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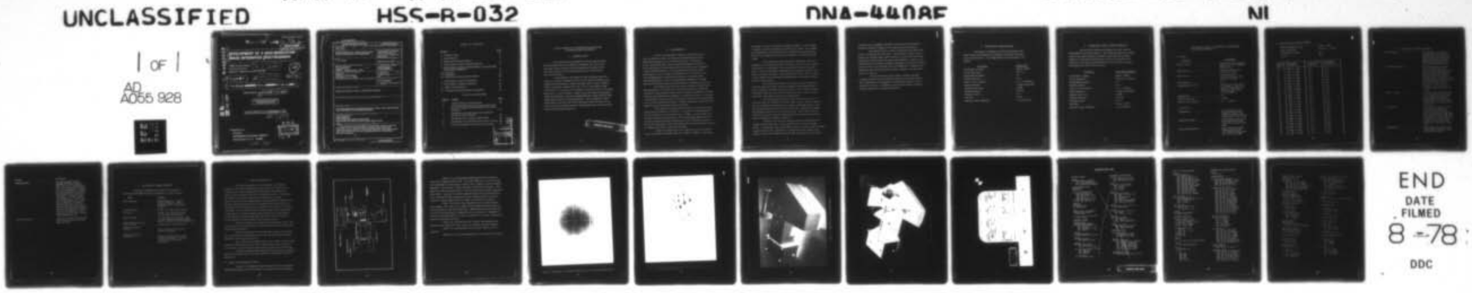

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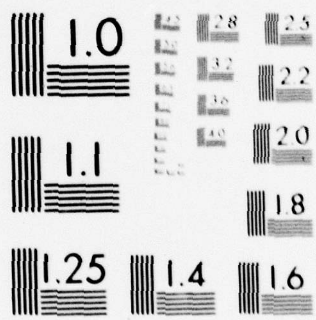

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DNA 4408F

DEVELOPMENT OF A HIGH-RESOLUTION IMAGE INTENSIFIED SPECTROGRAPH

HSS Incorporated
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Bedford, Massachusetts 01730

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19 Apr[redacted]77

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

Image Intensified
High Resolution
Cross Dispersed Echelle Spectrograph
Contact Film Recording on Fiber-Optic Output Screen

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

This instrument was developed to provide high resolution spectral information of low light level optical radiation from atomic and molecular species related to the infrared chemistry of the upper atmosphere when excited by electron bombardment from a rocket-borne electron accelerator.

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DEVELOPMENT OF A HIGH RESOLUTION IMAGE INTENSIFIED SPECTROGRAPH

1. INTRODUCTION

This instrument was developed to provide high resolution spectral information of low light level radiations from atomic and molecular species related to the IR chemistry of the upper atmosphere when excited by electron bombardment by a rocket-borne electron accelerator.

A near-optimum instrument has been developed under this contract to provide a diagnostic tool to record visible-radiating species related to the IR chemistry of the metastable state of atomic nitrogen, $N(^2D)$, and atomic oxygen $O(^1S)$ and $O(^1D)$ in the altitude range of 90-120 kms. The instrument combines several state-of-the-art design features; i.e., fast F/number, echelle and crossed dispersion gratings, image intensification, and direct photographic film contact with the fiber-optic output screen of an image intensifier. The combination of these design features increases the total sensitivity of this instrument far in excess of any spectrograph used for collecting this type of spectral information on Exceed-type programs.

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2. BACKGROUND

In 1974, operating under contract to Utah State University and AFCRL, HSS Inc developed an image-intensified spectrograph named Cygnus for use on Project Precede. The Precede event, sponsored by DNA, had as its principle objective the test of the performance of a rocket-borne electron accelerator in the altitute range of 90-120 kilometers. Ground based optical measurements, including the use of the Cygnus spectrograph, were performed as an aid to diagnosing the accelerator performance, as back-up to the payload photometers, and as an evaluation of techniques for making ground based measurements of electron-induced atmospheric processes.

The results of the Precede Event, conducted at White Sands Missile Range on 17 October 1974, demonstrated incontrovertibly the importance of ground based measurements to upper atmospheric aeronomy programs involving electron deposition. In the Precede case, for example, a malfunction of the system for removing the covers of the on-board photometers rendered those instruments, in effect, inoperative and the only data obtained was from the ground based instruments.

The Cygnus spectrograph obtained data over the entire operating period of the electron-accelerator. The data was of good quality but was contaminated by an unexpected source of light, as was the data from the other ground based instruments. The contaminating light source was related to unspent propellant emanating from the combustion chamber of the second stage booster which was deliberately left attached to the accelerator payload to improve vehicle neutralization.

Cygnus spectrograph is a low-dispersion survey-type instrument covering the wavelength region from 4200 Å to 8500 Å. The large wavelength coverage is perhaps its greatest attribute. Its wavelength resolution, spatial resolution and sensitivity are modest. Size, weight, and configuration of the instrument are such that the instrument lends itself to easy adaptation to any kind of automatic or manually trainable mount.

