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RAYTHEON

SPACE AND INFORMATION SYSTEMS DIVISION

ANALYSIS OF MULTI-SENSOR DATA

by

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**ORIGINAL CONTAINS
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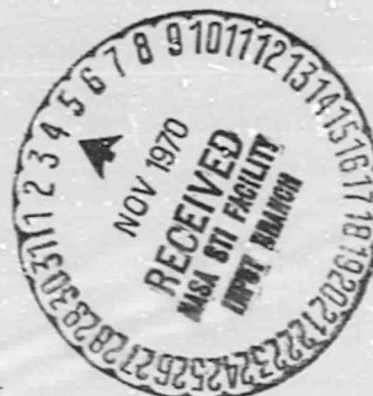
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FOREWORD

This report was prepared by the Autometric Operation of Raytheon Company under U. S. Geological Survey Contract Number 14-08-0001-11505 and represents the results of a study made of multi-sensor imagery, most of which was acquired by the NASA Earth Resources Aircraft Program for the Office of Emergency Preparedness. Funding was through the Office of Emergency Preparedness.

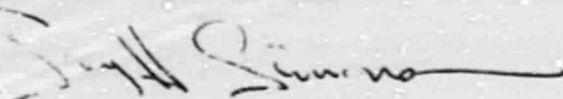
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ABSTRACT

This report represents the results of assessments made of multi-sensor imagery obtained, for the most part, from the interdisciplinary NASA Earth Resources Aircraft Program. The assessments derive from an investigation, funded by the Office of Emergency Preparedness, into the potential of various remote airborne sensors in meeting the emergency information requirements of the OEP. The imagery studied was: black-and-white, color, color infrared, multiband, and thermal infrared. Specifically, the analysis was conducted for the purpose of: 1) determining the level of detail interpretable from each type of sensor record; 2) examining industrial, urban and other cultural activities and installations for unique spectral signatures; and 3) determining the applicability of each type of sensor record to functional and structural analysis and to the post-emergency analysis of earthquake damage.

The conclusions derived with respect to the specific objectives of the assessment were: 1) that since the level of detail observed is a function of resolution and contrast, the black-and-white photography, having the largest scale, proved to be the most efficient sensor where the detection of fine detail was the objective; 2) that the results of the search for exclusive spectral signatures was inconclusive; 3) that large scale and good resolution were the principal factors affecting functional and structural analysis; 4) that oblique photography was a most useful adjunct to vertical photography in determining the extent and severity of earthquake damage; 5) that color infrared and thermal infrared are the best sensors for locating, respectively, chemical and thermal water pollution; 6) that the multiband camera shows promise in determining the unique signatures of roof materials; and 7) that thermal infrared imagery shows promise of applicability in examination of tank contents for fluid level detection.

On the basis of these conclusions it was recommended that: 1) color IR, thermal IR, and multiband imagery be acquired over sites that are known to exhibit a variety of spectral signatures; 2) that the use of side-looking radar for the assessment of flood damage be investigated; 3) that the use of a trimetrogon or panoramic photographic system for providing structural and compositional data be determined; 4) that the capabilities of satellite and classified Department of Defense imagery be studied; 5) that consideration be given to the establishment of a multi-sensor data base; 6) that new or updated photo interpretation keys, designed to meet specific OEP requirements, be prepared; 7) that more consideration be given to the use of original negatives and sensitometry data in order to better quantify data reduction results; and 8) that efforts be made to convert analyzed data into a format compatible with the National Resource Evaluation Center's computer simulation programs.

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1. INTRODUCTION

The subject of investigation is the determination of the capability and potential of a variety of sensor imagery to meet emergency information requirements.

This document contains descriptions of the interpretation procedures followed, the analyses performed, and the results obtained from the study. Imagery and funding were provided by the Office of Emergency Preparedness. Imagery consists of coverage of selected test sites in the United States flown for OEP within the framework of the NASA Earth Resources Aircraft Program. Additional imagery flown by the U. S. Air Force and U. S. Army was also used.

Since the results of the study are of interest to the Geographic Applications Program of the U. S. Geological Survey and to the NASA Earth Resources Program, copies will be provided these agencies by the OEP.

1.1 Objectives

The principal objective was to examine in detail the various types of sensor imagery provided in order to:

1. Determine the level of detail interpretable from each type of sensor record.
2. Determine unique spectral signatures.
3. Determine the applicability of each sensor record to functional and structural analysis.
4. Determine each sensor record's applicability to post-emergency analysis of man-made or natural disasters.
5. Make recommendations for further research and data analysis as appropriate.

2. ANALYSIS DATA

2.1 Target Sites

The target sites selected for analysis were:

1. NASA Michoud Assembly Facility; Michoud, La.; Test Site #133.
2. NASA Computer Operations Office; Slidell, La.; Test Site #134.
3. NASA Mississippi Test Facility; Gainesville, Miss.; Test Site #137.
4. New Orleans, La.; Test Site #132
 - a. Residential Area; New Orleans, La.; Part of Test Site #132.
 - b. Rail Yards; Part of Test Site #132.
 - c. Roof Materials Discrimination; Part of Test Site #132.
 - d. Water Pollution Analysis; Parts of Test Sites #132 and #133.
 - e. Thermal Analysis of Petroleum Tanks; Part of Test Site #132.
5. Anchorage, Alaska.

2.2 Imagery

Imagery for this study consisted of color IR, color, multiband thermal IR and black-and-white records.

Table I is a list of specific sensors, sites, altitudes, dates and film types supplied. All film, with the exception of the Alaskan film (duplicate negative), was duplicate positive.

In addition to the film listed below, selected paper prints were furnished of the color and the color IR. A variety of paper prints of the Alaskan earthquake area, flown by the U. S. Army, were also provided.

In general, the quality of the film provided ranged from fair to good, except for the thermal IR. This imagery suffered from loss of detail due to jitter-offset scan lines caused by improper synchronization of the scan drive motor with the recording drive motor. This defect was corrected in later imagery. Other imagery parameters not conducive to interpretation included:

TABLE I
SENSOR AND IMAGERY TYPES USED

<u>Mission</u> ¹	<u>Date</u>	<u>Sensor</u>	<u>Altitude (Ft.)</u>	<u>Film</u>	<u>Sites</u> ²
62	12-06-67	RC-8	2,000	Color IR	All but Anchorage
62	12-06-67	RC-8	8,000	Color IR	All but Anchorage
62	12-06-67	Recon IV	2,000	Tri-X	All but Anchorage
62	12-06-67	Recon IV	8,000	Tri-X	All but Anchorage
62	12-06-67	Multiband ³	2,000	B&W	All but Anchorage
62	12-06-67	Multiband ³	8,000	B&W	All but Anchorage
40	12-23-67	RC-8	15,000	Ek Color	All but Anchorage
40	12-23-67	Recon IV	15,000	Tri-X	All but Anchorage
66	02-09-68	RC-8	8,000	Color IR	New Orleans
66	02-09-68 & 02-10-68	T-11	8,000	B&W	New Orleans
Power- house 2	05-01-64 & 05-02-64			B&W	Anchorage
81	10-11-68	Recon IV	8,000 & 3,500	Tri-X	New Orleans
81	10-11-68	RC-8	8,000 & 3,500	Color IR	New Orleans
81	10-11-68	Multiband ³	8,000 & 3,500	B&W	New Orleans

¹Mission numbers are NASA Earth Resources Aircraft Program numbers
(except for Powerhouse 2).

²For identity of sites, see 2.1.

³The following filter-combinations for the Multiband camera were used

<u>Lens</u>	<u>Film</u>	<u>Filters</u>	<u>Peak Wavelength</u>
1	5401	36+38 A	420
2	5401	3+47	470
3	5401	65A+58	520
4	5401	21+57	560
5	5401	72 B	600
6	5401	21+34	700
7	5424	87B+1.2ND	1100
8	5424	87 +	950
9	5424	87 C	950

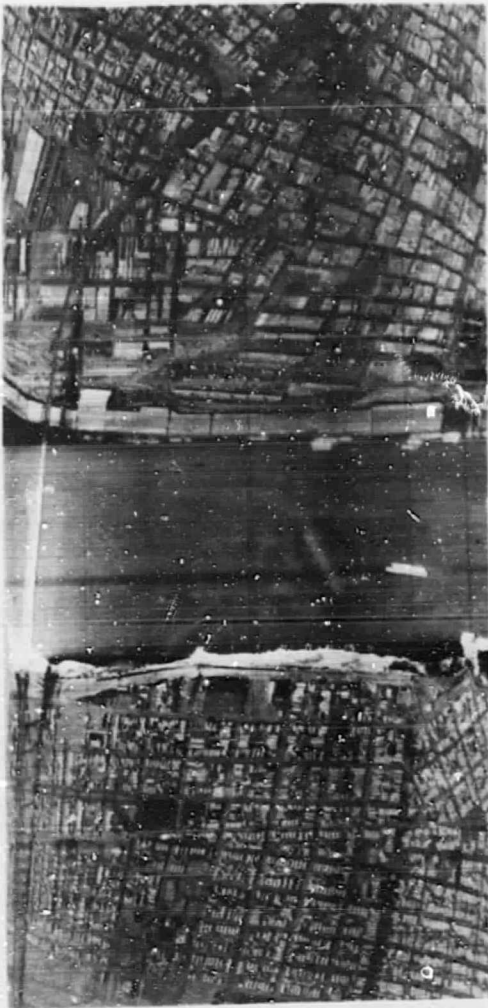
1. Poor color balance on most of the color and color IR.
2. No overlap on the multiband.
3. Insufficient overlap on the Alaskan earthquake imagery.
4. Severe loss of definition on the T-11 black-and-white imagery.

Figures 1-3 are representative samples of the imagery analyzed in this study.

