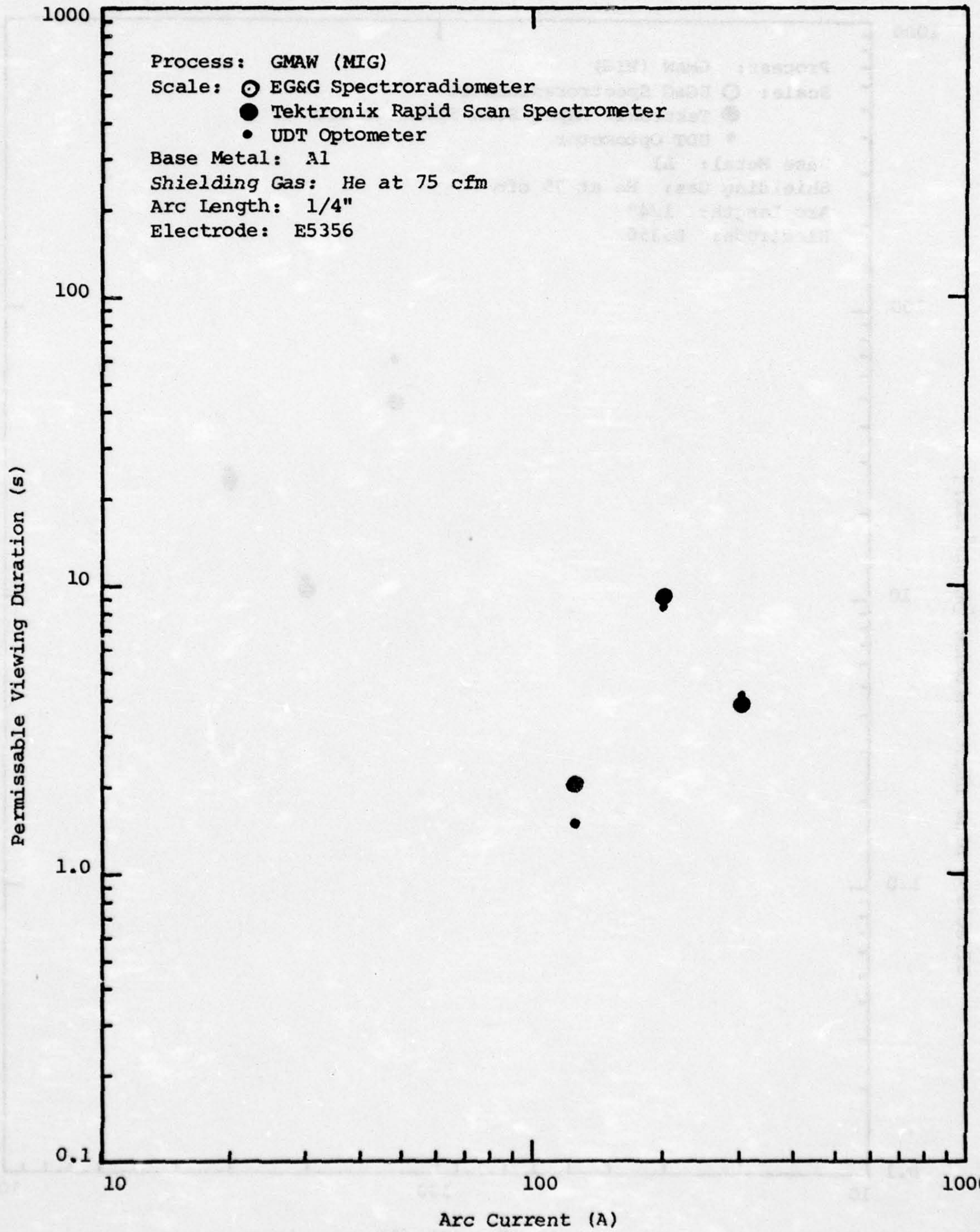


Figure 11f. Permissable Viewing Duration as a Function of Arc Current for Events 56, 57 and 60 at Distances less than 1.5 m.

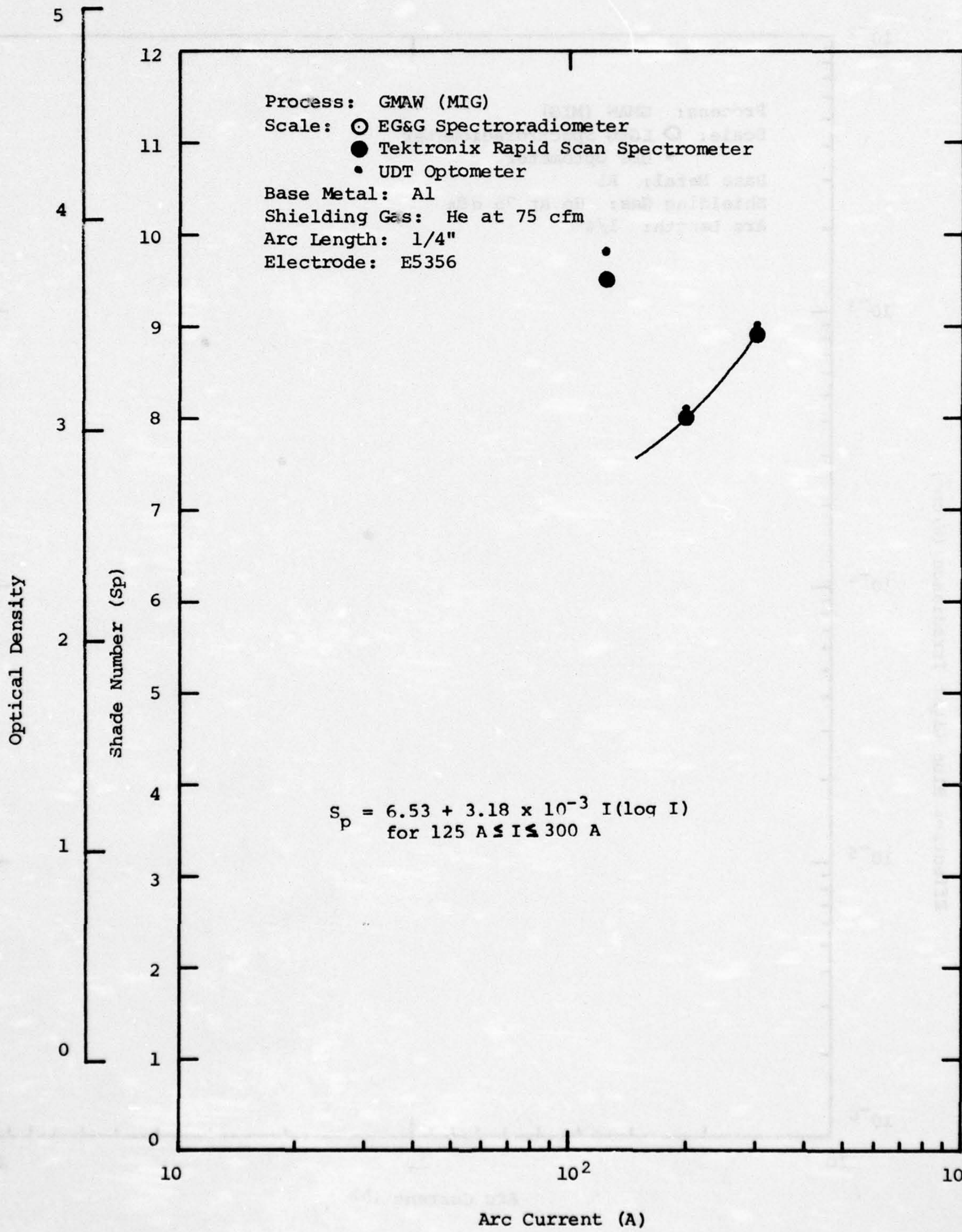


Figure 11g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted During Events 56, 57 and 60.

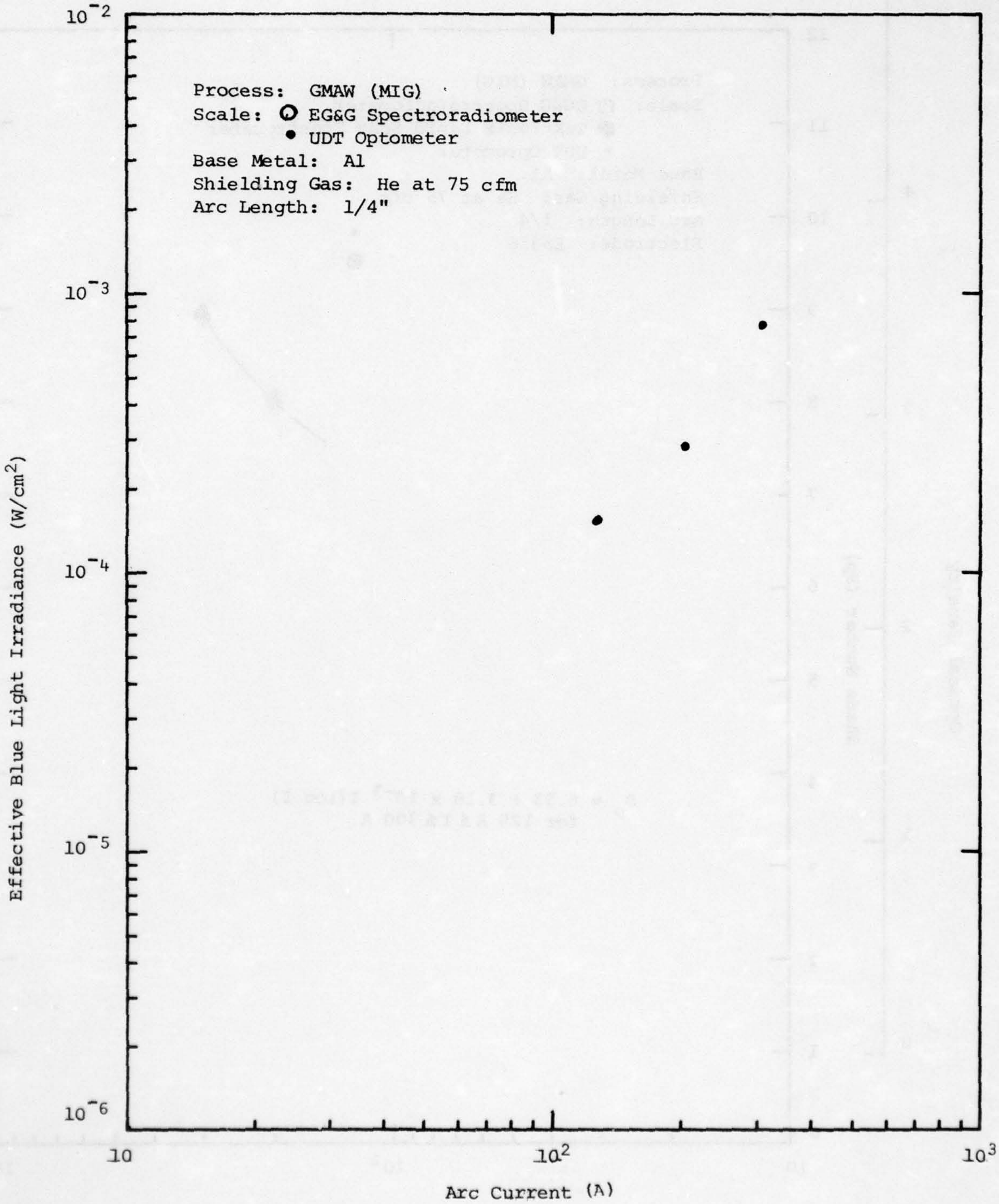
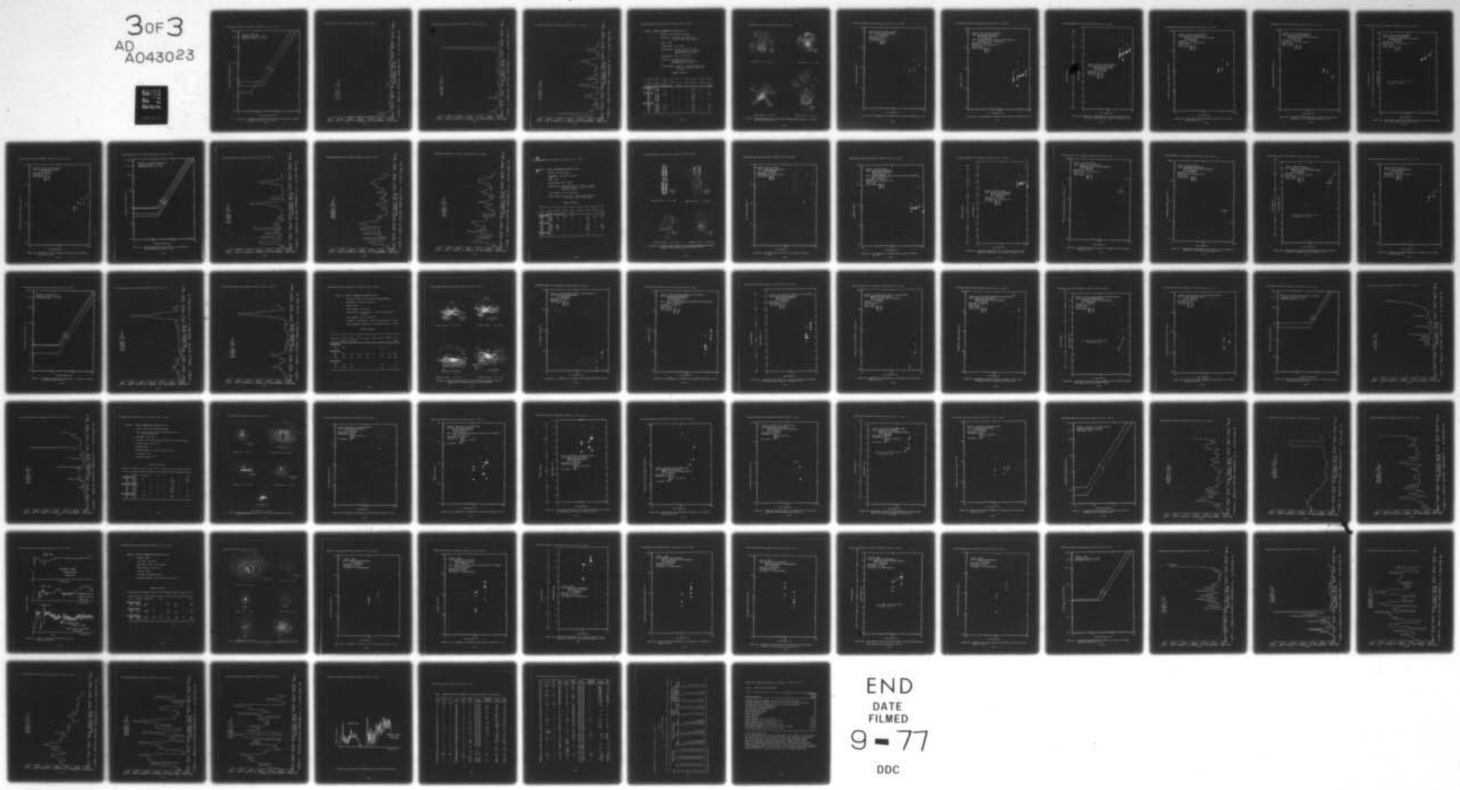


Figure 11h. Effective Blue Light Irradiance as a Function of Arc Current for Events 56, 57 and 60.

AD-A043 023 ARMY ENVIRONMENTAL HYGIENE AGENCY ABERDEEN PROVING GR--ETC F/G 6/18
EVALUATION OF THE POTENTIAL RETINAL HAZARDS FROM OPTICAL RADIAT--ETC(U)
AUG 77 W J MARSHALL, D H SLINEY, T L LYON

UNCLASSIFIED USAEHA-42-0312-77 NL

3 OF 3
AD A043023



END
DATE FILMED
9-77
DDC

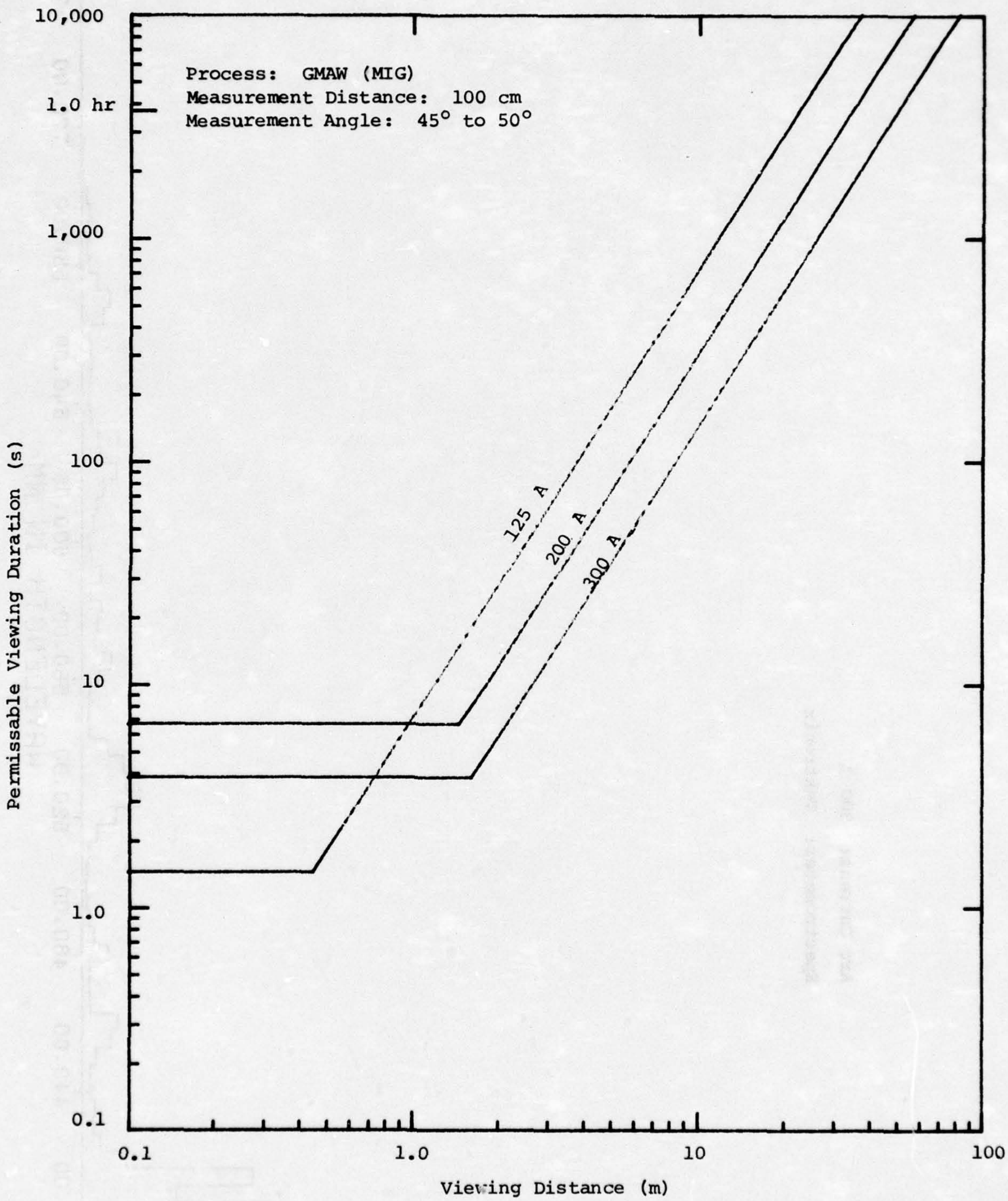


Figure 11i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 56, 57 and 60.

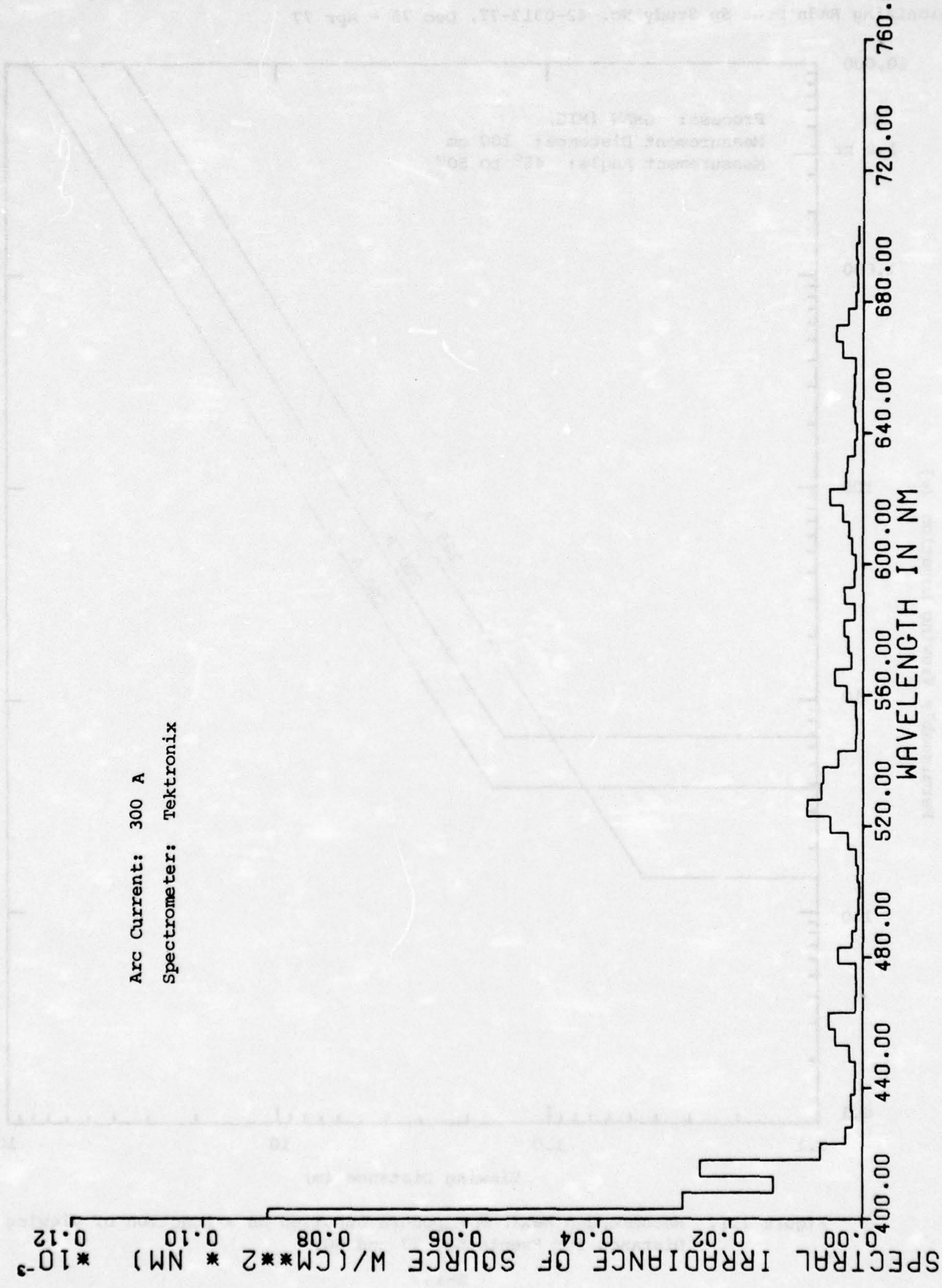


FIGURE 11j. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 56

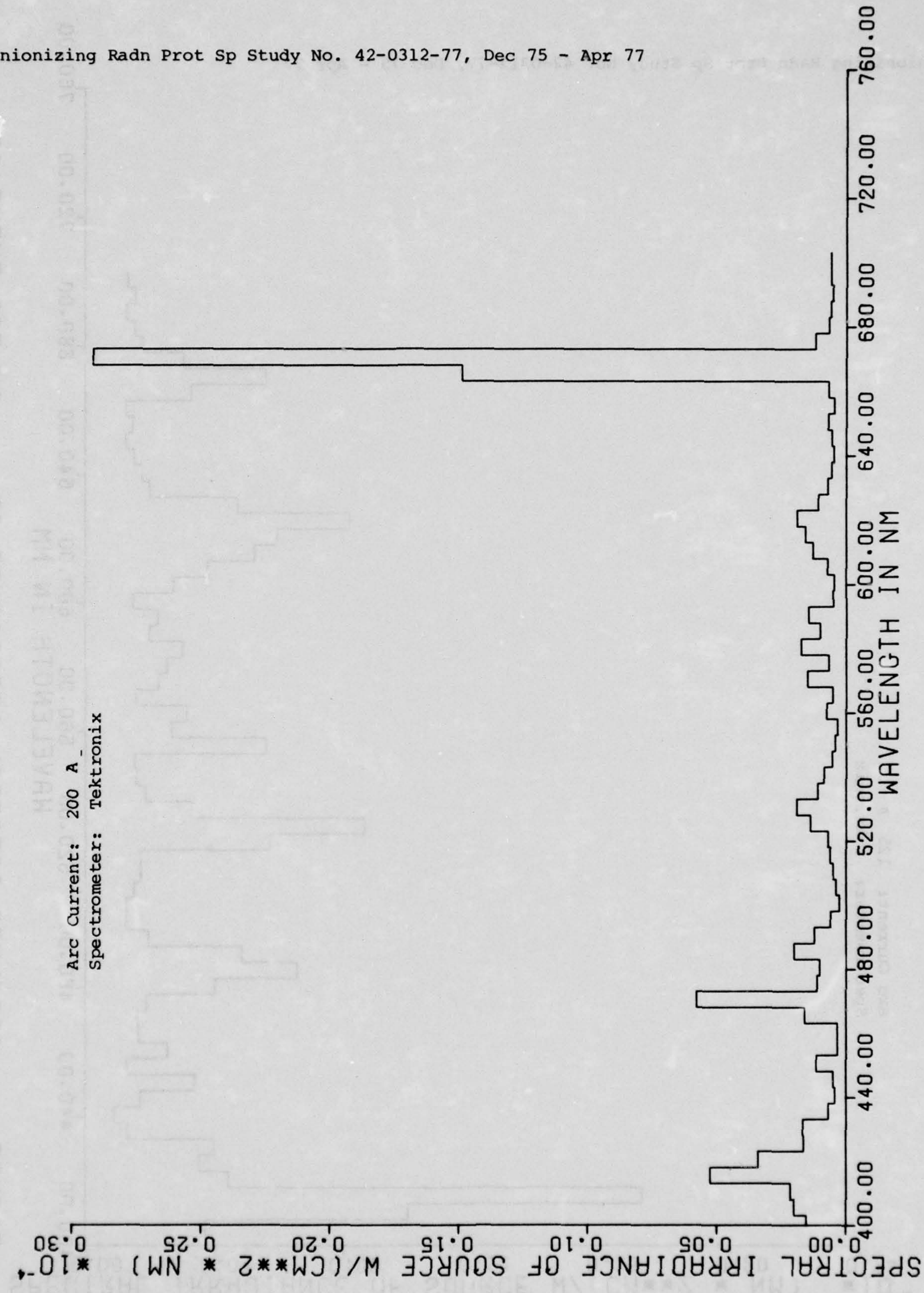


FIGURE 11k. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 57

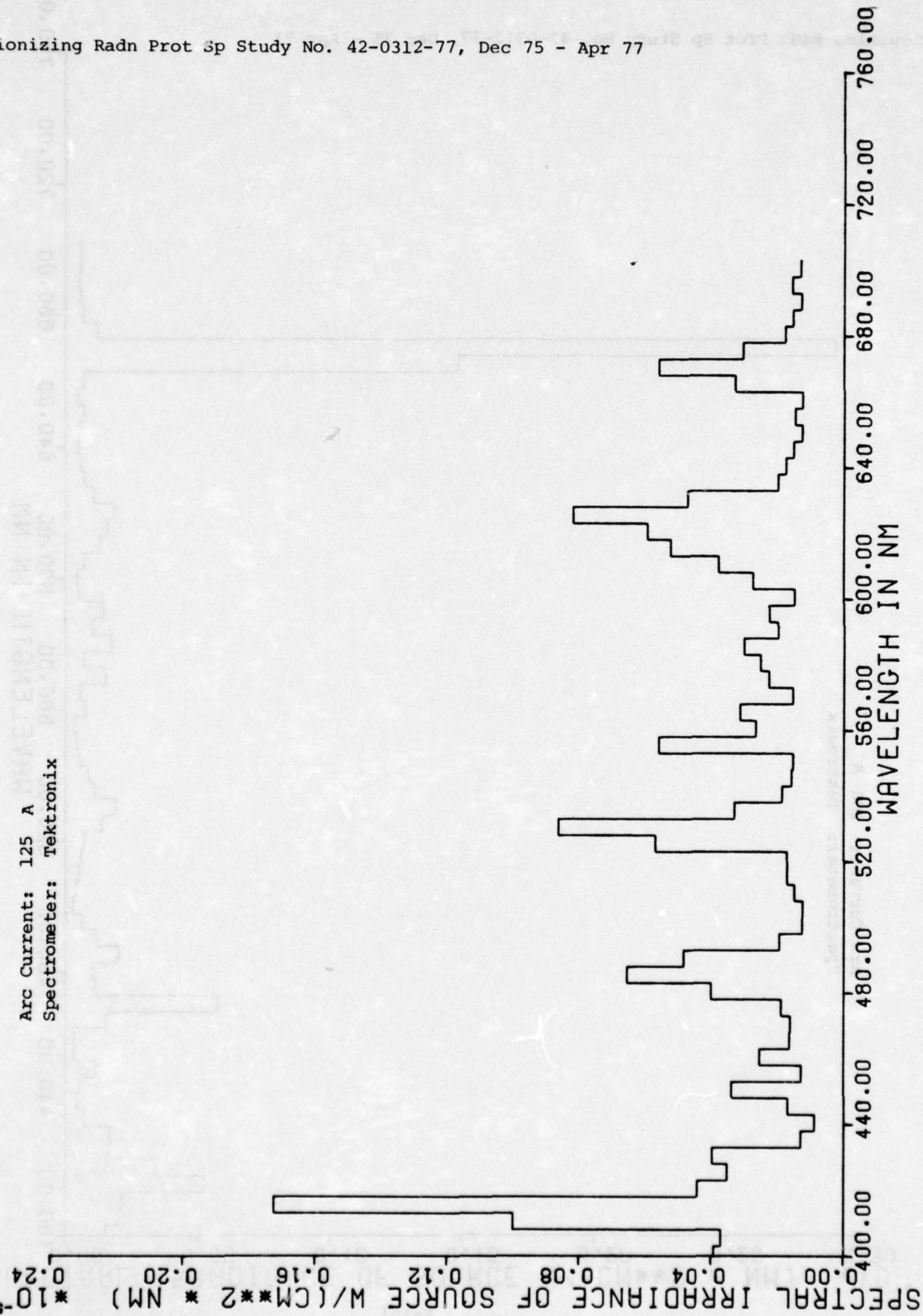


FIGURE 11ℓ. ABSOLUTE SPECTRAL IRRADIANCE AT 100 CM FOR EVENT 60

TABLE 12. WELDING PARAMETERS FOR EVENTS 61 to 72.

Process: PAC with water injection.

Base Metal: mild steel (5/8" thick for $I \leq 400$ A and 1" for $I \leq 600$ A)

Torch: PT-15

Current Range: 300 to 750 A

Shielding Gas: N_2 (140 cfh for $I \leq 400$ A, 180 cfh for $500 \text{ A} \leq I \leq 600$ A, and 200 cfh for $I = 750$ A)

Torch Heights: 1/4", 1/2" and 3/8"

Cut Water: 0.33 gpm for $I \leq 400$ A, 0.40 gpm for $500 \text{ A} \leq I \leq 600$ A, and 0.48 gpm for $I = 750$ A

Nozzle Diameter: 0.156" for $I \leq 400$ A, 0.200" for $500 \text{ A} \leq I \leq 600$ A, and 0.230" for $I = 750$ A

Summary of Results

I	L_v	L_e	L_b	t	S_a	S_c	S_p	d
(A)	(cd/cm^2)	[$W/(cm^2.Sr)$]		(S)	-	-	-	(cm)
1/4-inch gap								
300	2,400	-	-	-	-	8.8	-	-
400	3,300	-	-	-	-	9.1	-	-
3/8-inch gap								
300	3,600	80.6	-	-	-	9.2	-	148
400	1,500	-	-	-	-	8.3	-	-
500	4,500	-	-	-	-	9.4	-	-
600	4,800	-	-	-	-	9.5	-	-
750	5,400	-	-	-	-	9.6	-	-
1/2-inch gap								
300	3,000	-	-	-	-	9.0	-	
400	4,200	82.4	-	-	-	9.3	-	190
500	4,500	-	-	-	-	9.4	-	-
600	5,600	137	-	-	-	9.6	-	170
750	7,500	-	-	-	-	9.9	-	-

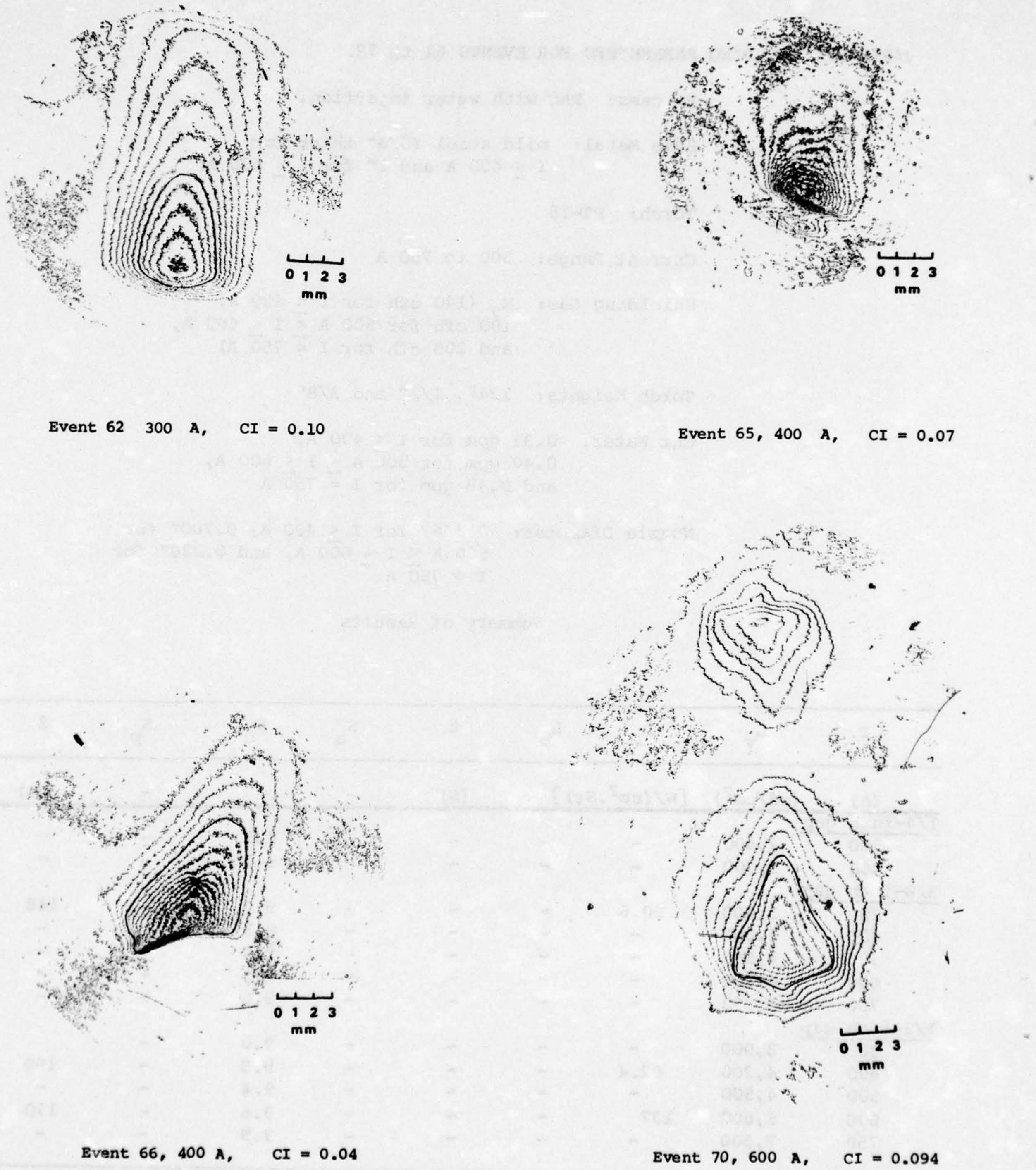


Figure 12a. Microdensitometer Scans of 35 mm Processed Photographic Negatives Exposed at 4 m from the Cutting Arcs for Events 61-72.

