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JUNE 1991

A MULTISPECTRAL SCANNER SURVEY
OF THE UNITED STATES DEPARTMENT OF ENERGY'S

PADUCAH GASEOUS DIFFUSION PLANT

PADUCAH, KENTUCKY

DATE OF SURVEY: MAY–JUNE 1990

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A multispectral scanner survey of the United States Department of Energy's Paducah Gaseous Diffusion Plant

Jun 1991

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Operated for the U.S. Department of Energy by
EG&G Energy Measurements, Inc.
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1. INTRODUCTION

Airborne multispectral scanner data of the Paducah Gaseous Diffusion Plant (PGDP) and surrounding area were acquired during late spring 1990. This survey was conducted by the Remote Sensing Laboratory (RSL) which is operated by EG&G Energy Measurements (EG&G/EM) for the U.S. Department of Energy (DOE) Nevada Operations Office. It was requested by the U.S. Department of Energy (DOE) Environmental Audit Team which was reviewing environmental conditions at the facility. These data were acquired in conjunction with vertical, aerial photographs and a complete gamma radiation survey of the same area conducted by the Nuclear Radiation Department of RSL.

The Paducah Gaseous Diffusion Plant physically separates gaseous uranium hexafloride (UF_6) molecules containing the ^{235}U isotope from those containing the ^{238}U isotope. It is located in McCracken County, 19 km west of Paducah, Kentucky. The buildings that comprise the facility are located within an approximately 750-acre fenced area. The Department of Energy owns a limited buffer zone on all sides of the fenced area. Beyond this buffer zone, there is an extensive wildlife management area that is leased or deeded to the state of Kentucky. The PGDF is built upon relatively flat land 115 meters above sea level. Drainage from the plant is into the Little Bayou Creek to the east and the Big Bayou Creek to the west. These creeks have little flow other than PGDF effluents except during periods of the year with the greatest precipitation. The creeks enter the Ohio River through a common discharge on the Tennessee Valley Authority Shawnee Plant Reservation.

The objectives of this survey were to:

1. Acquire 12-channel, multispectral scanner data of the PGDP from an altitude of 3,000 feet above ground level (AGL)
2. Acquire predawn, digital thermal infrared (TIR) data of the site from the same altitude

3. Collect color and color-infrared (CIR) aerial photographs over the facilities
4. Illustrate how the analyses of these data could benefit environmental monitoring at the PGDP.

This report summarizes the two multispectral scanner and aerial photographic missions at the Paducah Gaseous Diffusion Plant. Selected examples of the multispectral data are presented to illustrate its potential for aiding environmental management at the site.

2. MULTISPECTRAL SCANNER SYSTEM

The Daedalus AADS1268 multispectral scanner is an advanced, electro-optical scanner system designed for airborne data collection. The manufacturer's system specifications and measured channel sensitivities are summarized in Tables 1 and 2, respectively. An optional 3-5 micrometer detector can be used by replacing the imaging lens and detector preamplifier assembly for the 2.2 micrometer mid-infrared (MIR) band.

The scanner contains four detector packages with a total of eleven discrete elements (Figure 1). Reflected and/or emitted electromagnetic energy enters the scanner from the bottom and strikes a rotating "axe-blade" mirror which reflects it into the detector housing where a prism and a series of dichroic filters spectrally decompose the energy onto the detectors.

Channels 1-8 are generated by a single silicon detector array which is contained in an integrated, circuit-like package. The three infrared (IR) detectors that generate Channels 9-12 reside inside Dewars filled with liquid nitrogen in order to increase their sensitivity.

Electromagnetic energy striking the detectors produces a photovoltaic effect proportional to the number of photons striking at a given instant. The signal is amplified and converted into an 8-bit digital value which is recorded on a high-density digital tape.

Table 1. Daedalus AADS1268 Multispectral Scanner Specifications	
Number of Channels	12
Operating Wavelengths	0.4 - 10.5 micrometers
Scan Rate	12.5, 25, 50, 100 scans/second (selectable)
Instantaneous Field of View	2.5 milliradians (1.25 mrad half-angle mode)
Total Field of View	85.92 degrees
Temperature Resolution	0.1 C
Roll Correction	±15 degrees
Reference Sources	Infrared: two controllable, thermal blackbodies
Video Words/Scan Line	716
Digitizer Gains	0.5, 1, 2, 4, 8 (selectable)

Table 2. Measured Spectral Sensitivity of Daedalus AADS1268 Multispectral Scanner (MSS) Detectors

Channel	Wavelength Band (microns)	Color/Spectrum
1	0.42 - 0.45	Violet/blue
2	0.45 - 0.51	Blue/green
3	0.51 - 0.59	Green/yellow
4	0.58 - 0.62	Orange
5	0.61 - 0.66	Red
6	0.65 - 0.73	Near infrared
7	0.71 - 0.82	Near infrared
8	0.81 - 0.95	Near infrared
9	1.60 - 1.80	Near infrared
10	2.10 - 2.40	Mid-infrared
11	8.20 - 10.50	Thermal infrared (gain 0.5)
12	8.20 - 10.50	Thermal infrared (gain 1.0)
Alternate Configuration for Channels 10-12		
10	Empty	—
11	3.10 - 4.80	Thermal infrared
12	8.20 - 10.50	Thermal infrared