2.3 Ground Truth

Ground truth consisted of technical facilities catalogues, master plans and some miscellaneous 8x10 photographs of the sites in the New Orleans vicinity. Alaskan earthquake ground truth consisted of published geological articles. Specific ground truth information was provided by the following publications:

1. Technical Facilities Catalogue, NHB 8800.5, Volumes I and II, issued by NASA, 1968.
2. NASA Budget Estimates of 1966.
3. MSFC Master Plan, Michoud Assembly Facility, Volume II, 1968.
4. MSFC Master Plan, Slidell Computer Facility, Volume II, 1968.
5. MSFC Master Plan, Mississippi Test Facility, Volume III, 1968.
6. Geological Survey Professional Paper 542A, 1966, The Alaskan Earthquake, "Effects on Communities".
7. Geological Survey Circular 491, 1964, Alaska's Good Friday Earthquake, "A Preliminary Geological Evaluation".
8. Technical Data on Petroleum Tanks in New Orleans, La., provided by Sinclair Oil Company, Westwego, La.



RECONOFAX IV



T-11

FIGURE 1 SAMPLE IMAGERY - RECONOFAX IV AND T-11

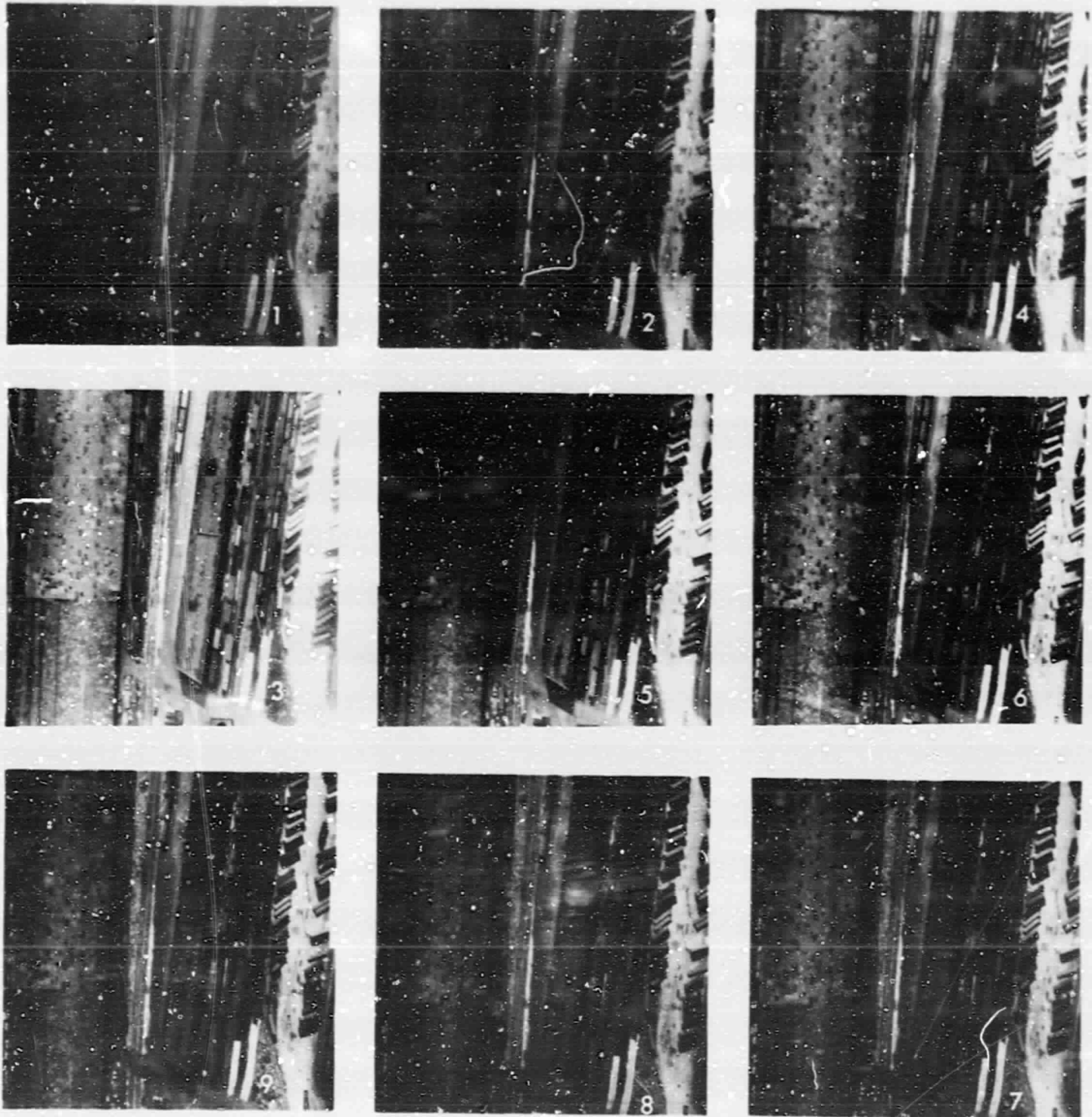
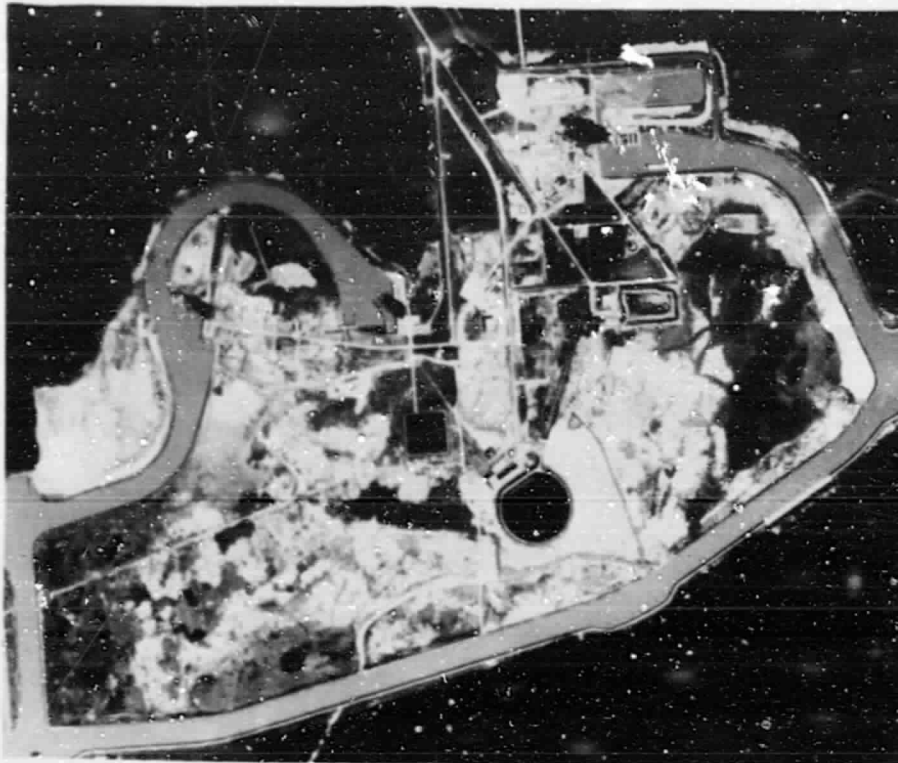


FIGURE 2 SAMPLE IMAGERY - MULTIBAND CAMERA



RC-8 COLOR



RC-8 COLOR INFRARED

FIGURE 3 SAMPLE IMAGERY - RC-8 COLOR AND RC-8 COLOR INFRARED

3. ANALYSIS PROCEDURES

Upon receipt of the imagery, a preliminary examination was made to determine the usefulness of each type to the objectives of the program. This determination was based on resolution, image definition, contrast, evident system malfunctions, photographic processing, deficiencies and over-all quality.

Each set of imagery was then plotted on a 1:62,500 scale map for location purposes and for the determination of areas having comparative coverage.

Selected areas were then interpreted for amount of detail, which included the identification of individual components of the test sites. Identified detail from each type of imagery was then tabulated and compared with detail identified on all other types of imagery to determine which kind of record combination presented the most information. Overlays were made scaled to the color IR imagery (scale 1:4000) with identifiable features annotated. The intent here was to illustrate the amount of detail obtainable from each sensor record.

An attempt was then made to perform a structural and functional analysis of each selected site. The structural analysis took the form of identifying roof types, roofing materials, predominant structural materials, building types, and roof support structures. The functional analysis was performed on the basis of visible indicators only.

4. RESULTS

The following section describes the analytical results. At each test site the structure and function of each component was first interpreted from the imagery and then checked against the ground truth. A comparison of the two columns of Table II shows that there was better than an 87% correlation between interpreted and ground truth detail, the chief difference being in level of specificity. For example, a component identified as a "shop" was subsequently found in the ground truth listing to be a "paint shop".

4.1 NASA Michoud Assembly Facility, Test Site #133

4.1.1 Visible Detail

For this facility, interpretation efforts were concentrated in the industrial area comprising the manufacturing building and the related close support services. These were felt to be the most important components, since all production and assembly are performed there, and were selected accordingly.

The level of detail interpretable at Michoud is more than sufficient for damage assessment. Figure 4 illustrates the amount of detail identified, and Table II illustrates the identification of facility components as interpreted from the imagery. Significant details noted were the electrical power source, the natural gas source and the rail ingress and egress. At the substation receiving power from outside, the three transformers were visible. Additional significant detail includes:

1. The cooling tower (No. 33) does not appear to be in operation, since the fans are not operating.
2. There is no evidence of smoke from the stacks of the boiler house, although this may as well be due to air pollution countermeasures as to inactivity.
3. The number of vehicles in parking areas indicates a full operating shift level.

4.1.2 Functional Analysis

The general function of this facility, as determined from the photography, is concerned with manufacture and/or assembly. The absence of large outside storage precludes identification as to the specific type of manufacture or assembly. The only indicator of significance is the barge at the pier with a large canister. This, being the type used to transport a major space vehicle component over water, suggests that the facility is associated with launch vehicle or missile production.