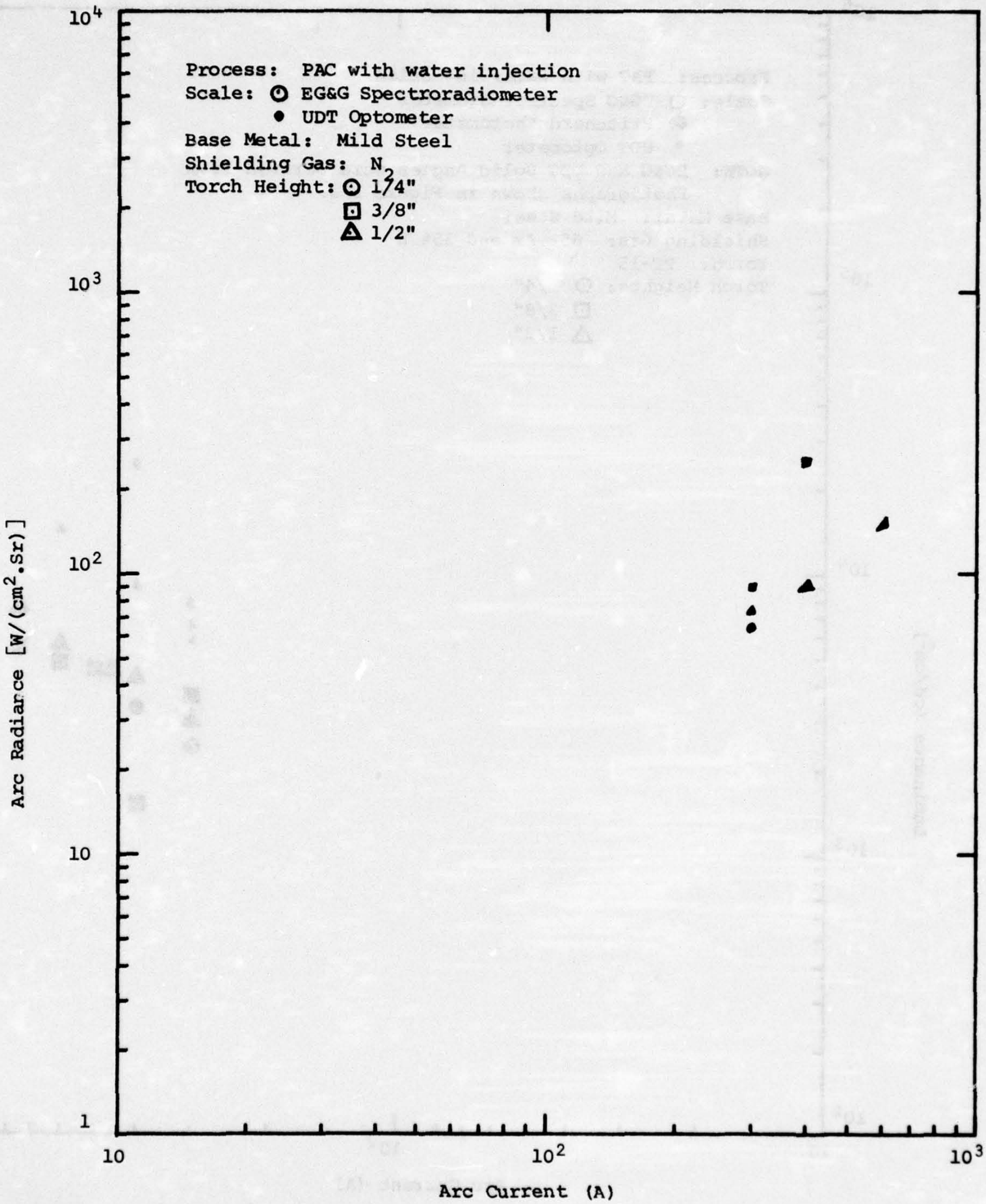


Figure 12b. Arc Radiance as a Function of Arc Current for Events 61 to 72.

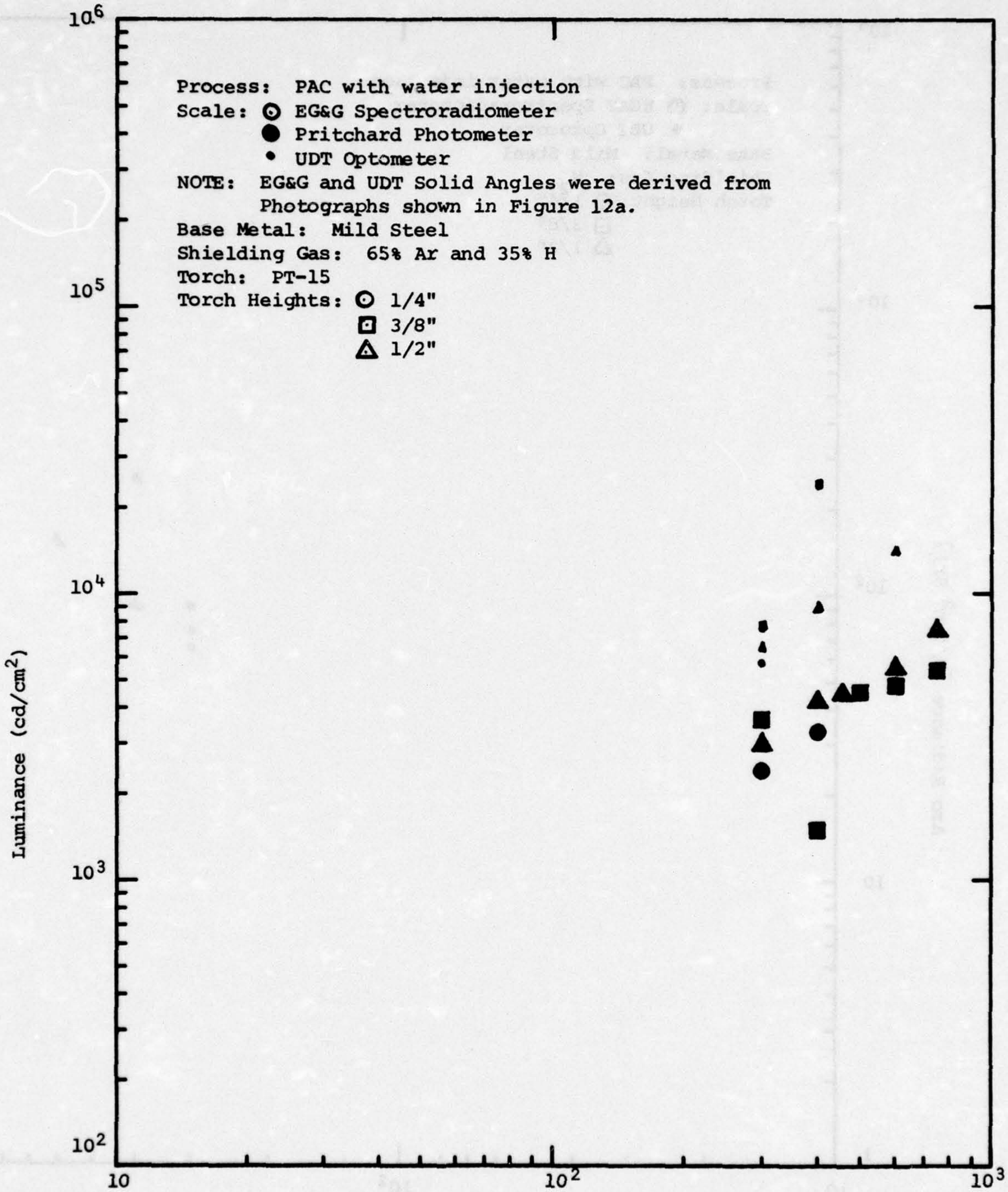


Figure 12c. Arc Luminance as a Function of Arc Current for Events 61 to 72.

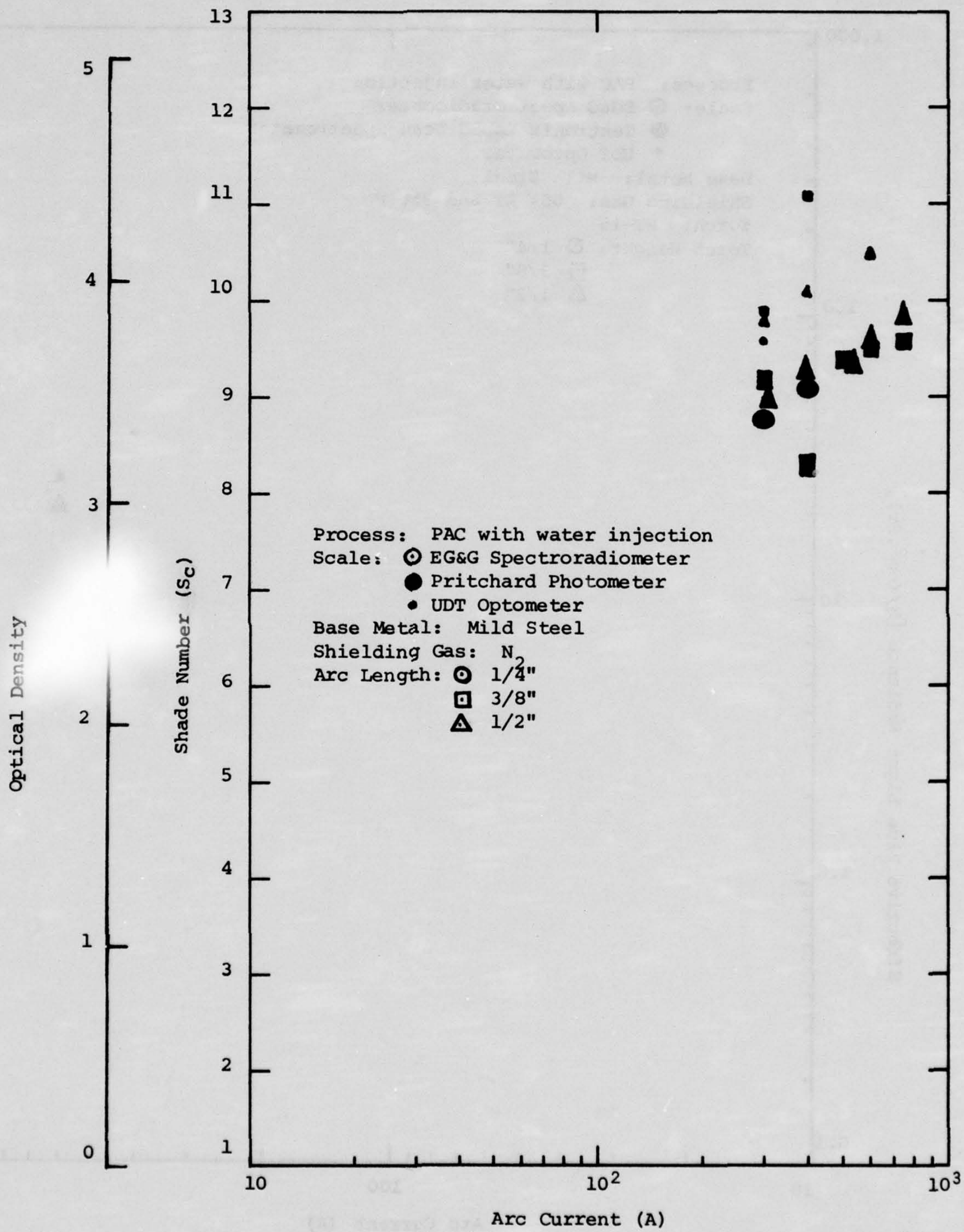


Figure 12d. Comfortable Shade Number (Sc) or Optical Density for Arc Viewing as a Function of Arc Current for Events 61 to 72.

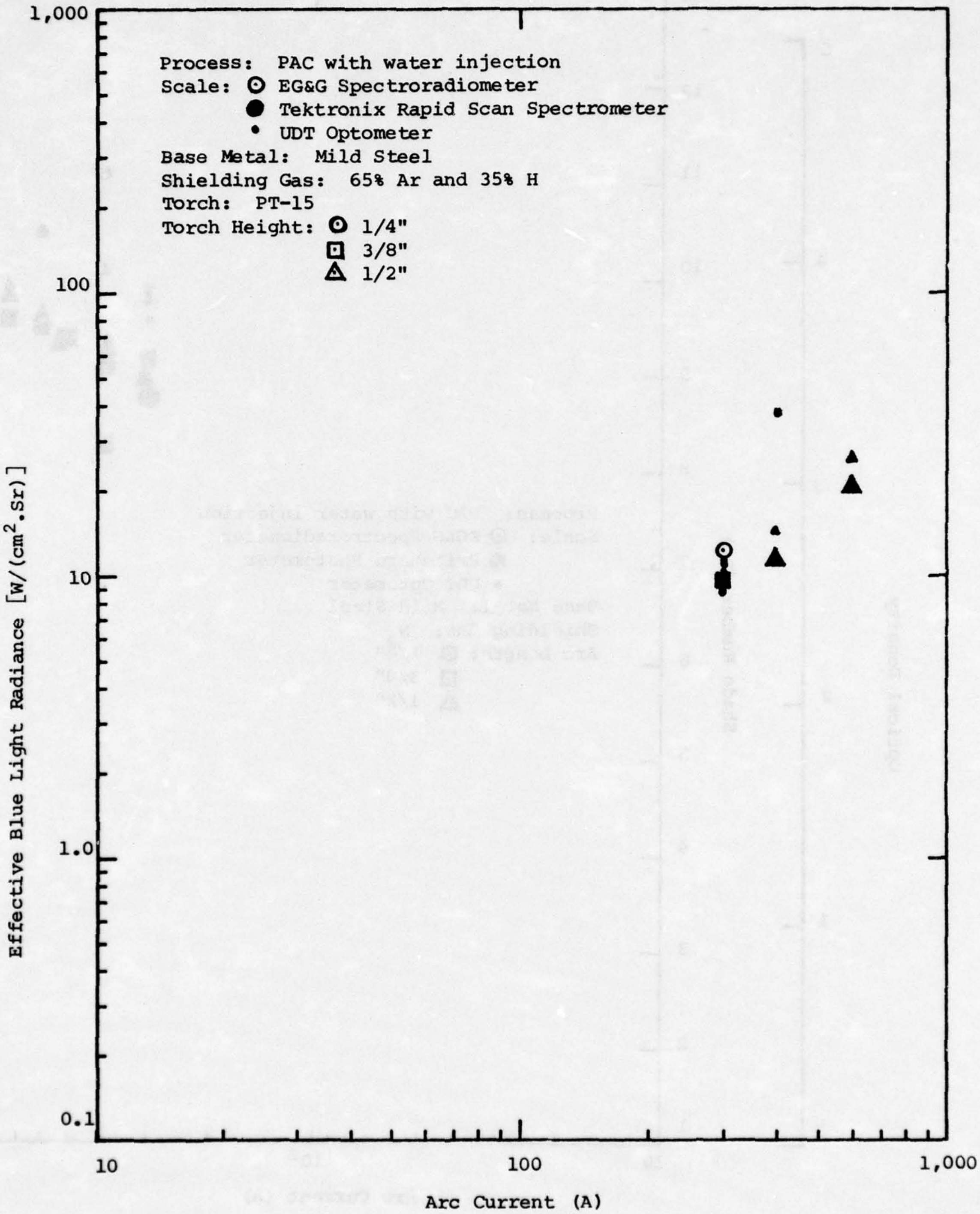


Figure 12e. Effective Blue Light Radiance as a Function of Arc Current for Events 61 to 72.

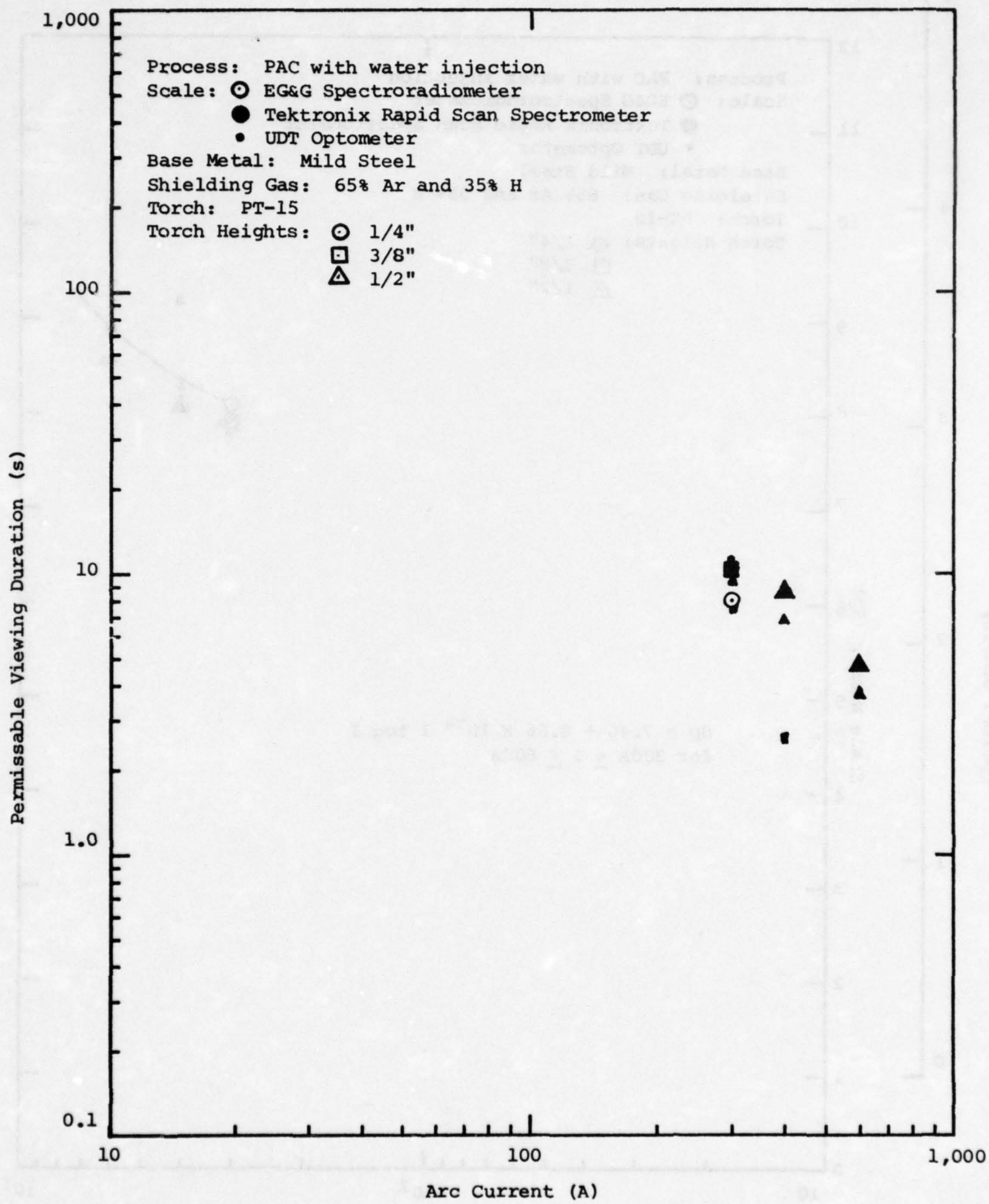


Figure 12f. Permissable Viewing Duration as a Function of Arc Current for Events 61 to 72 at Distances less than 1.8 m.

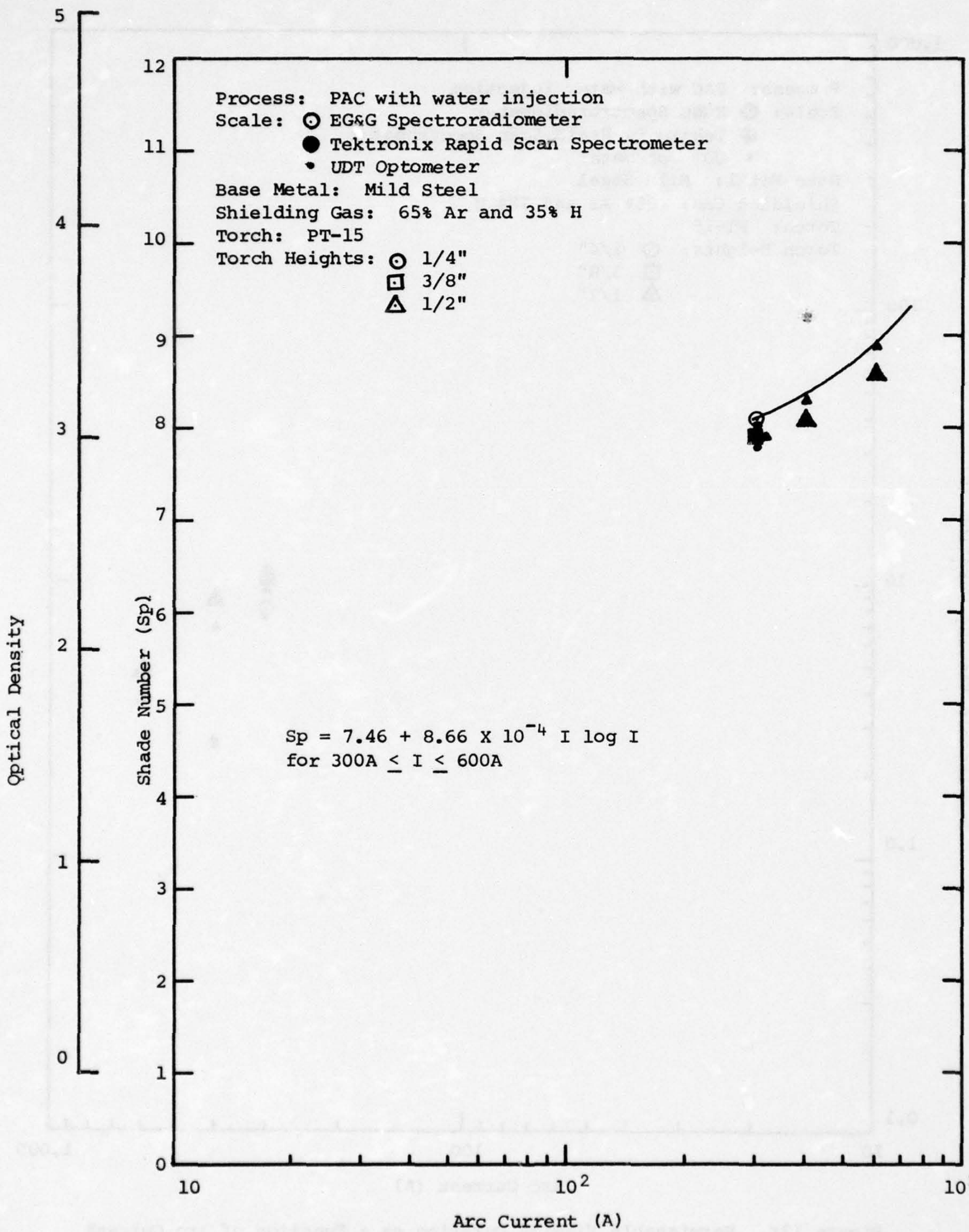


Figure 12g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted During Events 61 to 72.

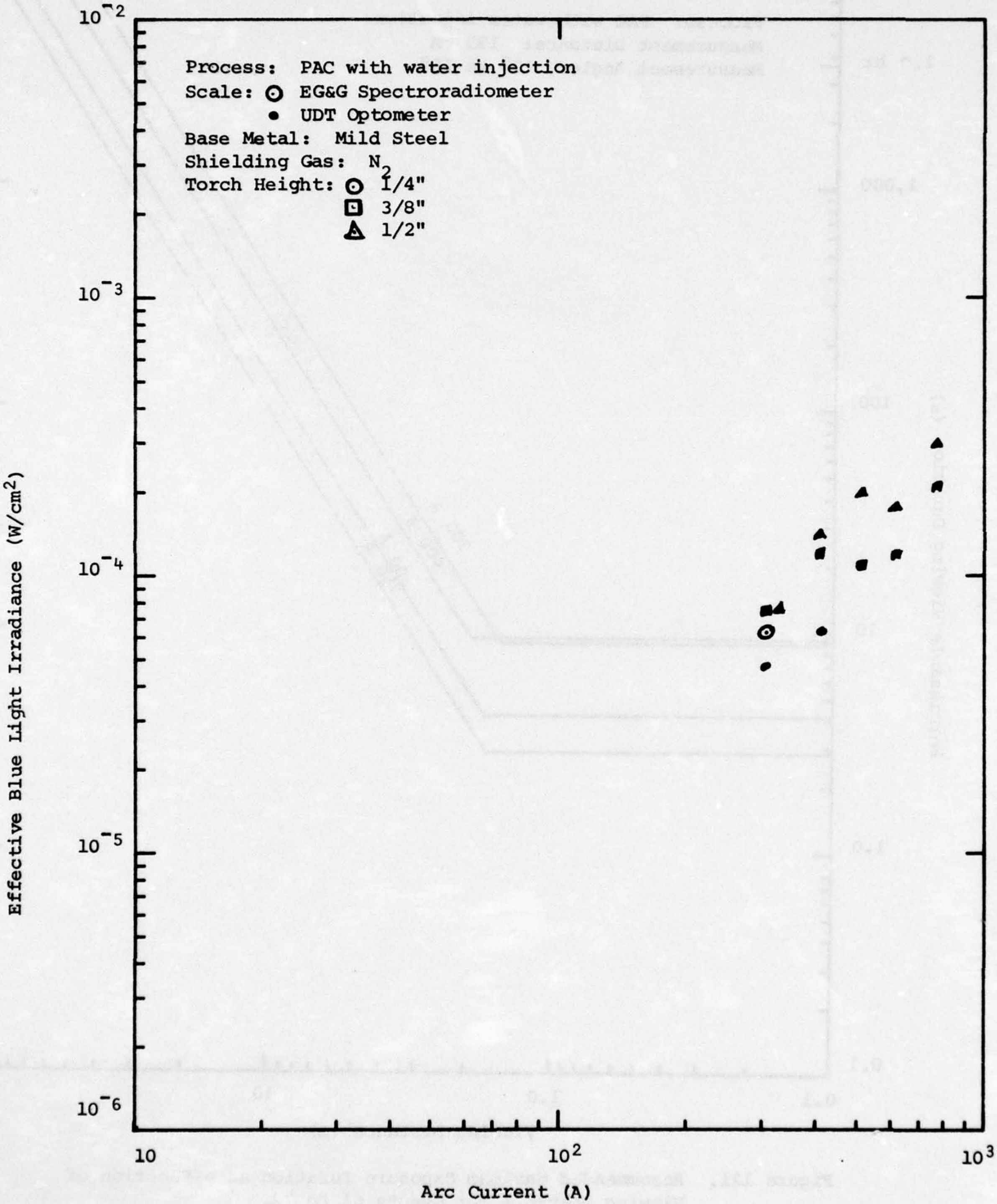


Figure 12h. Effective Blue Light Irradiance as a Function of Arc Current for Events 61 to 72.

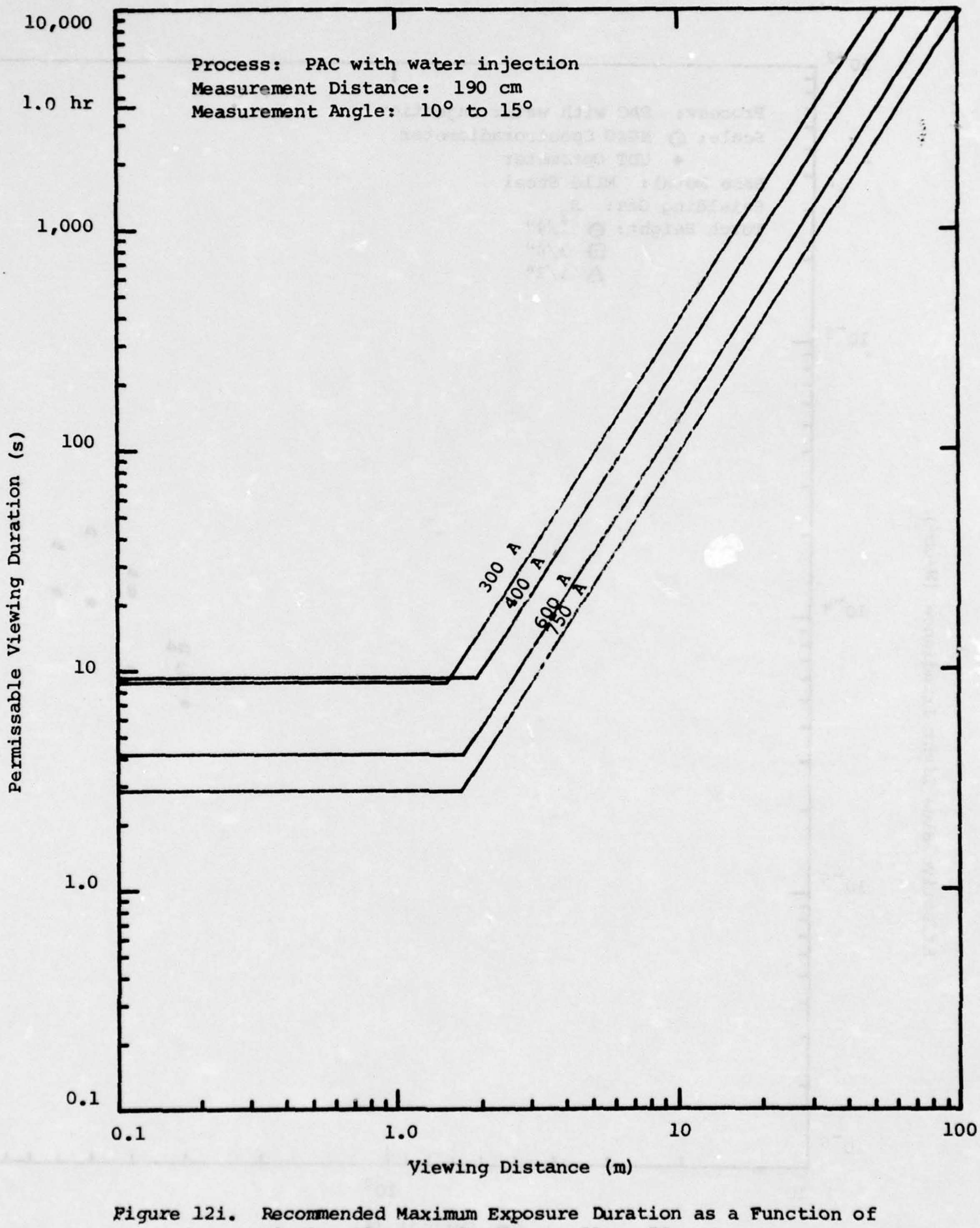


Figure 12i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 61 to 72.