The Cygnus instrument with its low dispersion, 220 Å per millimeter, and consequent modest resolution, 10 to 12 Å, is a suitable instrument for certain classes of measurements on Exceed type programs. It is the equivalent of 400 photometer channels each 10 Å wide, albeit of reduced sensitivity. With it, prominent features of the spectrum can be readily observed and their temporal and to some degree spatial features can be studied.

The goal of Exceed type events is the study of atmospheric chemistry processes in the vicinity of altitudes around 100 kilometers under controlled conditions of electron impact. The complex chemistry chains that result from this electron deposition must be understood for many upper atmospheric problems and applications.

The optical spectra induced by the chemical processes are primarily infrared radiations and weak visible or near-visible radiations. In a low resolution instrument such as Cygnus and in photometers, these weak visible radiations tend to be swamped by the radiations of neighboring prominent atomic lines or molecular bands. One is thus led to conclude that to improve upon present ground based spectral measurements better wavelength resolution is required.

Perhaps one of the most important visible-radiating species related to the IR chemistry is the metastable state of atomic nitrogen, $N(^2D)$. Consequently, any consideration of new or improved instrumentation should provide for the capability of recording this atomic doublet. The previous instrument CYGNUS did not have the sensitivity to record $N(^2D)$

emissions from any planned EXCEED event even if it had sufficient spectral resolution to isolate it from adjacent spectral features.

The requirement for improved sensitivity alone did not jus-justify a completely new instrument. Improvements could have been made to the existing Cygnus which would have increased its sensitivity and thereby improved its performance and capabilities. However, the requirement for increased wavelength resolution, an increase of between a factor of 10 or 20, could only have been fulfilled by a completely new approach to the spectral dispersion system, making a new instrument approach mandatory.

The new instrument Super Cygnus combines both high resolution and increased sensitivity to provide an instrument with far more capability for providing spectral information related to the IR chemistry problems. In addition, it has improved spatial resolution another limitation of the Cygnus instrument.

3. INSTRUMENT DESIGN GOALS

The optical, mechanical, and electrical design of the Super Cygnus spectrograph was designed in accordance with good commercial practices. The design goals of the instrument are as follows:

Parameter	Design Goal
Wavelength Coverage	4200 Å - 7500 Å
Linear Dispersion	15 Å/mm
Wavelength Resolution	1 Å
Relative Aperture	f/1.5
Field of View (variable)	0.5 - 2.0 degrees
Image Intensifier	3 stage electrostatic
Radiant Power Gain	40,000
Cathode Response	S-20 VR
Phosphor Screen	P-11
Film Size	70 mm
Exposure Times (Optional)	1,2,5,10,20 sec

4. INSTRUMENT FINAL CHARACTERISTICS

The instrument final characteristics are better than the design goals in two major respects. The image intensifier has a higher radiant power gain and using a reflective cross dispersion grating instead of a transmission type allowed us to have more grooves per millimeter thus larger separation between spectral orders and linear dispersions from 14 Å/mm to 25 Å/mm.

Parameter	Final Characteristics
Wavelength Coverage	4200 Å - 7500 Å
Linear Dispersion	14 Å/mm - 25 Å/mm
Wavelength Resolution	1 Å
Relative Aperture	f/1.5
Field of View (variable)	0.5 - 2.0 degrees
Image Intensifier	3 stage electrostatic
Radiant Power Gain	75,000
Cathode Response	S-20 VR
Phosphor Screen	P-11
Film Size	70 mm x 125 ft
Exposure Times (Optional)	1, 2, 5, 10, 20 sec.

5. INSTRUMENT OPTICAL COMPONENTS, PARAMETERS AND CHARACTERISTICS

5.1 Optical

Parameter	Specification
Objective Lens	Modified Maksutov Catadioptric 300 mm FL., F/3.0 w/field flattener lens.
Collimator Lens	Schneider Xenotar Lens 150 mm FL, F/2.8.
Camera Lens	Farrand Optical Co. Super Farron Lens w/IRIS 76 mm FL, F/0.87
Operating F/No.	F/1.5
Image Intensifier Tube	VARO Inc Type 8606, 40mm dia. Cathode, 3 stage intensification w/fiber optic extension on anode screen, w/P-11 Phosphor.
Magnification	0.9
Radiant Power Gain	75,000
Field of View (variable)	0.5 - 2.0 degrees

5.2 Spectral

Configuration	Cross dispersing system. Echelle Grating for high resolution and plane reflection grating for order sorting.
Dispersion Grating	Echelle grating, Bausch and Lomb Type 35-03-25-401 79 Grooves/mm. 63°26' blaze angle.
Order Sorting Grating	Plane reflectance grating. Bausch and Lomb Type 35-53-20-280, 1200 grooves/mm. 17°27' blaze angle.