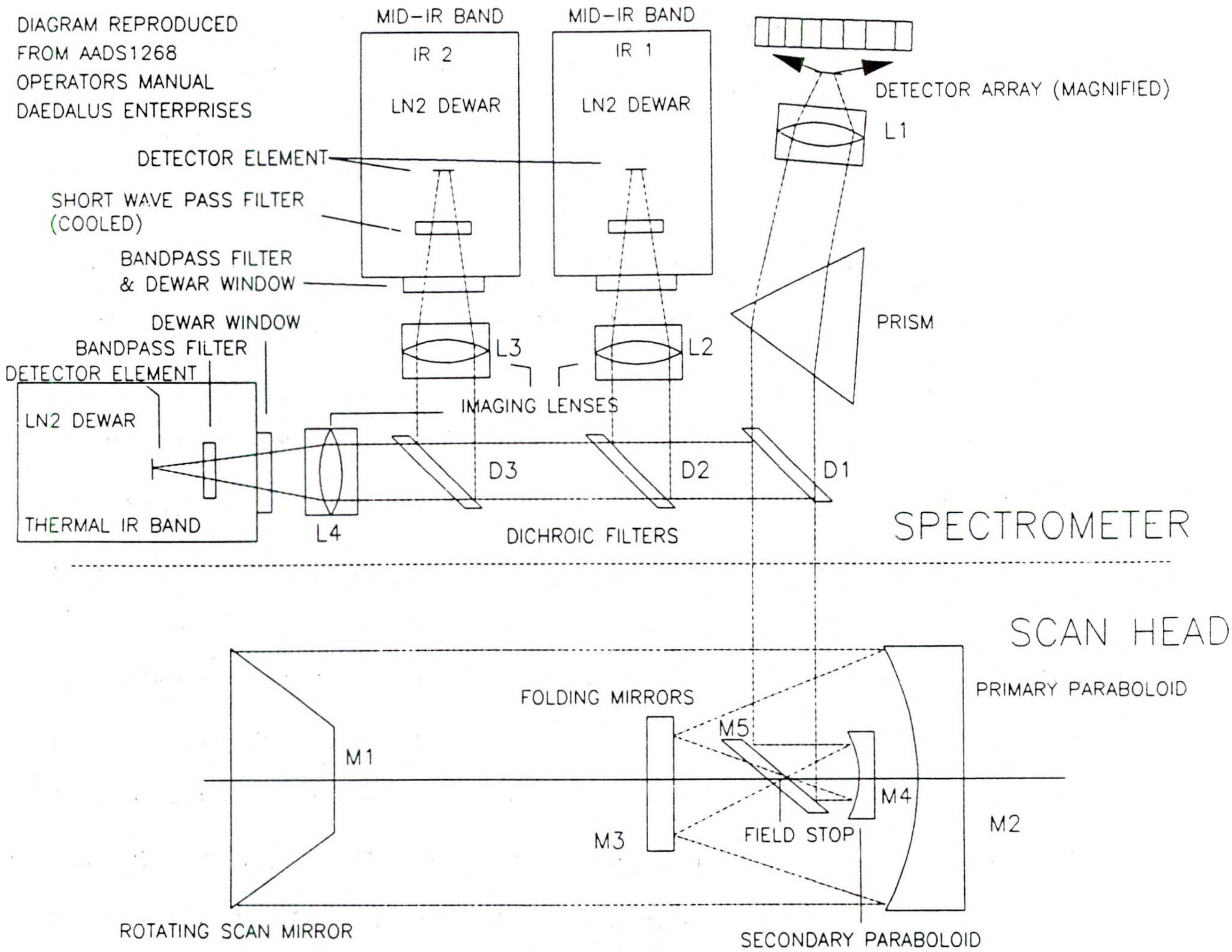

FIGURE 1. ***DESIGN OF DAEDALUS MULTISPECTRAL SCANNER***

The resulting spatial array of data represents a two-dimensional image proportional to reflectance and exitance of scene features. This scanner has selectable scan rates (up to 100 scan lines/sec) which are necessary to ensure contiguous coverage from different altitudes and relative ground speeds.

3. AERIAL DATA ACQUISITION

3.1 Daylight MSS Data Acquisition

The survey area was approximately 5 by 7 miles covering the area of the radiological survey and extending north to the Ohio River. Eleven east-west flight lines with a 3,000-foot spacing were required for contiguous coverage of the survey area from an altitude of 3,000 feet AGL. The exact coverage of each flight line is illustrated in Figure A-1 in Appendix A.

The parallel flight lines were flown with a heading of 290 degrees during a two-hour period from 09:50 to 11:15 local standard time. During these acquisitions, the solar off-axis azimuth ranged from 10 degrees east of the axis to 13 degrees west of the axis. The sun elevation varied from 47 degrees to 64 degrees above the horizon. Sky conditions were clear during the survey, but upper air turbulence was present during the daylight mission. The land surface was wet, and the Ohio River was above flood stage during the survey period due to above-normal precipitation immediately prior to the survey.

A microwave ranging system (MRS) was used to facilitate precise navigation during both daylight and predawn missions. The MRS transponders were placed at the control tower at the airfield and on a grain elevator near the town of Kevil.

Multispectral scanner data were decommutated from High Density Digital Tape (HDDT) format into a nine-track, Computer-Compatible Tape (CCT) format. Raw byte data can currently be provided in either 6,250 or 1,600 bits-per-inch (bpi) format with any blocking factor to satisfy user needs. The converted data were corrected for systematic geometric distortions. During this process, data were transformed and resampled to minimize the tangential distortion (s-bend) inherent in all electro-optical scanner data. The correction program also compensates for overscan based on the velocity/height ratio. Thermal infrared data were radiometrically calibrated based on the recorded reference blackbodies. This calibration is necessary when relative absolute temperature differences may be required.

Copies of original or corrected and calibrated MSS data in a user-specified CCT format can be obtained from EG&G/EM's Multispectral Remote Sensing Department of RSL. The MRSD can also provide photographic hard copy image renditions of the MSS data.

3.2 Predawn Thermal Infrared Data Acquisition

Thermal infrared data were collected from an altitude of 3,000 feet AGL with the AADS1268 scanner on June 1, 1990, between 01:48 and 03:04 local standard time. The 11 flight lines were flown on the same 290-degree track as the daytime data. Coverage was approximately the same area as the daylight missions (Figure A-2). Two channels of data were acquired in the thermal infrared spectral band (8.2-10.5 micrometers) with fixed gains of 0.5 and 1.0, respectively.

3.3 Aerial Photo Acquisitions

Small-scale, natural color (Aerocolor) photographs of PGDP and the surrounding area were collected on March 20, 1990, for use as the base for the radiation survey. The nine-inch format photographs were exposed with a Wild RC-10 camera equipped with a six-inch focal length lens. Images were collected from altitudes of 4,000; 5,500; 6,500; 10,000; and 25,000 feet AGL. The resulting photos had nominal scales ranging from 1:7,960 to 1:49,700.

Large format color-infrared photos (Aerochrome IR) were collected with the same camera and six-inch lens combination during daylight scanner missions. Nominal photo scales of 1:5,970 resulted from the mission altitude of 3,500 feet AGL. All photos were collected with 60 percent end lap to facilitate stereoscopic viewing and sufficient side lap to ensure contiguous coverage.

Proof books of the aerial photographs are available at the EG&G/EM Remote Sensing Laboratory. These proof books can be used to identify photos of specific interest. Each photo in the proof set has a unique roll and frame identifier imprinted along the top edge. The original photography is archived at the Remote Sensing Laboratory. Copies and/or enlargements of any aerial photographs can be produced by RSL's Photo/Video Department.

4. DISCUSSION OF THE ENHANCED IMAGES

The MSS system detects and records reflected and emitted electromagnetic energy from scene features. The "spectral signature" of features is determined by the unique reflectance and thermal emittance patterns that can be discriminated in each of the channels (Figure A-3). Forested areas have a relatively low reflectance in the visible and mid-infrared spectral bands producing dark grey tones on the respective images. They have a much higher reflectance in the near infrared and appear as light tones. In contrast, water has its greatest reflectance in the blue-green spectral bands and almost none in the reflected infrared channels. The thermal infrared imagery represents the apparent temperature profile of the surface with light tones indicating the highest temperatures.