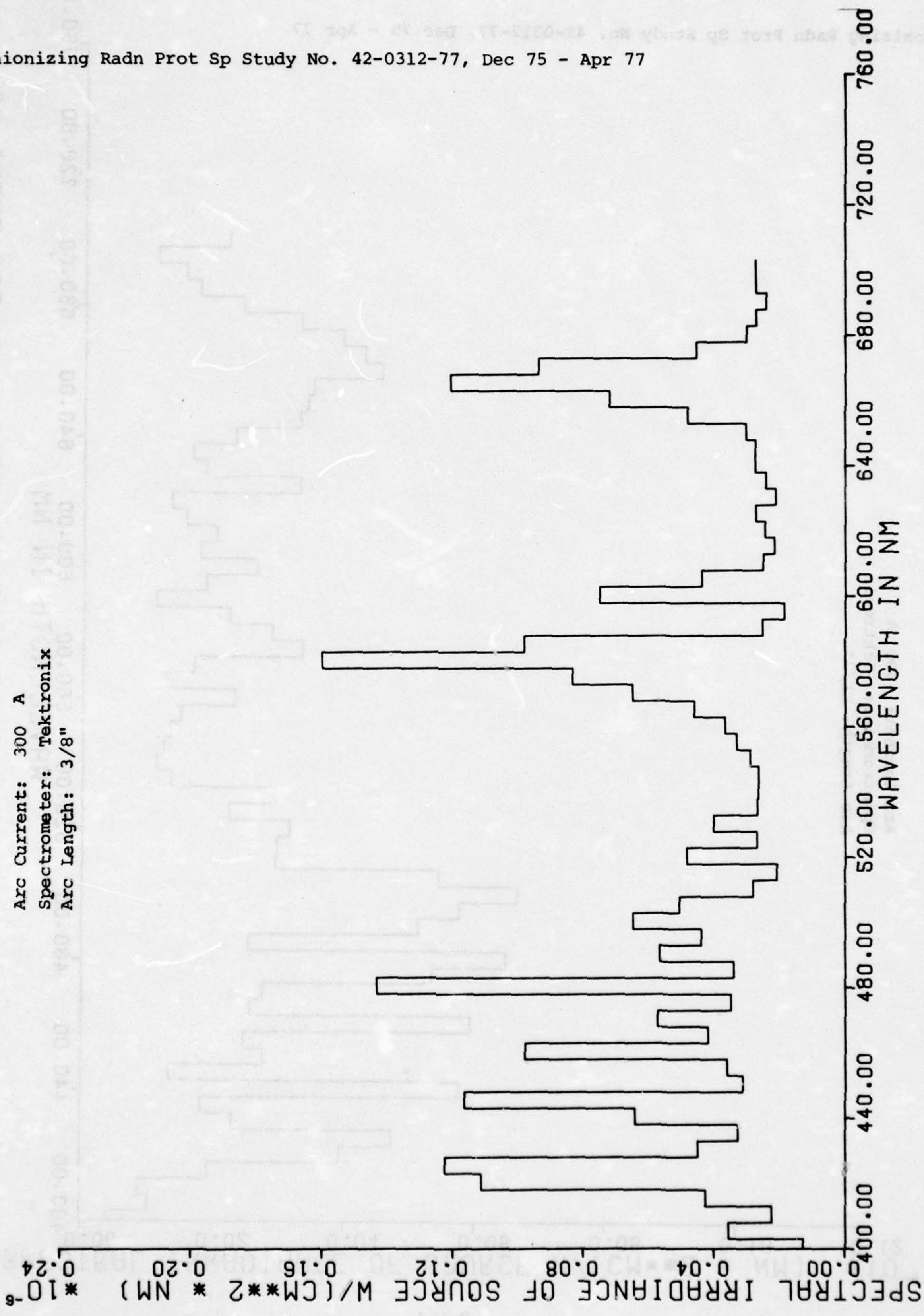


FIGURE 12j . ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 62

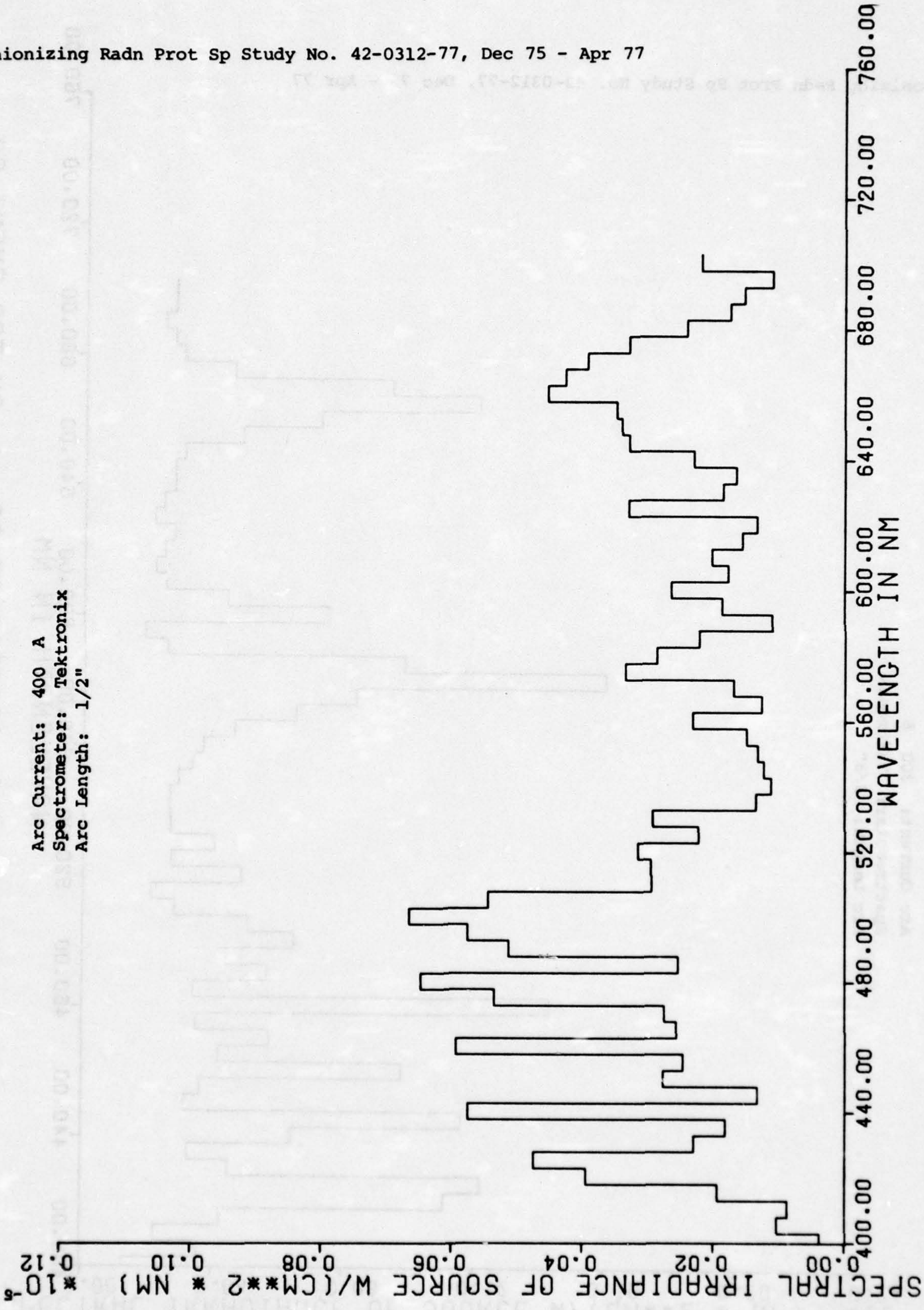


FIGURE 12k. ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 66

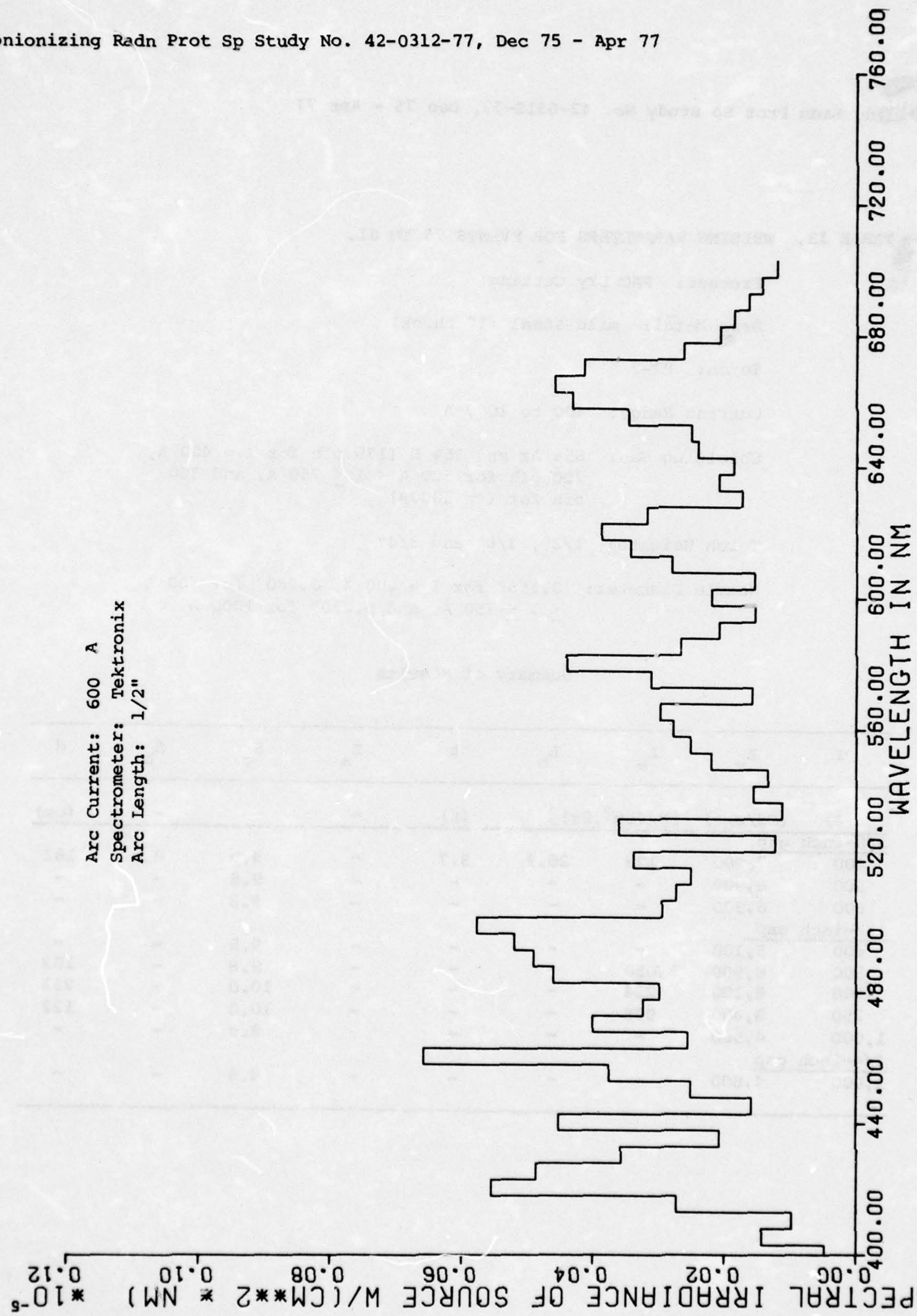


FIGURE 12ℓ. ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 70

TABLE 13. WELDING PARAMETERS FOR EVENTS 73 TO 81.

Process: PAC Dry Cutting

Base Metal: mild steel (1" thick)

Torch: PT-7

Current Range: 400 to 1000 A

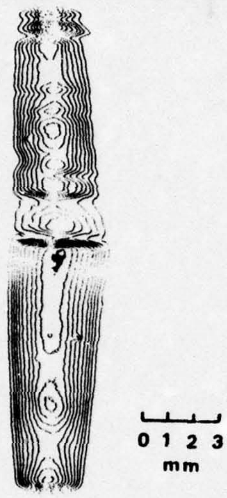
Shielding Gas: 65% Ar and 35% H (175 cfh for I = 400 A, 200 cfh for 500 A ≤ I ≤ 750 A, and 300 cfh for I = 1000A)

Torch Heights: 1/2", 3/8" and 3/4"

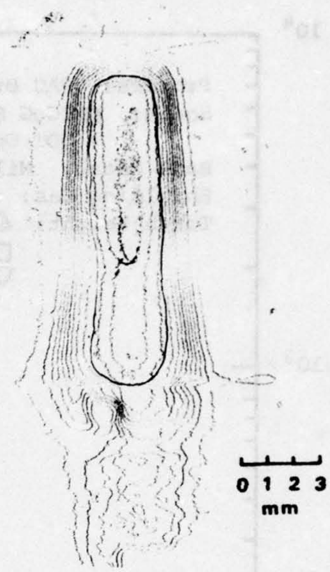
Nozzle Diameter: 0.156" for I = 400 A, 0.200" for 500 A ≤ I ≤ 750 A, and 0.230" for 1000 A

Summary of Results

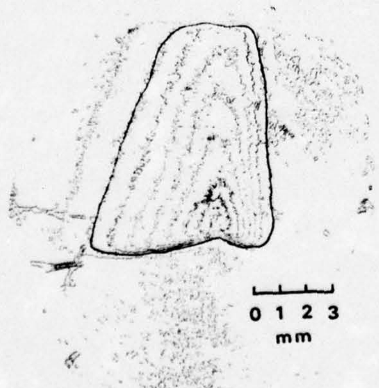
I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(Cd/cm^2)	[$W/(cm^2.Sr)$]		(S)	-	-	-	(cm)
3/8-inch gap								
400	7,200	123	26.9	3.7	-	9.9	8.9	182
500	6,900	-	-	-	-	9.8	-	-
600	6,900	-	-	-	-	9.8	-	-
1/2-inch gap								
400	5,100	-	-	-	-	9.5	-	-
500	6,900	3,050	-	-	-	9.8	-	182
600	8,100	224	-	-	-	10.0	-	232
750	8,400	978	-	-	-	10.0	-	122
1,000	4,500	-	-	-	-	9.4	-	-
3/4-inch gap								
1,000	4,800	-	-	-	-	9.5	-	-



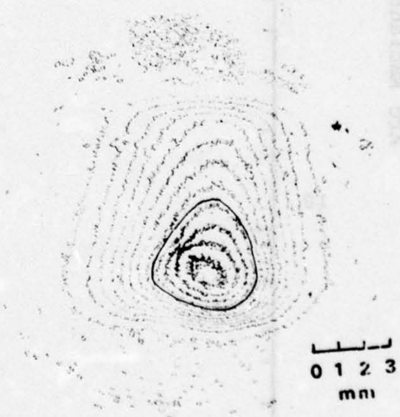
Event 73, 400 A, CI = 0.08



Event 76, 500 A, CI = 0.12



Event 78, 600 A, CI = 0.06



Event 79, 750 A, CI = 0.10

Figure 13a. Microdensitometer Scans of 35 mm Processed Photographic Negatives Exposed 4 m from the Cutting Arcs for Events 73-81.

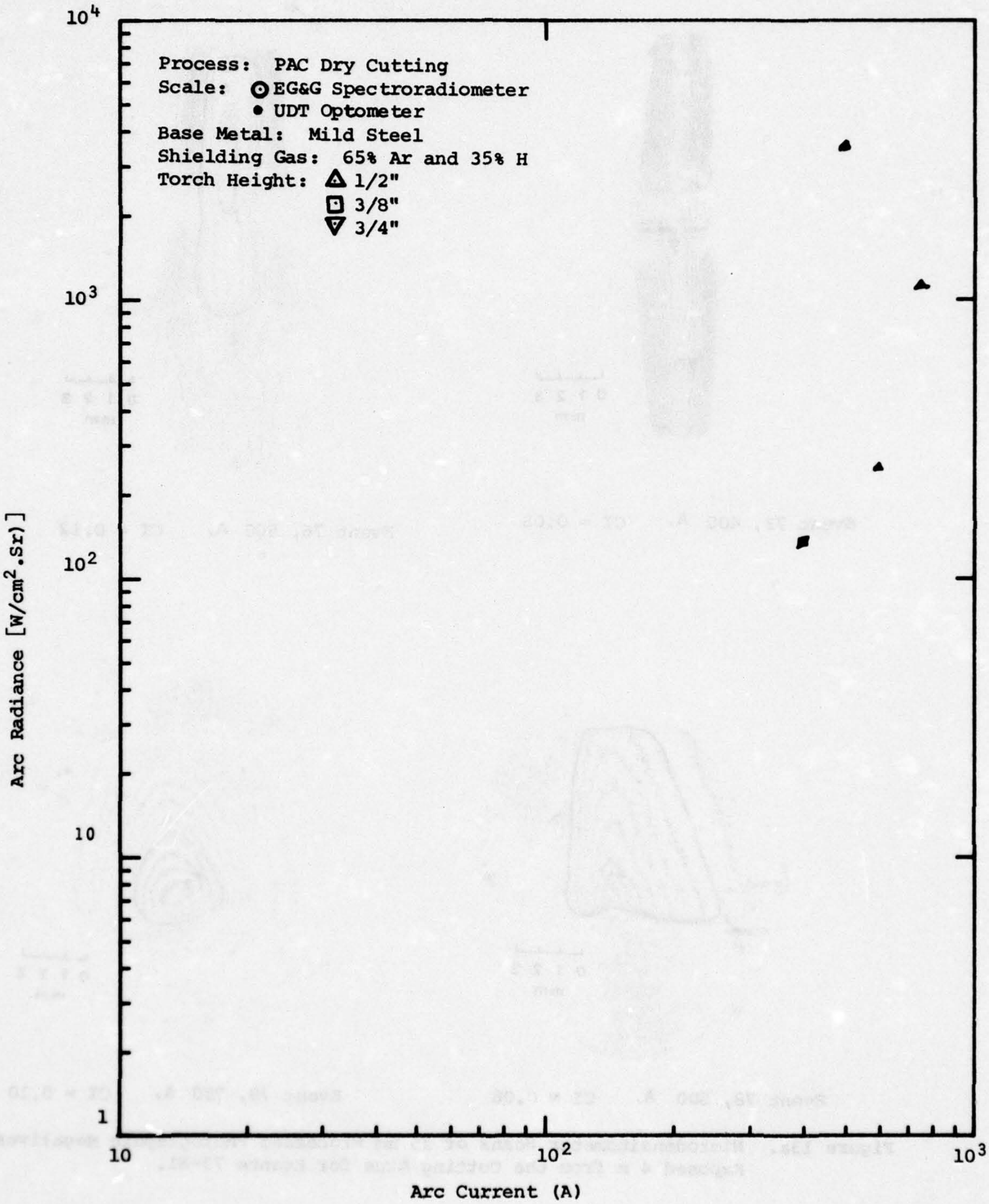


Figure 13b. Arc Radiance as a Function of Arc Current for Events 73 to 81.

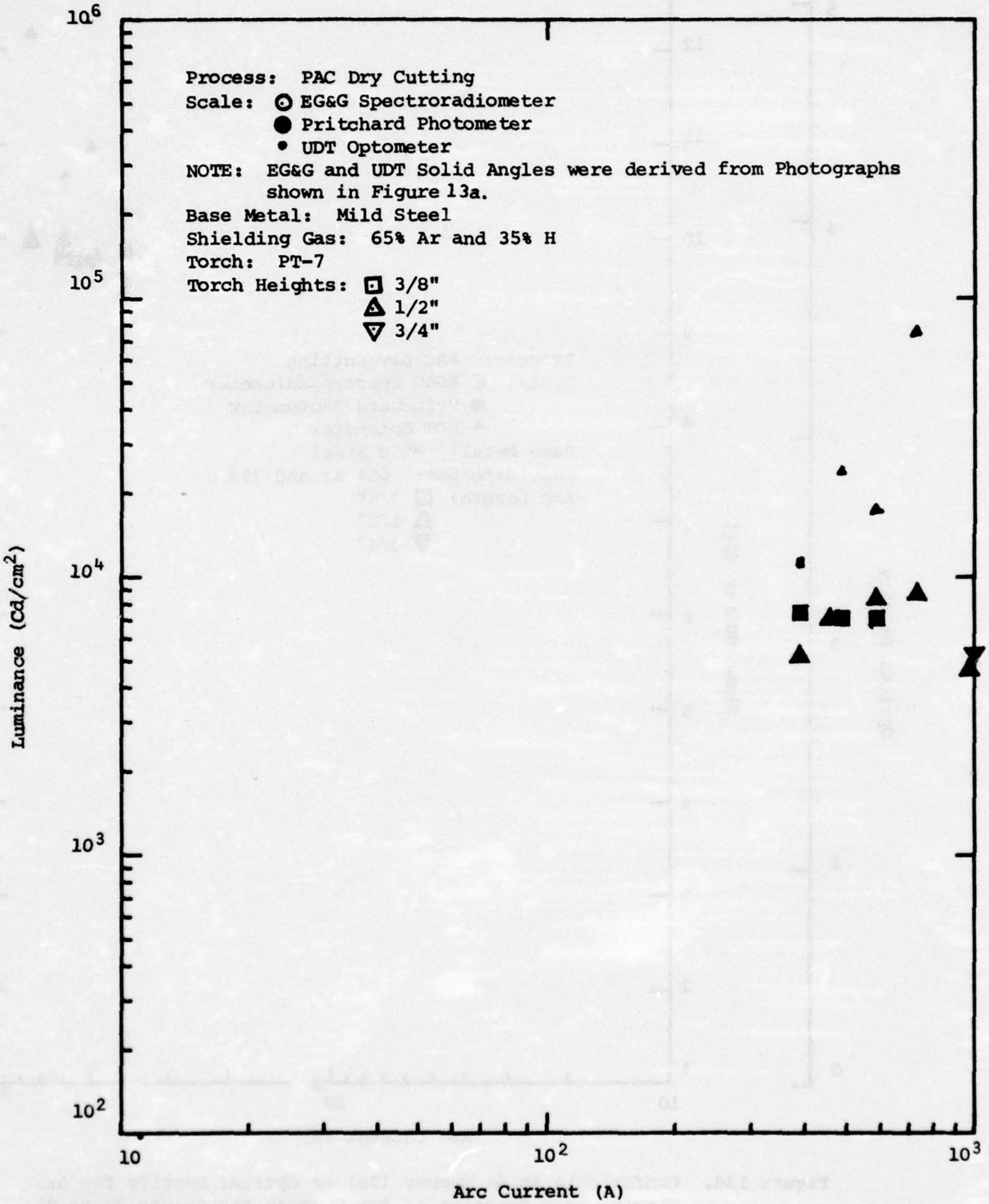


Figure 13c. Arc Luminance as a Function of Arc Current for Events 73 to 81.

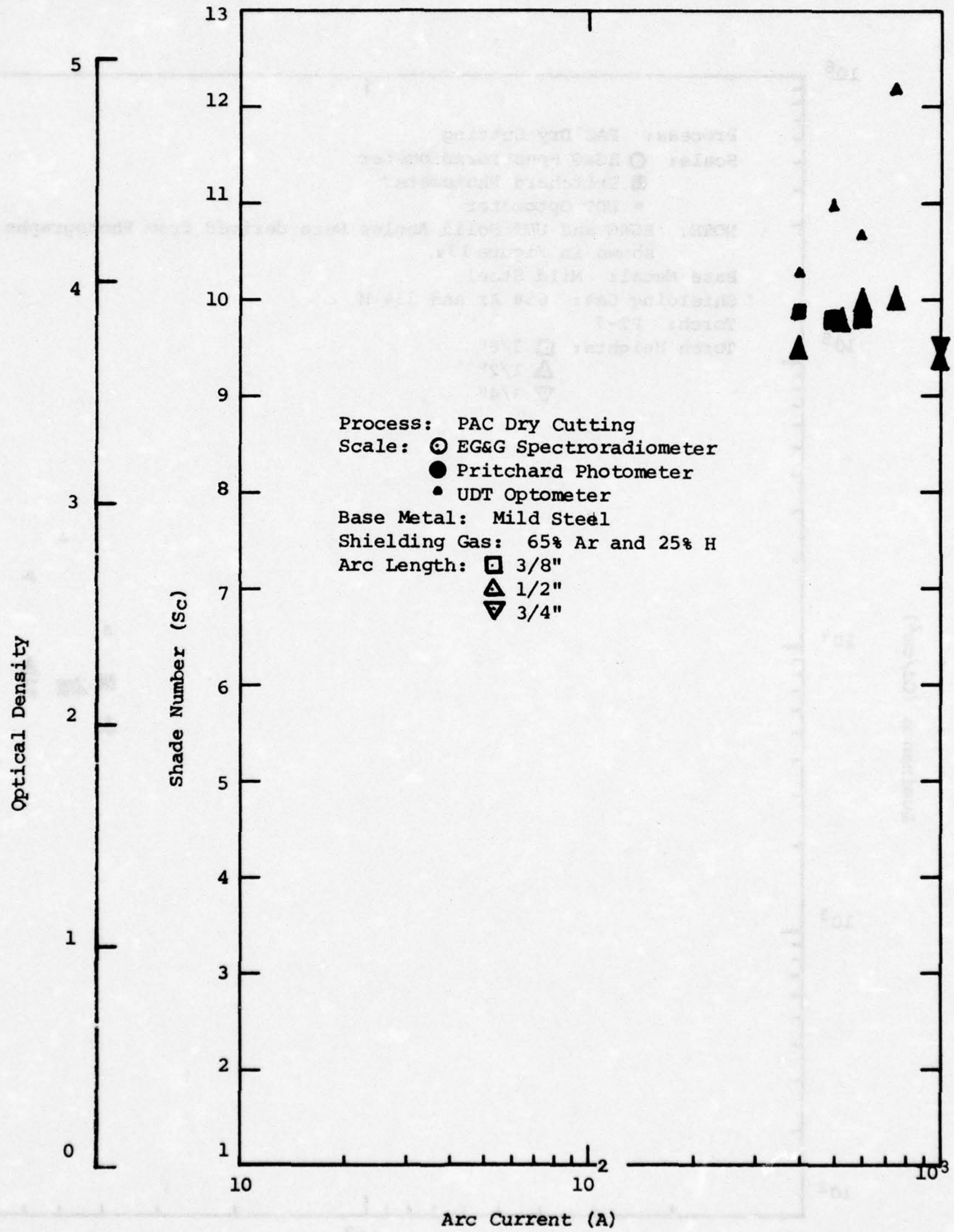


Figure 13d. Comfortable Shade Number (Sc) or Optical Density for Arc Viewing as a Function of Arc Current for Events 73 to 81.

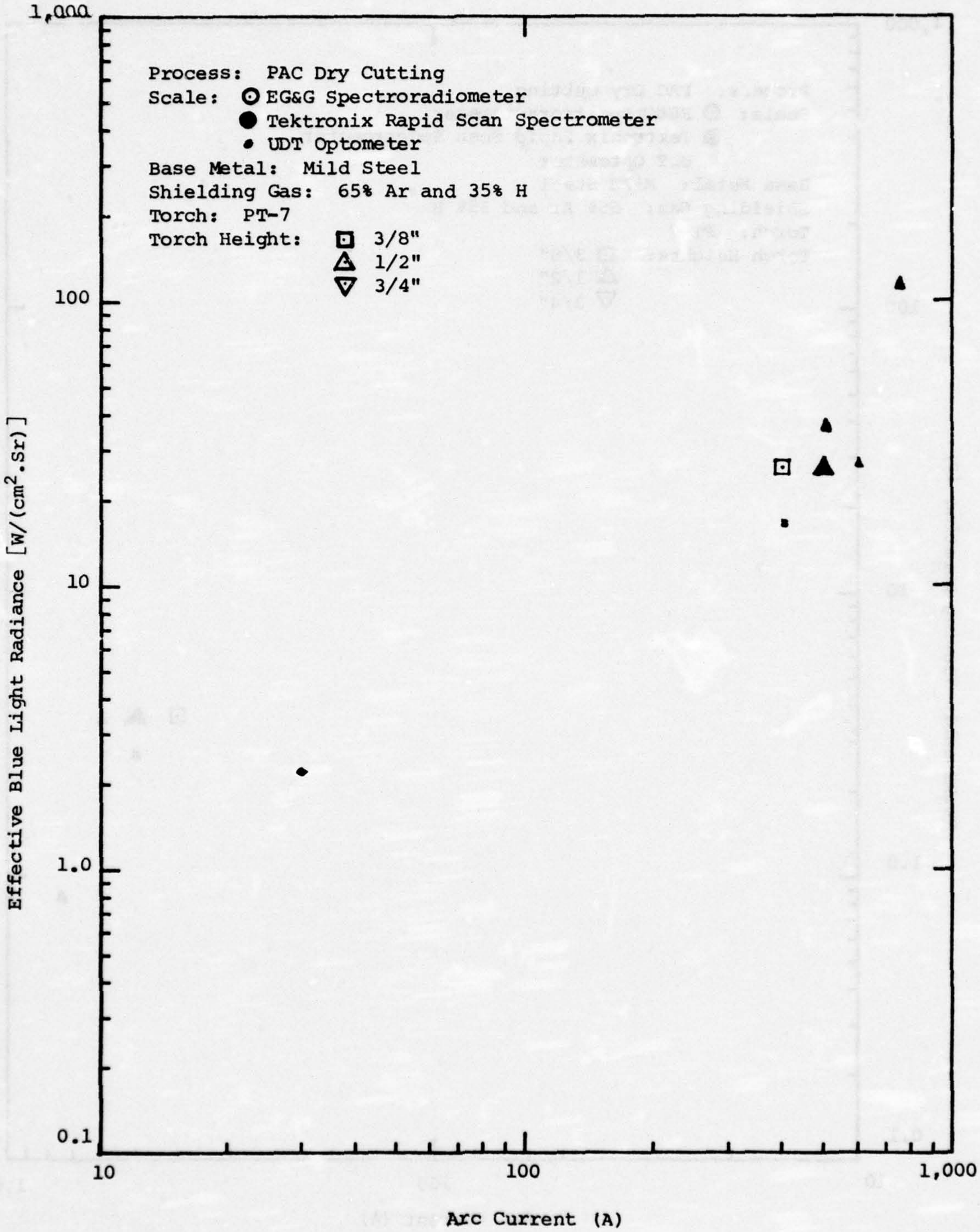


Figure 13e. Effective Blue Light Radiance as a Function of Arc Current for Events 73 to 81.

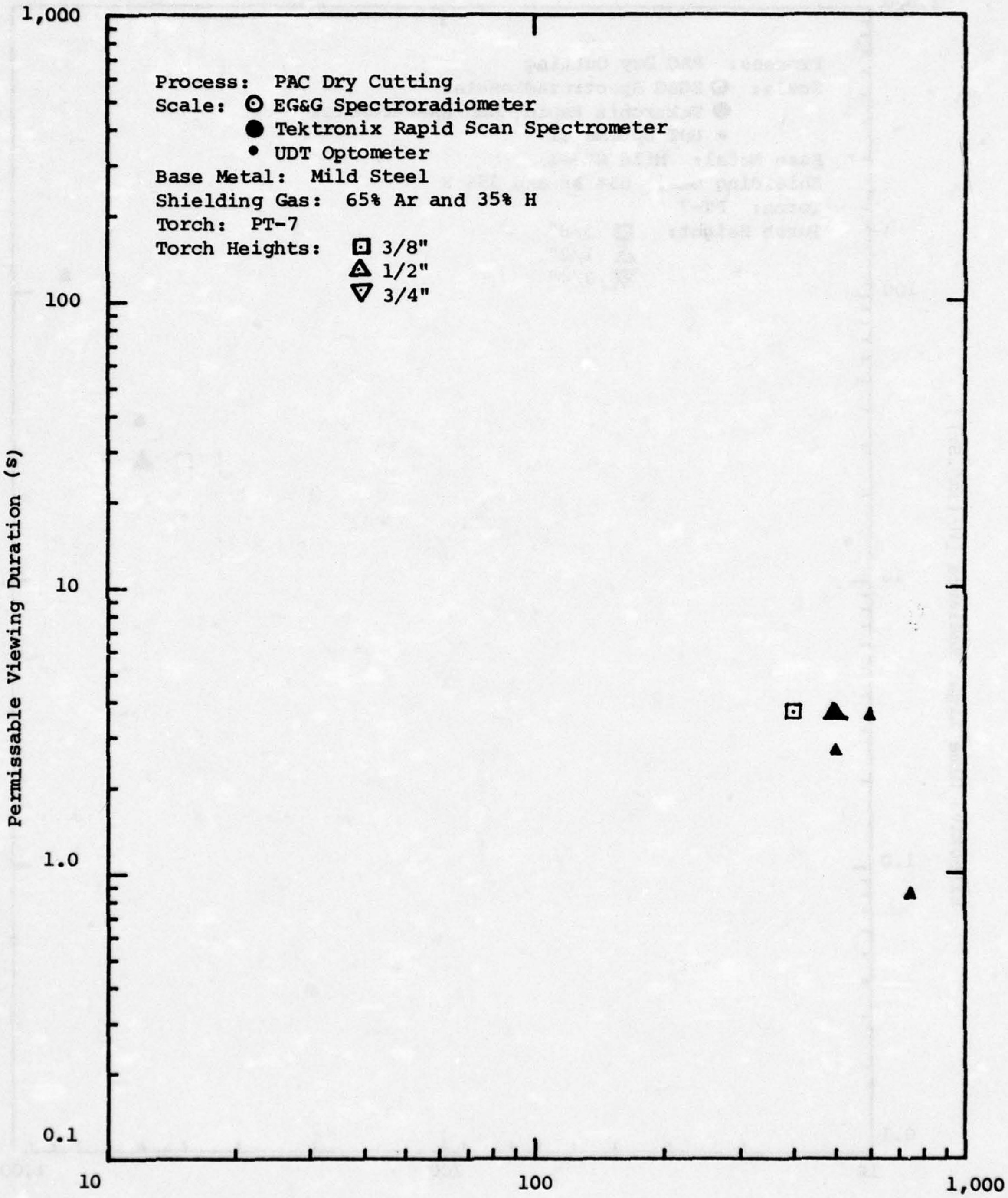


Figure 13f. Permissable Viewing Duration as a Function of Arc Current for Events 73 to 81 at Distances less than 2.0 m.

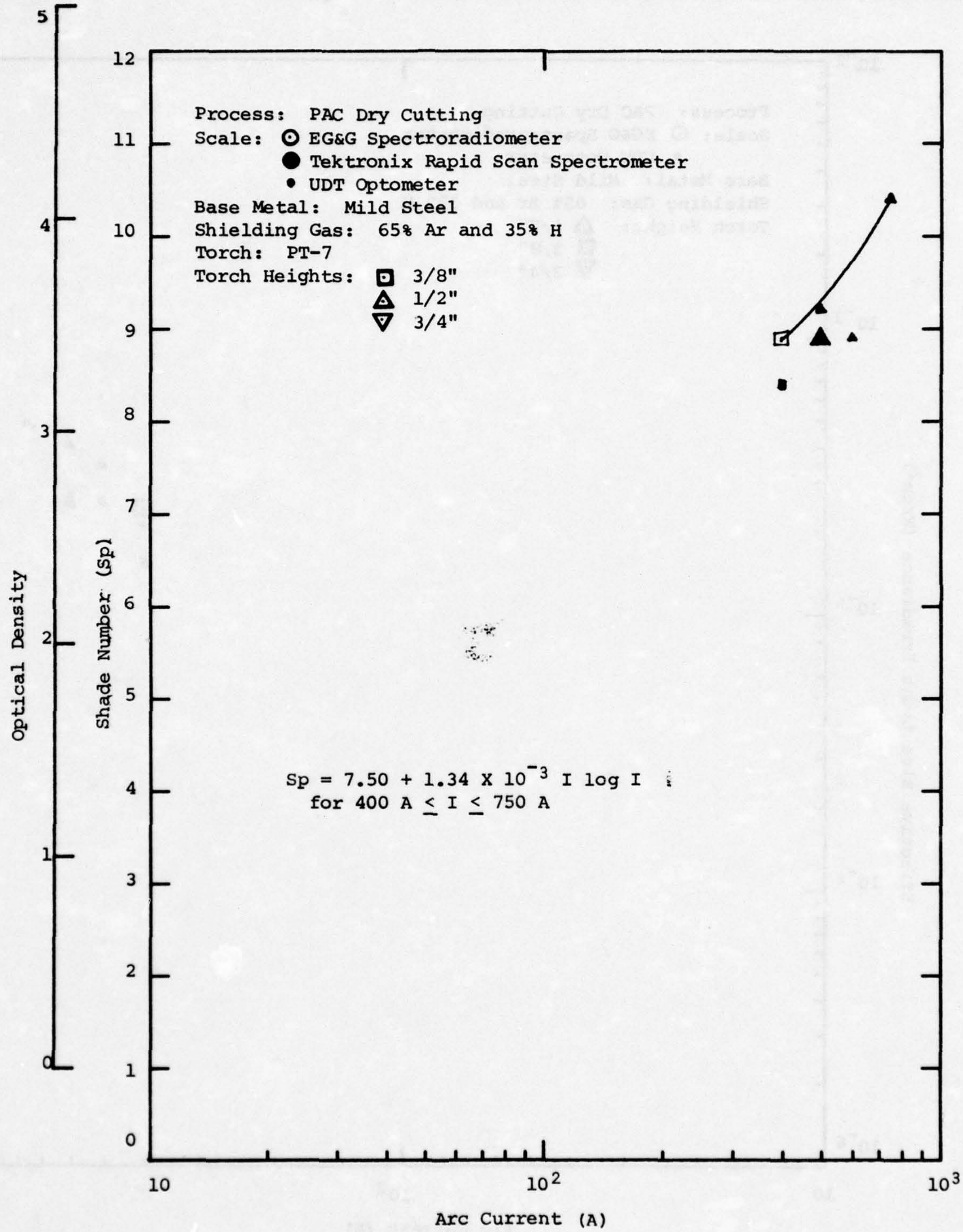


Figure 13g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 73 to 81.

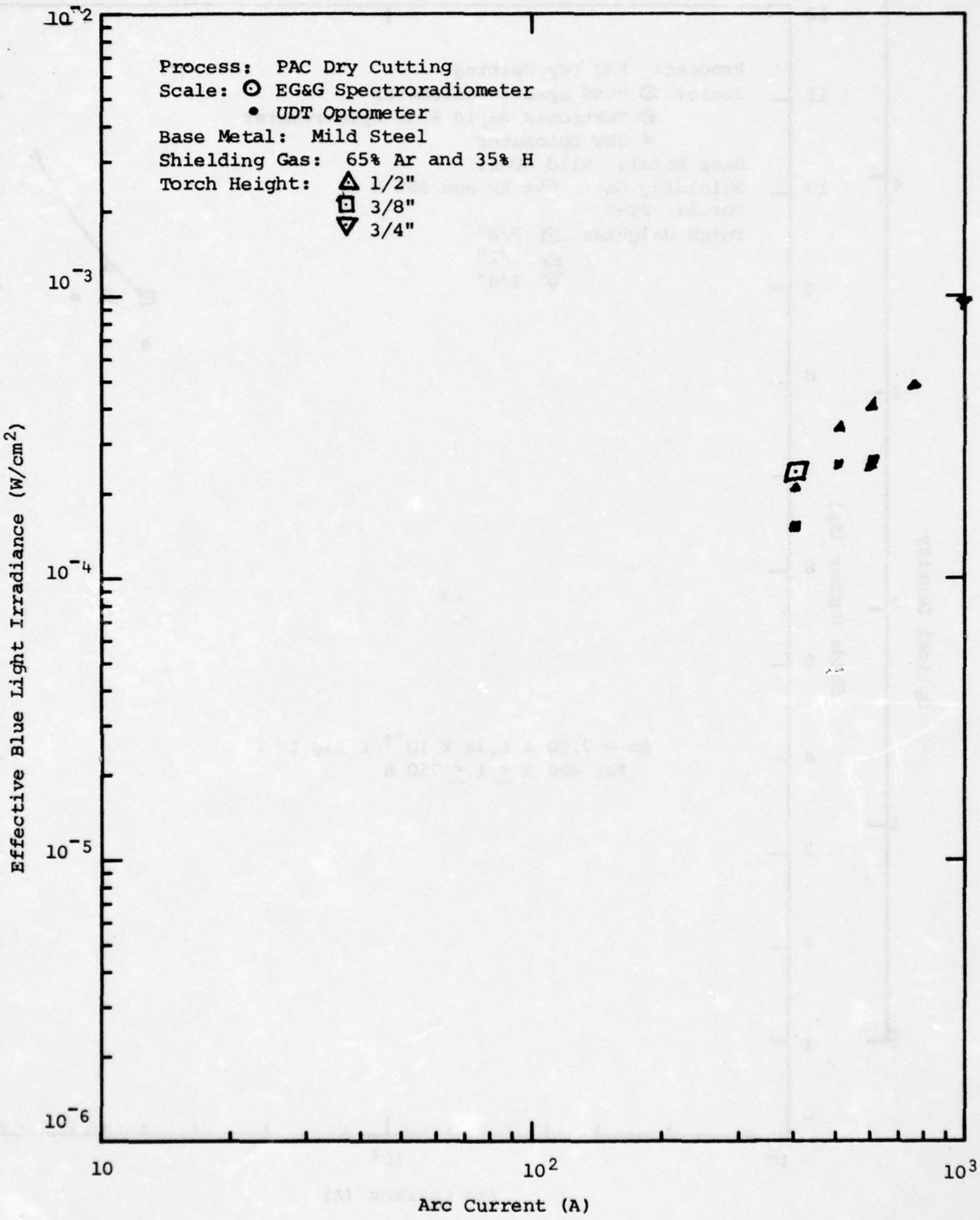


Figure 13h. Effective Blue Light Irradiance as a Function of Arc Current for Events 73 to 81.