5.3 SPECTRAL WAVELENGTH ORDERS

Total wavelength coverage . . . . 4200 Å - 7500 Å

Linear dispersion . . . . 14 Å/mm - 25 Å/mm

Wavelength Resolution . . . . 1 Å

Orders 30-52

Spectral Order	Wavelength Coverage (Å)	Linear (Å/mm) Dispersion	Wavelength Resolution (Å)
30	7220 to 7720	24.8	0.99
31	6990 to 7460	24.0	0.96
32	6750 to 7220	23.3	0.93
33	6580 to 6990	22.5	0.90
34	6390 to 6780	21.9	0.88
35	6220 to 6580	21.3	0.85
36	6050 to 6390	20.7	0.83
37	5890 to 6220	20.1	0.80
38	5740 to 6050	19.6	0.78
39	5590 to 5890	19.1	0.76
40	5460 to 5440	18.6	0.74
41	5330 to 5590	18.1	0.72
42	5200 to 5460	17.7	0.70
43	5090 to 5330	17.3	0.69
44	4970 to 5200	16.9	0.68
45	4870 to 5090	16.5	0.66
46	4760 to 4970	16.2	0.65
47	4660 to 4870	15.8	0.63
48	4570 to 4760	15.5	0.62
49	4480 to 4660	15.2	0.60
50	4390 to 4570	14.9	0.59
51	4300 to 4480	14.6	0.58
52	4220 to 4390	14.3	0.57

6. MECHANICAL CHARACTERISTICS

Film Transport	70 mm film movement enclosed in a light tight case painted reflective white, with a reciprocating film pressure platen for providing direct contact of the film with the image intensifier fiber optic output face plate screen.
Film Transport Rates	The film transport is operated with a camera programmer Model CC-384X. The spectrograph incorporates an internal shutter which is synchronized with the film movement. It operates in a normally open to open mode, closing only when the film is advanced. The choice of film rates are 1 picture per second, 1 every 2 seconds, 1 every 5 seconds, 1 every 10 seconds, and 1 every 20 seconds.
Shutter (capping)	A 2 inch diameter HARVARD shutter is incorporated in the optical path to cap the input light to the image intensifier during film transportation. It is synchronized with the film transport and camera control unit.
Spectrograph	All of the optical and mechanical components are mounted to a common frame and base plate which is enclosed with a light tight cover painted reflective white with access hatches, one to change slits or field of view limiters and one to adjust the camera lens focus for extreme temperature compensation.
Grating Holders	Both gratings are mounted in front surface pivoted adjustable, goniometric grating mounts.

Weight	157 pounds
Mounting points	The spectrograph has two optional mounting configurations. One is for "in laboratory use", three adjustable leveling pads are arranged on an 18-inch per leg triangle pattern attached to the bottom of the instrument base plate. The other method of mounting is for "in field use" on a tracking mount rail. When this is required, an interface plate with two shoes attached is bolted to the three threaded bases that normally hold the "in laboratory use" leveling pads. These shoes in turn bolt to the tracking mount instrument rail.
Center of Gravity	The center of gravity is indicated in three axes on the instrument with CG decals.

7. ELECTRICAL CHARACTERISTICS

All electrical functions are controlled by an electrical switch panel with lights to indicate all functions. (see Fig. 6, pg 20)

Item	Function
Film Transport	Switch Position Up = Automatic (Programed) Center = OFF, Momentary Down = Manual Film Advance.
Image Intensifier	On-Off = 6.75 VDC Battery Power.
AC Power	On-Off = 115 VAC Power to Film Transport and Capping Shutter.
Shutter Disable	Up = Normally Open. Light Off. Down = Closed, Light On, indicating that the shutter is disabled and in the capping mode.
Electrical Connector and Camera Cable	Control Power to Film Transport.
Electrical Connector 115 VAC	Power for control circuit to film transport and shutter.
Electrical Connector Programmer	Signals for exposure rates to film transport and shutter are supplied by a Model CC-384X camera programmer.

8. FINAL TEST RESULTS.

The contracting officer's representative, Mr. William Isengard, visited HSS Inc laboratory on the week of 19 October 1976. At that time we conducted final optical alignment of the optical components and permanently bolted these components in place. The system was operated and spectral sources were photographed on film. A Nikon camera was used to photograph the Image Intensifier output because the film transport enclosure was not completely fabricated at that time. Resolution and dispersion tests were conducted and evaluated. The instrument either met or surpassed all of the design goals and was tentatively accepted by Mr. Isengard pending a final integrated test incorporating the film transport coupled to the image intensifier fiber-optic output screen with the electrical control circuit in full operation.

The film transport was completed in mid November 1976. The spectrograph was electrically wired and the switch and relay control panel was installed and tested.

The film transport was tested with film in direct contact with the Image Intensifier output fiber optic screen and spectrums were photographed of several spectral sources.

The results were excellent; there were no static electric charge problems with the film in direct contact with the fiber optic face plate or in transport. The entire instrument system operated very satisfactorily.

The high resolution image intensified spectrograph is completed and Final Acceptance by the contracting officer was conducted on April 21 and 22, 1977.