Color composites of three bands can be generated to enhance and portray specific spectral differences with more distinguishable hues and chromas. The color of features in a composite image is a function of relative reflectance differences in the spectral bands selected for the composite. A simulated, natural color image was produced by compositing Channels 5, 3, and 2 in red, green, and blue, respectively (Figure A-4). In this composite, the colors of scene features are similar to colors as they would appear visually. A sample, false color infrared composite was generated using MSS Channels 7, 5, and 3 (Figure A-5). Growing vegetation appears as red hues in this composite because of the higher reflectance in the near infrared compared to the visible bands.

The effects of environmental problems can often be detected in the vegetation as differences in species composition, density, and vigor or stress. Spectral greenness images that enhance apparent differences in green biomass can be calculated from different combinations of spectral bands. In the context of this preliminary analysis, the terms "spectral greenness" and "greenness" are used synonymously and refer to what are commonly known as vegetation indices (VIs) in the remote sensing literature.

Healthy vegetation has a relatively high reflectance in the green and near-infrared spectra due to the presence of chlorophyll and the intracellular structure, respectively. Red energy absorbed for chlorophyll production produces a relatively lower reflectance. Soils which are normally the background for vegetation typically have higher reflectance than vegetation in the visible spectra, but lower reflectance in the near infrared.

The "tasseled cap" transformation is based on the biophysical observation that bare soil spectral responses generally fall along a single dominant axis (brightness). A vegetation axis (greenness) orthogonal to this axis can be defined (Kauth and Thomas 1976, Crist and Kauth 1986). Subsequent axes for wetness, yellow matter, and other spectrally related factors have also been identified (Crist and Cicone 1984a).

The tasseled cap technique has proven useful in crop surveys and vegetation vigor assessment studies (Crist and Cicone 1894b). The transformation coefficients were applied to a subset of Daedalus AADS1268 MSS channels that correspond to the appropriate Landsat Thematic Mapper bands (Figure A-6). Lighter tones on the resultant vegetation index images indicate the greater brightness, greenness, or yellowness, respectively. In the greenness image, forested areas have the lightest tones indicating the greatest greenness. Bare soils and buildings have the darkest tones.

On thermal infrared images, differences in apparent temperature are represented by differences in grey tones (Figure A-7). The lightest tones indicate the highest temperatures. Thermal imagery can provide more than a relative surface temperature profile. Information related to the physical properties of scene features can often be inferred from the data. The physical properties of objects affect solar absorption and/or thermal emmission and can produce large, apparent surface temperature differences on thermal infrared images. The apparent surface temperatures also depend on the heat flux, the heat capacity of objects, and the exchange rate with the atmosphere.

During periods of direct solar illumination, solar loading can mask relevant temperature variations. Important thermal anomalies are often detected on data acquired during early morning hours when the effects of solar loading are minimized. When both daylight and predawn data are available, the amplitude of diurnal variations can be used as a measure of the relative thermal inertia of scene features. Areas with obvious relative differences in thermal inertia are circled on Figure A-7. In this case, these differences are probably related to the operation of the plant, but this technique is also applicable for identifying surface and subsurface environmental contamination. To date, no attempt has been made to correlate field observations with the results of this analysis.

5. SUMMARY AND CONCLUSIONS

The Remote Sensing Laboratory, operated by EG&G/EM, conducted two airborne, multispectral scanner surveys of the Paducah Gaseous Diffusion Plant and the surrounding area. On May 31, 1990, daylight multispectral data were collected from an altitude of 3,000 feet AGL. A predawn thermal survey was conducted from the same altitude on June 1, 1990. All scanner data have been converted to CCT format and corrected for systematic geometric distortions. Thermal infrared data were calibrated to internal reference blackbodies.

Several different analysis techniques including color compositing and vegetation index transformations were performed to illustrate the capabilities of the data. To date, there has been no attempt to correlate ground observations with the scanner data. The data that were acquired offer a unique opportunity for further analysis because of the availability of temporal, multispectral, and predawn data sets. Requests for data and/or further analysis assistance should be directed to the DOE Nevada Operations Office.

REFERENCES

Crist, E.P. and R.C. Cicone, 1984a. "Comparisons of the Dimensionality and Features of Simulated Landsat 4 MSS and TM Data," *Remote Sensing of the Environment*, 14:235-246.

Crist, E.P. and R.C. Cicone, 1984b. "Application of the Tasselled Cap Concept to Simulated Thematic Mapper Data," *Photogrammetric Engineering and Remote Sensing*, 50:343-352.

Crist, E.P. and R.J. Kauth, 1986. "The Tasseled Cap De-Mystified," *Photogrammetric Engineering and Remote Sensing*, 52:81-86.

Kauth, R.J. and G.S.Thomas, 1976. "The Tasseled Cap - a Graphic Description of the Spectral - Temporal Development of Agricultural Crops as Seen by Landsat," *Proceeding of the Symposium on the Machine Processing of Remote Sensing Data*, Purdue University, Lafayette, Indiana, pp. 4B41-4B51.