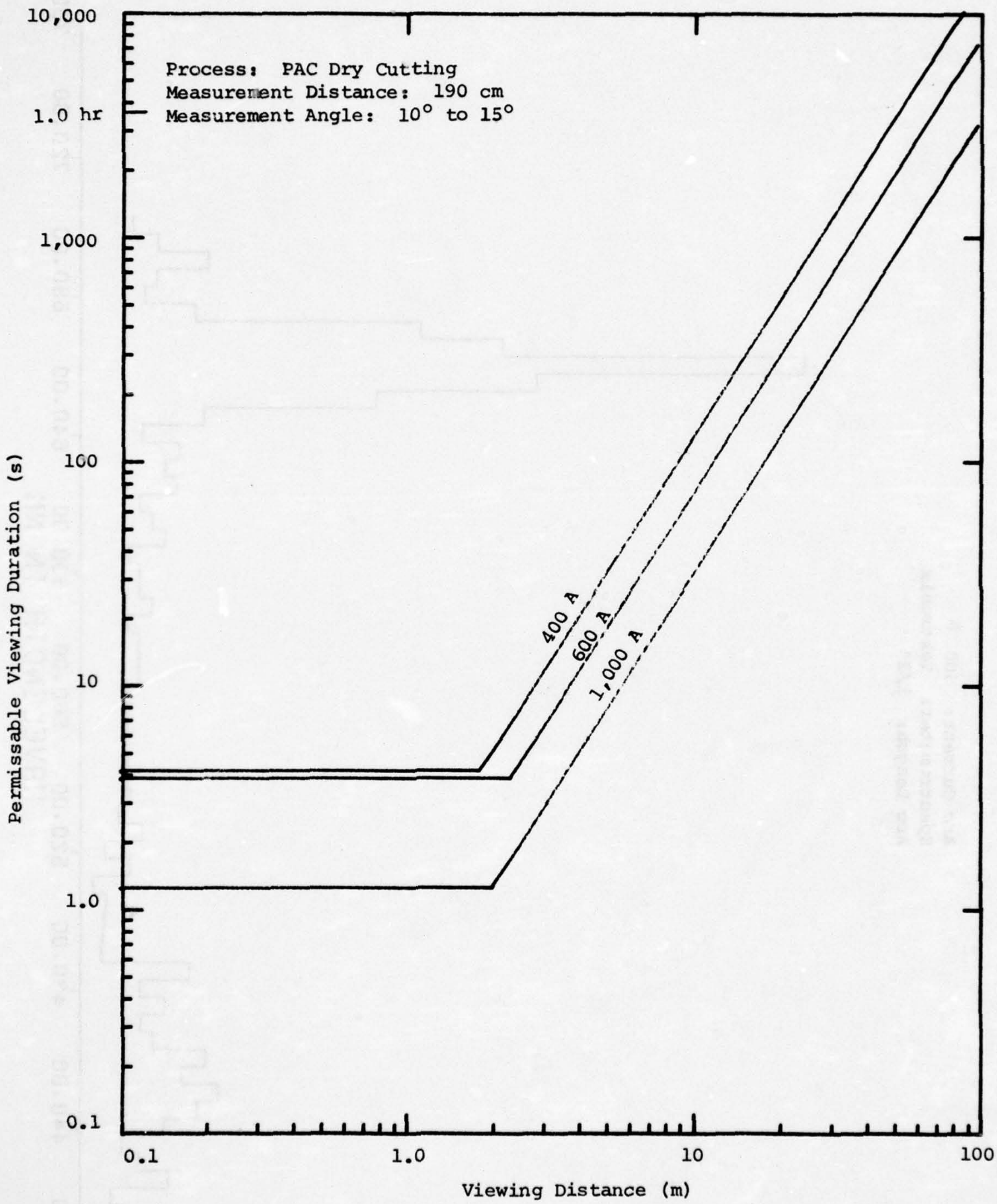


Figure 13i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 73 to 81.

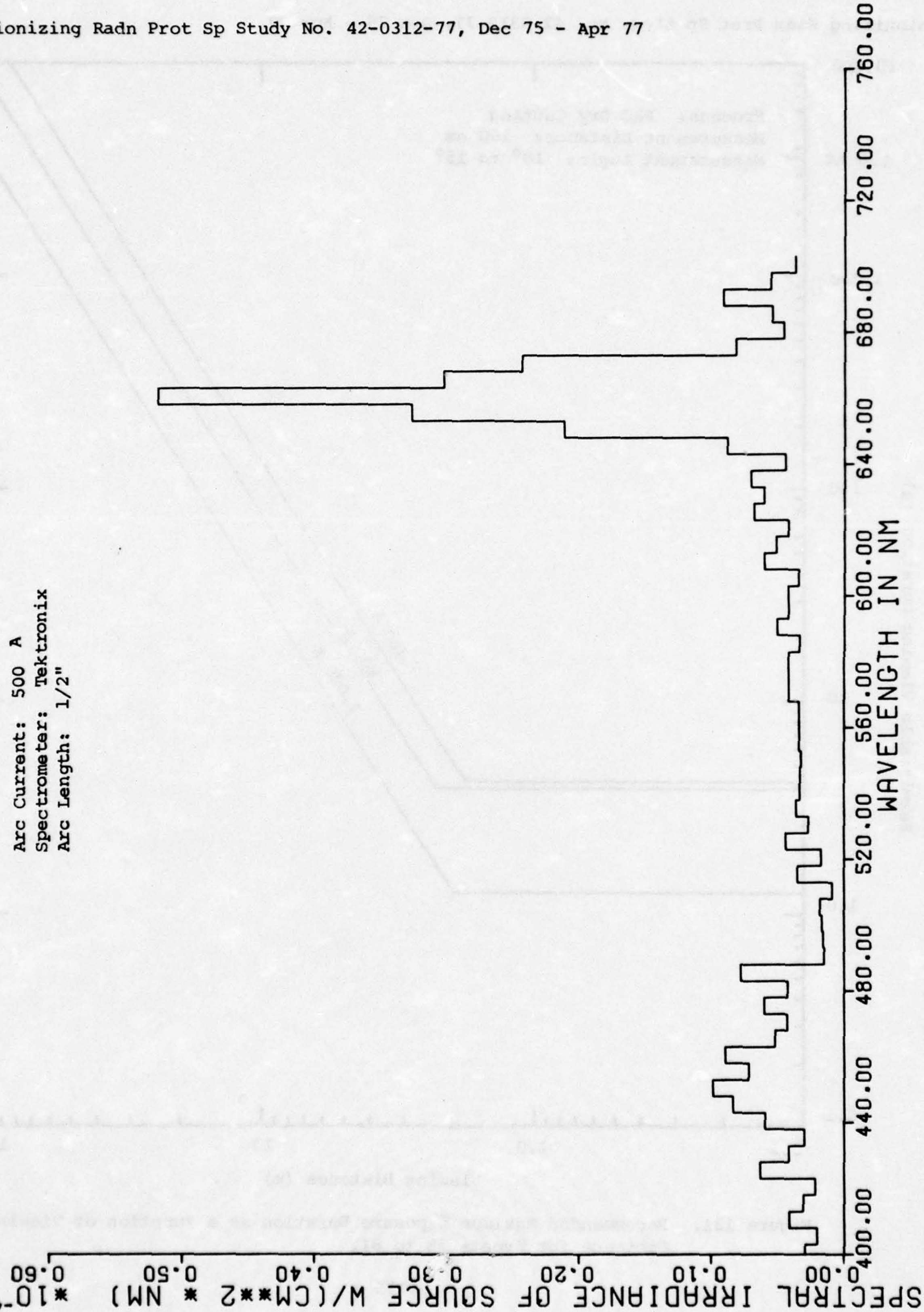


FIGURE 13j . ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 76

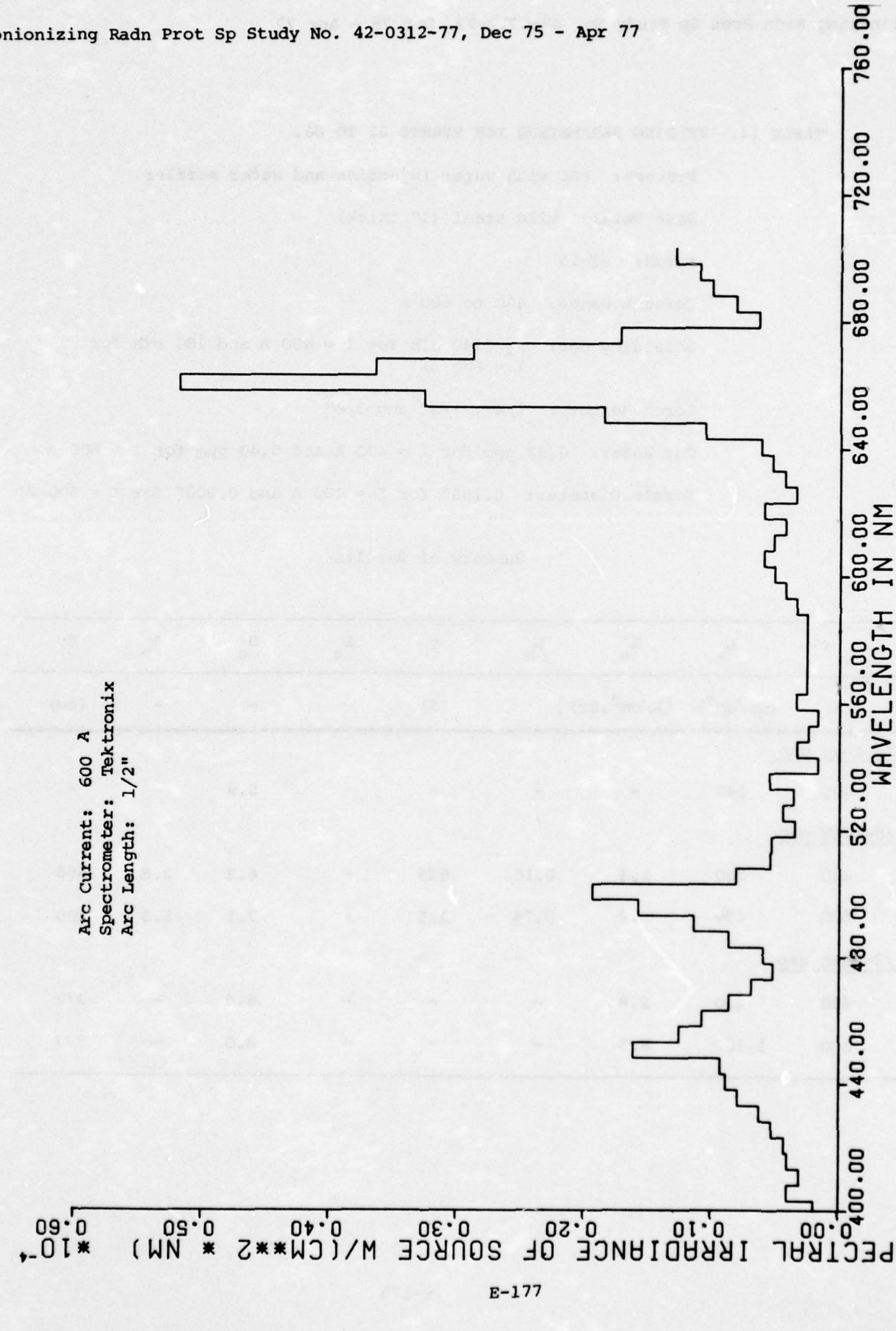


FIGURE 13k. ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 78

TABLE 14. WELDING PARAMETERS FOR EVENTS 82 TO 86.

Process: PAC with water injection and water muffler

Base Metal: mild steel (1" thick)

Torch: PT-15

Current Range: 400 to 600 A

Shielding Gas: N_2 (140 cfh for I = 400 A and 180 cfh for I = 600 A)

Torch Heights: 1/4", 1/2" and 3/8"

Cut Water: 0.33 gpm for I = 400 A and 0.40 gpm for I = 600 A

Nozzle Diameter: 0.156" for I = 400 A and 0.200" for I = 600 A

Summary of Results

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d'
(A)	(Cd/cm^2)	[W/cm^2.Sr)]		(S)	-	-	-	(cm)
1/4-inch gap								
400	140	-	-	-	-	5.9	-	-
3/8-inch gap								
400	180	1.4	0.16	625	-	6.2	3.8	656
600	450	7.2	0.74	135	-	7.1	5.3	400
1/2-inch gap								
400	210	2.8	-	-	-	6.4	-	377
600	1,100	8.5	-	-	-	8.0	-	377

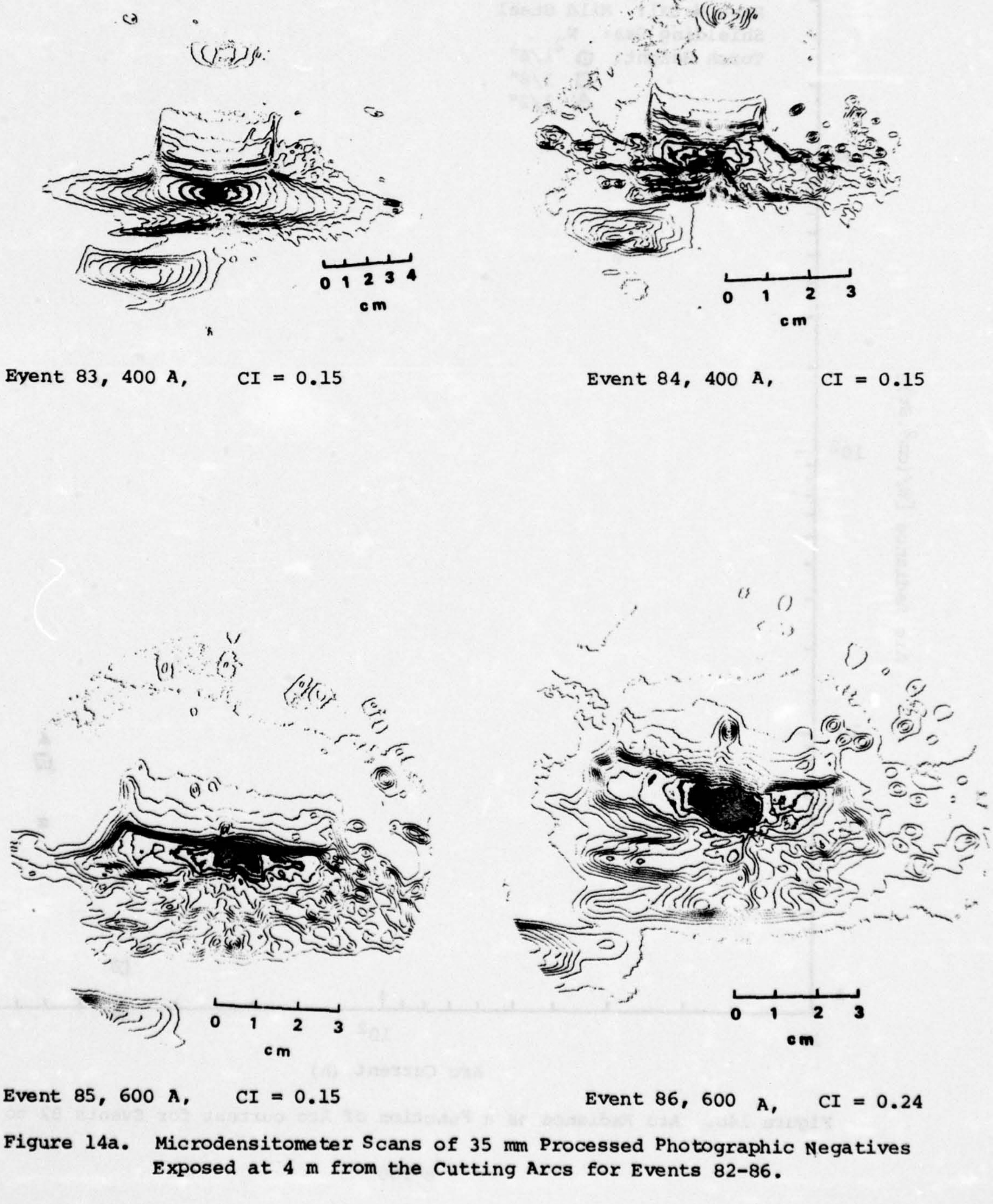


Figure 14a. Microdensitometer Scans of 35 mm Processed Photographic Negatives Exposed at 4 m from the Cutting Arcs for Events 82-86.

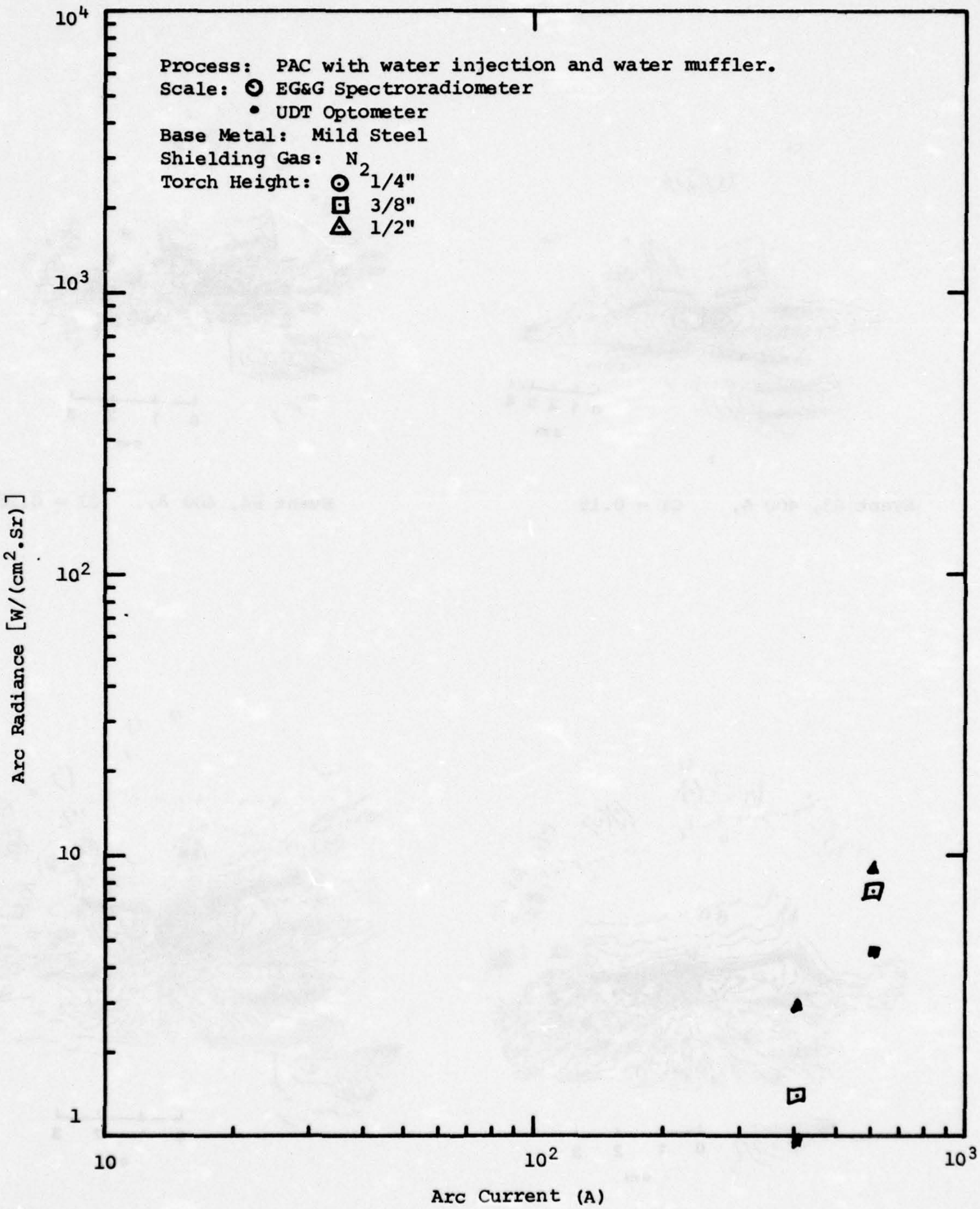


Figure 14b. Arc Radiance as a Function of Arc current for Events 82 to 86.

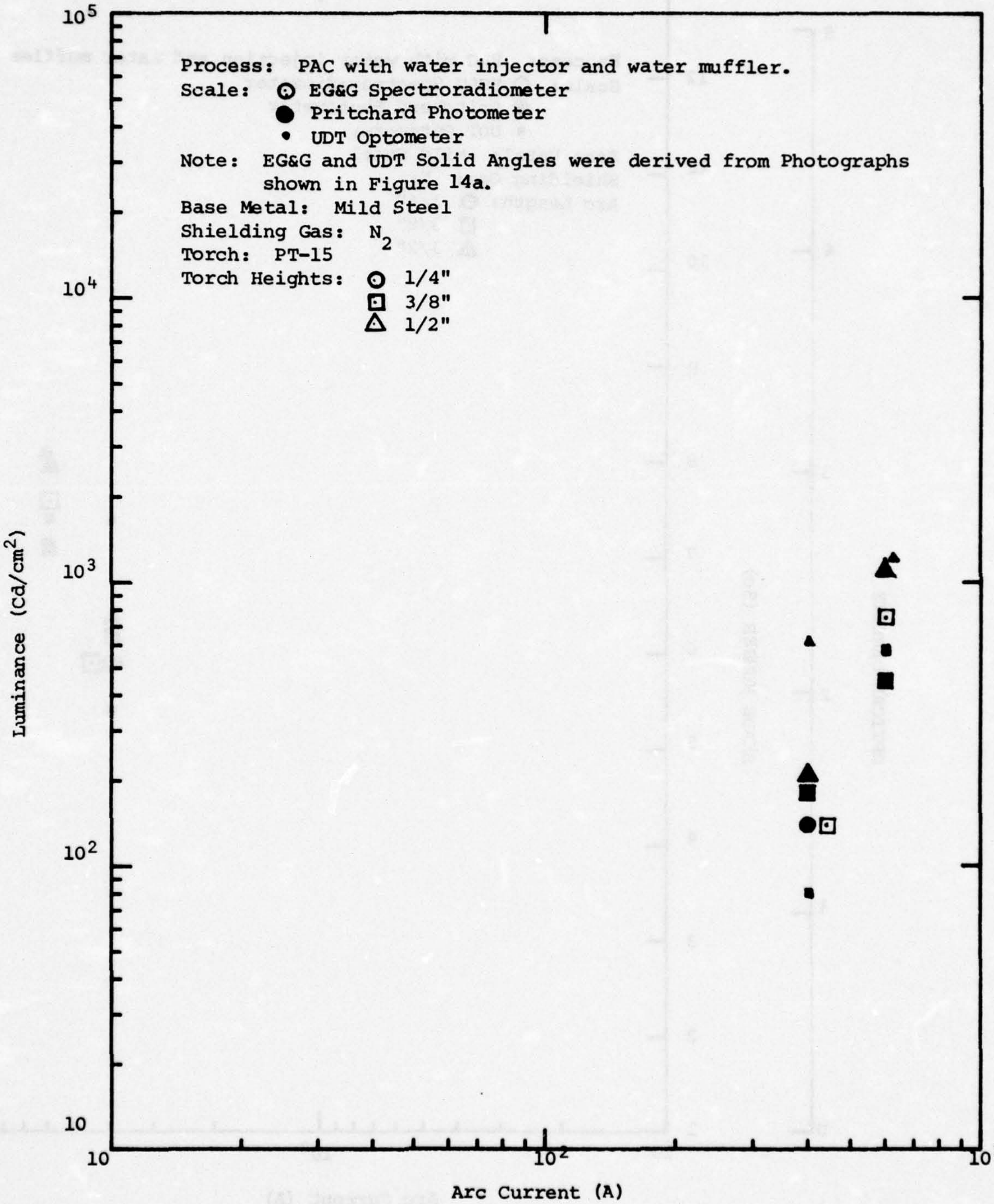


Figure 14c. Arc Luminance as a Function of Arc Current for Events 82 to 86.

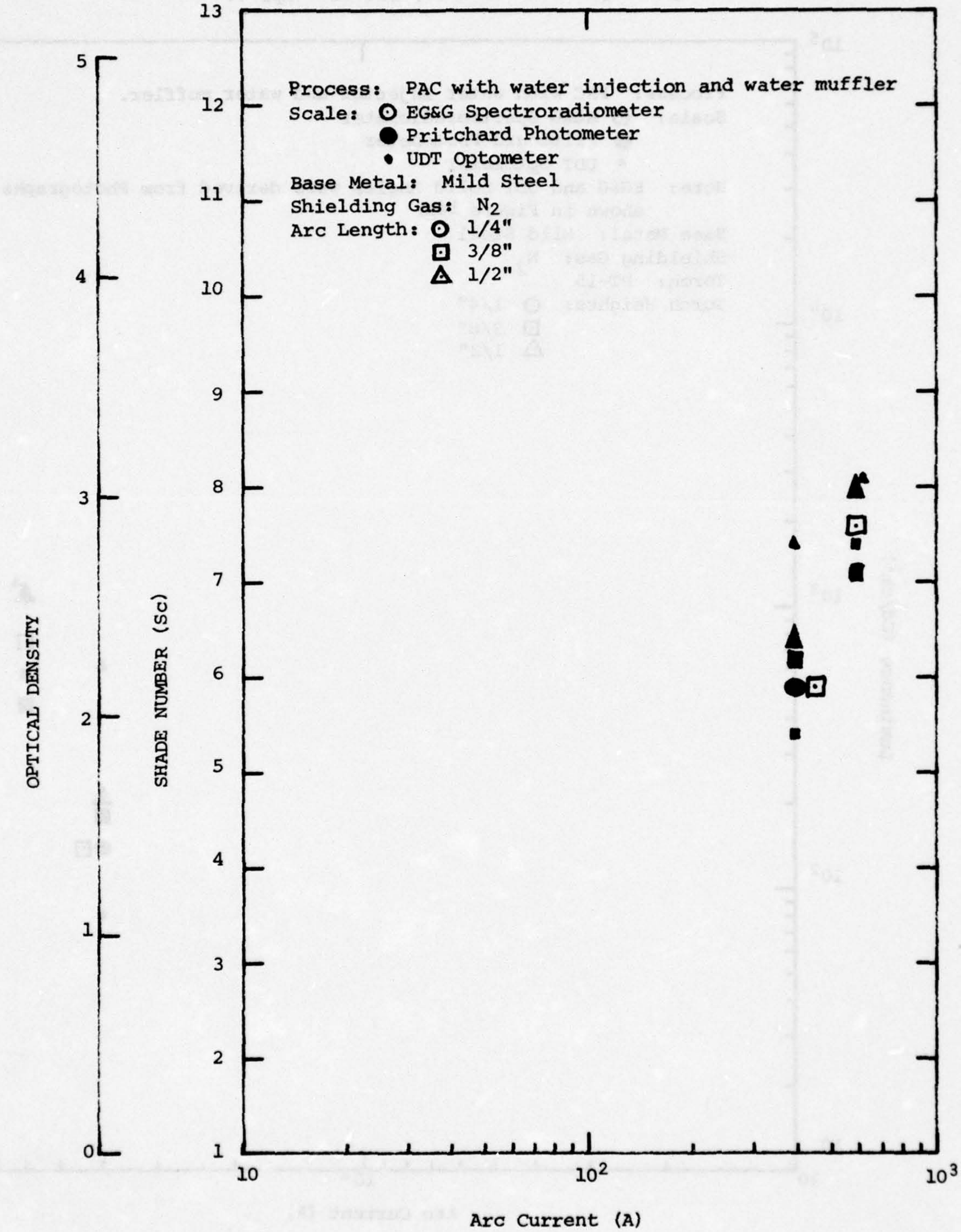


Figure 14d. Comfortable Shade Number (S_c) or Optical Density for Arc Viewing as a Function of arc current for Events 82 to 86.

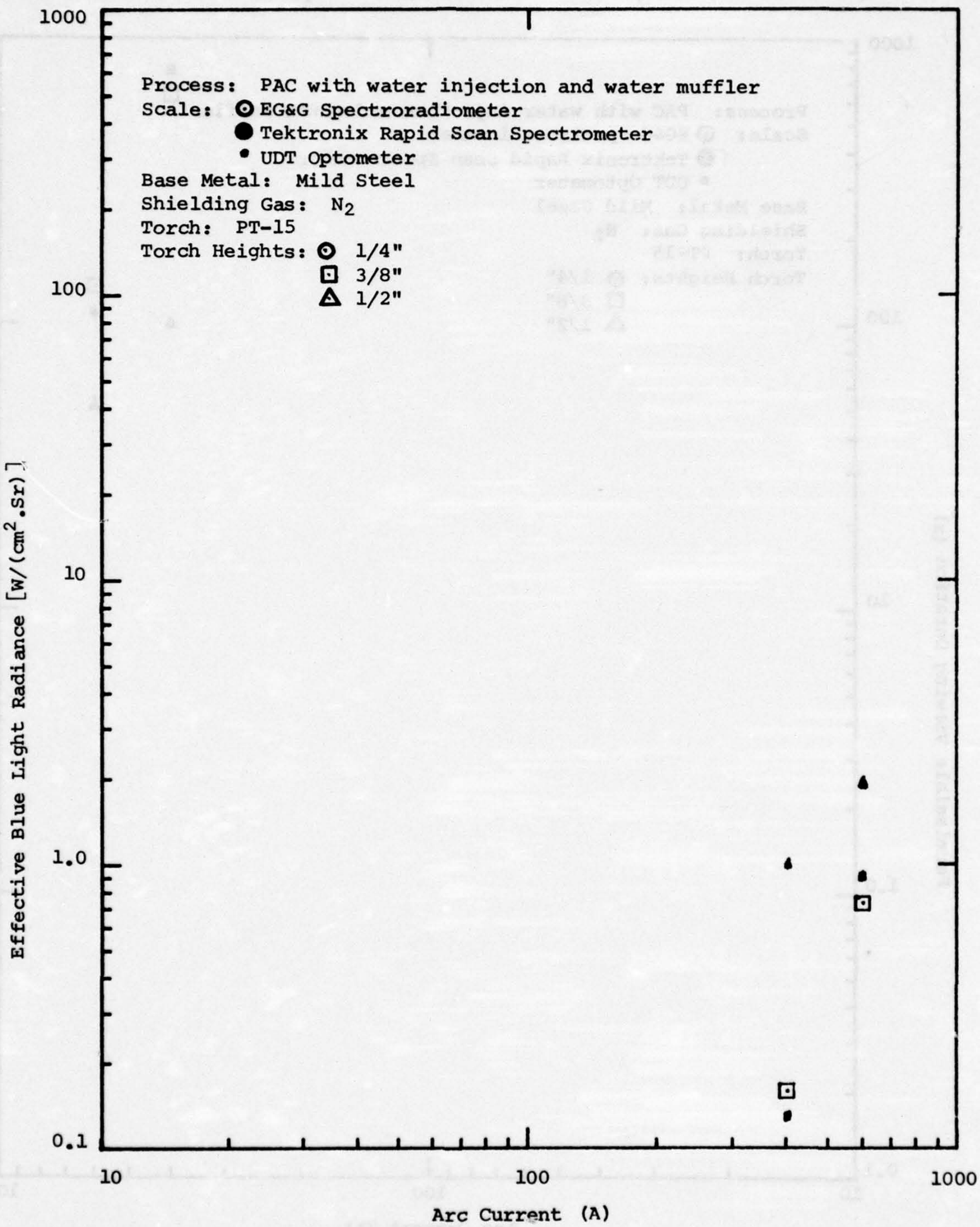


Figure 14e. Effective Blue Light Radiance as a Function of Arc Current for Events 82 to 86.

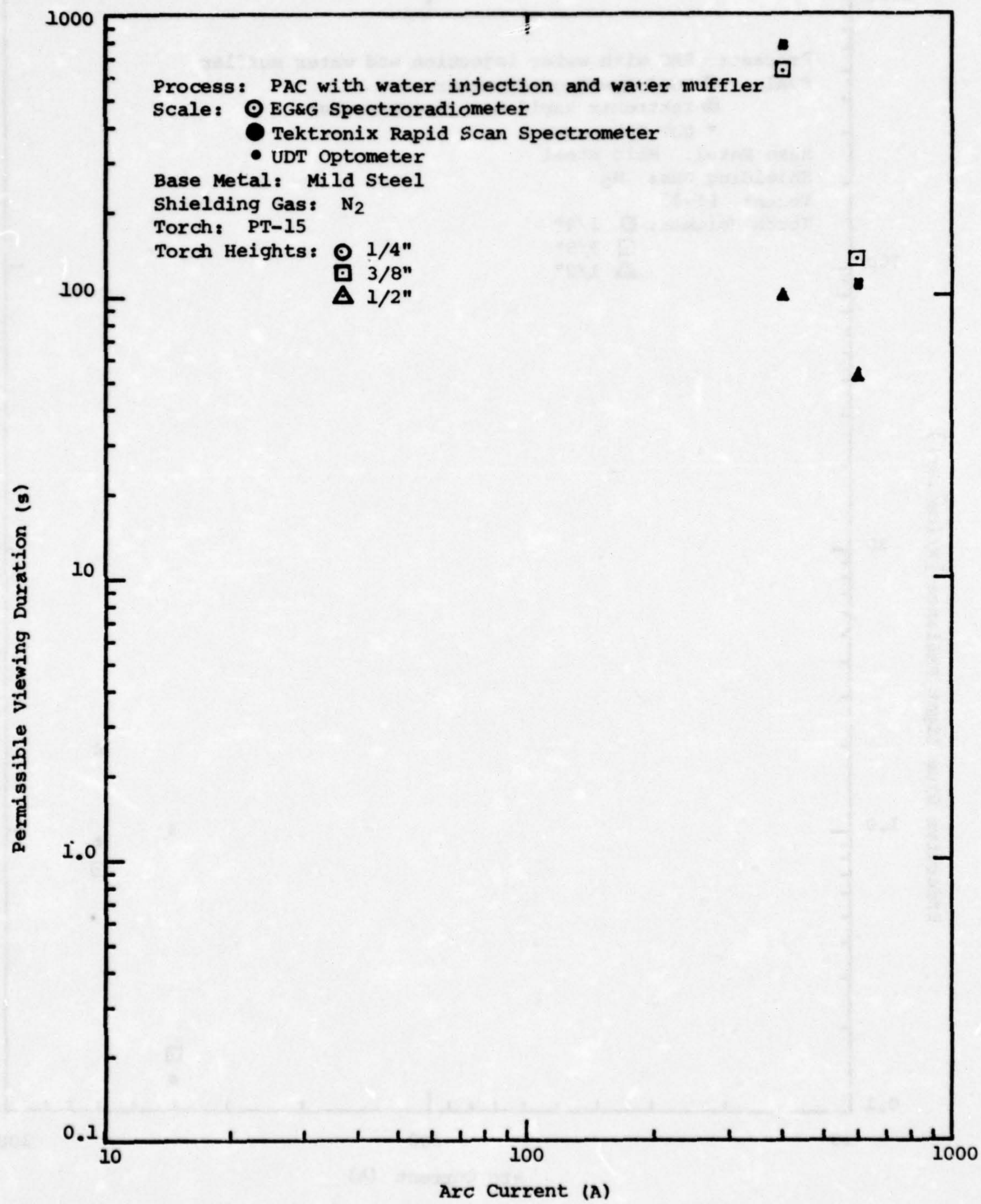


Figure 14f. Permissible Viewing Duration as a Function of Arc Current for Events 82 to 86 at Distances less than 3.0 m.