8.1 Figure and Photograph Comments.

Figure 1 is a diagramatic layout in plan view of the instrument identifying the location of all the principal components of the spectrograph.

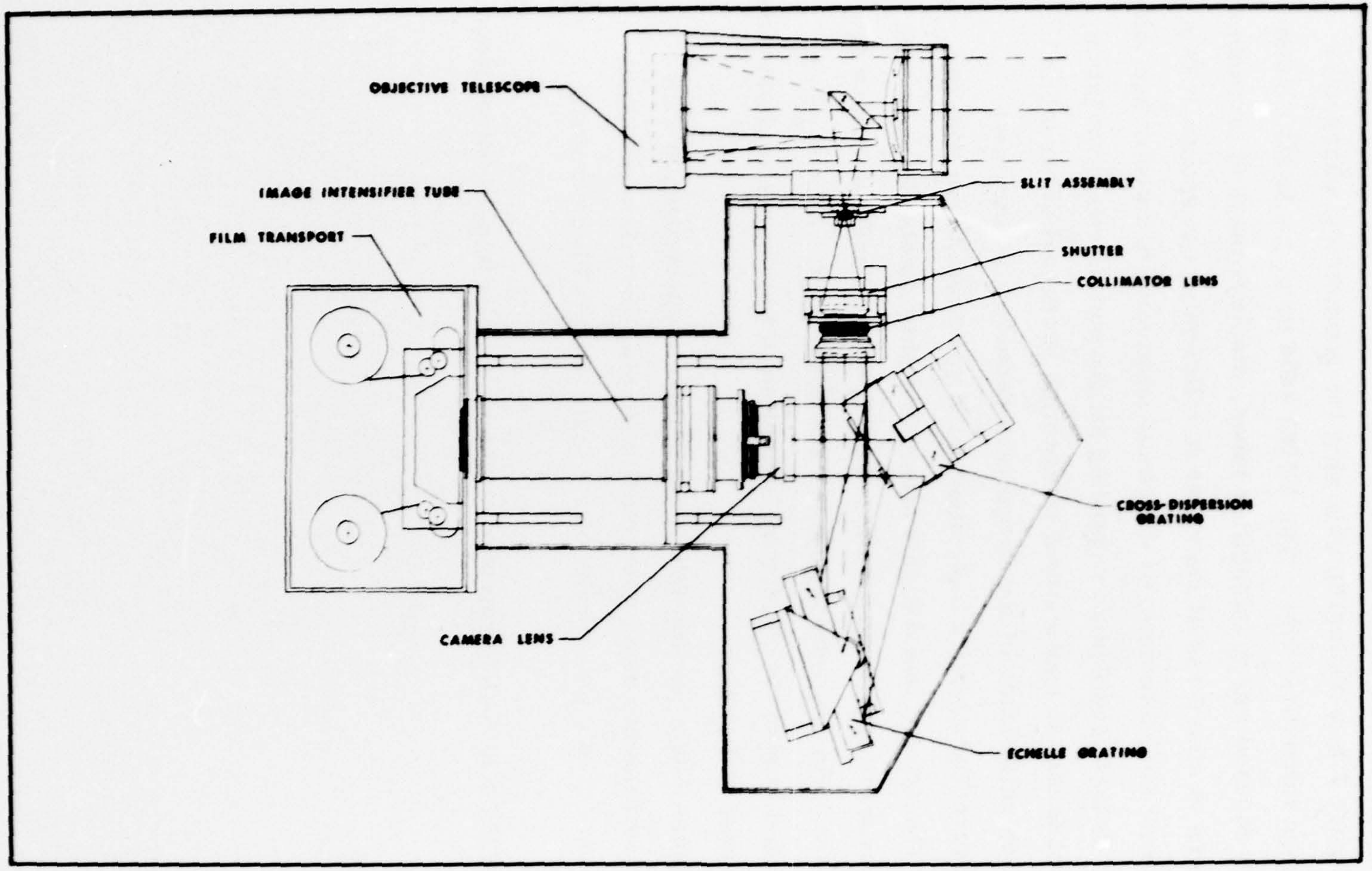

Figure 1. Optical Diagram of Spectrograph.

Figure 2 is a photograph showing the geometrical characteristics of the image intensifier tube. The VARO 8606 tube, as do all 3-stage electrostatically focused image intensifier tubes, displays marked pincushion distortion. There is also a radial decrease in efficiency of response. This again is an inherent characteristic of the electrostatically focused image intensifier tubes. A general conclusion regarding all geometric characteristics of the instrument is that in applications where high positional accuracy is required, detailed calibration of the image tube geometry is essential.

Figure 3 presents a high-dispersion spectrum taken with the spectrograph. The source was a highly attenuated glow discharge spectrum of iron excited by a microwave generator. Twenty-three spectral orders are covered by the spectrogram, although some are quite faint. A transparent overlay is provided to give the reader an indication of the degree of distortion present in each spectral order.