APPENDIX A
MULTISPECTRAL SCANNER IMAGES

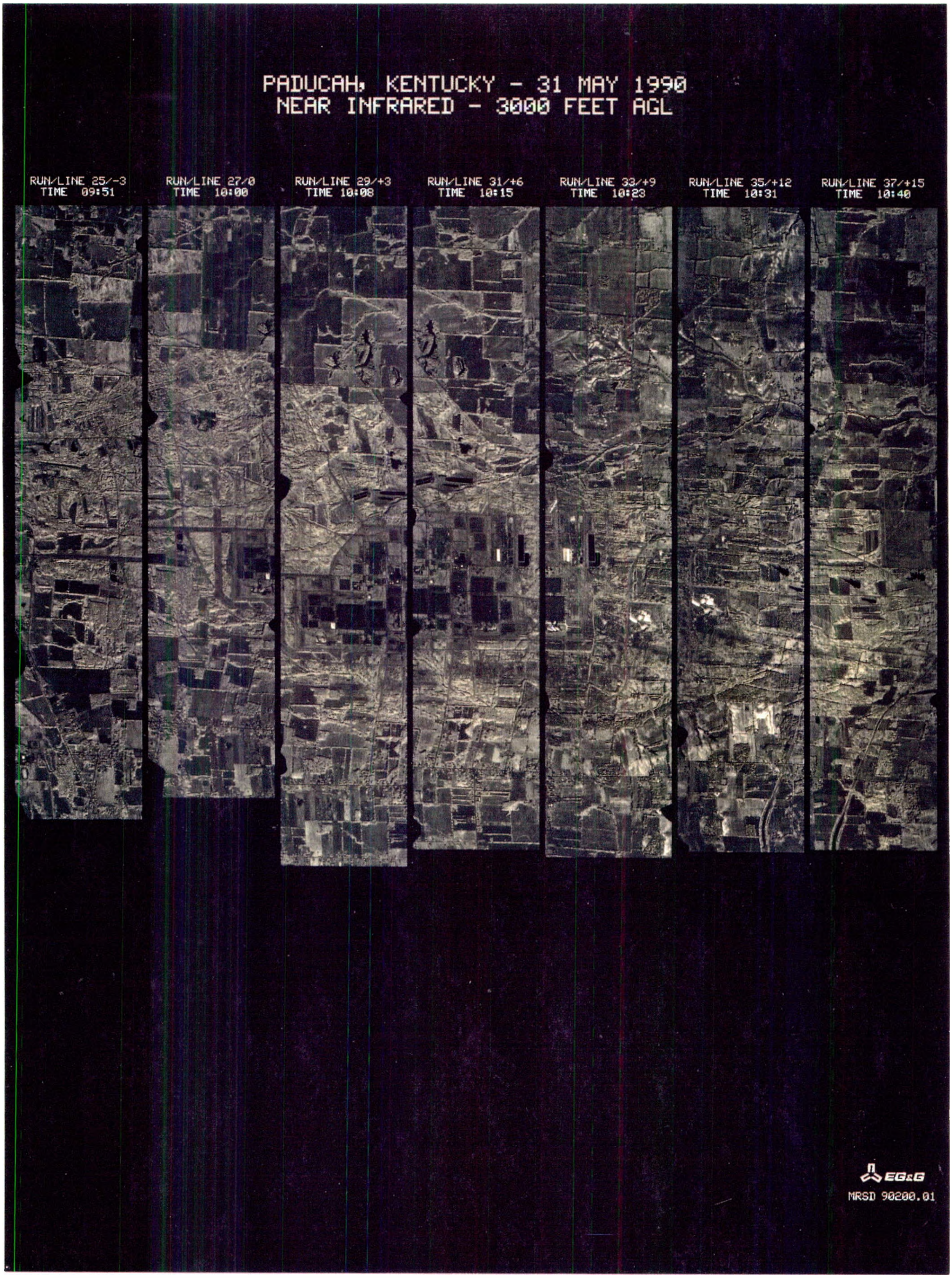

FIGURE A-1. *COVERAGE OF MULTISPECTRAL SCANNER DATA ACQUIRED ON MAY 31, 1990 (MRSD 90200.01)*

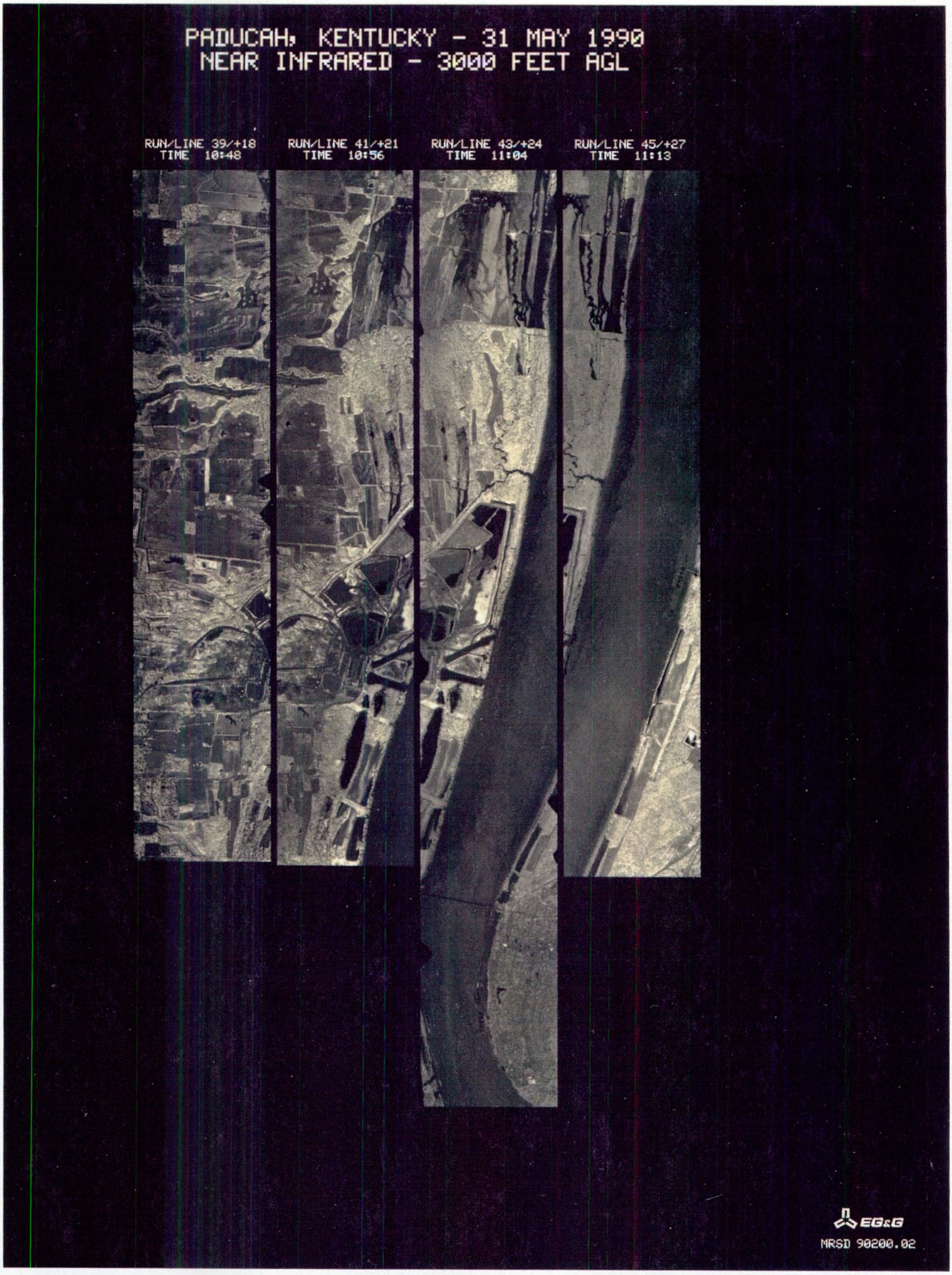

FIGURE A-1. *COVERAGE OF MULTISPECTRAL SCANNER