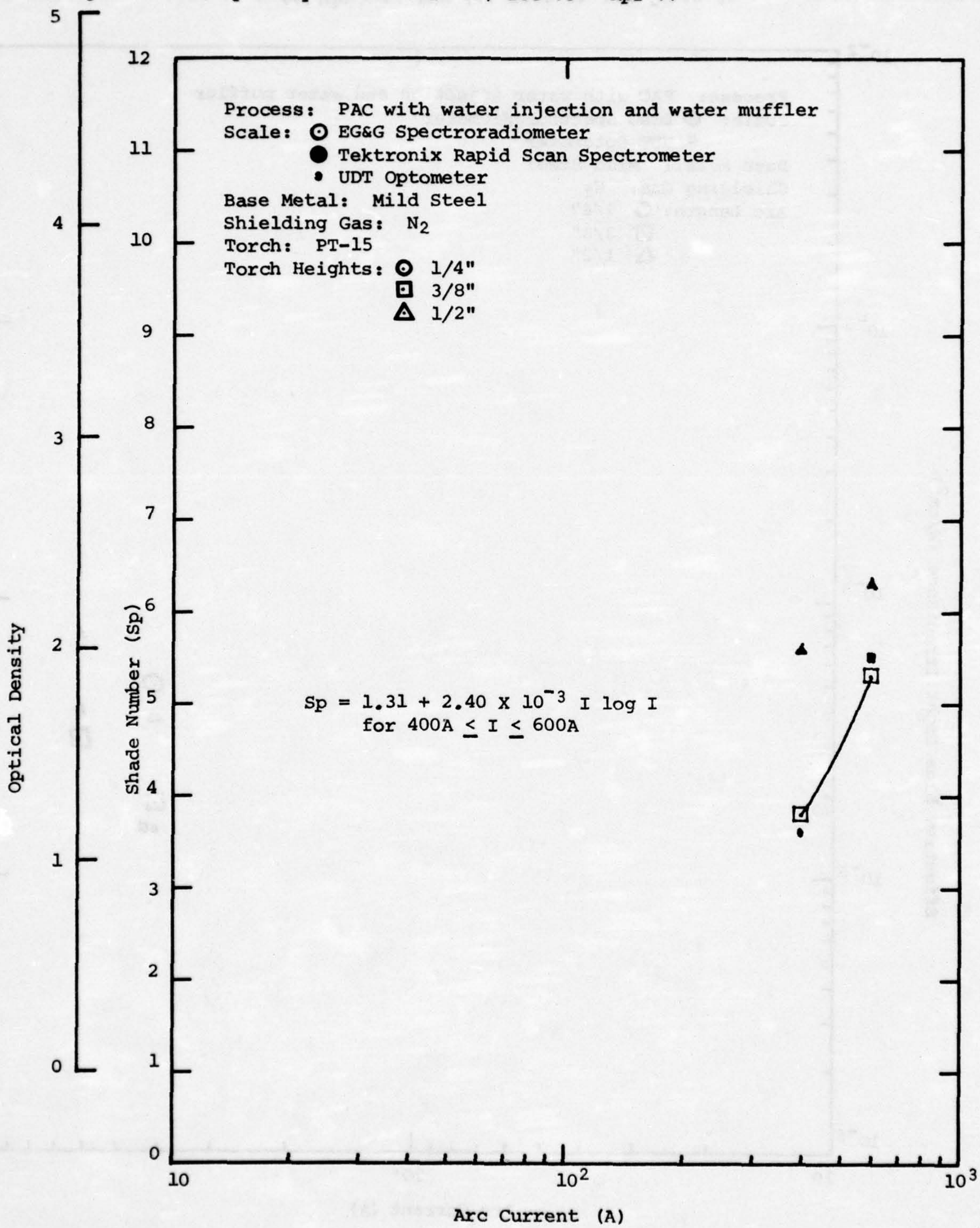


Figure 14g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 82 to 86.

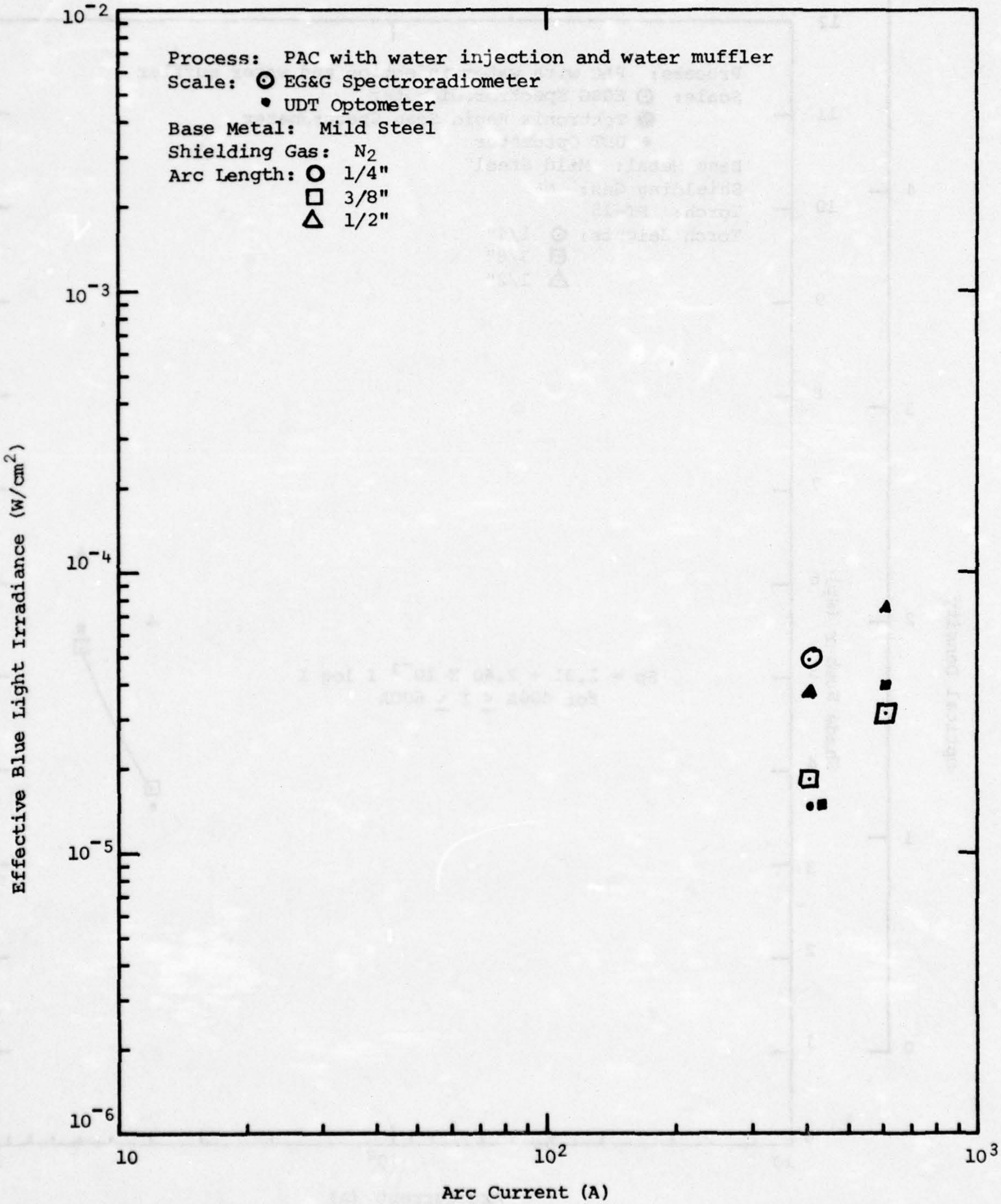


Figure 14h. Effective Blue Light Irradiance as a Function of Arc Current for Events 82 to 86.

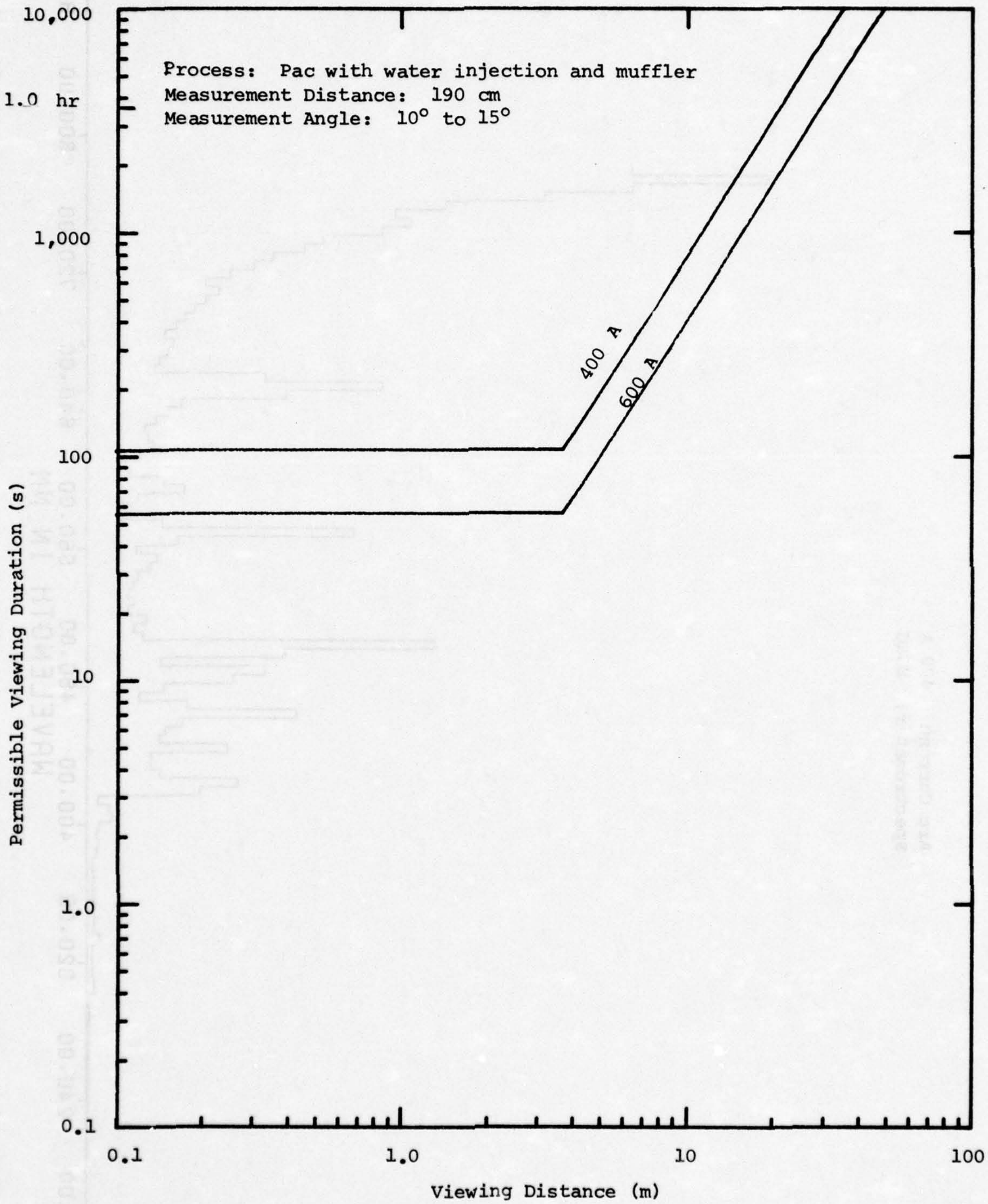


Figure 14i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 82 to 86.

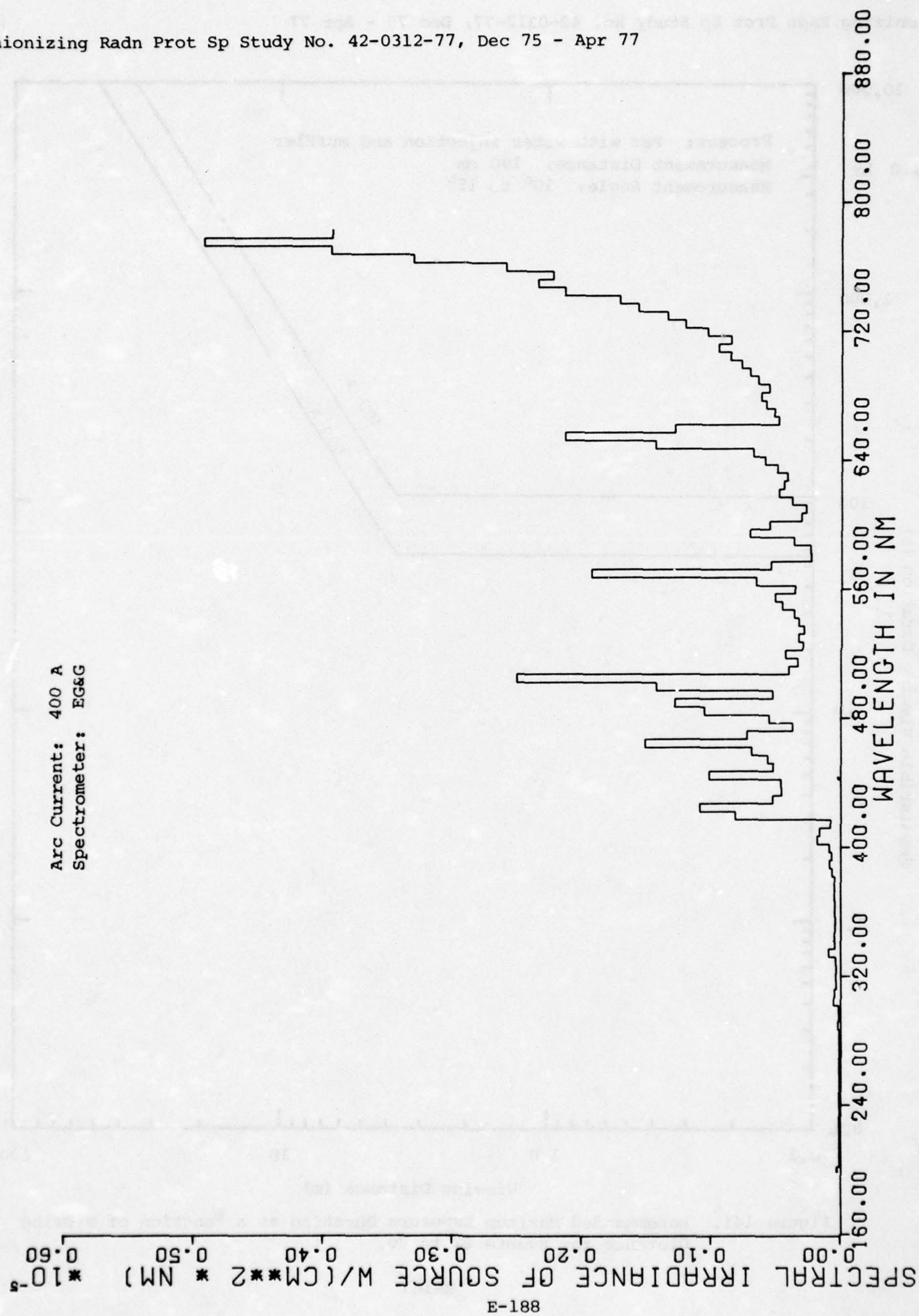


FIGURE 14j. ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 82

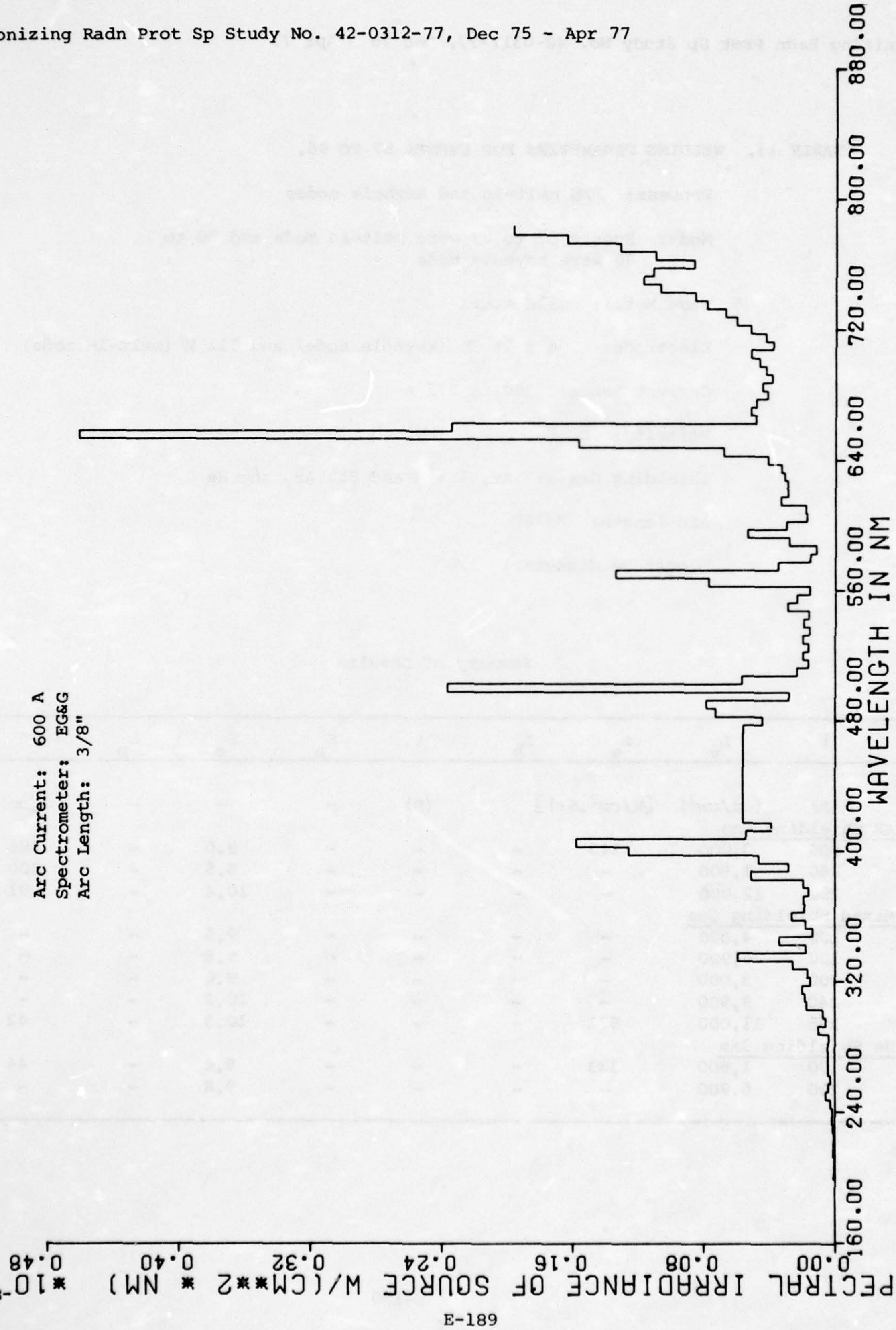


FIGURE 14k . ABSOLUTE SPECTRAL IRRADIANCE AT 190 CM FOR EVENT 85

TABLE 15. WELDING PARAMETERS FOR EVENTS 87 TO 96.

Process: PAW melt-in and keyhole modes

Mode: Events 87 to 89 were melt-in mode and 90 to 96 were keyhole mode

Base Metal: mild steel

Electrode: 304 x 2% Th (keyhole mode) and 111 M (melt-in mode)

Current Range: 100 to 275 A

Polarity: DCSP

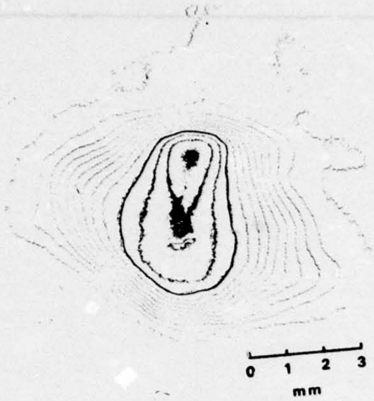
Shielding Gases: Ar, 15% H and 85% Ar, and He

Arc Length: 3/16"

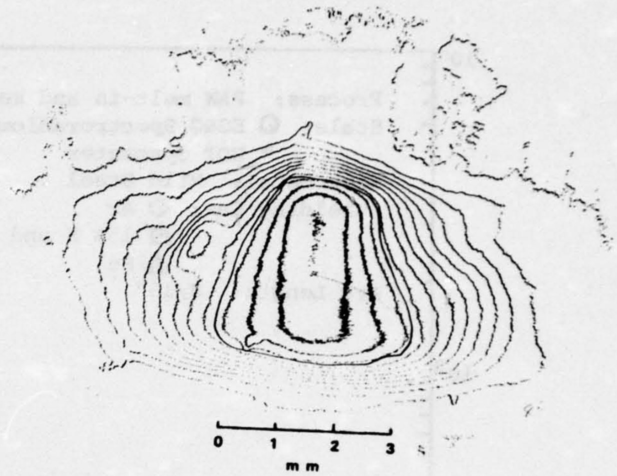
Electrode diameter: 1/8"

Summary of Results

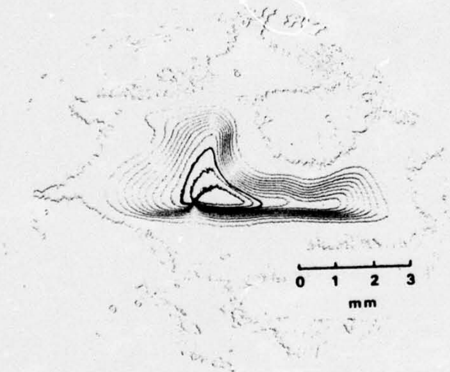
I	L_v	L_e	L_b	t	S_a	S_c	S_p	d
(A)	(cd/cm^2)	[W/cm^2.Sr)]		(S)	-	-	-	(cm)
AR Shielding Gas								
200	3,000	113	-	-	-	9.0	-	106
260	1,800	-	-	-	-	8.5	-	100
260	12,000	-	-	-	-	10.4	-	91
Mixed Shielding Gas								
100	4,800	-	-	-	-	9.5	-	-
100	6,900	-	-	-	-	9.8	-	-
200	3,000	-	-	-	-	9.0	-	-
240	9,900	-	-	-	-	10.2	-	-
275	11,000	571	-	-	-	10.3	-	42
He Shielding Gas								
100	1,600	333	-	-	-	8.4	-	44
200	6,900	-	-	-	-	9.8	-	-



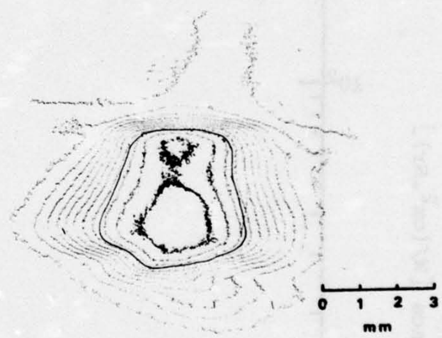
Event 87, 260 A, CI = 0.14



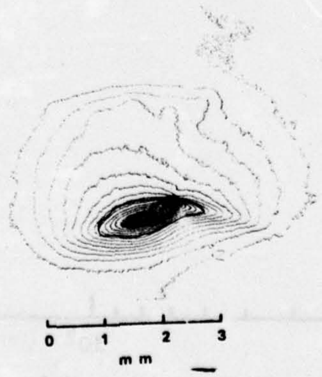
Event 88, 260 A, CI = 0.125



Event 90, 275 A, CI = 0.14



Event 93, 200 A, CI = 0.12



Event 95, 100 A, CI = 0.08

Figure 15a. Microdensitometer Scans of 35 mm processed Photographic Negatives Exposed at 4 m from the Welding Arcs for Events 87 - 96.

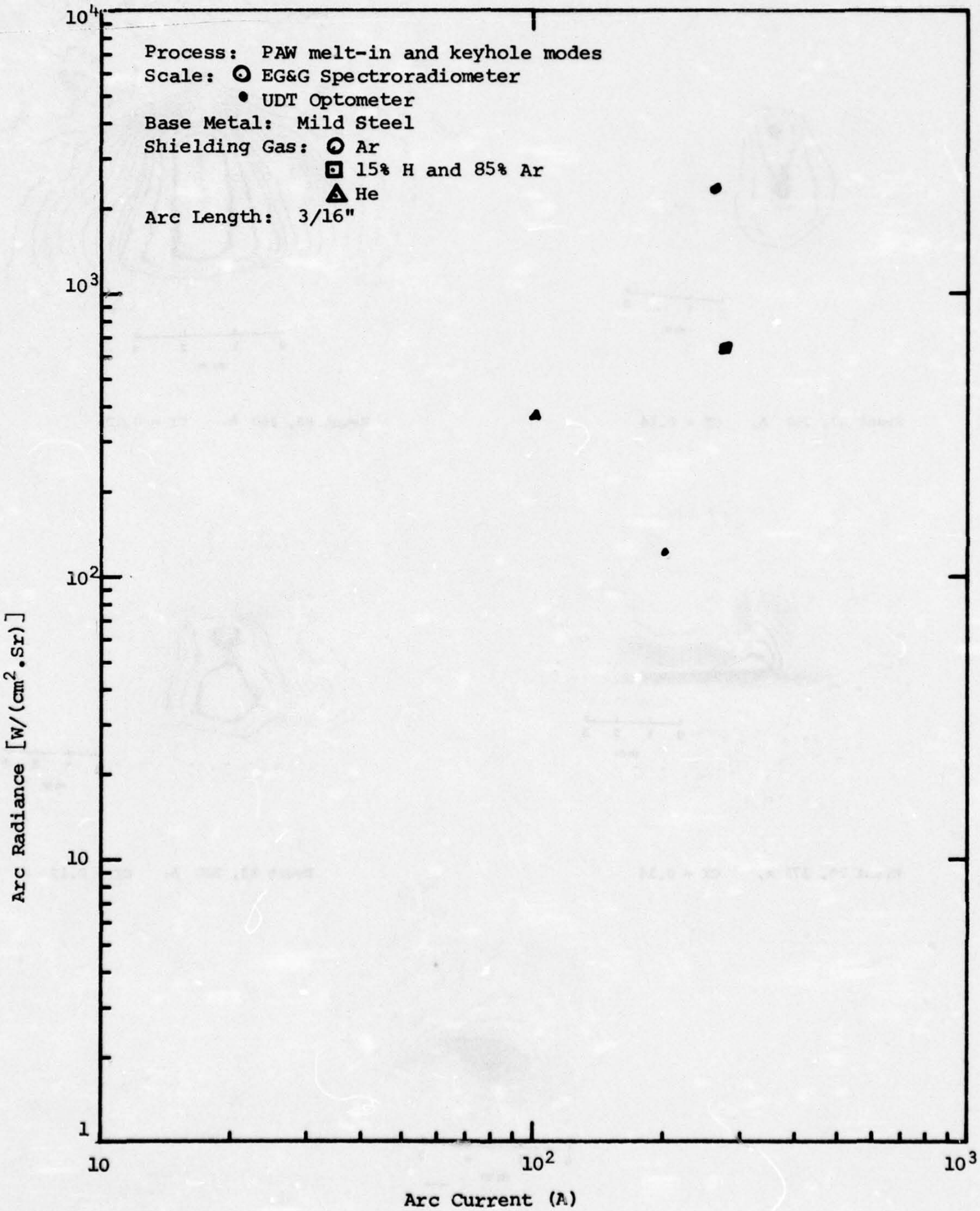


Figure 15b. Arc Radiance as a Function of Arc Current for Events 87 to 96.

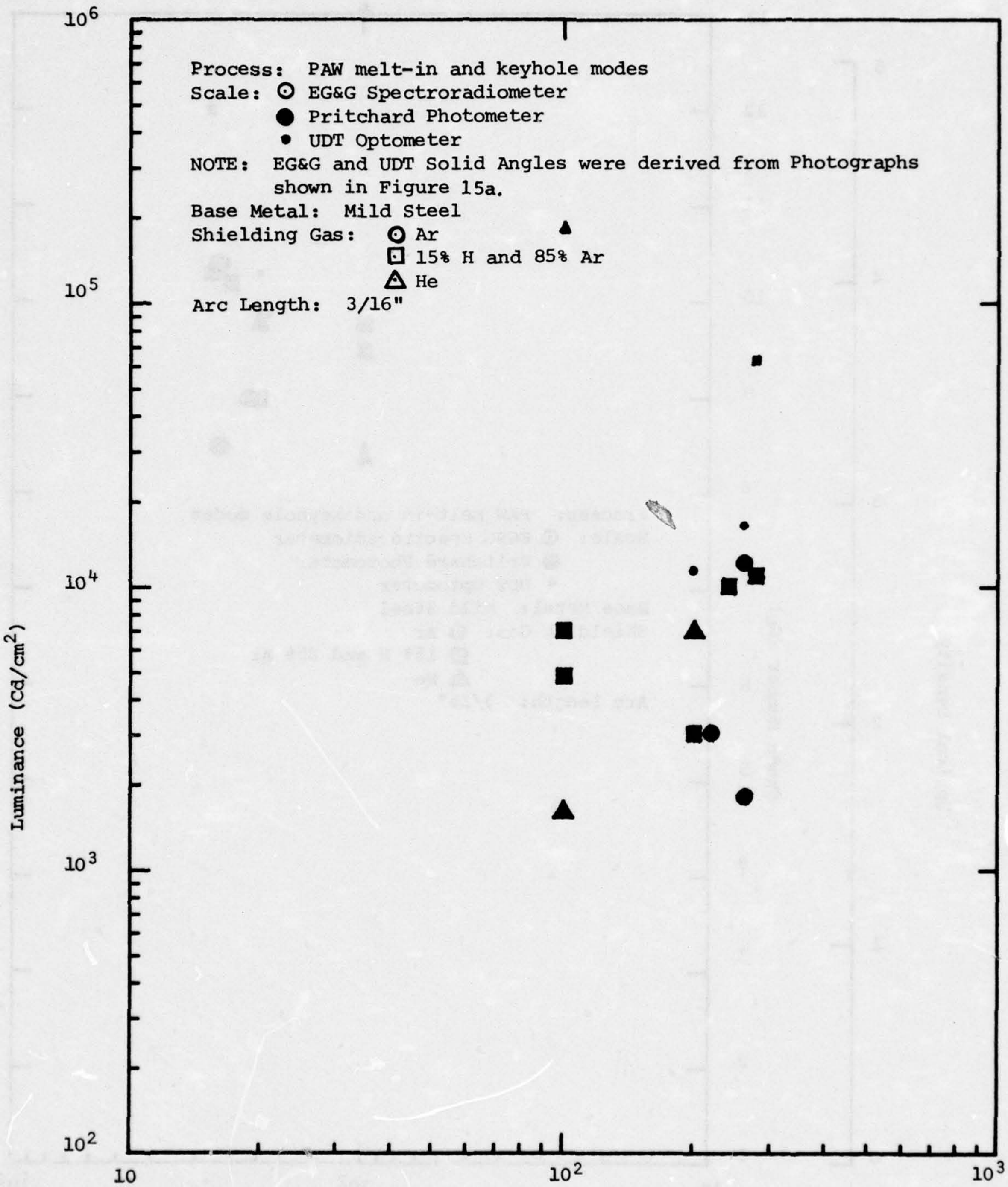


Figure 15c. Arc Luminance as a Function of Arc Current for Events 87 to 96.

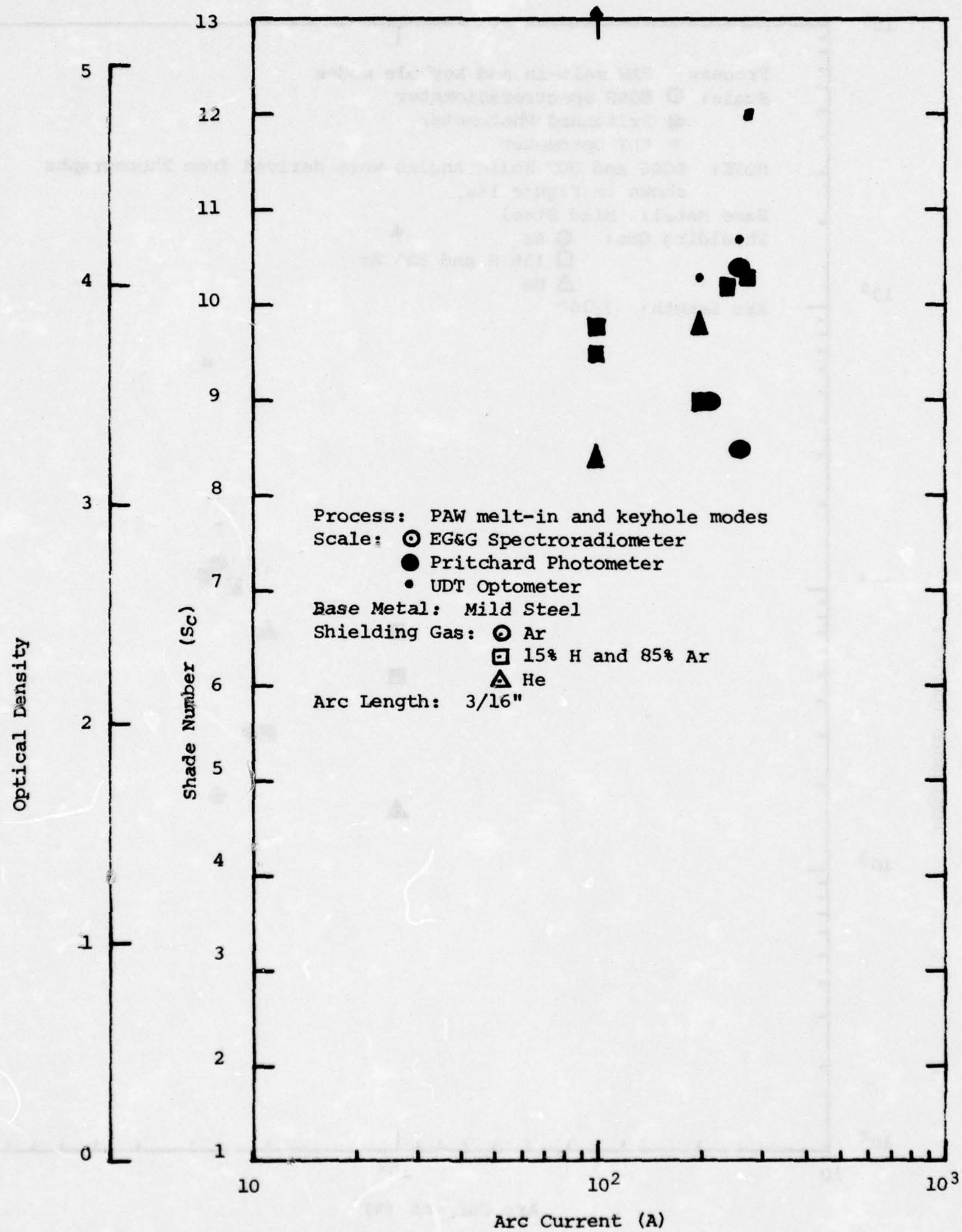


Figure 15d. Comfortable Shade Number (Sc) or Optical Density for Arc Viewing as a Function of Arc Current for Events 87 to 96.