Figure 4 is a photograph of the complete spectrograph with objective lens, instrument cover, electrical controls, and film transport.

Figure 5 is a photograph of the instrument with the covers removed.

Figure 6 is a close-up photograph of the electrical control panel.

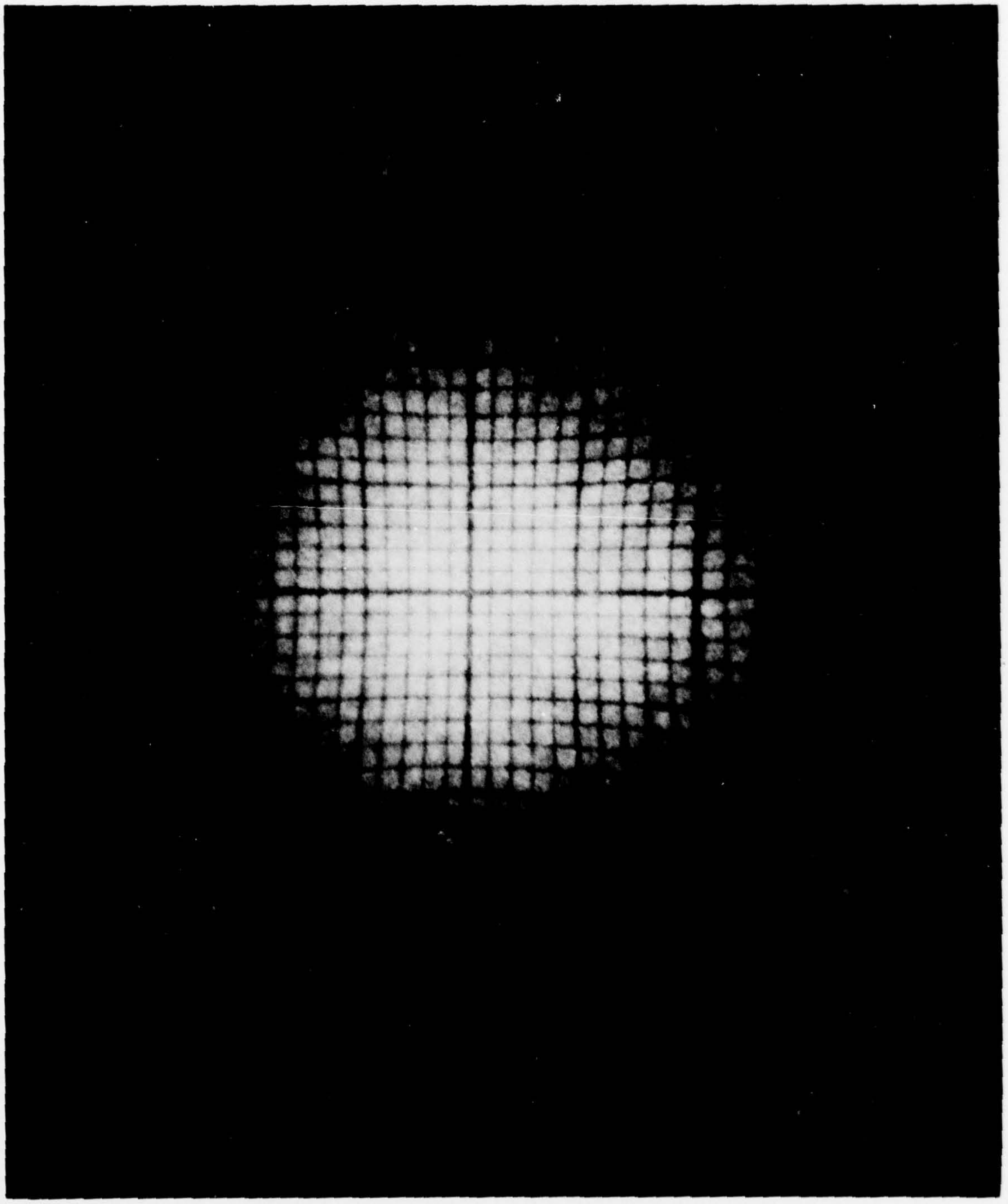

Figure 2. Photograph of rectangular grid placed on face of image intensifier tube.