DATA ACQUIRED ON MAY 31, 1990 (MRSD 90200.02) (Continued)*

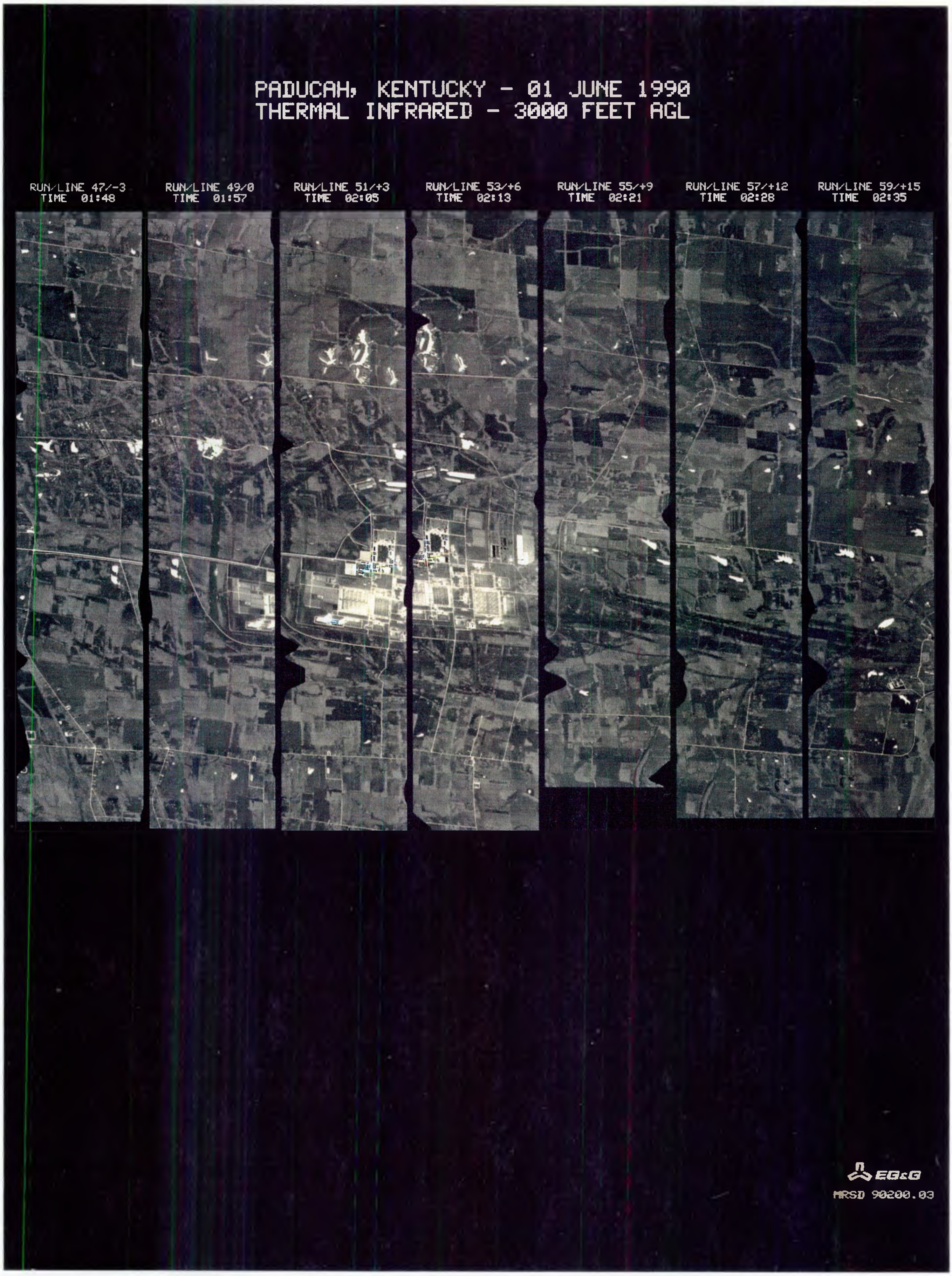

FIGURE A-2. *COVERAGE OF PREDAWN THERMAL INFRARED DATA ACQUIRED ON JUNE 1, 1990 (MRSD 90200.03)*

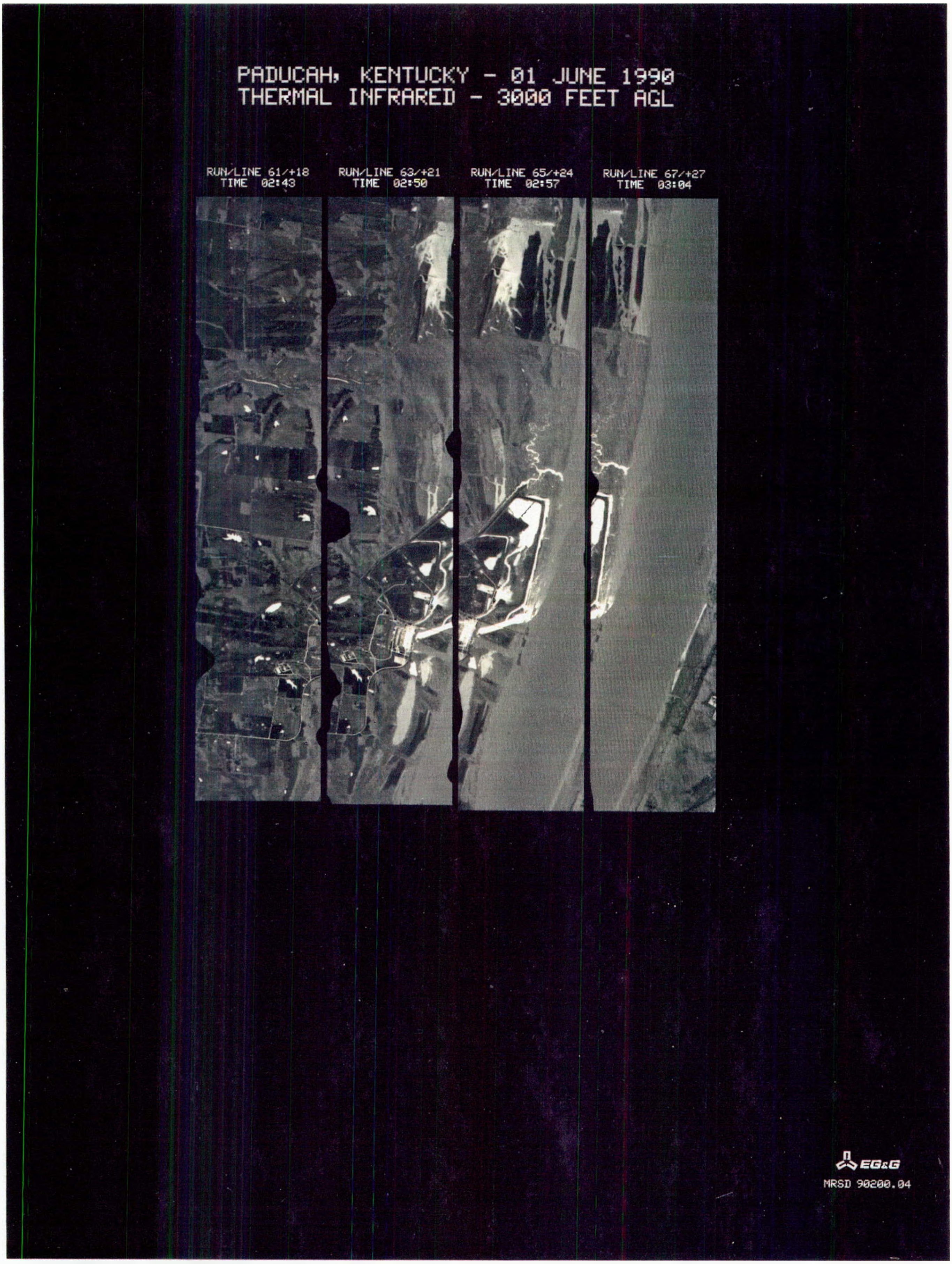