TABLE II

IDENTIFICATION OF MICHOD ASSEMBLY
FACILITY COMPONENTS

<u>Interpreted Function</u>	<u>Ground Truth Function</u>
1. Office Space	Administrative & Engineering
2. Parking, Concrete Surface	Parking
3. Parking, Asphalt Surface	Parking
4. Electrical Sub-Stations	East & West Master Sub-Stations
5. Shop	Paint Shop
6. Shop	S-1B Laboratories
7. Shop	Battery Charge & Storage
8. Powerhouse	Boiler House
9. Warehouse	Stores & Hardware Storage
10. Waste Pond	Chemical Waste Holding Pond
11. Cooling Tower	Process Water Cooling Tower
12. Shop	Vehicle Dispatch - Maintenance
13. Shop	Minor Electrical Repairs
14. Shop	Emergency Power Pump House
15. Pump House	Pumping Station
16. Shop	Laboratories & Storage
17. Unknown	S-1C Vertical Assembly
18. Storage	Booster Storage
19. Shop	Woodworking, Sheet Metal & Machine Shop
20. Storage Tank	No Information
21. Surge Tanks	High Pressure Air
22. Cooling Towers	Process Water Cooling Tower
23. Shops	No Information
24. Rail Shed	Rail Shed
25. Shop	Maintenance Shop
26. Shop	Maintenance Shop
27. Storage Tank	Potable Water Tank
28. Platform W/Shed	Loading Ramp
29. Rail Shed	Rail Shed
30. Manufacturing Bldg.	S-1C & S-1B Manufacturing
31. Water Tower	Water Tank (Fire)
32. Pipe Lines	Pipe Lines
33. Cooling Tower	Condensed Water Cooling Tower

→ = Source of Utilities

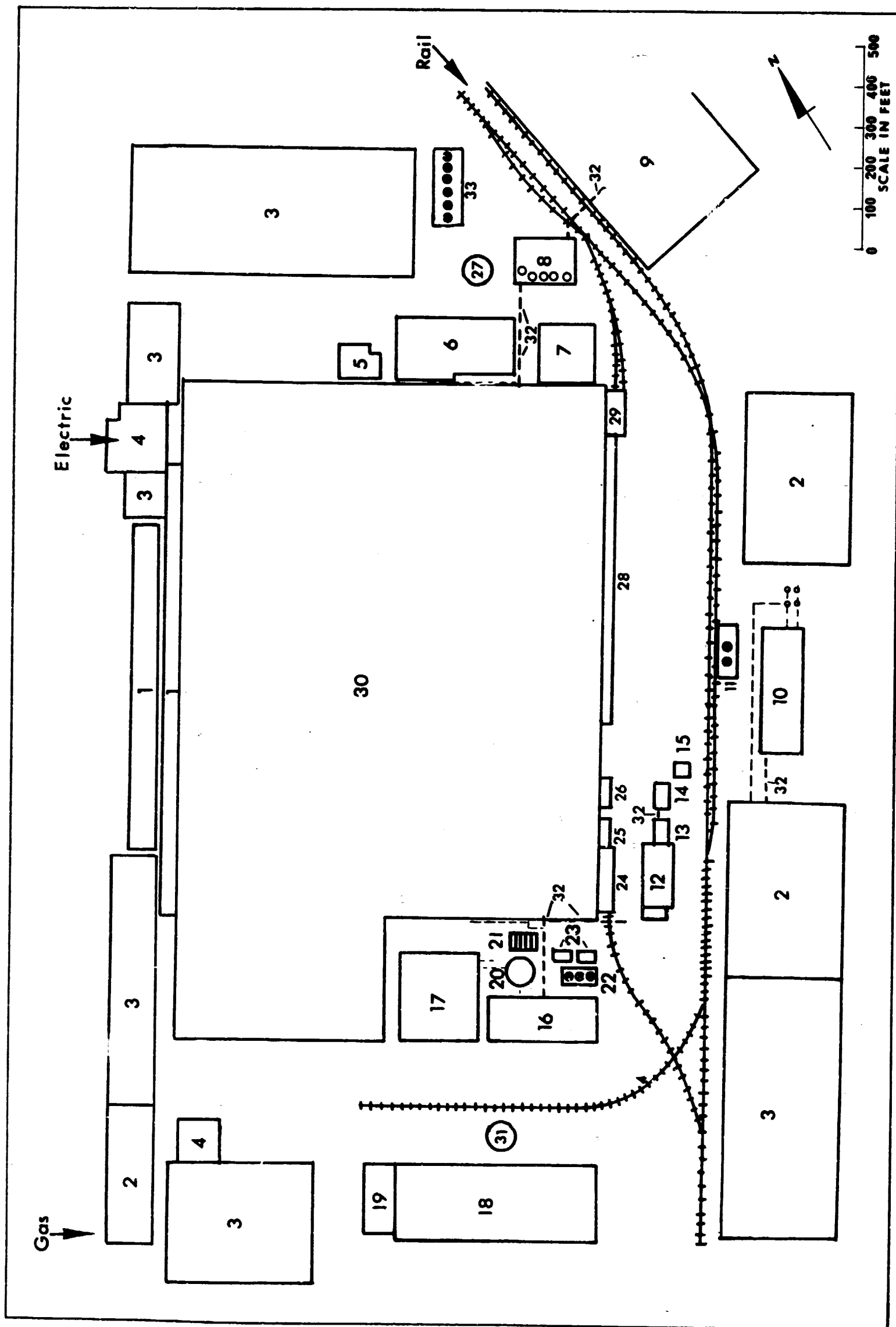


FIGURE 4 INTERPRETABLE DETAIL - MICHOD ASSEMBLY FACILITY

4.1.3 Structural Analysis

Structural analysis, on the basis of photography alone, is a difficult task, heavily grounded on inference. Neither the color, color IR nor the multiband presented any unique signatures. Table III shows the results of the structural analysis.

4.2 NASA Slidell Computer Operations Office, Test Site #134

4.2.1 Visible Detail

The detail interpretable at Slidell is shown in Figure 5. Significant details are the location of the electrical power input (No. 1), the absence of other power facilities, and the apparently motionless fans at the cooling tower (no. 11).

4.2.2 Functional Analysis

It was not possible to identify this installation precisely since the observable criteria of identification pertain equally well to research, engineering and light industrial facilities.

4.2.3 Structural Analysis

Table IV is an estimate of the structure of all units identified during the detailed interpretation task. There were no unique signatures present on any of the photography analyzed. Component designations in Table IV were taken from the ground truth provided.

Identification as a research or engineering facility is based on the neat, clean appearance and the absence of numerous roof vents.

The light industry identification is based on the presence of a shipping and receiving area (No. 17), a tractor-trailer van, and a van (No. 16) on the loading ramps.

4.3 NASA Mississippi Test Facility, Stage Test Area, Test Site #137

Interpretation efforts were concentrated in the S-II stage test area because it is one of the two major functional areas of this facility.

4.3.1 Visible Detail

Interpretable detail is shown in Figure 6. Significant detail noted at this facility includes:

TABLE III

MULTI-SENSOR STRUCTURAL ANALYSIS OF MICHOUX ASSEMBLY FACILITY

LOCATION: New Orleans Area Test Site #133

GROUND TRUTH		INTERPRETATION		
Table II Designation	Component	Structural Materials	Structural Description	No. of Floors Roof Type Roof Material
30	Manufacturing Building	Steel	Steel Truss Roof, Structural Steel Frame. Single Story High Bays	1 Multiple Pitch Asphalt Composition
1	Administrative Building	Brick or Masonry	2 Story, Possible Wall Bearing Structure	2 Flat Asphalt Composition
1	Engineering Building	Brick or Masonry	Unknown	2 Flat Asphalt Composition
7	Battery Charger & Storage Building	Brick or Masonry	Possible Brick or Masonry Composite Structure W/ Steel Roof Beams	1 Modified Monitor Asphalt Composition
12	Garage	Composite	Possible Wall Bearing	1 Pitch Asphalt Composition
14	Emergency Power Building	Concrete Block	Probably Brick or Masonry Wall Bearing Structure	1 Flat Asphalt
26	Maintenance Shop	Masonry	Possible Brick or Masonry Wall Bearing Structure	1 Flat Asphalt Composition
13	Electrical Shop	Brick	Probable Brick or Masonry Wall Bearing Structure	1 Flat Asphalt Composition
25	Valve and Pipe Shop	Brick	Possible Brick or Masonry Wall Bearing Structure	1 Flat Asphalt Composition
17	Vertical Assembly Building	Steel Frame Corrugated Asbestos Skin	Multi-Story Structure	? Flat Asphalt Composition

TABLE III (Cont'd.)

GROUND TRUTH			INTERPRETATION			
Table II Designation	Component	Structural Materials	Structural Description	No. of Floors	Roof Type	Roof Material
6	Sl-B Laboratory	Steel Frame	Composite Structure	1	Twin Monitor	Asphalt Composition
5	Paint Shop	Brick	Probable Brick or Masonry Wall Bearing Structure	1	Flat	Asphalt Composition
4	East and West Sub-Station	Reinforced Concrete & Brick	Probable Brick or Masonry Wall Bearing Structure	1	Flat	Asphalt Composition
16	Systems Engineering	Steel & Brick	Composite Structure	1	Flat	Asphalt Composition
15	Pump House	Concrete Block	Probable Brick or Masonry Wall Bearing Structure	1	Flat	Asphalt Composition
8	Boiler House	Composite Reinforced Concrete/Steel Frame	Composite Steel and Brick or Masonry Structure	1	Monitor	Asphalt Composition
19	Maintenance Shop	Steel Frame Corrugated Walls	Possible Composite Structure	1	Pitch	?
18	Booster Hanger	Steel Frame	Composite Structure	1	Multiple Pitch	Asphalt Composition
9	Vehicle Component Supply Building	Light Steel Frame Concrete Walls	Flat Truss Supported by Exterior Walls or Columns	1	Flat	Asphalt Composition

NOTE: This analysis was initially accomplished using the color IR. After comparison with color and multiband, it was discovered that they contained neither more nor less information. The T-11 B&W photography did not cover this area.