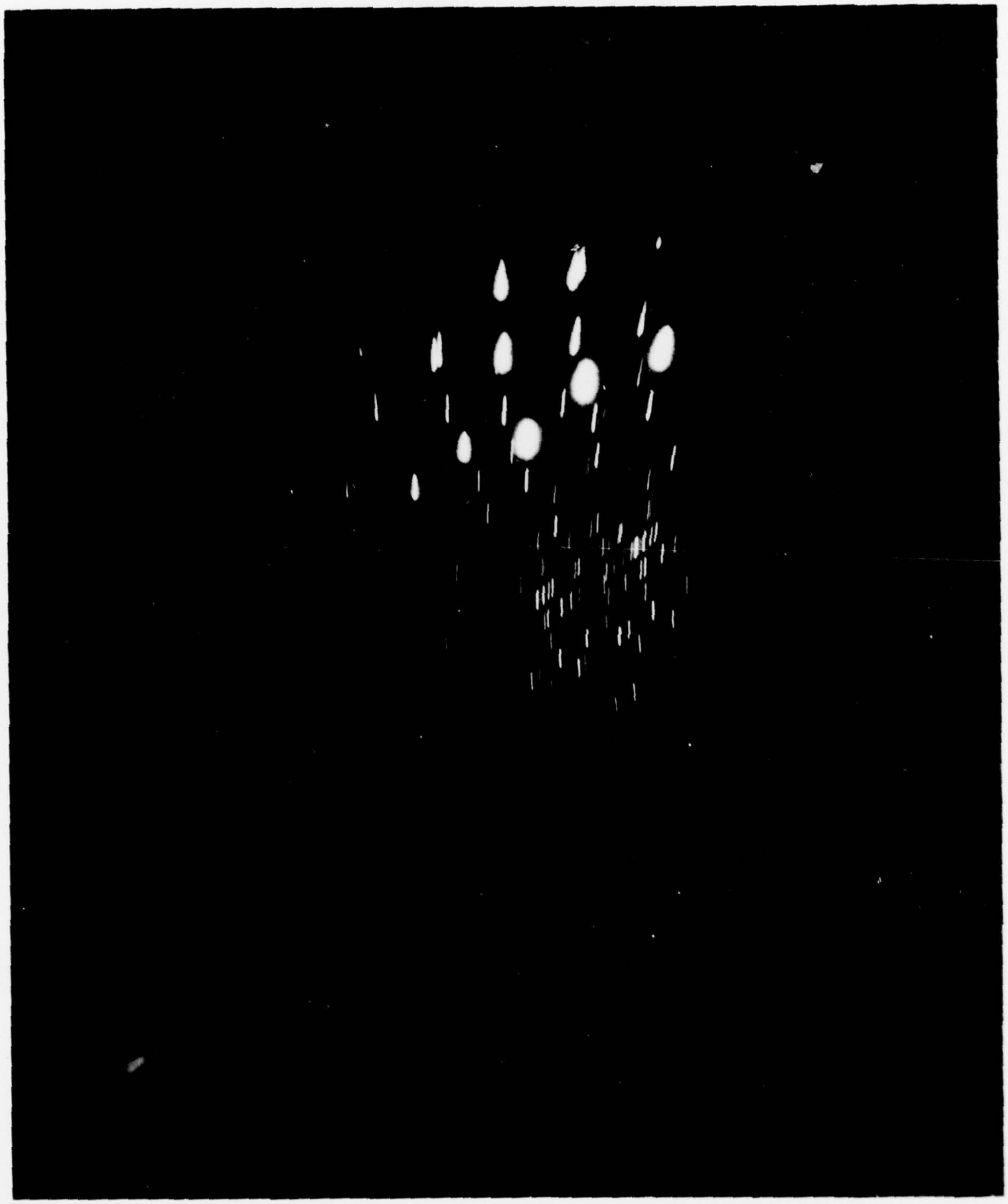

Figure 3. Spectrogram of Iron glow-discharge source with transparent overlay of pincushion distortion grid.