FIGURE A-2. *COVERAGE OF PREDAWN THERMAL INFRARED DATA ACQUIRED ON JUNE 1, 1990 (MRSD 90200.04) (Continued)*

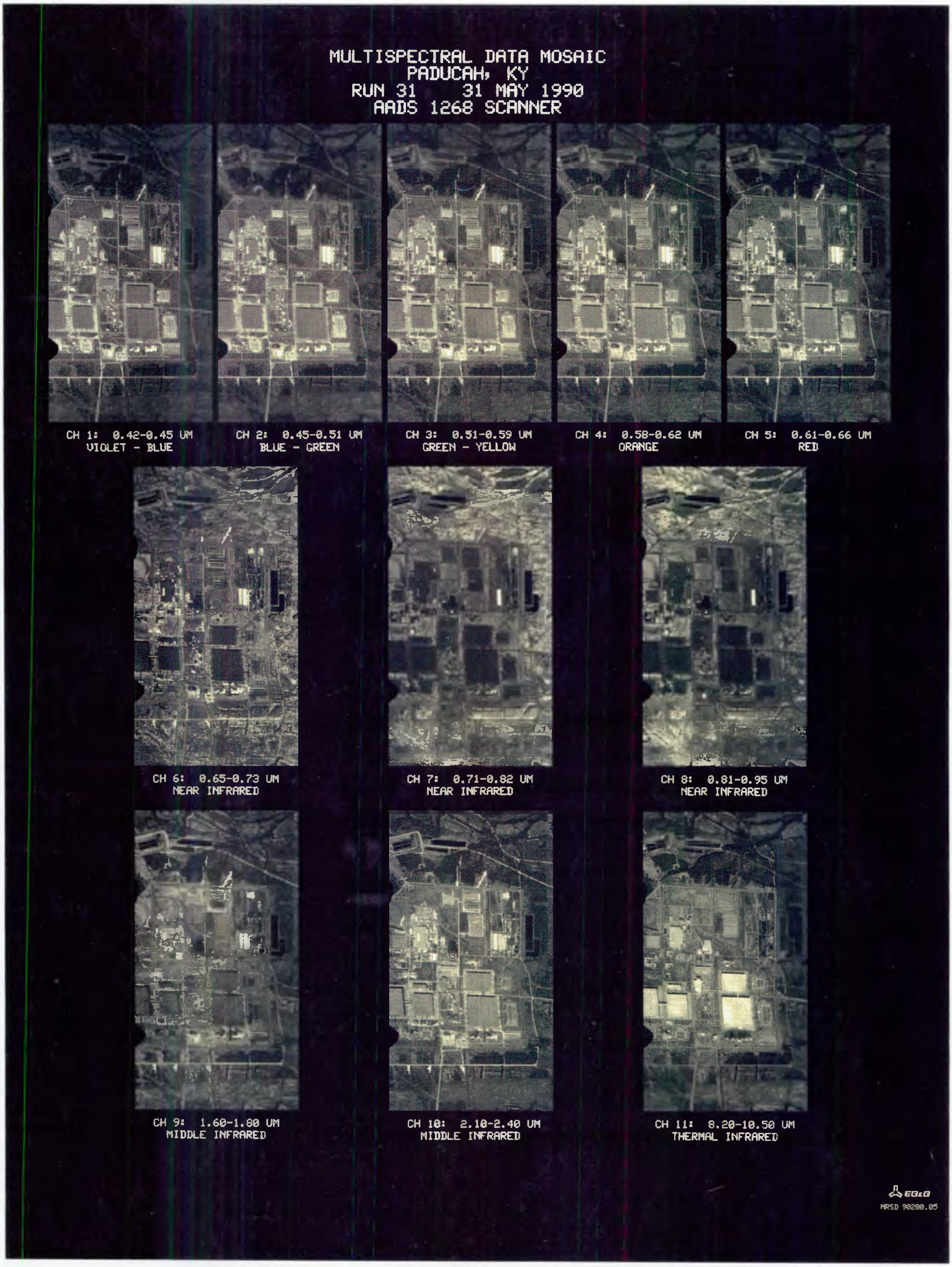

FIGURE A-3. *MOSAIC OF 11-CHANNEL MULTISPECTRAL SCANNER IMAGES (MRSD 90200.05)*

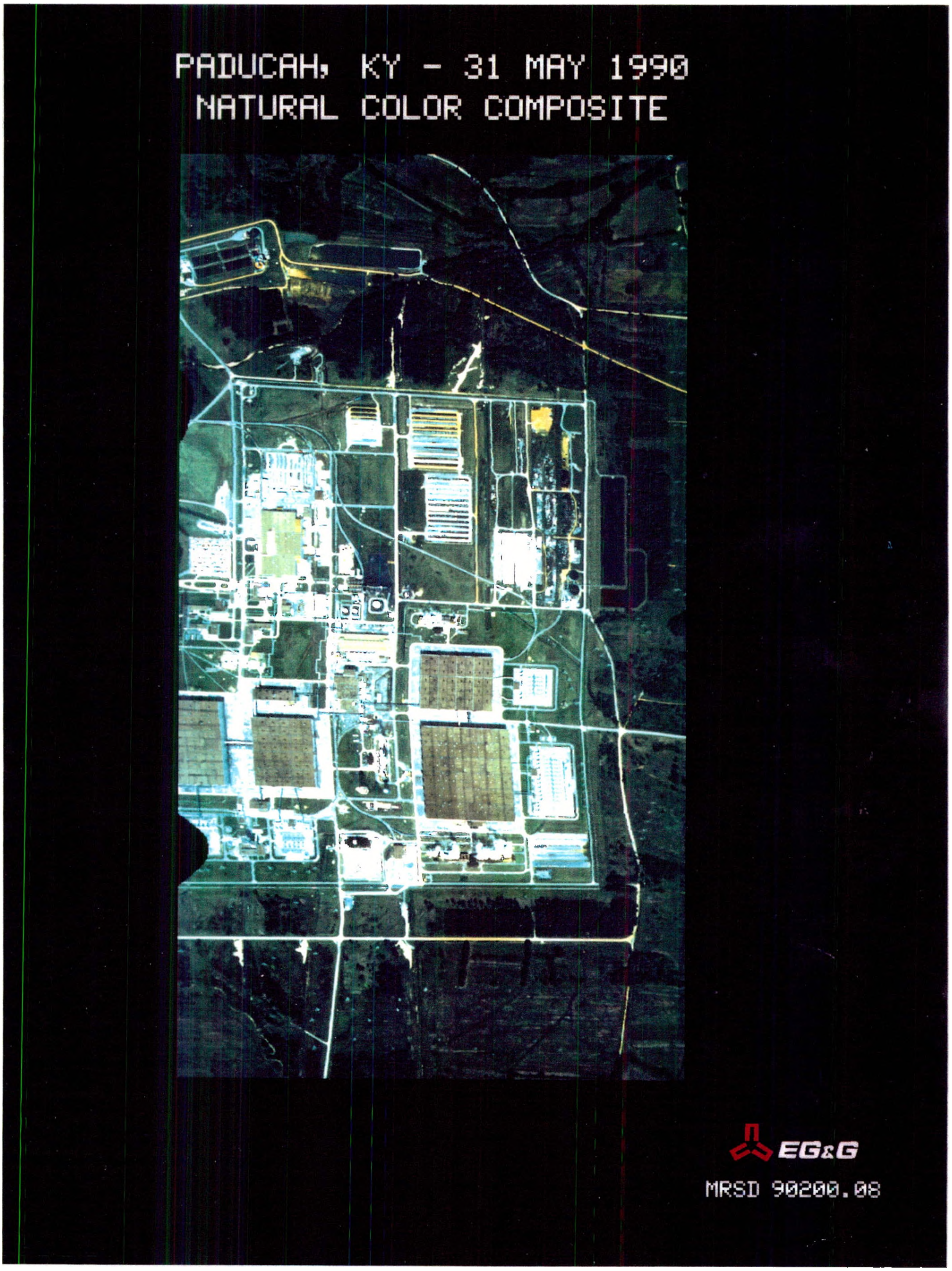