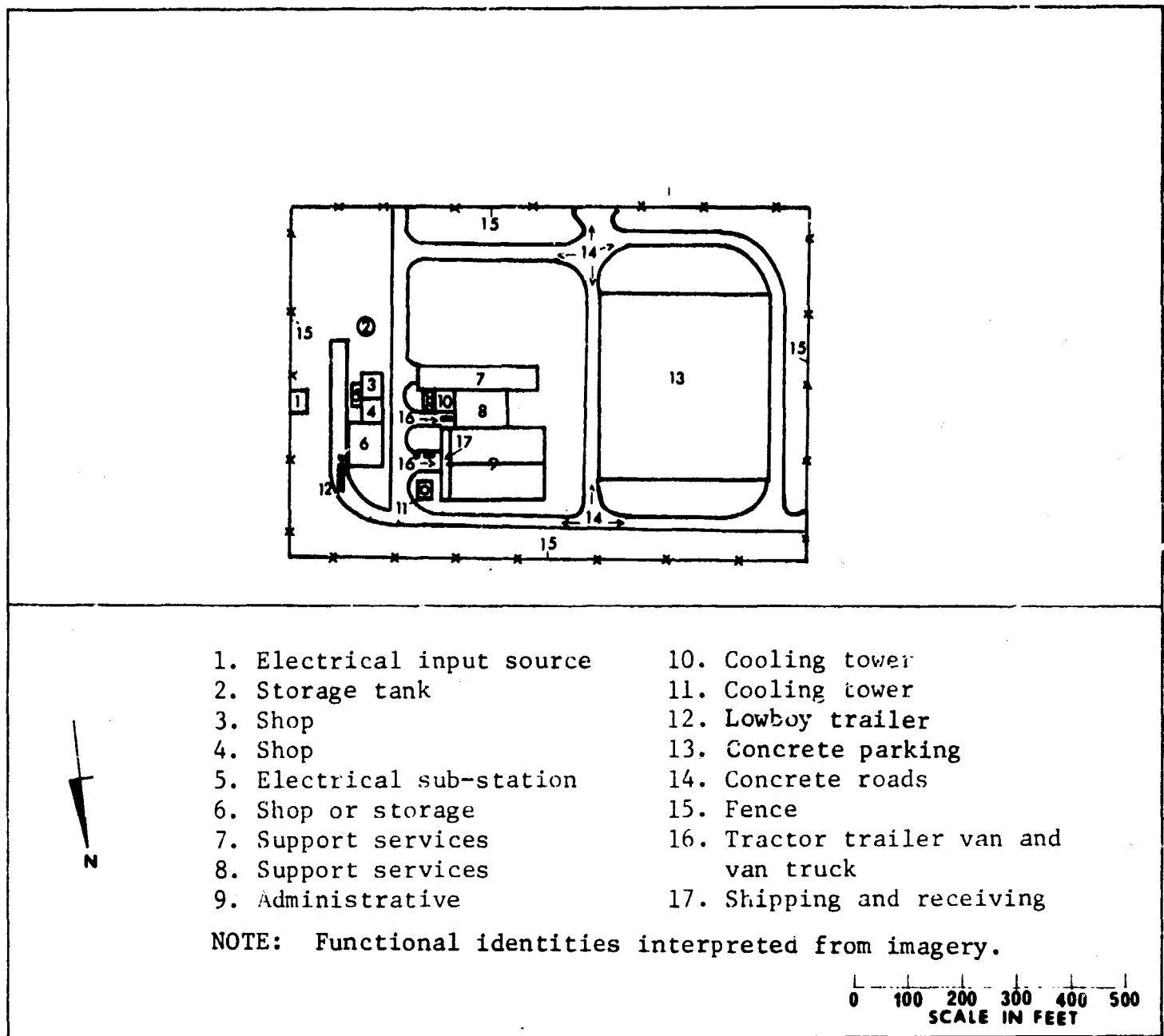


FIGURE 5 INTERPRETABLE DETAIL - SLIDELL COMPUTER OPERATIONS OFFICE

TABLE IV

MULTI-SENSOR STRUCTURAL ANALYSIS OF SLIDELL COMPUTER OPERATIONS OFFICE

LOCATION: Slidell, Louisiana Test Site #134

GROUND TRUTH		INTERPRETATION			
Figure 5 Designation	Component	Structural Materials	Structural Description	No. of Floors	Roof Type Roof Material
7, 8 & 9	Administration and Central Computer Area	Steel Frame Brick, Glass & Metal Walls	Composite Structure of Steel and Brick or Masonry	3	Flat Flat Asphalt Composition
	Garage	Steel Frame Brick Walls	Possible Wall Bearing Structure	1	Flat Asphalt Composition
	Maintenance Shop	Steel Frame Brick Walls	Possible Wall Bearing Structure	1	Flat Asphalt Composition
	Card and Tape Storage	Steel Frame	Possible Composite or Wall Bearing Structure	1	Flat Asphalt Composite

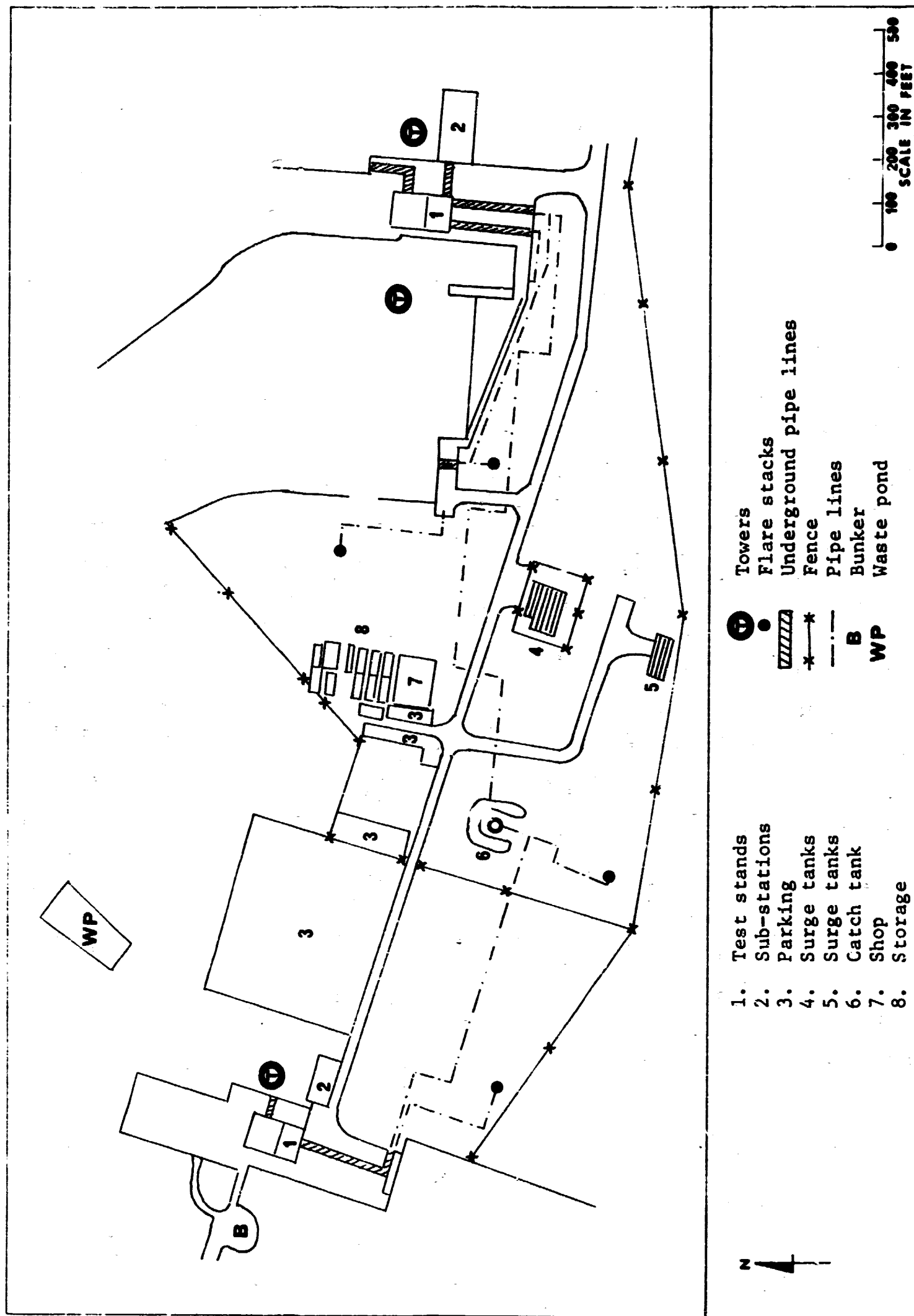


FIGURE 6 INTERPRETABLE DETAIL -- STAGE II TEST AREA, MISSISSIPPI TEST FACILITY

1. Absence of burn-off from flare stacks.
2. Number of vehicles present (indicates near full operating level at west test stand, but below full at east test stand).
3. Shed over west test stand.

4.3.2 Functional Analysis

This installation was readily identified as a launch vehicle test facility, due to the presence of test stands and observation bunkers.

4.3.3 Structural Analysis

The test stands (annotations 1, Figure 6) are the single most characteristic components of the facility. Their shape, height, and steel frame structure, along with the presence of cranes as an organic part of the structure, allow for positive identification.

The observation bunkers (annotation B, Figure 6) are, after the test stands, the next most characteristic components. Their structure is of reinforced concrete.

Annotation No. 7 of Figure 6 refers to what appears to be a single story structure with flat roof and parapet walls. The roofing material is probably asphalt composition. This is possibly a wall bearing structure made of brick or concrete. The associated structures appear to be trailers and metal sheds.