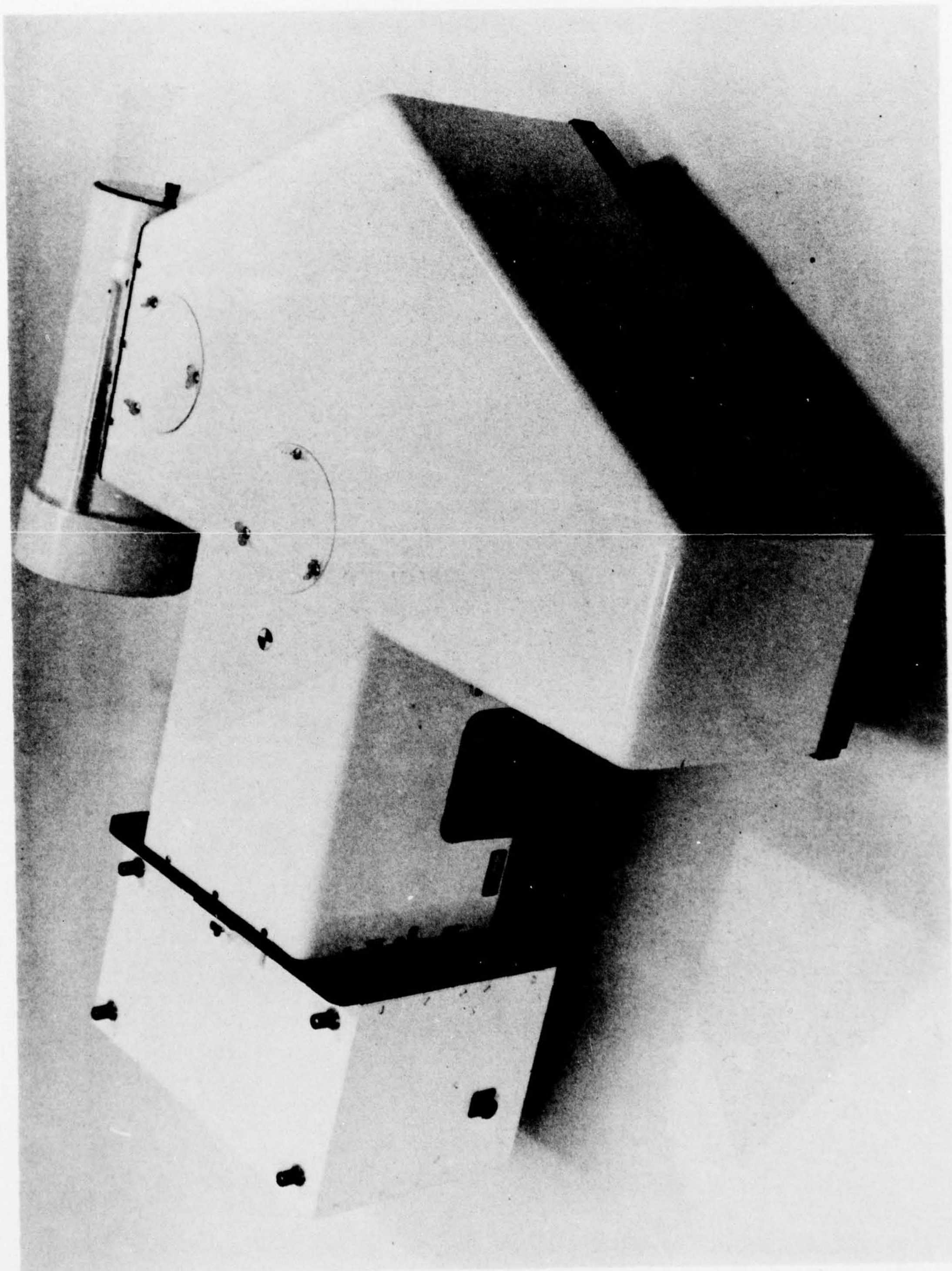

Figure 4. Completed Super Cygnus Spectrograph.