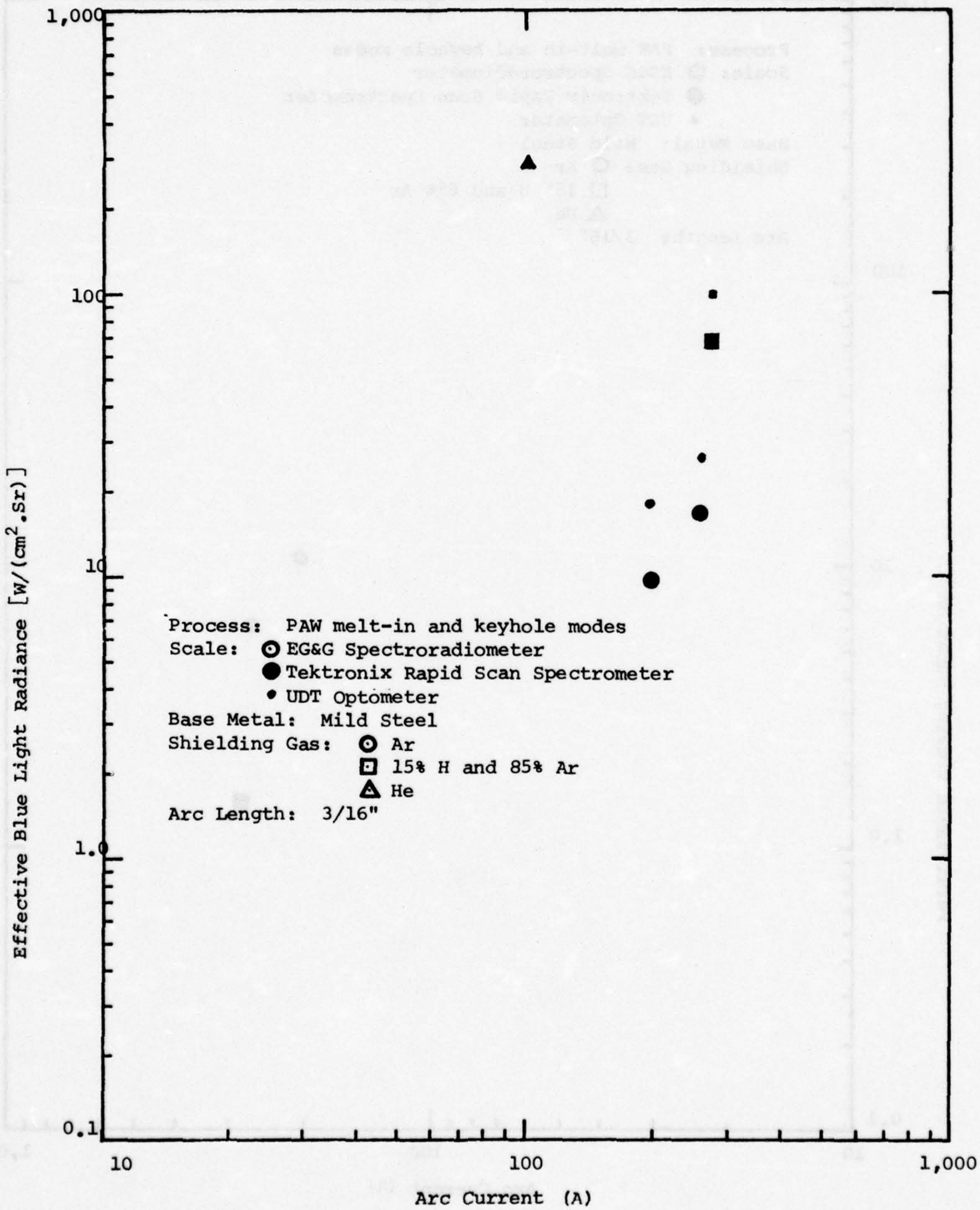


Figure 15e. Effective Blue Light Radiance as a Function of Arc Current for Events 87 to 96.

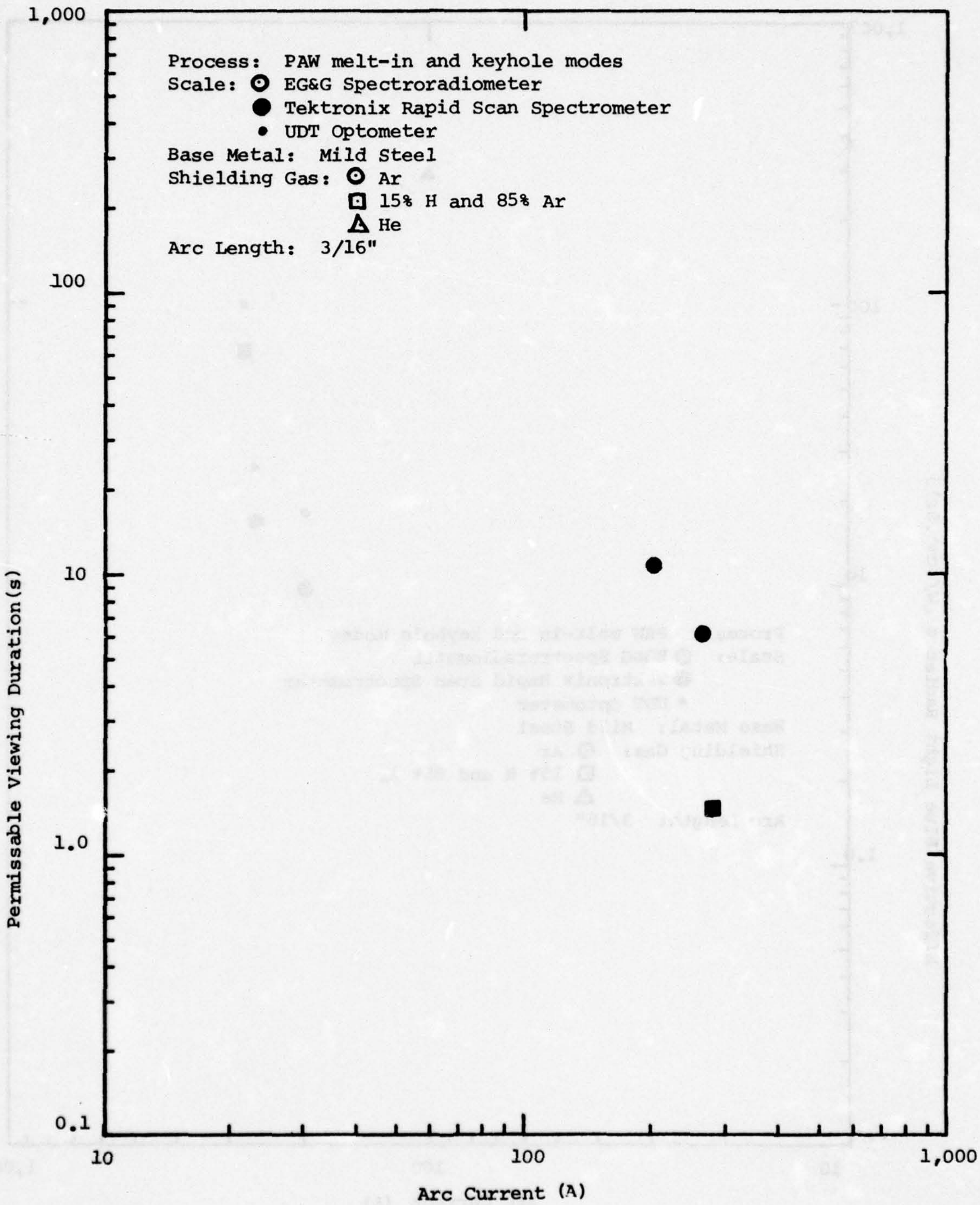


Figure 15f. Permissible Viewing Duration as a Function of Arc Current for Events 87 to 96 at Distances less than 0.4 m.

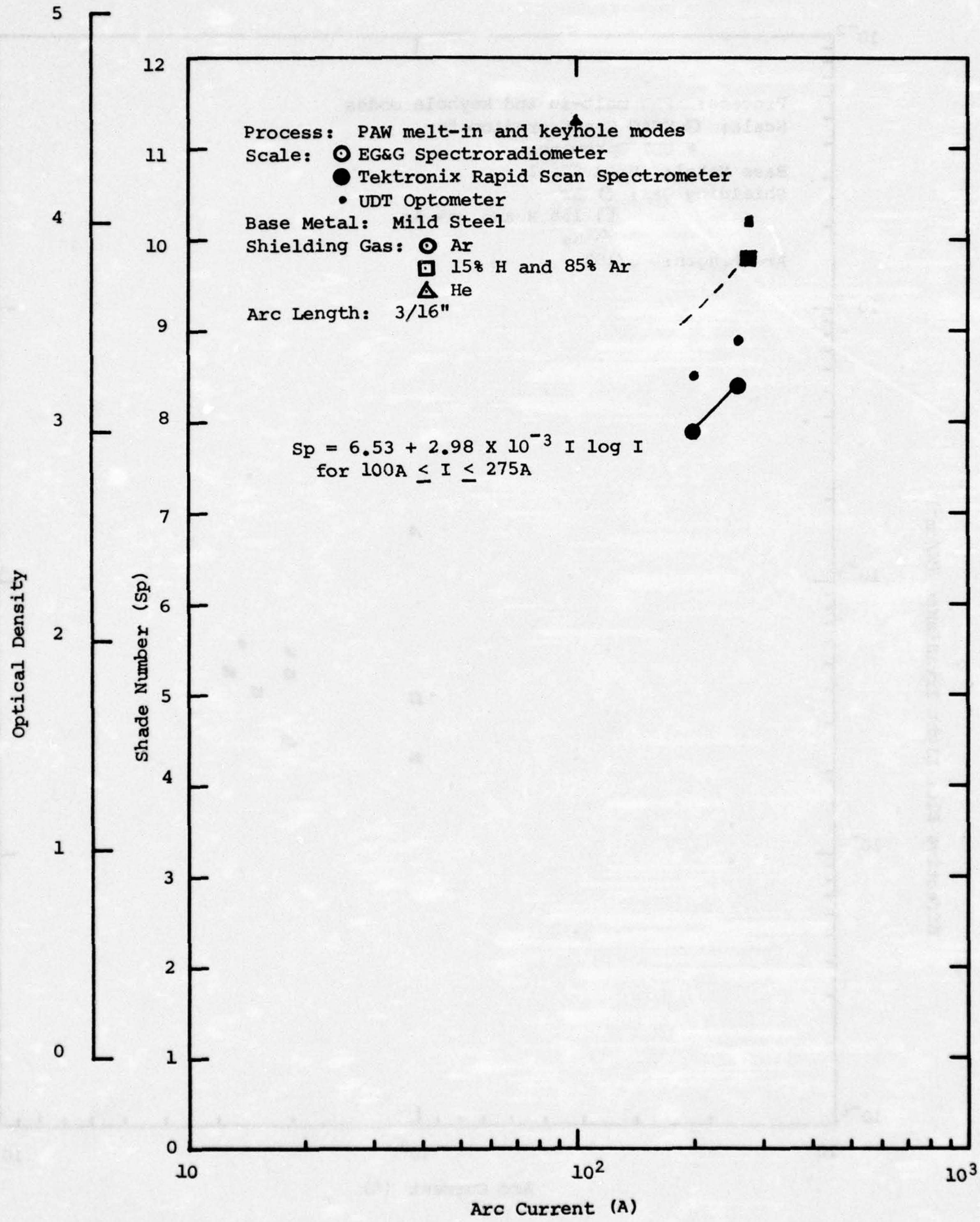


Figure 15g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 87 to 96.

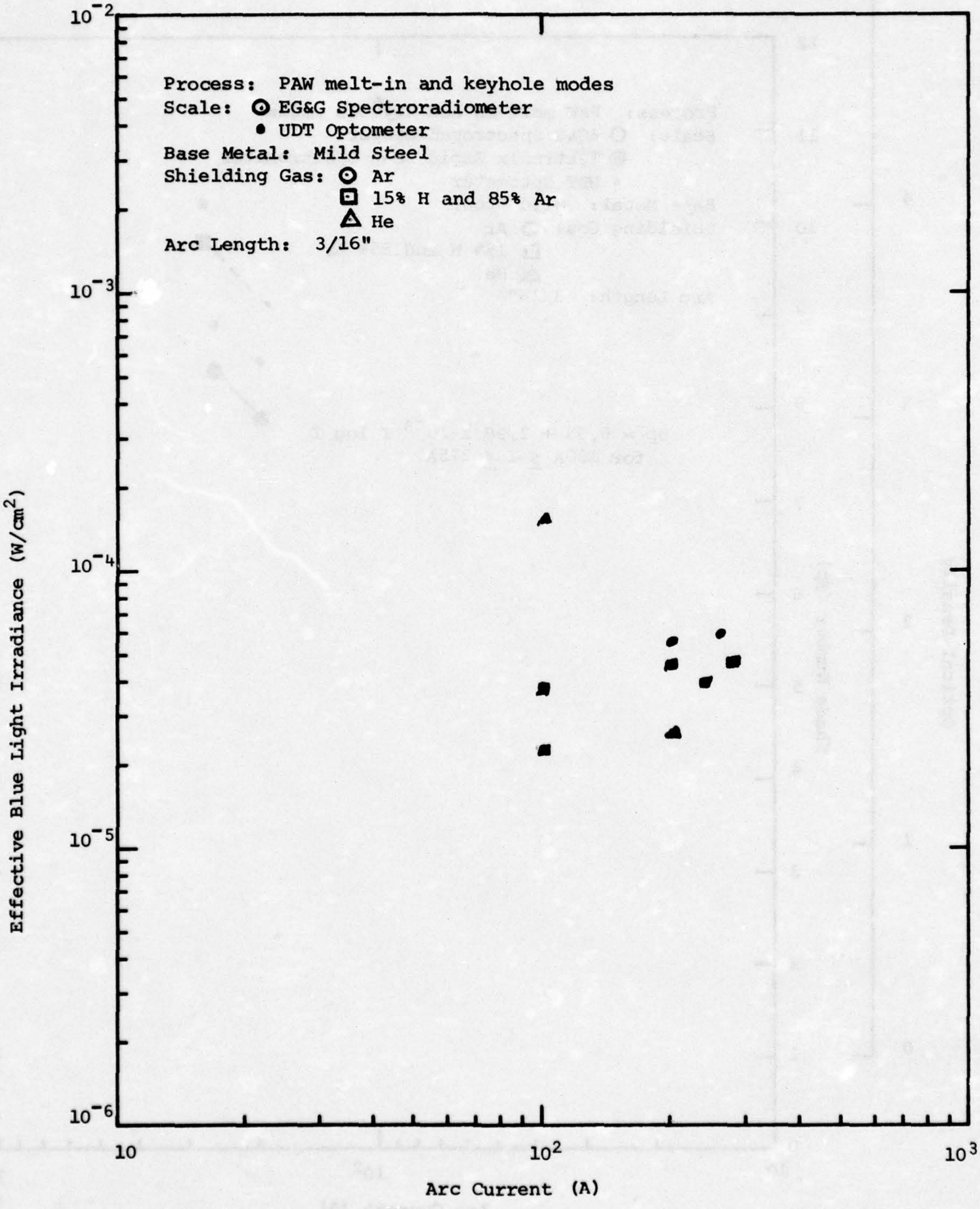


Figure 15h. Effective Blue Light Irradiance as a Function of Arc Current for Events 87 to 96.

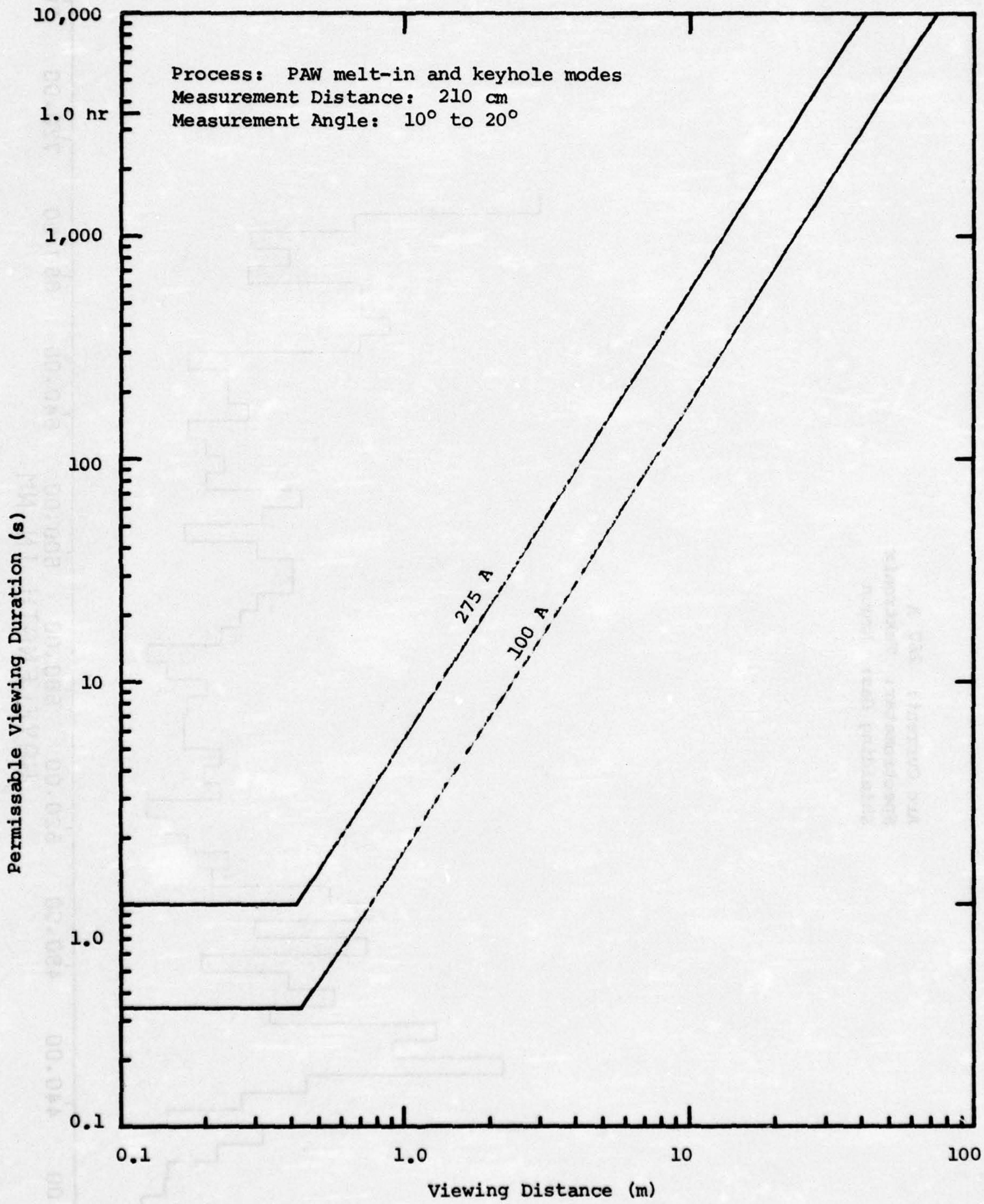


Figure 15i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 87 to 96.

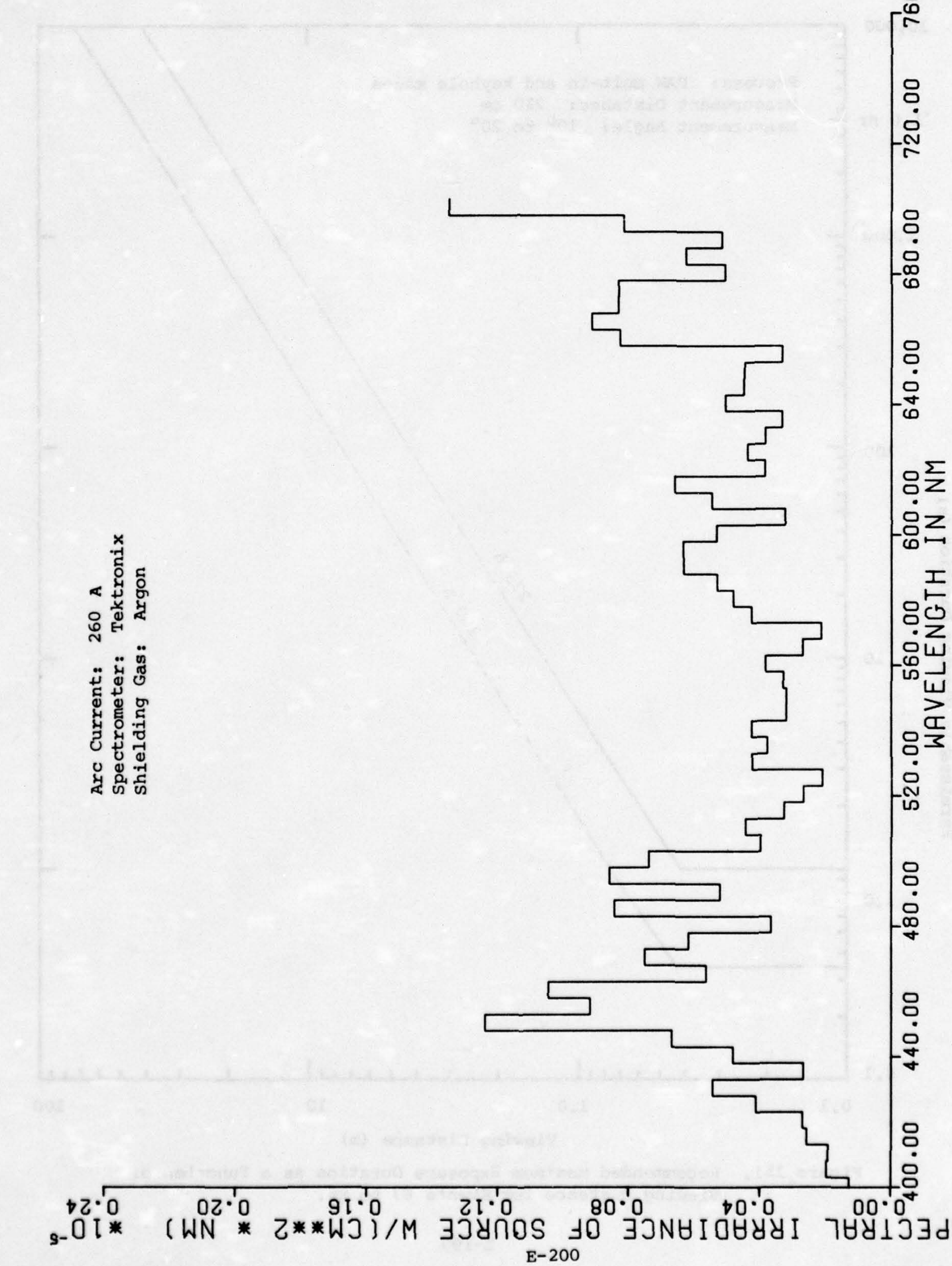


FIGURE 15j . ABSOLUTE SPECTRAL IRRADIANCE AT 210 CM FOR EVENT 87

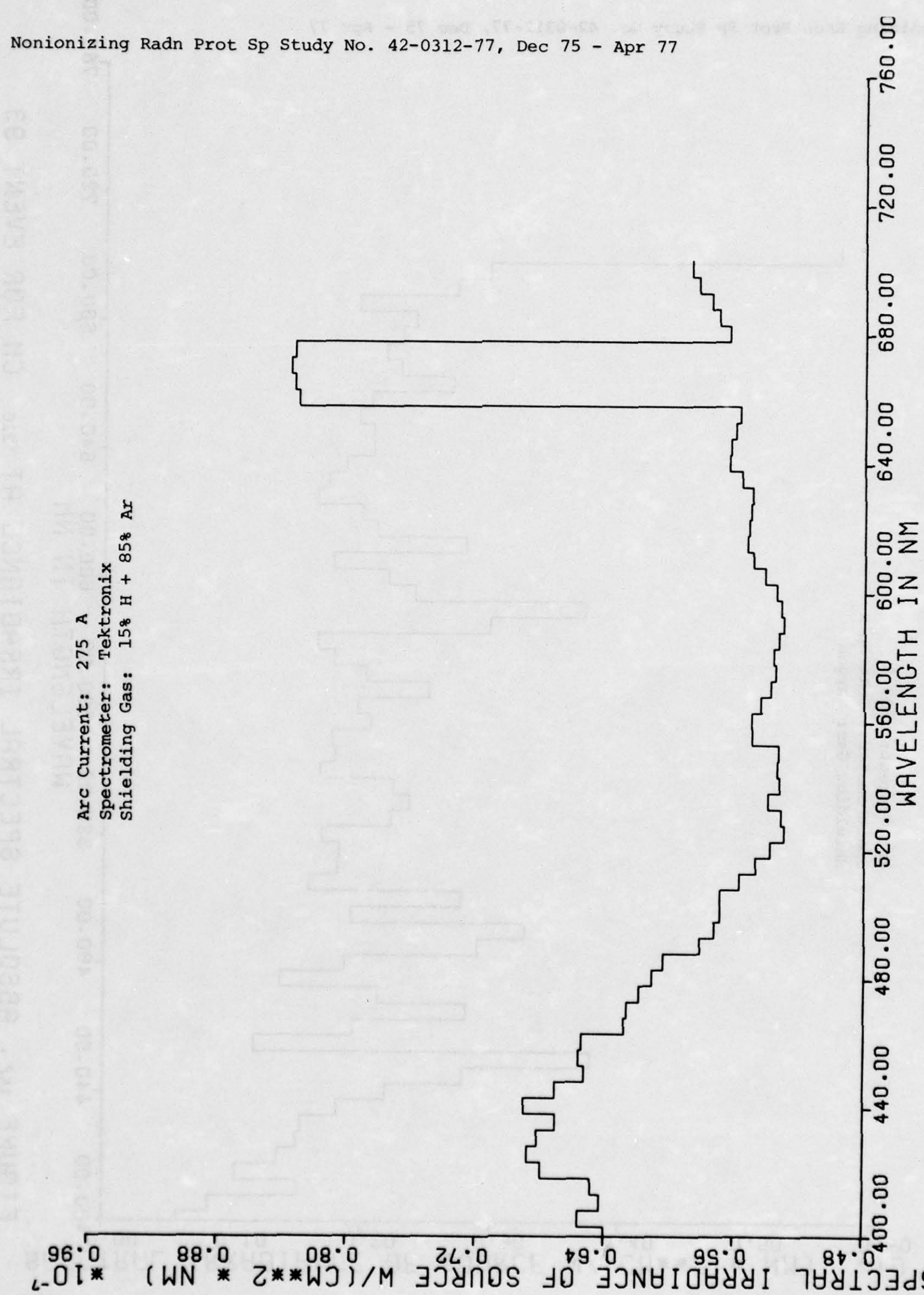


FIGURE 15k. ABSOLUTE SPECTRAL IRRADIANCE AT 210 CM FOR EVENT 90

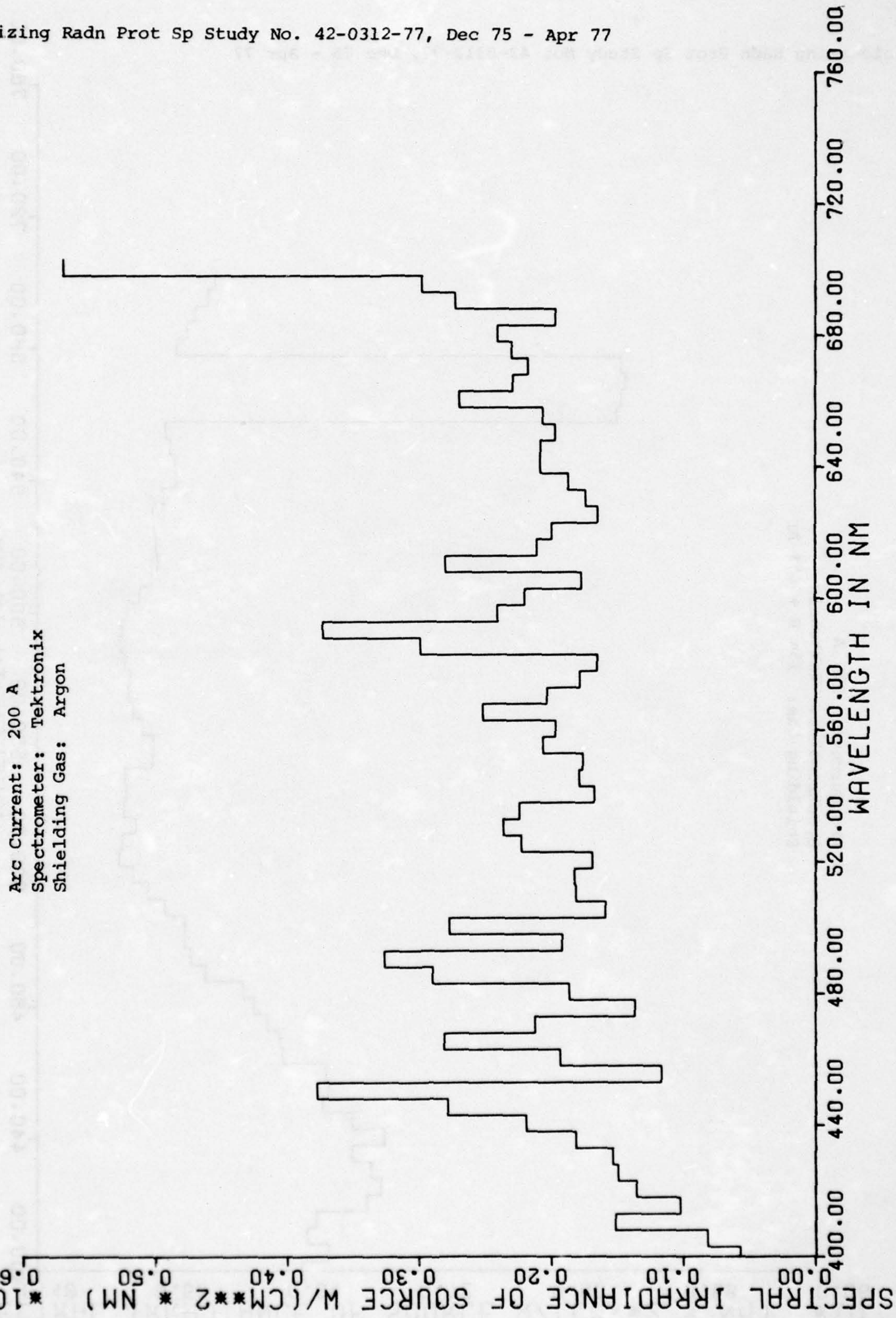


FIGURE 15ℓ. ABSOLUTE SPECTRAL IRRADIANCE AT 210 CM FOR EVENT 93

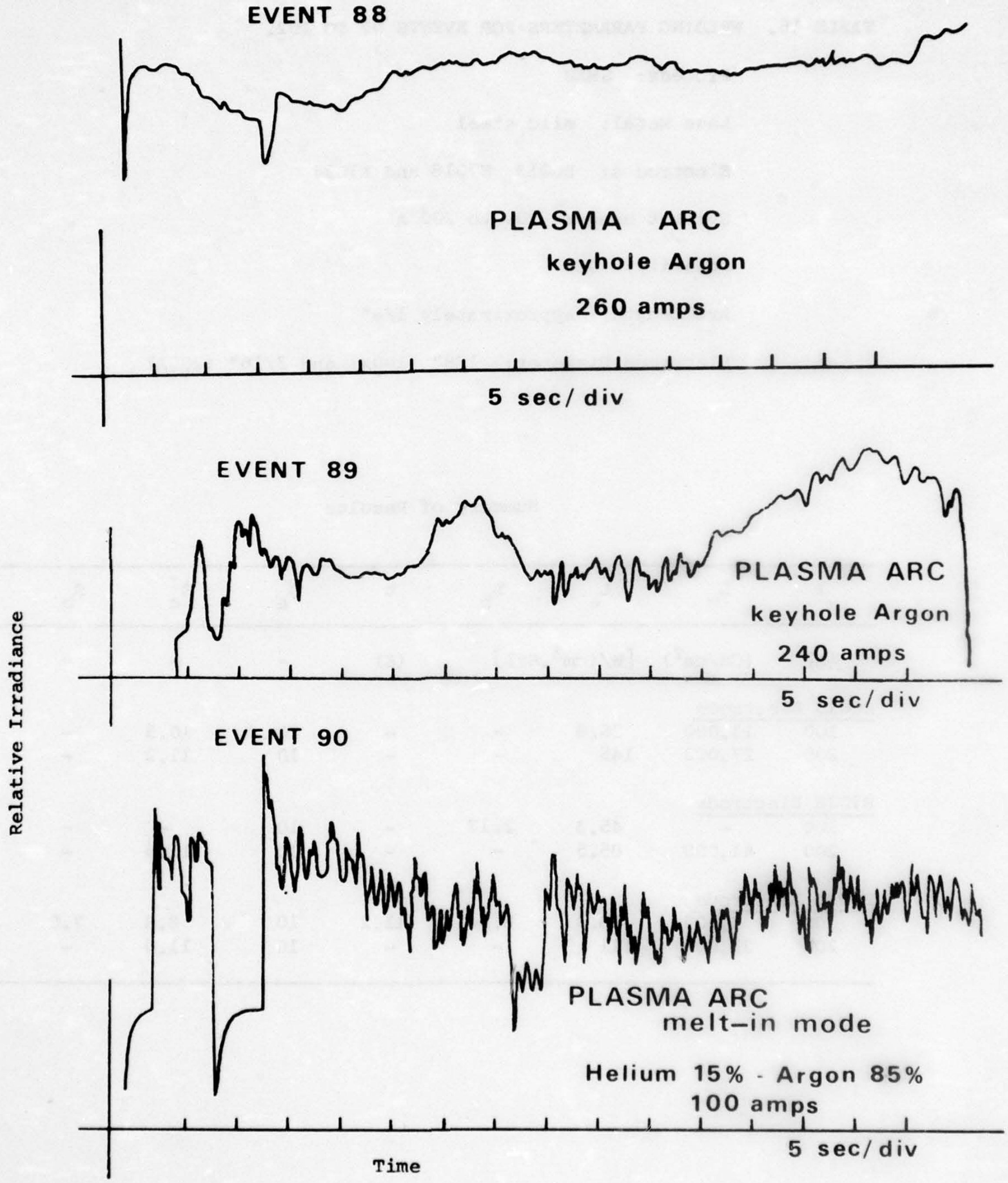


Figure 15m. Relative Irradiance (UDT 40X) versus Time for Events 88, 89, and 90.

TABLE 16. WELDING PARAMETERS FOR EVENTS 97 TO 102.