4.4 Residential Areas; New Orleans, La.; Part of Test Site #132

4.4.1 Visible Detail

Visible detail in the residential areas includes:

1. Telephone and Power Poles
2. Fire Hydrants (Possible)
3. Vehicles
4. Roof Design
5. Stoops/Porches
6. One-way and Two-way Traffic Streets
7. Parks
8. Cemeteries
9. Lane Markers
10. Cross Walk Markers

See Figure 7 for an illustration of the area interpreted.



FIGURE 7 ILLUSTRATION OF NEW ORLEANS RESIDENTIAL AREA

4.4.2 Structural Analysis

The close spacing of buildings in the residential area in the city of New Orleans precludes individual structural analysis. A subjective estimate of general construction type would be: single and two story frame structures with a variety of roof shapes; roofing material is probably of asphalt shingle; some houses with high front stoops. The outer materials cannot be estimated; they could be wood, brick or masonry.

4.5 Rail Yards; New Orleans, La.; Part of Test Site #132

4.5.1 Visible Detail

Details visible at the rail yards are shown in Figure 8. In addition to those annotated, such things as track switches and specific types of rolling stock were identifiable. The types of rolling stock found include:

1. Box Cars
2. Gondola Cars
3. Flat Cars
4. Tank Cars
5. Piggyback Cars
6. Chemical Hopper Cars

The amount of detail allows for the possibility of a rolling stock count to determine yard capacity, individual track identification for damage assessment, and the location of high voltage towers.

4.5.2 Functional Analysis

This yard appears to be a transshipment yard. Evidence of this includes: the absence of repair facilities; location near dock area warehouses; spurs to industrial area; and the presence of numerous piggyback cars and the trailers to be carried.

4.5.3 Structural Analysis

No structural analysis of this facility was performed, since there were no structures present other than warehouses.

4.6 Roof Material Discrimination; New Orleans, La.; Part of Test Site #132

Early in the analysis it became apparent that roofing materials could not reliably be distinguished as to composition. Since a knowledge of

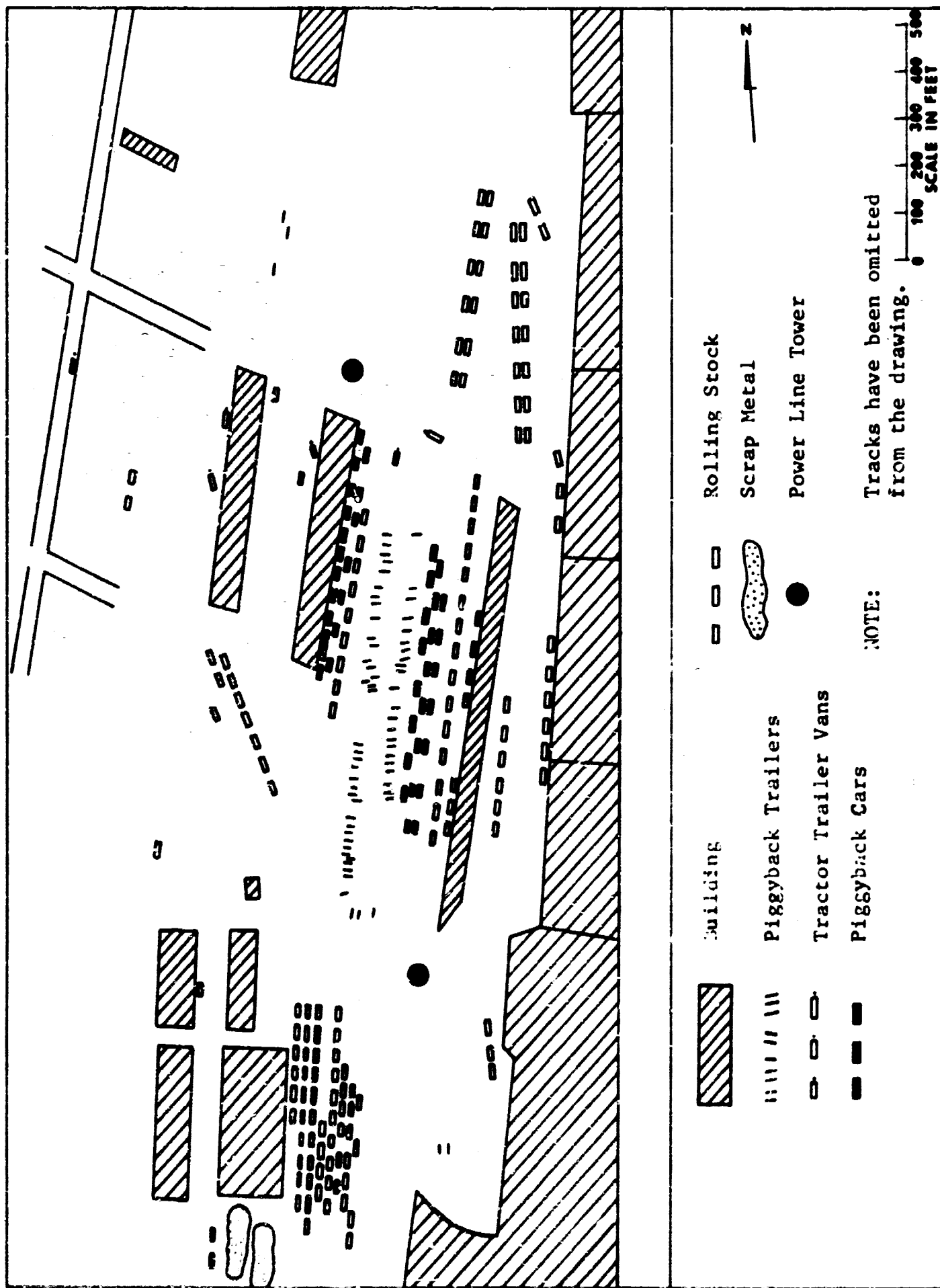


FIGURE 8 INTERPRETABLE DETAIL - RAIL YARDS, NEW ORLEANS

roof composition is essential in estimating susceptibility to fire or to blast overpressure, an attempt was made to find if this parameter could be determined by its spectral signature. Microdensitometric traces were run across the images of two roofs and the top of a tank on each frame of a multispectral camera diapositive (see Figure 9, Band 3). The average density of each roof type was extracted from each of the curves (see Figure 10) and the resulting graphs of film density vs. wavelength are shown in Figure 11. Roof #1 is a gable roof, the two sides of which were differentially illuminated but presumably of the same material on either side of the ridgepole. From it we expected to get two curves, very nearly parallel to one another, and this is, in fact, what happened. This served as a calibration of sorts by showing that the relative reflectance was not significantly affected by different conditions of lighting. It can be seen that Roof No. 2 exhibits a lesser density at all wavelengths than does Roof No. 1, although the shapes of the curves are similar. The tank, however, not only has a greater reflectivity at all wavelengths but also, between 560 and 600 microns, shows a decrease in density, whereas both roof types show an increase. All three of the sampled objects, therefore, are of a different material. Confirmation of this conclusion, however, as well as a determination of material types, awaits a ground check.

It should be mentioned here that precise densitometric work having near-absolute, rather than relative values, requires original negatives and the sensitometric data of exposure and development of the film. (See Section 6, paragraph I.) These data are usually obtained by means of the sensitometric wedge, which provides a range of discrete gray tones representative of the film's gamma, or sensitivity, range. In this way exposure and processing are referenced to an unambiguous standard.

4.7 Water Pollution; New Orleans, La.; Part of Test Site #132

The imagery was analyzed in detail with the aim of discovering actual or potential sources of water pollution. Of additional interest was the possibility of determining the flow patterns of effluents as they affect dilution rates and the distribution of wastes. As expected, oil wastes were identifiable, floating on the Mississippi River at New Orleans, on the Panchromatic and Ektachrome infrared photography. The refraction of light caused by thin films of oil or other fuel was interpretable on the black-and-white photography. Additionally, the coolant wastes from a thermal power plant near the Michoud Assembly Facility were detectable on the thermal infrared imagery.

Figure 12 is an enlarged example of the thermal IR imagery acquired over this plant. As an explanation of the tonal variations in the water it can be said that the amount of energy emitted by a surface is a function of numerous variables which include its temperature, emissivity, and dielectric constant. The amount of energy arriving at a detector is a function of:

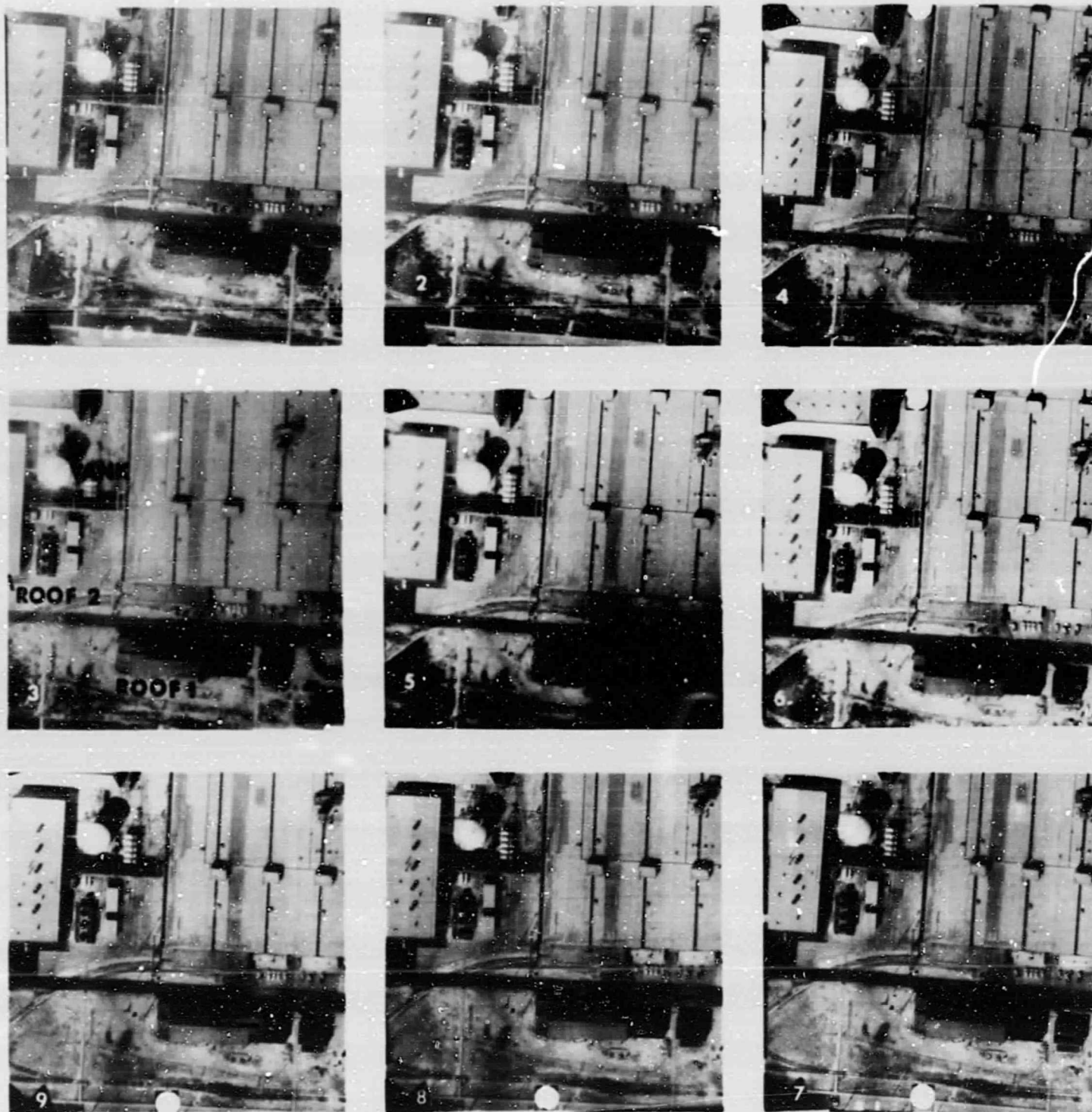
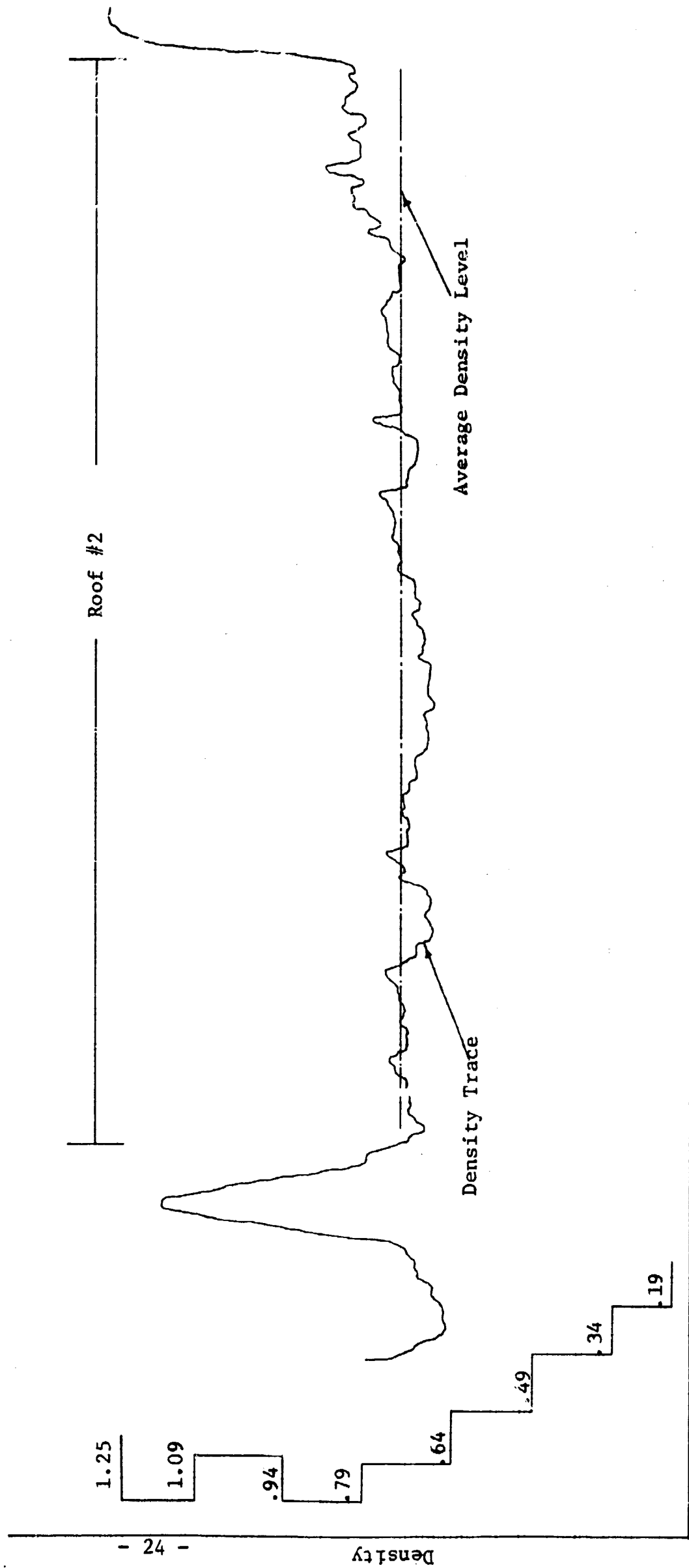


FIGURE 9 MICRODENSITOMETER TRACE AREA - MULTIBAND PHOTOGRAPHY



Distance

FIGURE 10 SAMPLE MICRODENSITOMETRIC PLOT - ROOF #2, 600 MICRON BAND

Each point on the curves represents the mean density of the roof material as measured by the microdensitometer on one of the nine images of the multi-band camera.