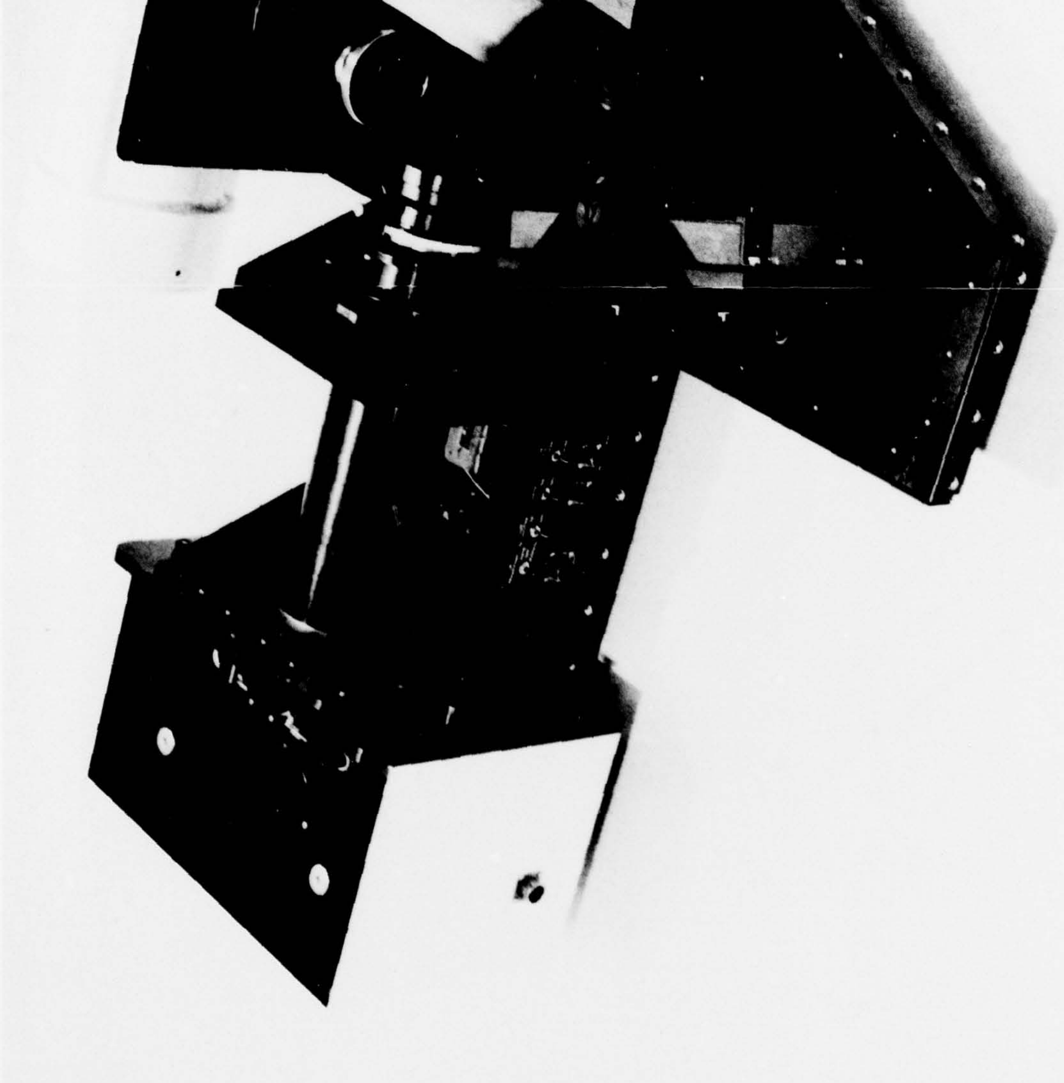

Figure 5. Super Cygnus with instrument covers removed.

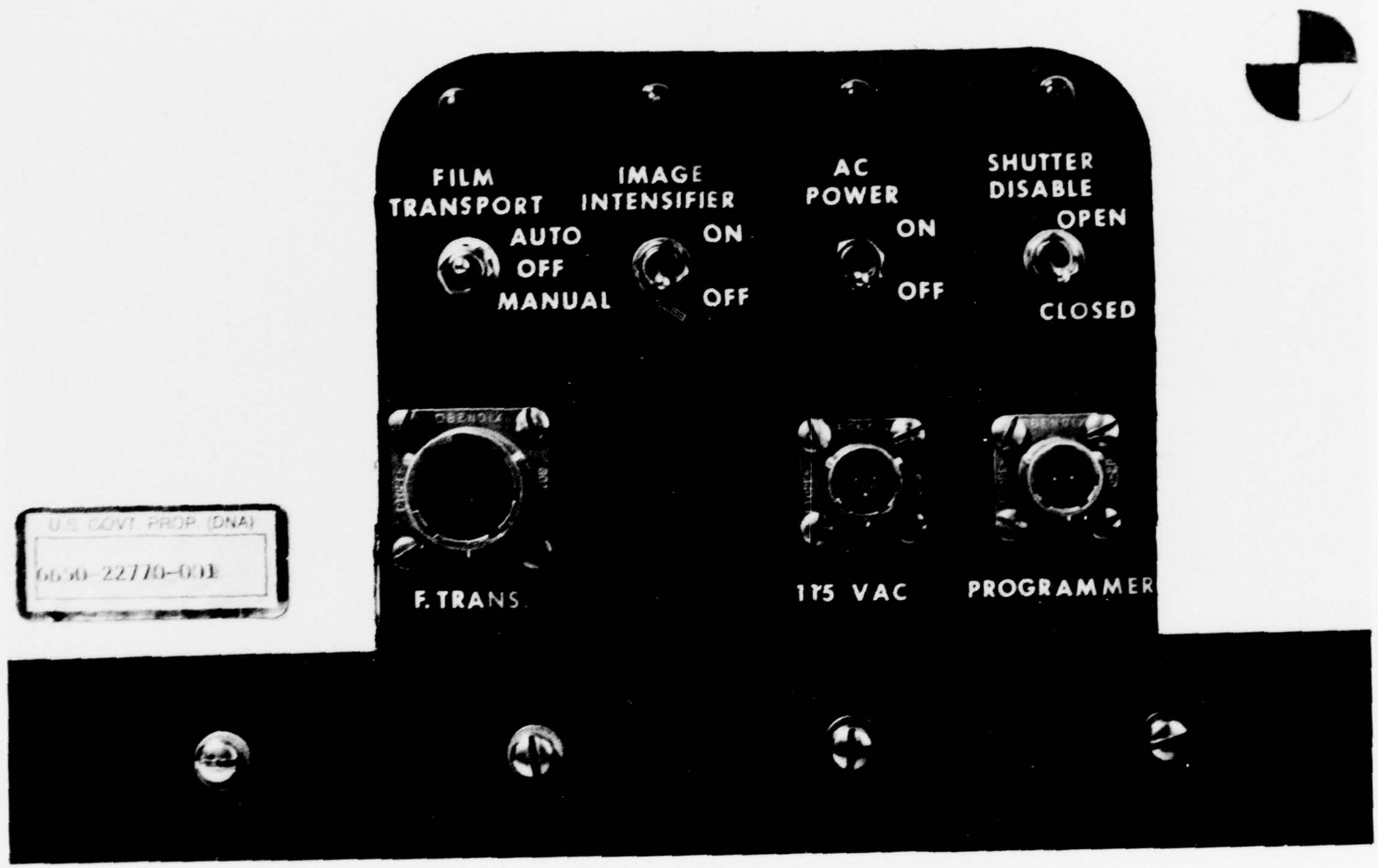

Figure 6. Close-up of electrical control panel.

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