Process: SMAW

Base Metal: mild steel

Electrodes: E6013, E7018 and E7024

Current Range: 100 to 200 A

Polarity: DCRP

Arc Length: approximately 1/8"

Electrode Diameter: 1/8" (100A) and 3/16" (200A)

Summary of Results

I	L_v	L_e	L_b	t	S_a	S_c	S_b	d
(A)	(Cd/cm^2)	[$W/(cm^2 \cdot Sr)$]		(S)	-	-	-	(cm)
E6013 Electrode								
100	13,000	26.8	-	-	10	10.5	-	211
200	27,000	145	-	-	10	11.2	-	235
E7018 Electrode								
100	-	45.3	2.17	-	10	-	-	152
200	41,000	85.5	-	-	10	11.6	-	216
E7024 Electrode								
100	1,500	68.4	8.94	11.2	10	8.3	7.8	176
200	23,000	111	-	-	10	11.0	-	268

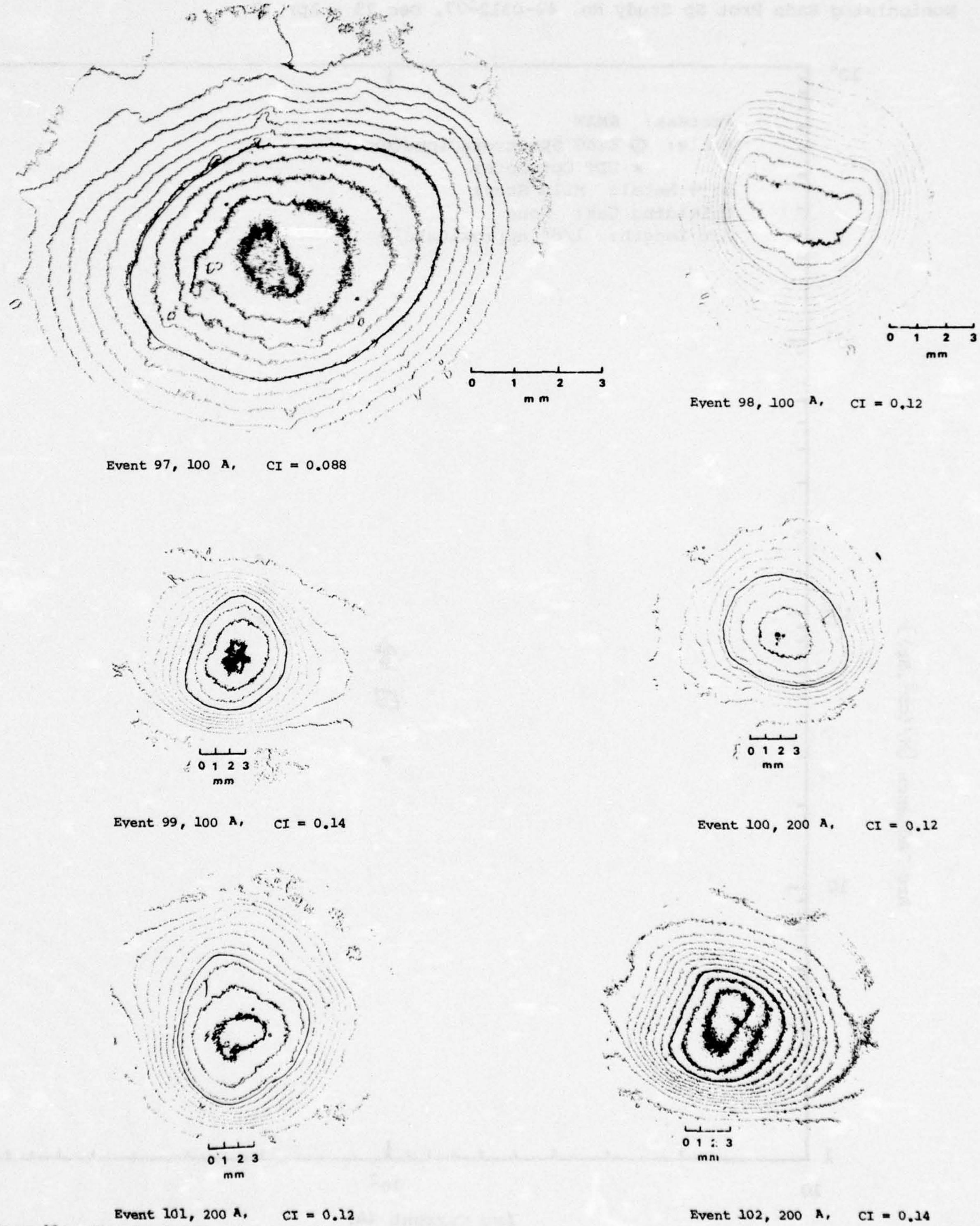


Figure 16a. Microdensitometer Scans of 35 mm Processed Negatives Exposed 4 m from the Welding Arcs for Events 97 to 102.

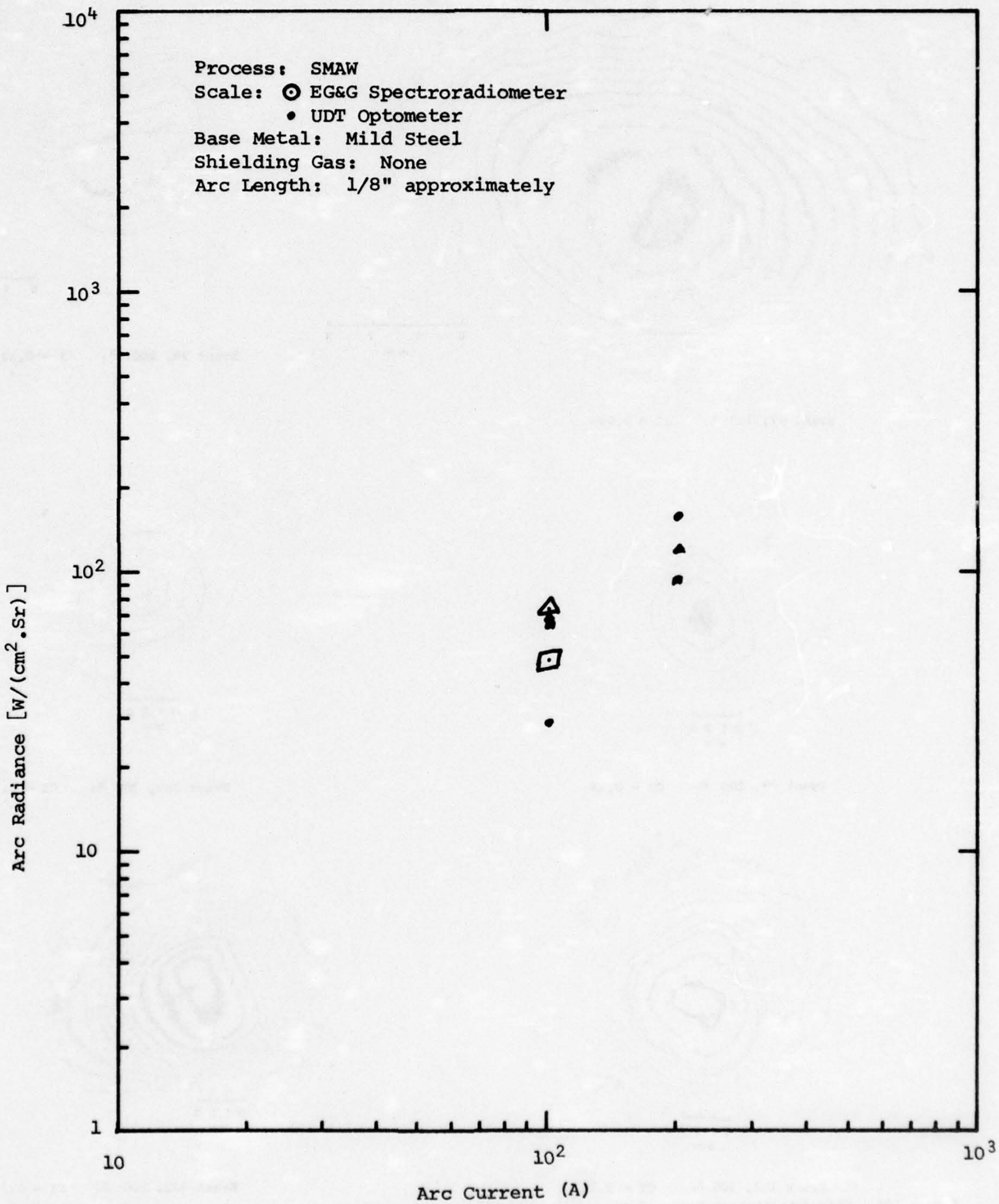


Figure 16b. Arc Radiance as a Function of Arc Current for Events 97 to 102.

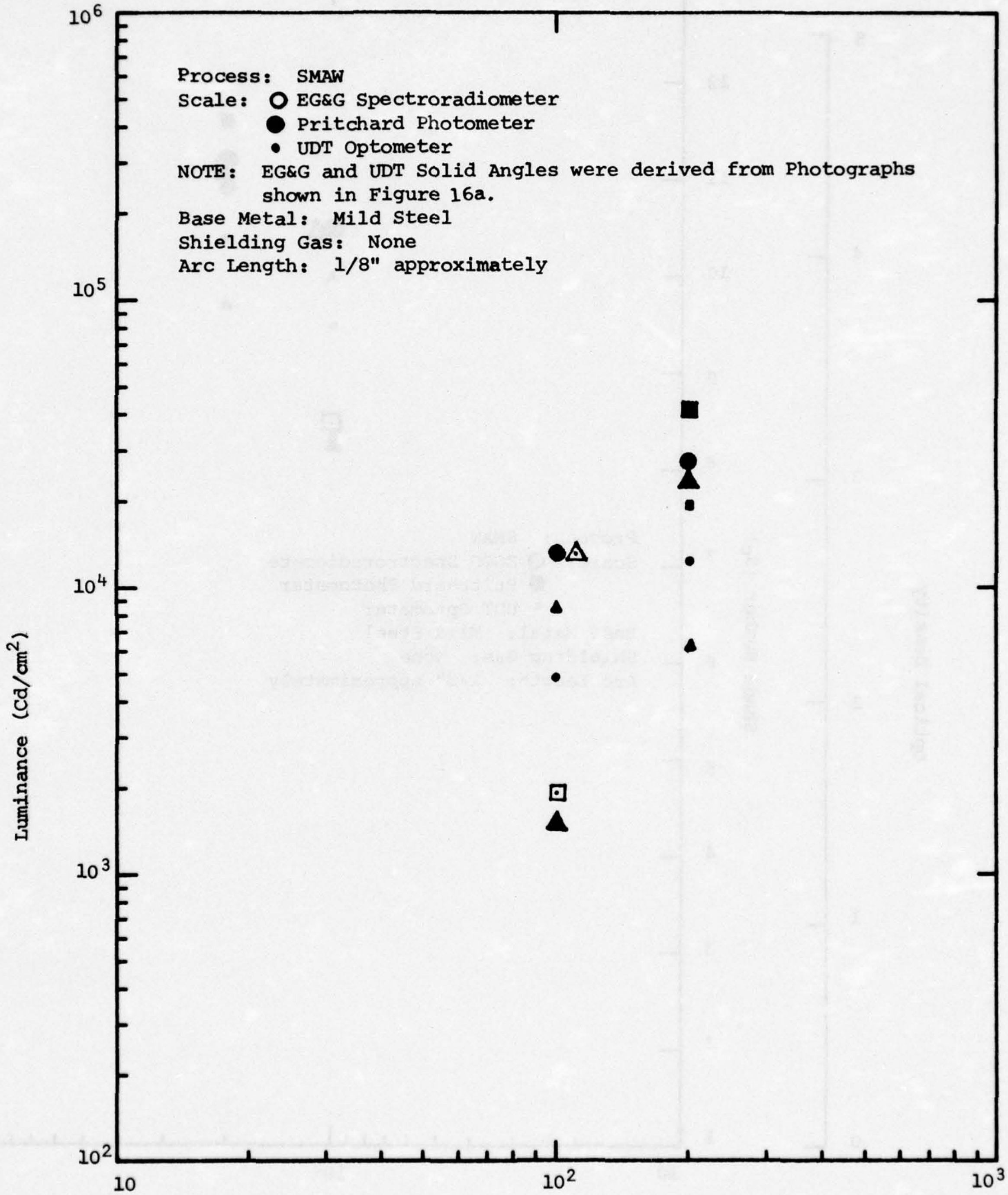


Figure 16c. Arc Luminance as a Function of Arc Current for Events 97 to 102.

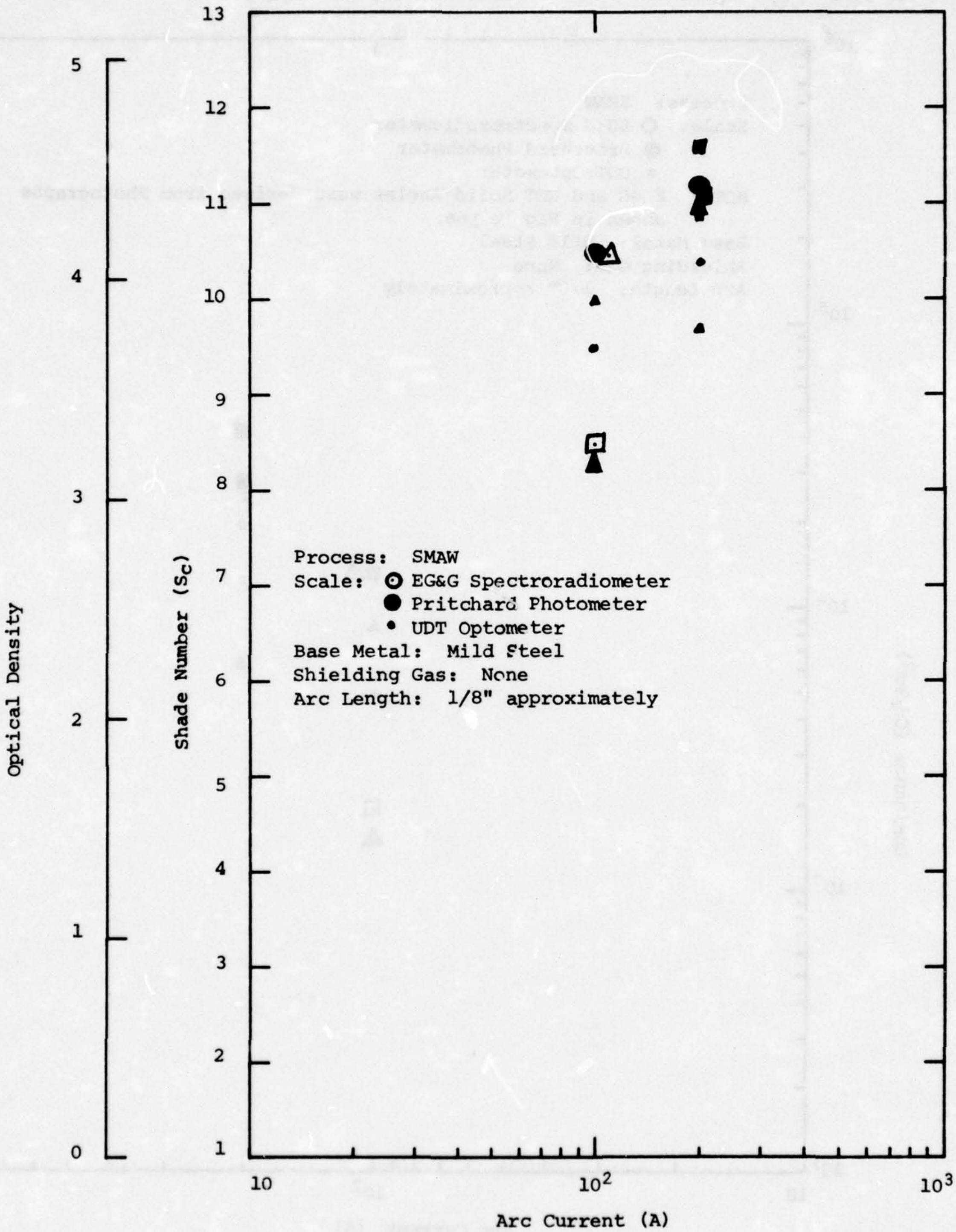


Figure 16d. Comfortable Shade Number (Sc) or Optical Density for Arc Viewing as a Function of Arc Current for Events 97 to 102.

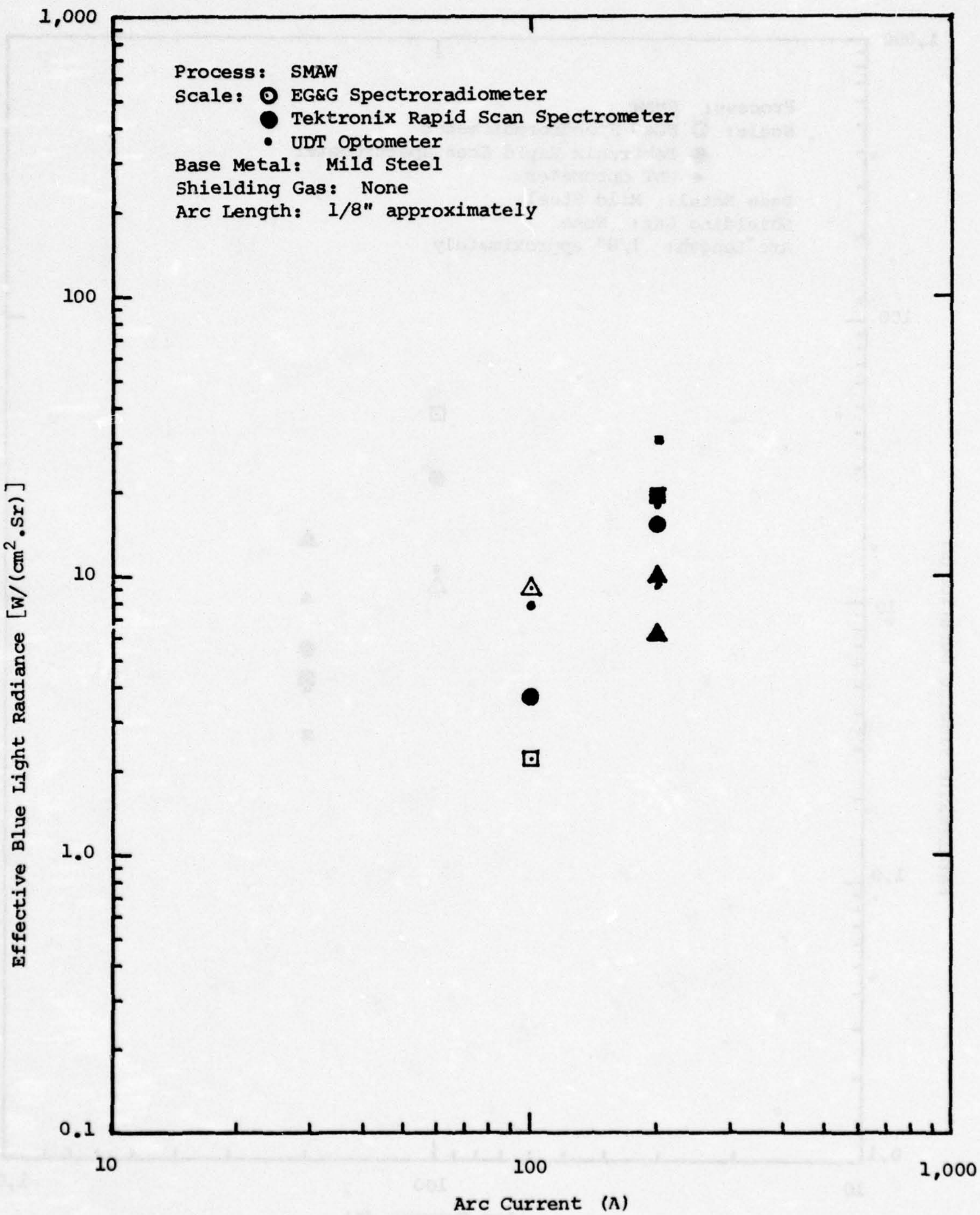


Figure 16e. Effective Blue Light Radiance as a Function of Arc Current for Events 97 to 102.

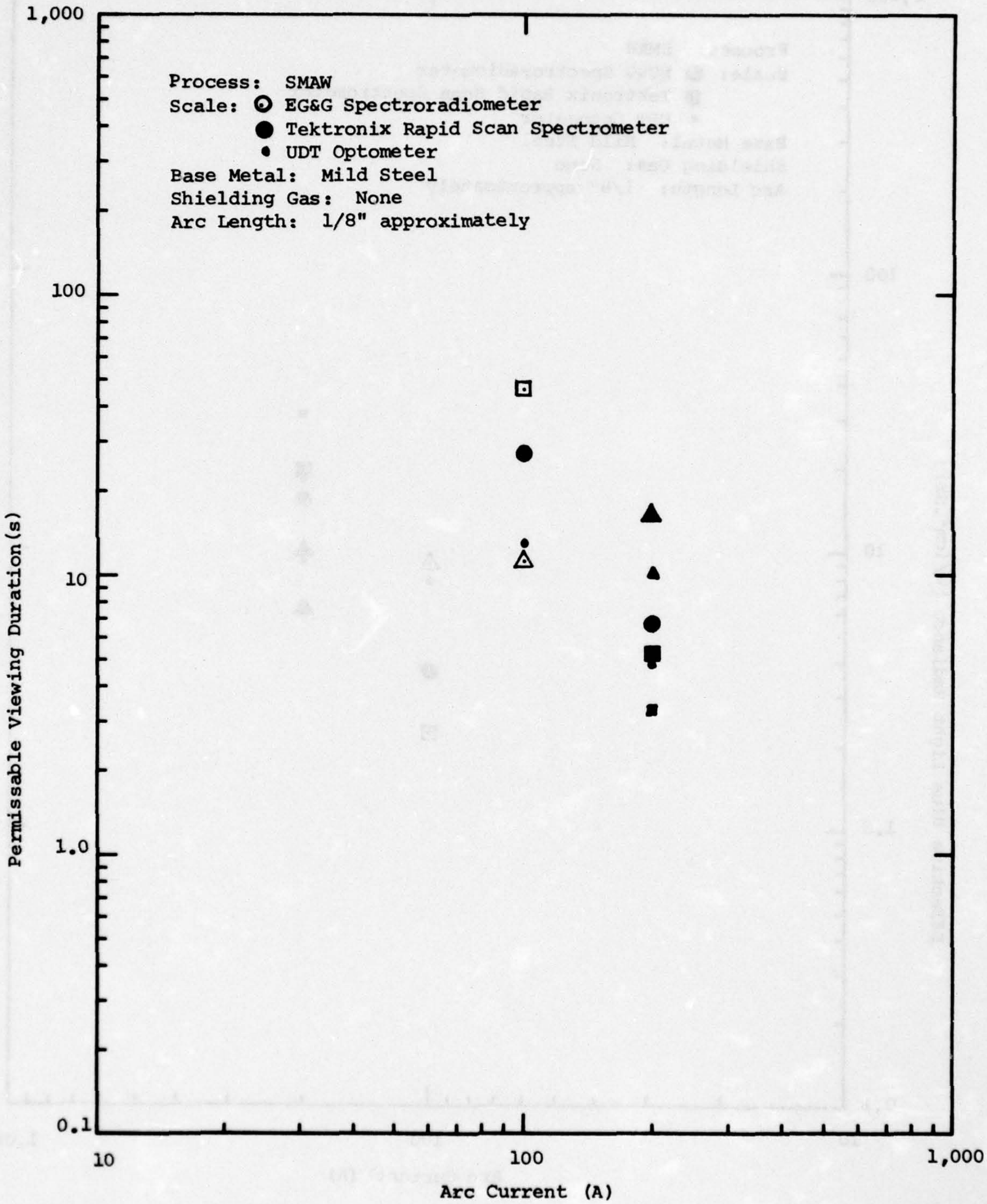


Figure 16f. Permissable Viewing Duration as a Function of Arc Current for Events 97 to 102 at Distances less than 3.0 m.

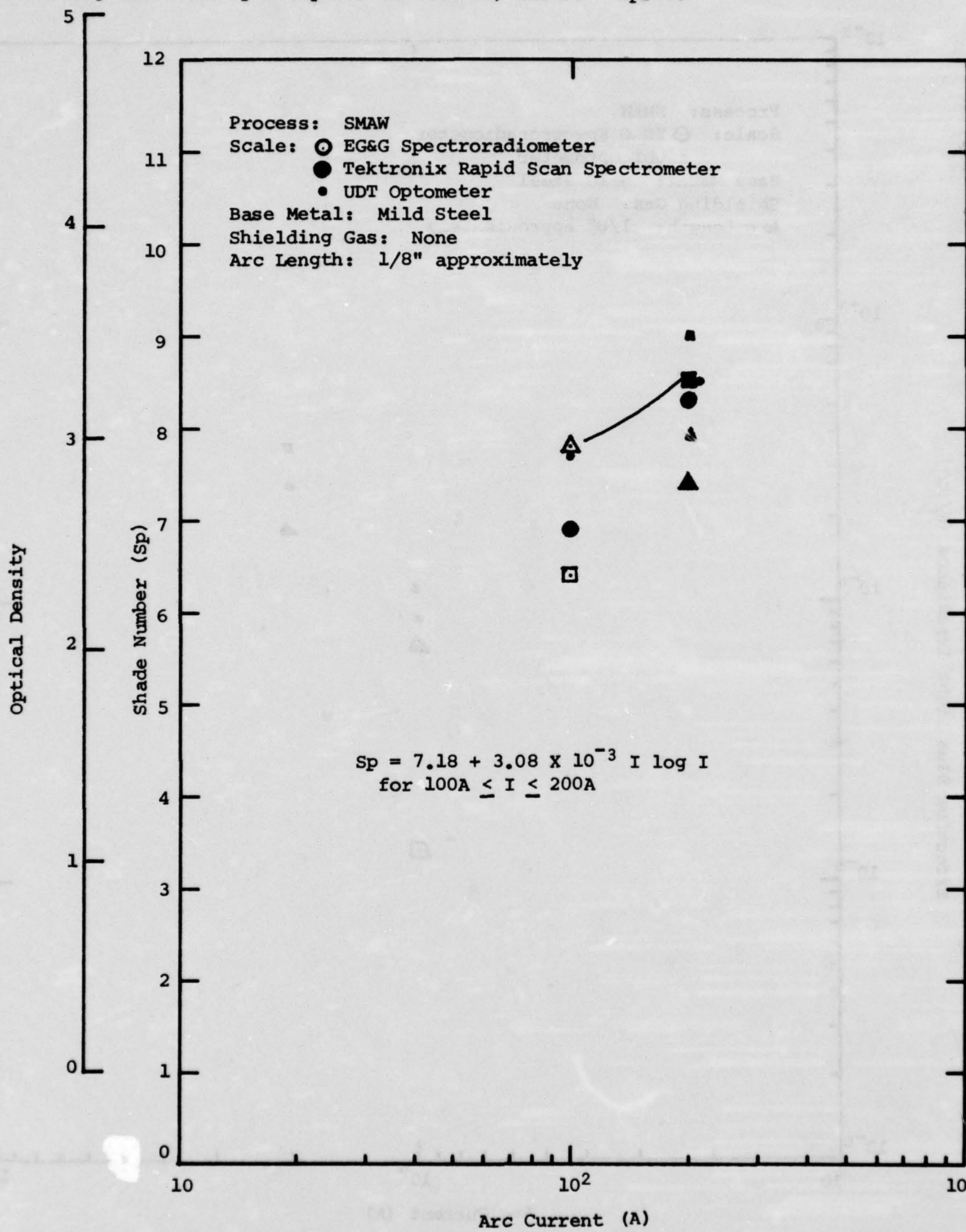


Figure 16g. Shade Number or Optical Density Necessary for Eye Protection against Blue Light Emitted during Events 97 to 102.

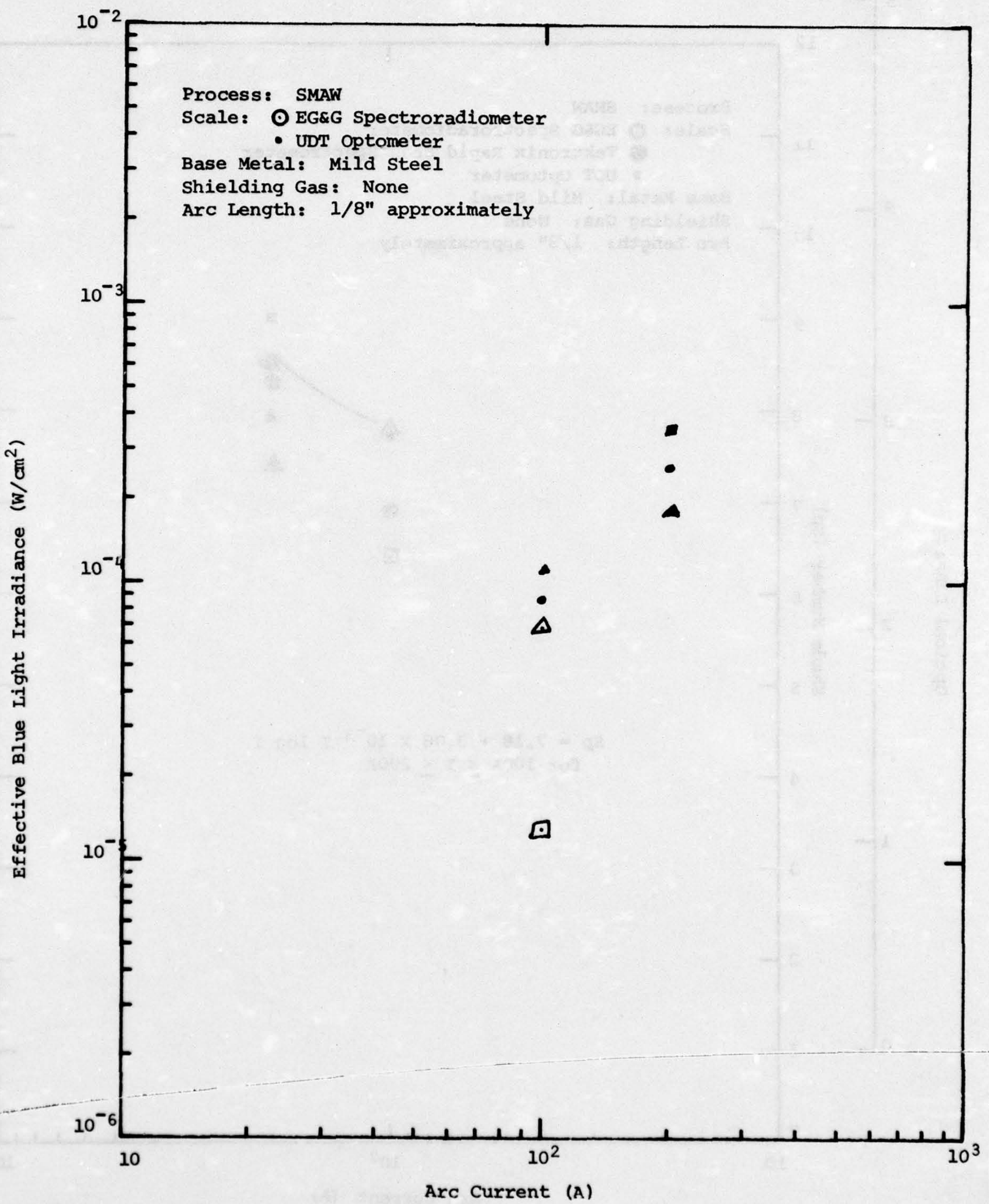


Figure 16h. Effective Blue Light Irradiance as a Function of Arc Current for Events 97 to 102.

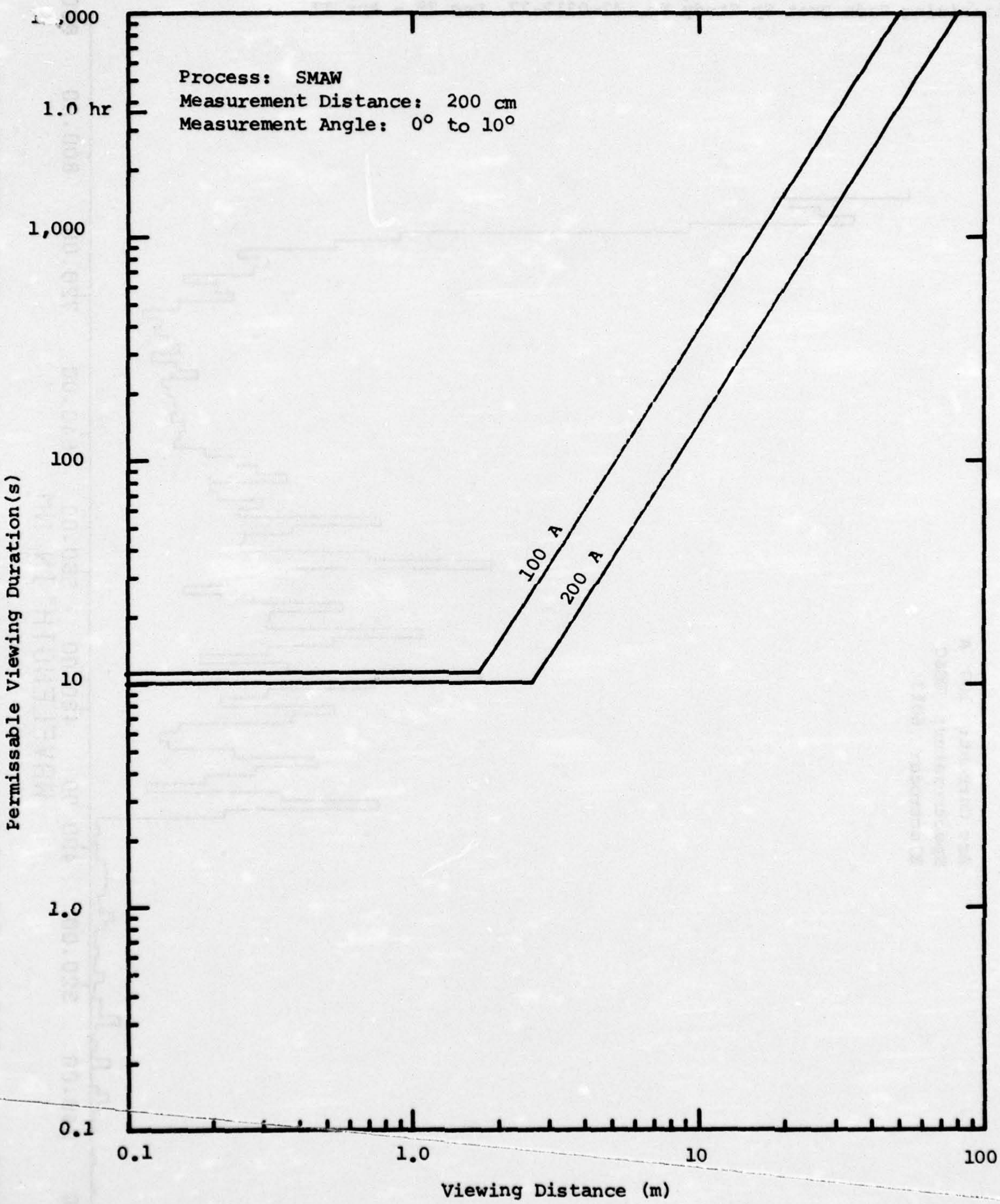


Figure 16i. Recommended Maximum Exposure Duration as a Function of Viewing Distance for Events 97 to 102.