FIGURE A-4. *NORMAL COLOR COMPOSITE, MAY 31, 1990: CHANNELS 5, 3, 2 (MRSD 90200.08)*

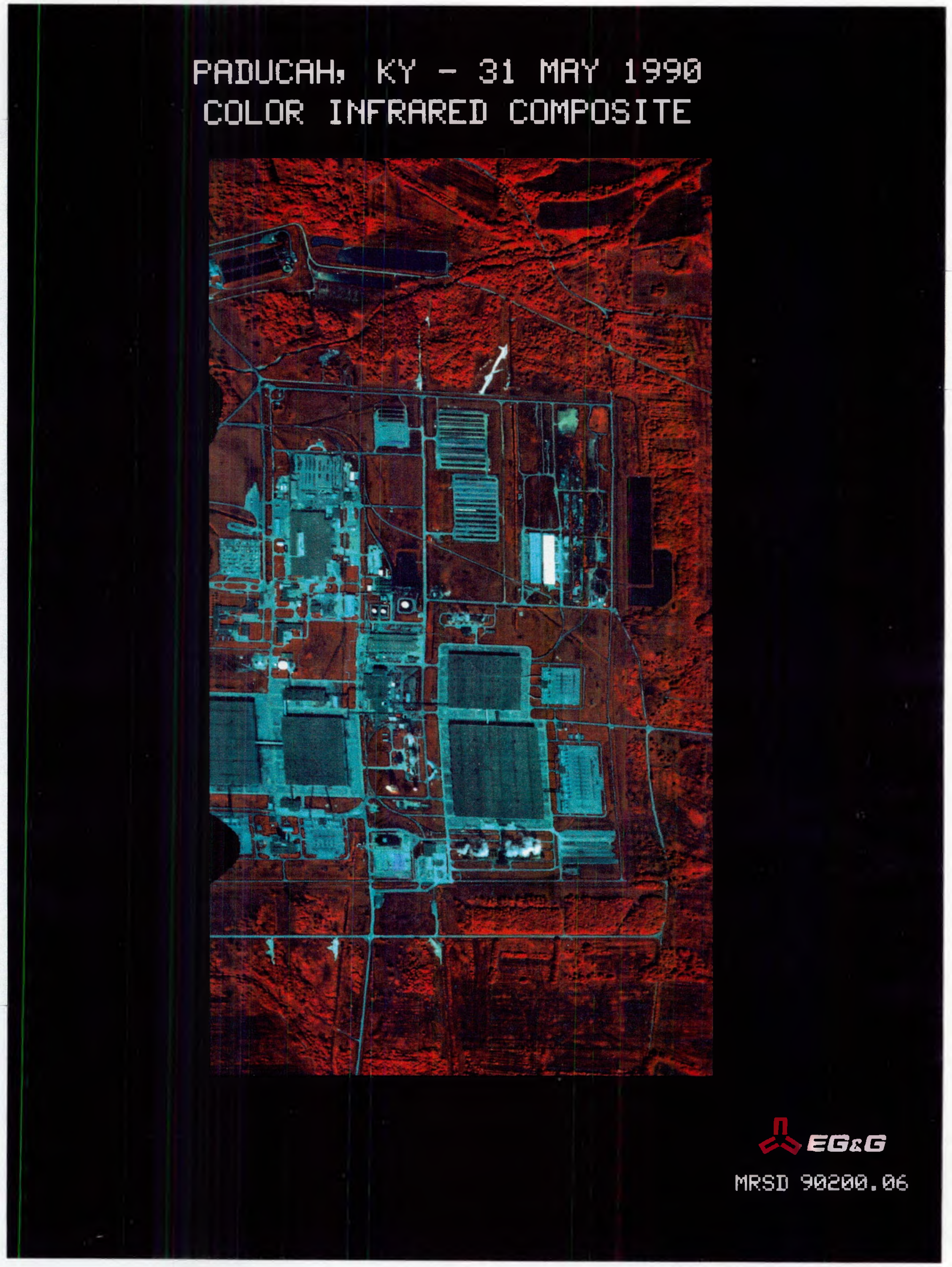

FIGURE A-5. *FALSE COLOR INFRARED COMPOSITE, MAY 31, 1990: CHANNELS 7, 5, 3 (MRSD 90200.06)*

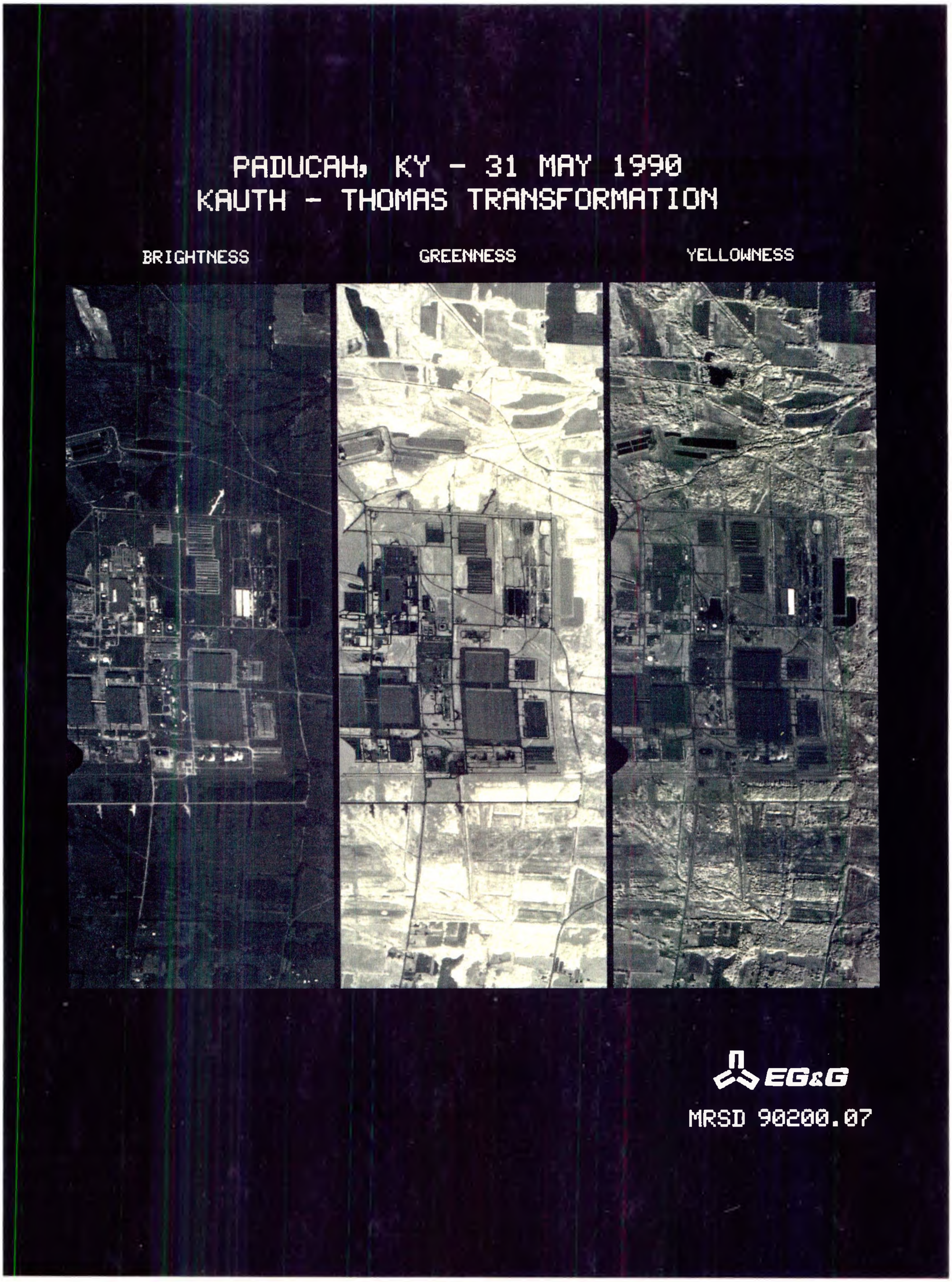