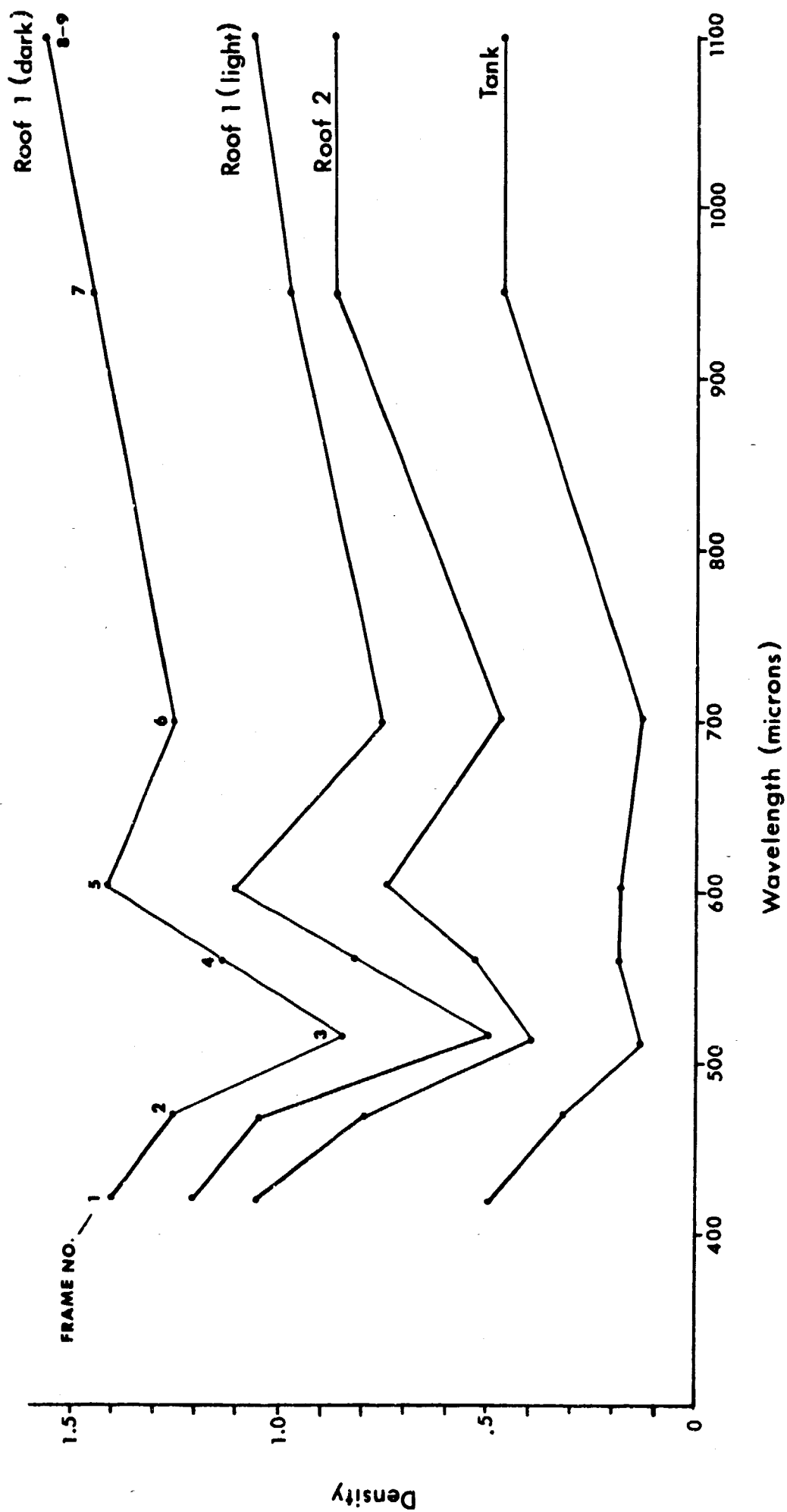


FIGURE 11 PLOT OF FILM DENSITY VERSUS WAVELENGTH

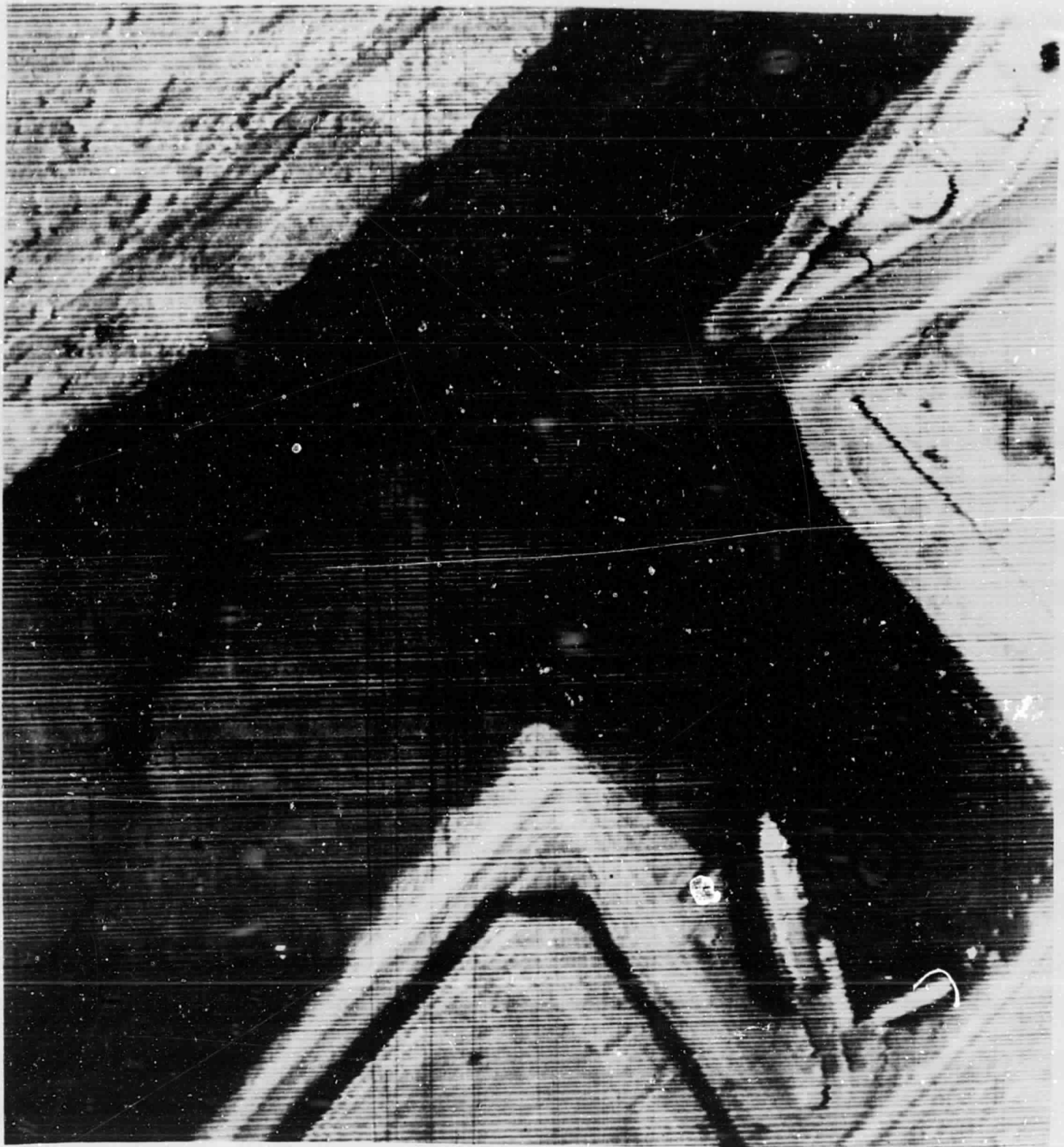


FIGURE 12 THERMAL INFRARED IMAGE OF THERMAL WATER POLLUTION

atmospheric transmission, scattering, and absorption; the elevation angle of the detector relative to an emitting surface; and the distance between the detector and the emitting source. As scanners are presently configured, it is not usually possible to determine quantitatively the temperature of the ground. In the case of water surfaces, however, there are ways in which such absolute measurements can be made. The exception for water primarily results from the fact that water surfaces have a nearly uniform emissivity, and transient surface films (dust, oil, etc.) can be ignored.

Therefore, if the photographic densities of an infrared image can be measured absolutely, and if simultaneous sample surface water temperature measurements are available, it is possible to establish the isotherms throughout the imaged scene. In order to derive isodensity contours, the thermal infrared imagery is processed in a specially configured densitometer. This instrument successively scans along several lines, using the drop-line technique common in making contour maps. The write-out pen changes its mode of writing whenever the density changes by a small, pre-selected amount, or discrete density increment. The graphic output of this instrument is in the form of a code -- dots, dashes, and blanks -- which must be interpreted from calibration data in order to draw absolute density contours.

Figure 13 is an actual isodensity tracing made from the imagery. The contours have been delineated and numbered, the lowest number being equivalent to the highest temperature.

Another observation which has potential significance was made at the sewage treatment plant at Michoud. This plant serves the assembly facility, and, therefore, it can be safely assumed that any unusual wastes it processes, originate at that plant.

On the Ektachrome infrared photography (Figure 14) the effluent from the sewage plant was imaged as bright pink. It was concluded that the color was not caused by algal or other plant organisms, because the colors were distinctly visible in both the settling tanks and the trickling filters. Thus the substance must have been input to the plant from the main sewage feeder line. Considering the fact that pink represents high infrared reflectivity, and that this color is rarely associated with man-made features on infrared photos, it appears that there is a uniqueness of the effluent in the following ways:

- It is highly reflective in the infrared but is not caused by the presence of plant biota.
- Infrared reflection resulting from non-plant sources is seldom seen on this kind of imagery.



FIGURE 13 ISODENSITY TRACING OF THERMAL POLLUTION SHOWN IN FIGURE 12



FIGURE 14 SEWAGE PLANT EFFLUENT - COLOR INFRARED

- The substance is not amenable to immediate treatment by filtering or biodegradation.

Therefore, it is concluded that the substance is in solution and may be uniquely identifiable if ground truth were available.

A further observation regarding this phenomenon is that it was not visible on the thermal infrared and therefore was not significantly warmer or highly emissive. In addition, on the multiband photography, Figure 15, it evidenced high contrast on all bands except those at the blue end of the spectrum. Therefore the true color of the effluent was yellowish.

It is probable that additional sources of pollution were present that escaped detection due to the masking effect on the Mississippi's high suspension load of sediment.

4.8 Thermal Analysis of Petroleum Tanks, New Orleans, La.; Part of Test Site #132

Isolated instances have been observed of the capability of thermal infrared sensors to detect the level of the contents of petroleum, oil, and lubricant storage tanks. Since such a capability could be of great potential use in OEP studies, an attempt was made to further document it. For this purpose an additional flight was conducted on 11 October over POL tanks, for which ground truth was obtained from commercial sources in the city of New Orleans. The ground truth consisted of identification of tank contents, gauge readings of fuel levels, and the temperatures of the contained fuels at the time of overflight. Although the thermal infrared imagery acquired was superior in quality to that which was used in the previous analysis, the attempt, nevertheless, did not succeed because the aircraft passed almost directly over the tanks, thereby providing an aspect angle insufficient to bring their sides into view, a necessary condition for determining the level of their contents. This emphasizes the importance of oblique views in meeting certain OEP objectives.

(A parenthetical reminder might be appropriate here to the effect that fuel levels in float-type tanks can, of course, be readily determined photogrammetrically. This is a procedure commonly practiced - on overlapping photographs by means of a parallax bar or wedge; and on single photographs by means of a scale, such as a tube magnifier. In either case, the height displacement of the lid is divided by the displacement of the tank, giving the percent of capacity to which the tank is filled.)

The color infrared acquired on the 11 October mission, like the thermal IR, was of a superior quality to that used for the original analysis of the site. Careful examination revealed, however, that although it enabled interpretation and analysis tasks to be performed with greater ease and rapidity, it contained no additional information.