Nonionizing Radn Prot Sp Study No. 42-0312-77, Dec 75 - Apr 77

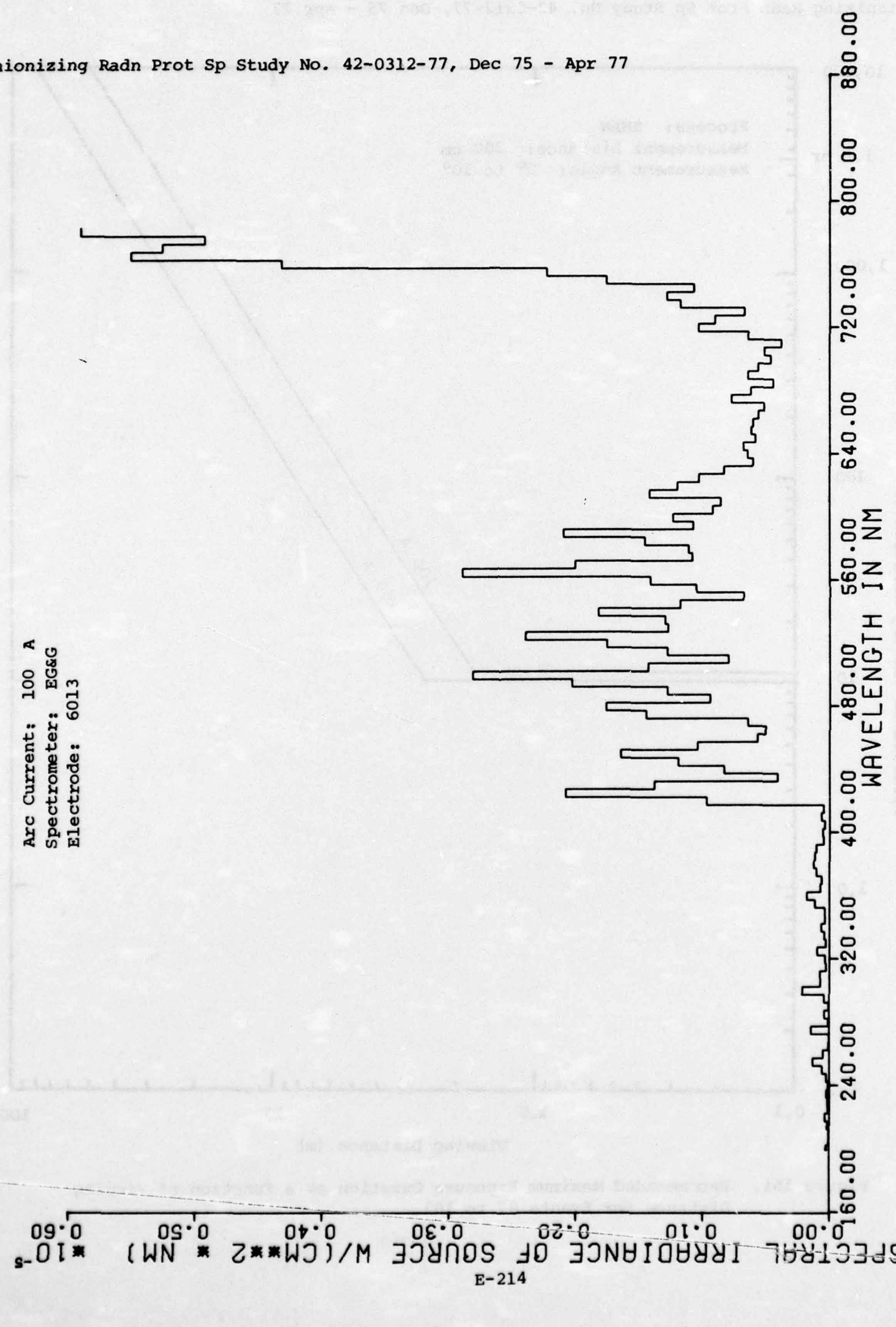


FIGURE 16j. ABSOLUTE SPECTRAL IRRADIANCE AT 200 CM FOR EVENT 97

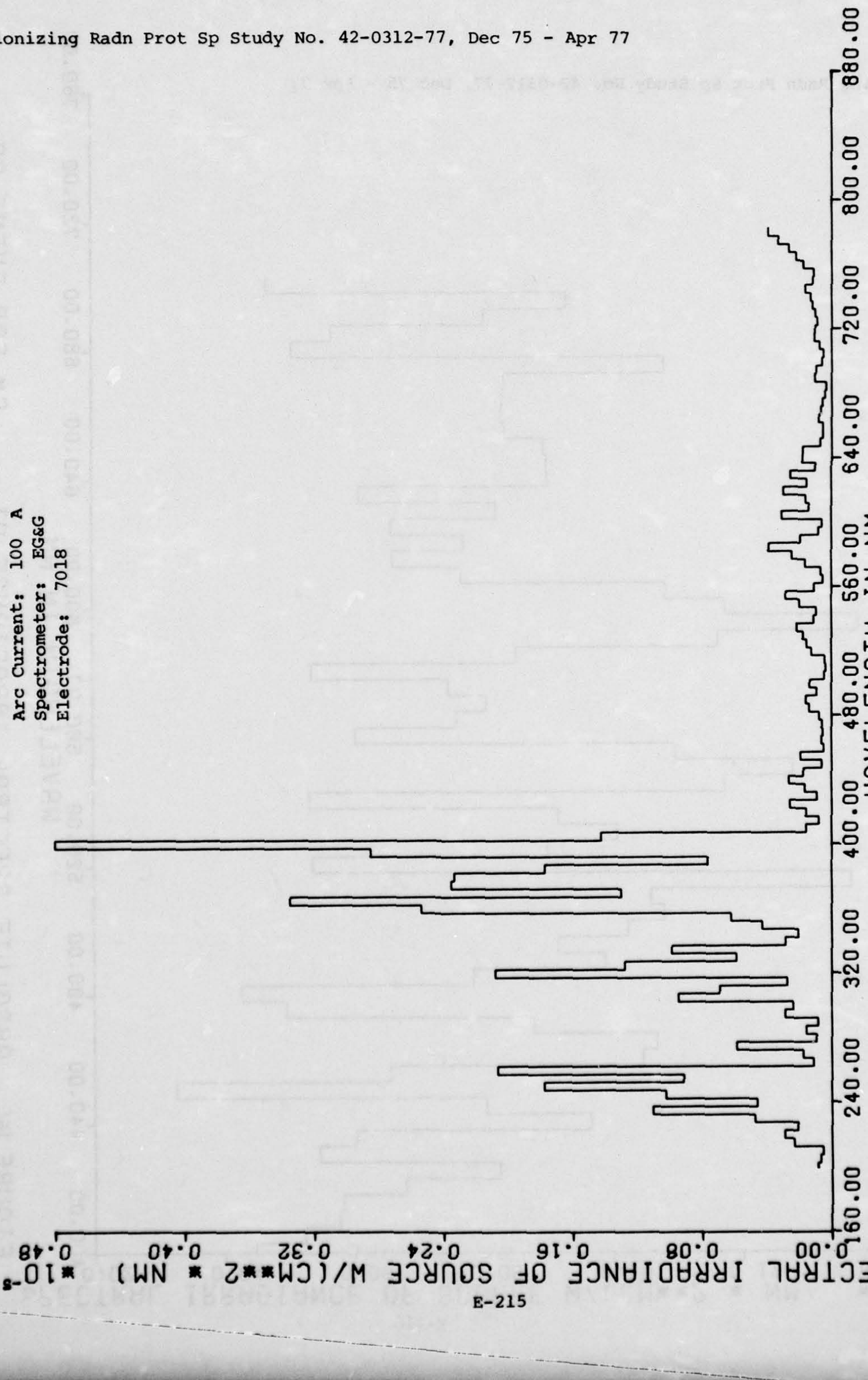


FIGURE 16k. ABSOLUTE SPECTRAL IRRADIANCE AT 200 CM FOR EVENT 98

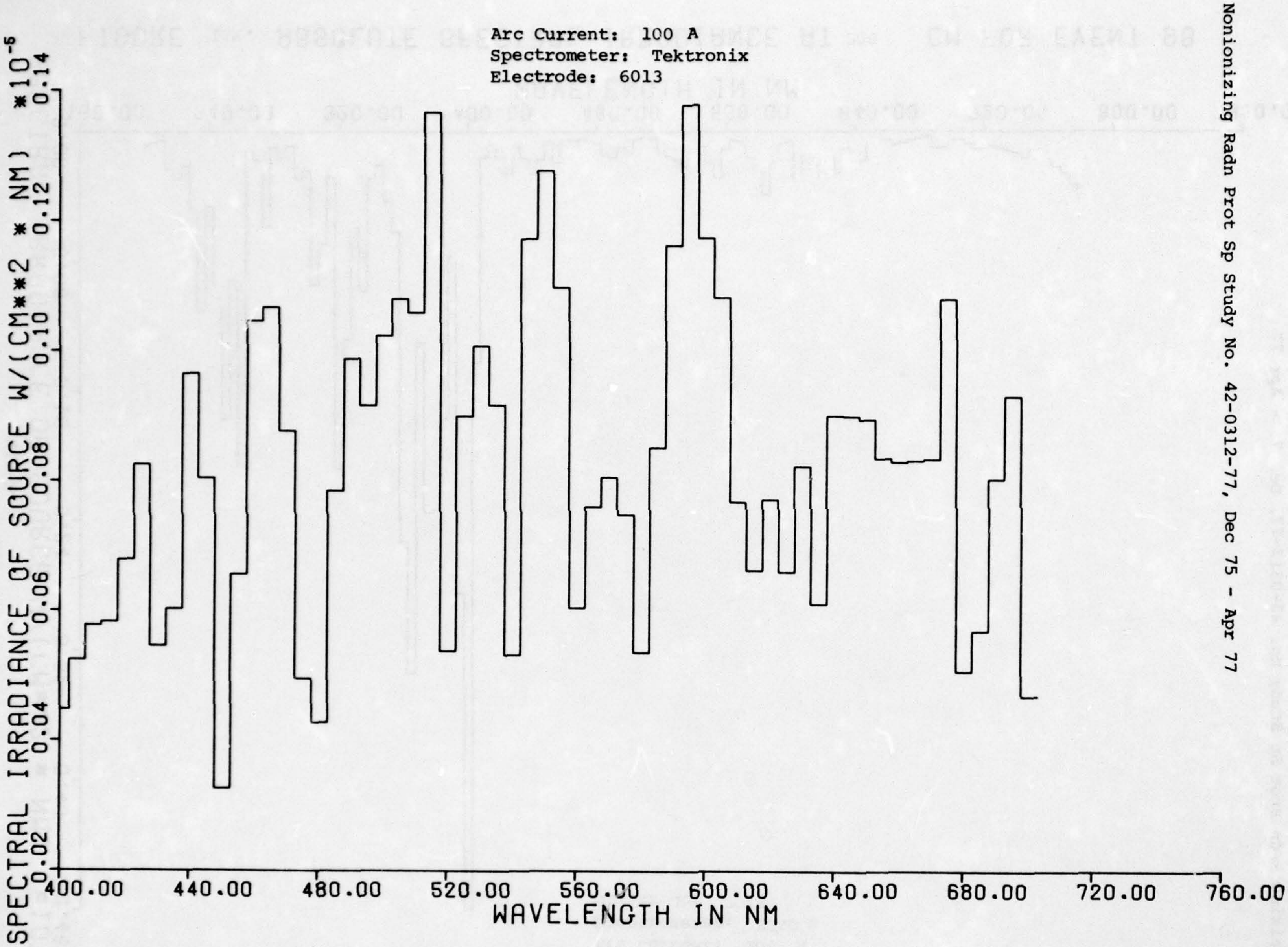


FIGURE 16ℓ . ABSOLUTE SPECTRAL IRRADIANCE AT 200 CM FOR EVENT 99

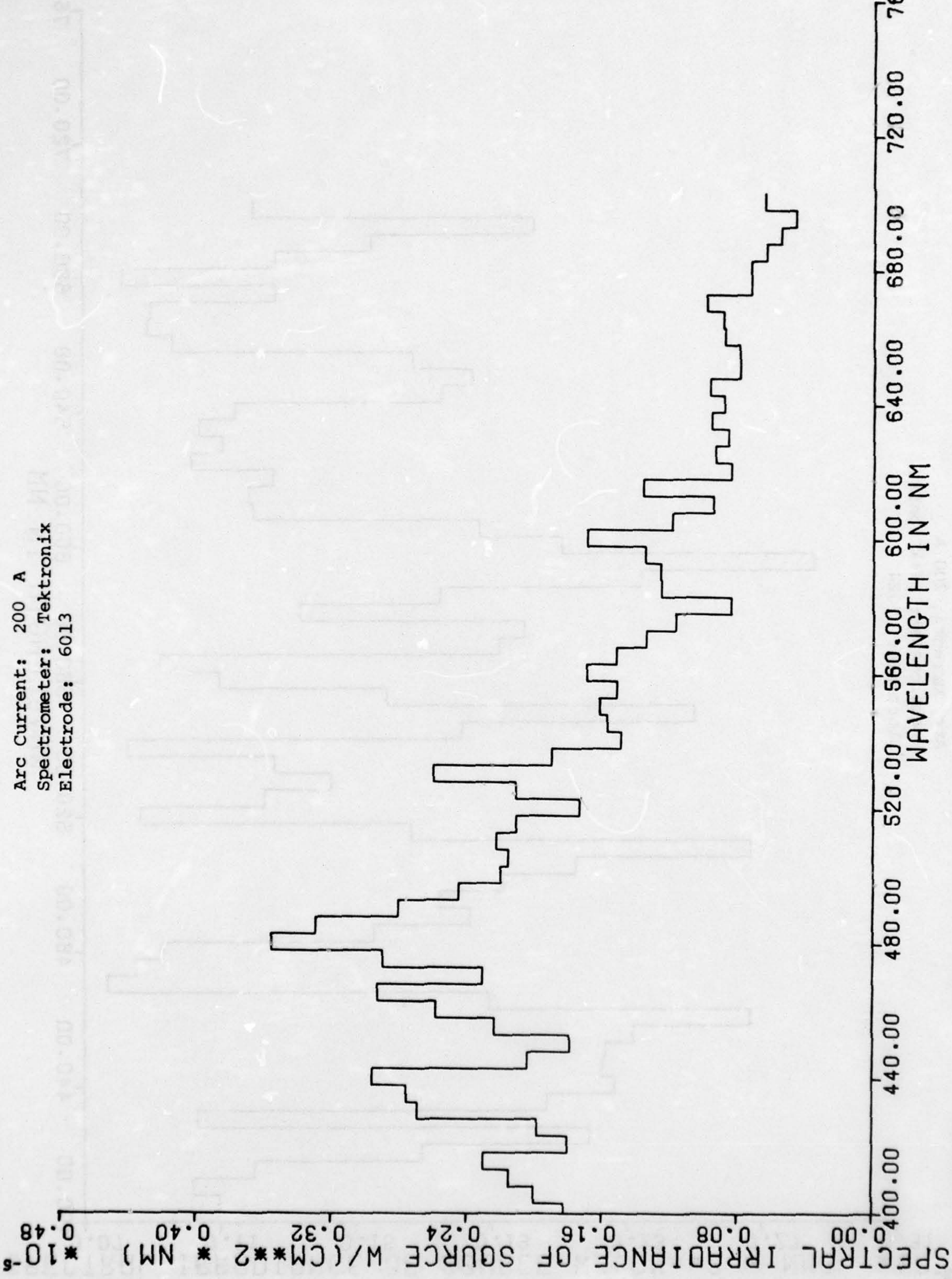


FIGURE 16m. ABSOLUTE SPECTRAL IRRADIANCE AT 200 CM FOR EVENT 100

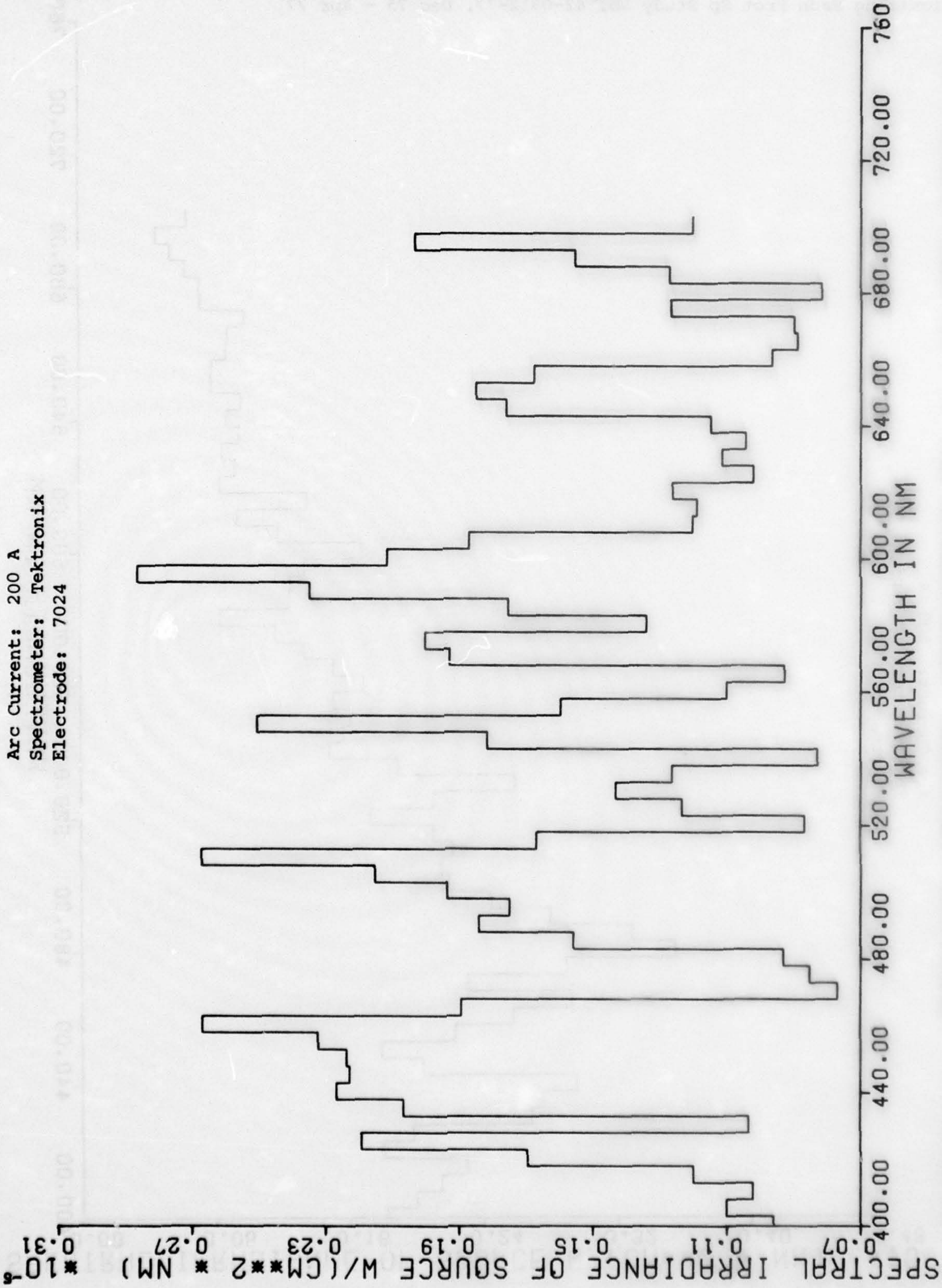


FIGURE 16n. ABSOLUTE SPECTRAL IRRADIANCE AT 200 CM FOR EVENT 101

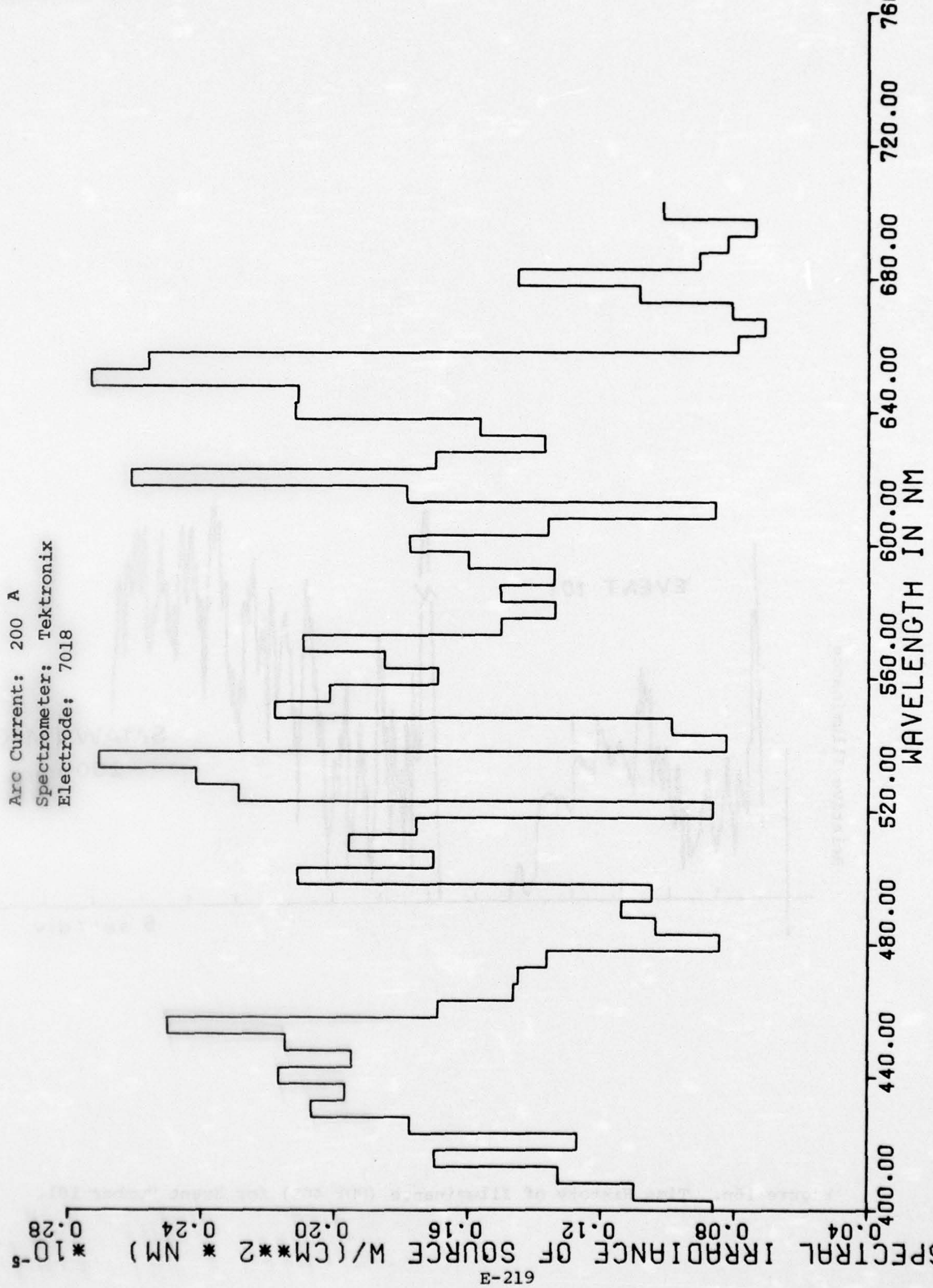


FIGURE 160 ABSOLUTE SPECTRAL IRRADIANCE AT 200 CM FOR EVENT 102

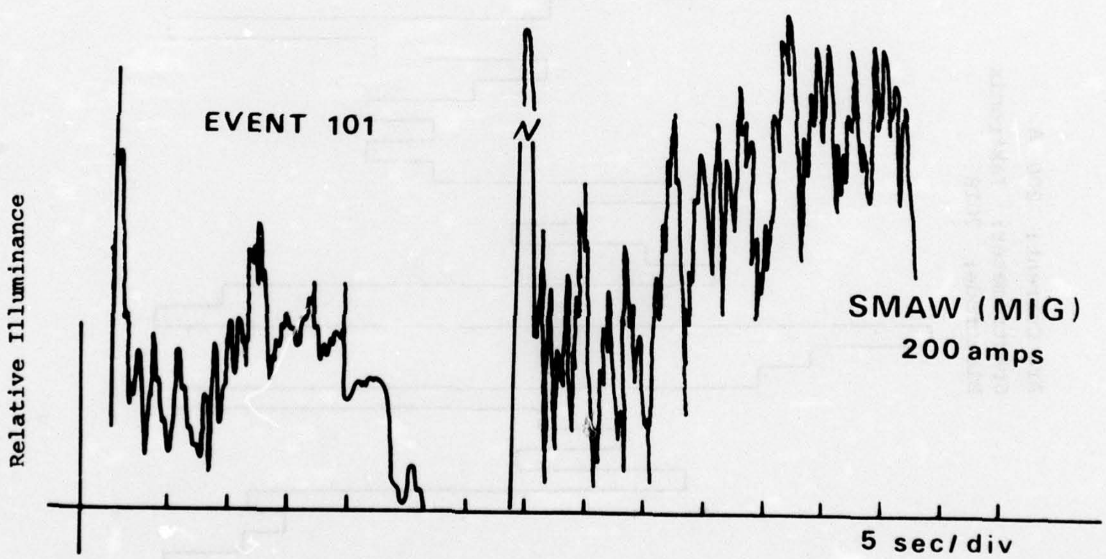


Figure 16p. Time History of Illuminance (UDT 40X) for Event Number 101.

TABLE 17. SUMMARY OF RADIOMETRIC MEASUREMENTS IN THE VISIBLE AND NEAR-INFRARED OF THE WELDING ARCS.

Event No.	Process	Metal	Current I(A)	Shield Gas	Arc Length (in)	Luminance L_v (cd/cm^2)	Blue Light Radiance [$W/(cm^2 \cdot sr)$]	Radiance [$W/(cm^2 \cdot sr)$]	Arc Area (mm^2)
1	GTAW	Steel	50	Ar	1/16	2.1×10^3	-	-	-
2	"	"	100	"	"	3.9×10^3	9.26	94.6	3.5
3	"	"	150	"	"	4.5×10^3	12	76.6	6.2
4	"	"	200	"	"	6.4×10^3	22.5	474	4.3
5	"	"	250	"	"	9.0×10^3	60.7	353	4.3
6	"	"	300	"	"	1.0×10^4	135	738	2.9
7	"	"	200	"	"	7.5×10^3	-	-	-
8	"	"	50	"	1/8	2.5×10^3	8.65	60.4	2.3
9	"	"	100	"	"	4.2×10^3	-	*110	5.2
10	"	"	188	"	"	7.5×10^3	-	*160	9.5
11	"	"	300	"	"	6.3×10^3	45.2	345	8.3
12	"	"	250	He	"	4.8×10^3	24.8	281	6.4
13	"	"	200	"	"	2.7×10^3	-	* 60	10
14	"	"	100	"	"	4.5×10^2	-	* 39	6.1
15	"	"	50	"	"	4.5×10^2	1.41	28.4	6.9
16	"	"	50	"	1/16	2.4×10^2	4.38	75.3	1.9
17	"	"	100	"	"	1.5×10^2	-	* 15.9	8.8
18	"	"	200	"	"	3.6×10^2	-	* 81.4	4.3
19	"	"	275	"	"	3.3×10^2	5.22	47.2	25
20	"	"	300	Ar	3/16	9.0×10^3	28.9	183	19
21	"	"	200	"	"	7.5×10^3	-	-	-
22	"	"	100	"	"	4.6×10^3	9.63	54.2	9.9
23	"	"	200	"	1/8	6.6×10^3	-	-	-
24	"	Al	50	"	"	4.2×10^3	3.26	29.8	8.1
25	"	"	100	"	"	4.5×10^3	-	* 25.1	3.5
26	"	"	200	"	"	5.2×10^3	9.3	57.7	17
27	"	"	265	"	"	2.8×10^3	-	-	-
28	"	"	250	"	"	1.5×10^3	-	158	19
29	"	"	250	"	3/16	1.5×10^3	-	* 37.6	82.4
30	"	"	250	"	1/4	5.0×10^3	-	*112	40.3
31	"	"	200	"	3/16	5.3×10^3	-	*102	26.5
32	"	"	100	"	"	2.5×10^3	-	-	-
33	"	"	50	"	"	7.0×10^3	-	-	-
34	"	"	50	He	"	4.4×10^3	-	-	-
35	"	"	65	"	1/8	-	-	* 19	2.6
36	"	"	100	"	"	-	-	*245	1.9
37	"	"	200	"	"	-	-	* 56	7.1
38	"	"	200	"	3/16	1.2×10^3	-	-	-
39	"	"	150	"	"	-	-	-	-
40	GMAW	Steel	90	CO_2	N/A	8.3×10^3	17.5	131	4.2
41	"	"	150	"	"	-	53.7	379	3.5
42	"	"	150	O_2 + Ar	3/8	-	-	*173	17.3
43	"	"	190	"	1/4	1.9×10^4	-	-	-
44	"	"	200	"	3/8	2.4×10^4	-	*321	13.9
45	"	"	250	"	1/4	2.3×10^4	64.5	709	10.4
46	"	"	260	"	3/8	1.9×10^4	-	*116	17.3

Event No.	Process	Metal	Current I(A)	Shield Gas	Arc Length (in)	Luminance L_v (cd/cm^2)	Blue Light Radiance [$W/(cm^2 \cdot sr)$]	Radiance [$W/(cm^2 \cdot sr)$]	Arc Area (mm^2)
47	GMAW	Steel	350	O_2 + Ar	1/4	3.0×10^4	-	* 737	9.5
48	"	"	350	"	3/8	9.0×10^4	-	*2890	3.5
49	"	"	350	CO_2	N/A	2.1×10^4	-	* 909	2.2
50	"	"	250	"	"	1.0×10^4	-	* 385	5.2
51	FCAW	"	350	"	"	2.0×10^4	-	*1540	2.6
52	"	"	250	"	"	3.0×10^4	-	* 489	9.2
53	"	"	175	"	"	2.6×10^4	-	* 362	6.9
54	GMAW	Al	300	Ar	1/4	1.6×10^4	-	* 289	19
55	"	"	300	"	3/8	1.7×10^4	-	* 131	34
56	"	"	300	He	1/4	1.1×10^4	-	* 114	26.3
57	"	"	200	"	"	5.4×10^3	-	* 68.8	21.8
58	"	"	200	Ar	"	3.9×10^3	-	* 101	27.5
59	"	"	130	"	"	8.1×10^3	-	* 64.4	19.4
60	"	"	125	He	"	3.0×10^3	-	* 299	2.01
61	PAC/W	Steel	300	N_2	1/4	2.4×10^3	-		
62	"	"	"	"	3/8	3.6×10^3	-	* 80.6	22
63	"	"	"	"	1/2	3.0×10^3	-		
64	"	"	400	"	1/4	3.3×10^3	-		
65	"	"	"	"	3/8	1.5×10^3	-		
66	"	"	"	"	1/2	4.2×10^3	-	82.4	36
67	"	"	500	"	3/8	4.5×10^3	-	-	
68	"	"	"	"	1/2	4.5×10^3	-	-	
69	"	"	600	"	3/8	4.8×10^3	-	-	
70	"	"	"	"	1/2	5.6×10^3	-	137	29
71	"	"	750	"	3/8	5.4×10^3	-	-	
72	"	"	"	"	1/2	7.5×10^3	-	-	
73	PAC/D	"	400	Ar/H_2	3/8	7.2×10^3	26.9	* 123	33
74	"	"	"	"	1/2	5.1×10^3	-	-	-
75	"	"	500	"	3/8	6.9×10^3	-	-	-
76	"	"	"	"	1/2	6.9×10^3	-	*3050	33
77	"	"	600	"	3/8	6.9×10^3	-	-	-
78	"	"	"	"	1/2	8.1×10^3	-	* 224	54
79	"	"	750	"	"	8.4×10^3	-	* 978	15
80	"	"	1000	"	"	4.5×10^3	-	-	-
81	"	"	"	"	3/4	4.8×10^3	-	-	-
82	PAC/W & Muffler	"	400	N_2	1/4	1.4×10^2	-	-	
83	"	"	"	"	3/8	1.8×10^2	0,16	1.4	430
84	"	"	"	"	1/2	2.1×10^2	-	* 2.8	142
85	"	"	600	"	3/8	4.5×10^2	0,74	7.2	160
86	"	"	"	"	1/2	1.1×10^3	-	* 8.5	142
87	PAW	"	260	Ar	3/16	1.8×10^3	-	-	10
88	"	"	"	"	"	1.2×10^4	-	-	8.3
89	"	"	240	15% H 85% Ar	"	9.9×10^3	-	-	-
90	"	"	275	"	"	1.1×10^4	-	* 571	1.75
91	"	"	100	"	"	4.8×10^3	-	-	-
92	"	"	200	"	"	3.0×10^3	-	-	-
93	"	"	"	Ar	"	3.0×10^3	-	* 113	11.3
94	"	"	100	15% H 85% Ar	"	6.9×10^3	-	-	-
95	"	"	"	He	"	1.6×10^3	-	* 333	1.92
96	"	"	200	"	"	6.9×10^3	-		-
97	SMAW	"	100	None	1/8	1.5×10^3	8.94	68.4	30.9
98	"	"	"	"	"	-	2.17	45.3	23.2
99	"	"	"	"	"	$1,3 \times 10^4$	-	* 26.8	44.7
100	"	"	200	"	"	2.7×10^4	-	* 145	55.1
101	"	"	"	"	"	2.3×10^4	-	* 111	71.9
102	"	"	"	"	"	4.1×10^4	-	* 85.5	46.8

APPENDIX F

WELDING FILTER STANDARDS

TABLE 1. TRANSMITTANCES AND TOLERANCES IN TRANSMITTANCE OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES, AND PLATES*

Shade No.	Optical Density Max	Optical Density Std	Optical Density Min	Luminous Transmittance Max Percent	Luminous Transmittance Std Percent	Luminous Transmittance Min Percent	Maximum Infrared Transmittance Percent	Maximum Spectral Transmittance in the Ultraviolet and Violet 313 nm Percent	334 nm Percent	365 nm Percent	405 nm Percent
1.5	0.26	0.214	0.17	67	61.5	55	25	0.2	0.8	25	65
1.7	0.36	0.300	0.26	55	50.1	43	20	0.2	0.7	20	50
2.0	0.54	0.429	0.36	43	37.3	29	15	0.2	0.5	14	35
2.5	0.75	0.643	0.54	29	22.8	18.0	12	0.2	0.3	5	15
3.0	1.07	0.857	0.75	18.0	13.9	8.50	9.0	0.2	0.2	0.5	6
4.0	1.50	1.286	1.07	8.50	5.18	3.16	5.0	0.2	0.2	0.5	1.0
5.0	1.93	1.714	1.50	3.16	1.93	1.18	2.5	0.2	0.2	0.2	0.5
6.0	2.36	2.143	1.93	1.18	0.72	0.44	1.5	0.1	0.1	0.1	0.5
7.0	2.79	2.571	2.36	0.44	0.27	0.164	1.3	0.1	0.1	0.1	0.5
8.0	3.21	3.000	2.79	0.164	0.100	0.061	1.0	0.1	0.1	0.1	0.5
9.0	3.64	3.429	3.21	0.061	0.037	0.023	0.8	0.1	0.1	0.1	0.5
10.0	4.07	3.857	3.64	0.023	0.0139	0.0085	0.6	0.1	0.1	0.1	0.5
11.0	4.50	4.286	4.07	0.0085	0.0052	0.0032	0.5	0.05	0.05	0.05	0.1
12.0	4.93	4.714	4.50	0.0032	0.0019	0.0012	0.5	0.05	0.05	0.05	0.1
13.0	5.36	5.143	4.93	0.0012	0.00072	0.00044	0.4	0.05	0.05	0.05	0.1
14.0	5.79	5.571	5.36	0.00044	0.00027	0.00016	0.3	0.05	0.05	0.05	0.1

* As specified in ANSI Z87.1-1968

TABLE 2. GUIDE FOR SHADE NUMBERS*

Welding Operation	Suggested Shade Number †
Shielded Metal-Arc Welding, up to 5/32 in (4 mm) electrodes	10
Shielded Metal-Arc Welding, 3/16 to 1/4 in (4.8 to 6.4 mm) electrodes	12
Shielded Metal-Arc Welding, over 1/4 in (6.4 mm) electrodes	14
Gas Metal-Arc Welding (Nonferrous)	11
Gas Metal-Arc Welding (Ferrous)	12
Gas Tungsten-Arc Welding	12
Atomic Hydrogen Welding	12
Carbon Arc Welding	14
Torch Soldering	2
Torch Brazing	3 or 4
Light Cutting, up to 1 in (25 mm)	3 or 4
Medium Cutting, 1 to 6 in (25 to 150 mm)	4 or 5
Heavy Cutting, over 6 in (150 mm)	5 or 6
Gas Welding (Light) up to 1/8 in (3.2 mm)	4 or 5
Gas Welding (Medium) 1/8 to 1/2 in (3.2 to 12.7 mm)	5 or 6
Gas Welding (Heavy) over 1/2 in (12.7 mm)	6 or 8

* From ANSI Z49.1-1973

† The ANSI Standard also noted the following: "The choice of a filter shade may be made on the basis of visual acuity and may, therefore, vary widely from one individual to another, particularly under different current densities, materials, and welding processes. However, the degree of protection from radiant energy afforded by the filter plate or lens when chosen to allow visual acuity will still remain in excess of the needs of eye filter protection. Filter plate shades as low as shade 8 have proven suitably radiation-absorbent for protection from the arc welding processes."