FIGURE A-6. *KAUTH-THOMAS TRANSFORMATION, MAY 31, 1990: BRIGHTNESS, GREENNESS, YELLOWNESS (MRSD 90200.07)*

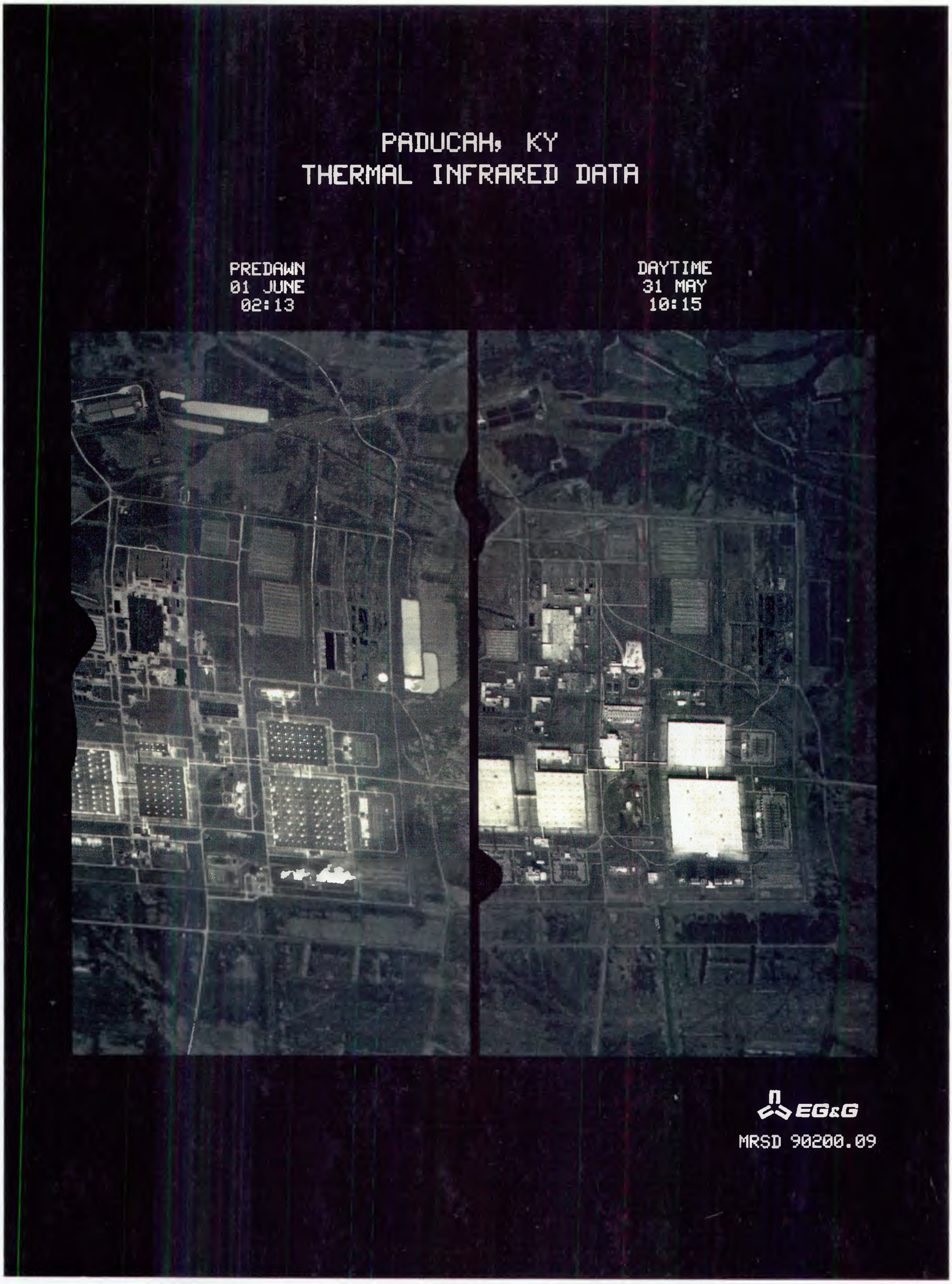

FIGURE A-7. *PREDAWN AND DAYTIME THERMAL INFRARED IMAGES (MRSD 90200.09)*

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