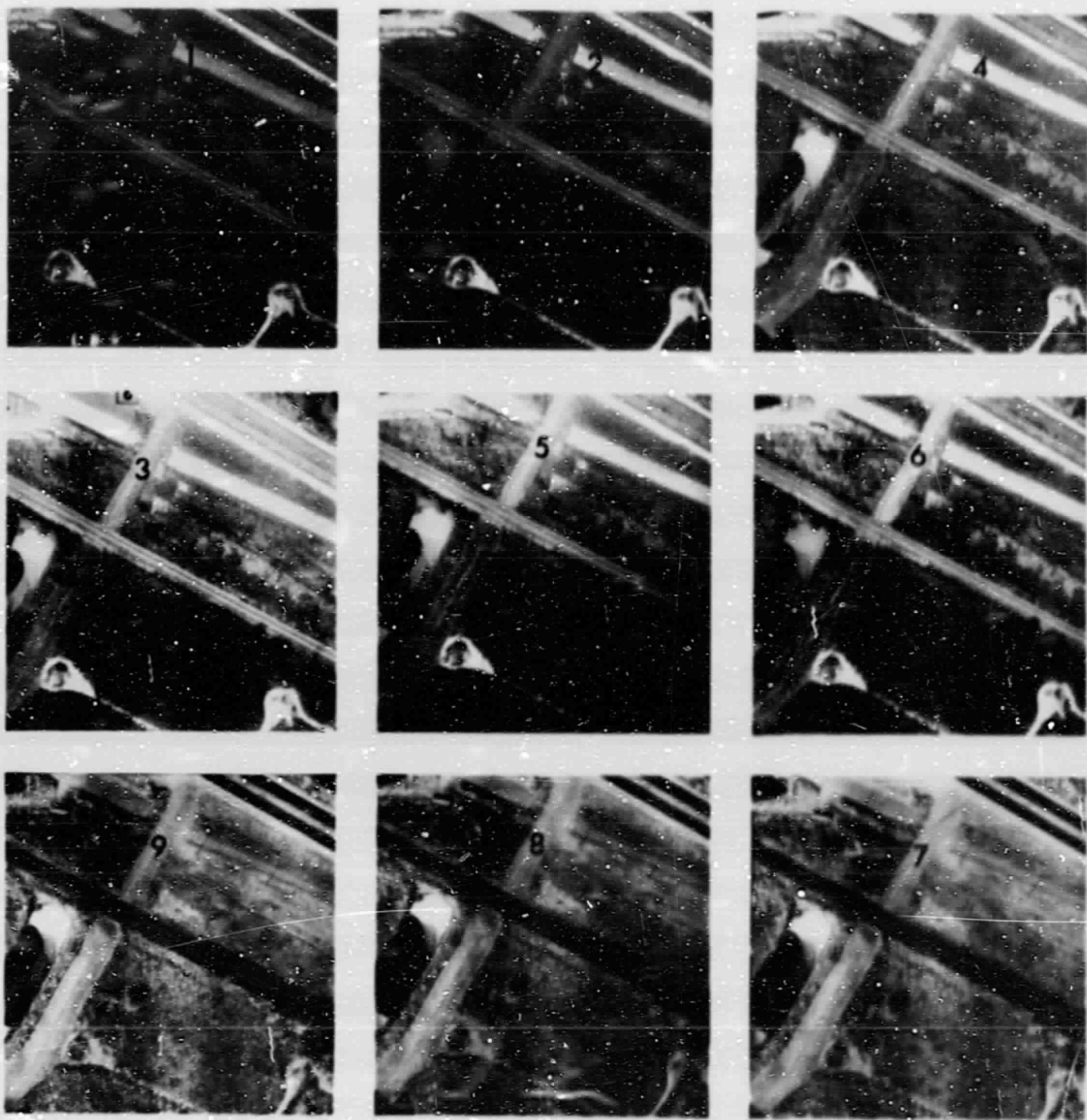


FIGURE 15 SEWAGE PLANT EFFLUENT - MULTIBAND CAMERA

Examples of the thermal IR and color IR are given in Figure 16 and 17, respectively.

Much of the multiband imagery acquired on this mission was unusable because of camera malfunction.

4.9 Analysis of the Anchorage, Alaska Earthquake

4.9.1 Analysis Procedure

An analysis of photography flown subsequent to the 27 March 1964 earthquake at Anchorage, Alaska was conducted. The photography, flown by the USAF, consisted of three rolls of 9" x 18" panchromatic film, taken the first and second of May, 1964, and was provided by the Office of Emergency Preparedness. Also used were selected vertical and oblique panchromatic photography flown by the U. S. Army during the period 28 March 1964 and 4 April 1964. The aim of the analysis was to determine the extent and kind of damage interpretable from the photography.

Ground truth for the analysis consisted of a report, The Effects of the Earthquake of March 27, 1964, at Anchorage Alaska,¹ which gives a comprehensive picture of the types, area, extent, and cause of damage within the immediate Anchorage area.

4.9.2 Analysis Results

4.9.2.1 Building Damage

The most immediate finding was that damage of a slight or subtle nature could not be identified on the vertical photography as it was flown and at the scales and resolutions available. For example, damage to small structures such as private dwellings, though severe and extensive, could not be identified since the effects of such damage were not directly visible on the photography. The effects were indirectly inferred through secondary clues. Figures 18 and 19 are examples of such inferred damage. The annotated houses in Figure 18 are located directly on a large fissure, which is a tension fracture at the head of a translatory slide. The houses annotated in Figure 19 are located on the edge of the graben area of the L Street slide.

Another finding was the enhancing value to damage assessment of oblique photography when used in combination with vertical photography. Figure 20 contains examples of damage which were visible only on the oblique photography; Figure 21 illustrates the value of vertical and oblique photography in combination

¹Geological Survey Paper 542-A.



FIGURE 16 SAMPLE IMAGERY - THERMAL INFRARED FROM MISSION 81

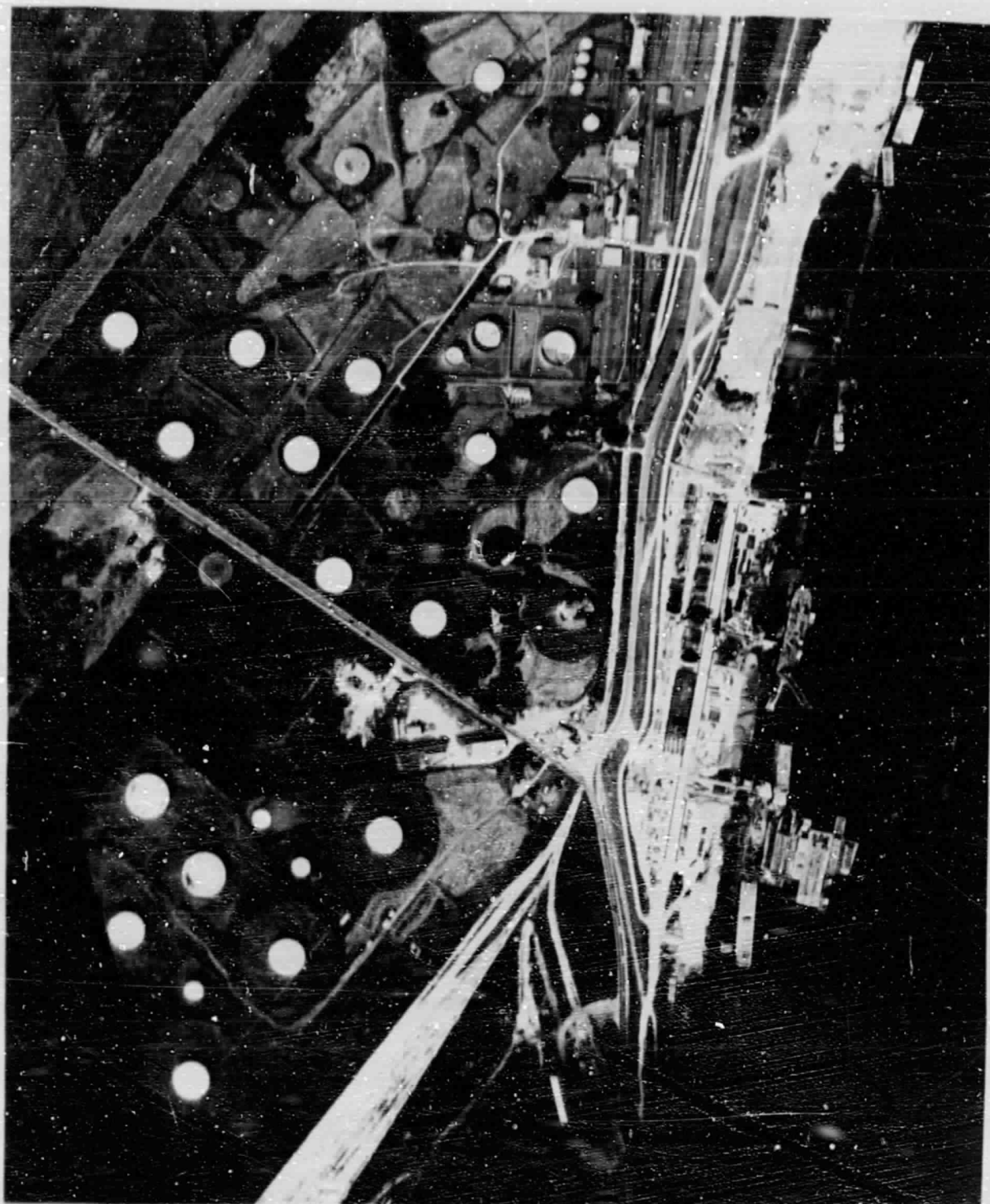
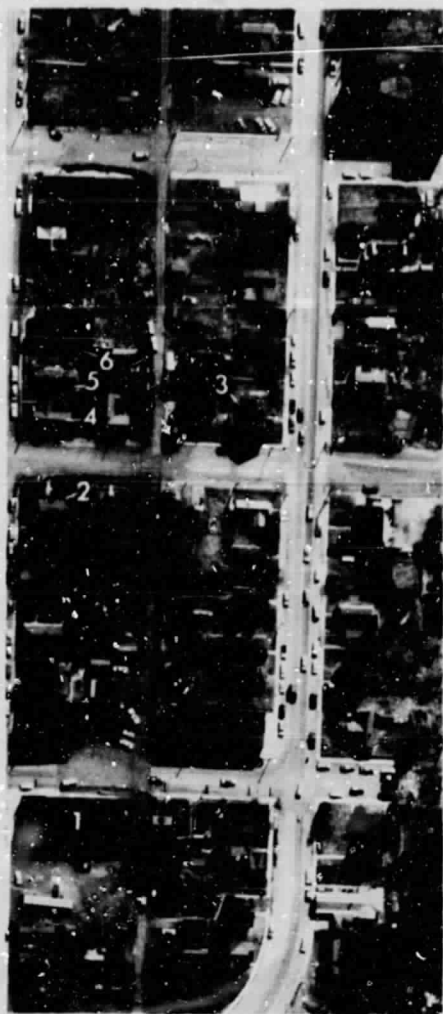


FIGURE 17 SAMPLE IMAGERY - COLOR INFRARED FROM MISSION 81



FIGURE 18 INFERRED DAMAGE - TURNAGAIN HEIGHTS SLIDE



A



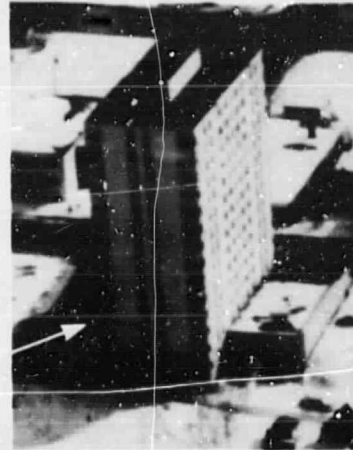
B

FIGURE 19 INFERRED DAMAGE - L STREET SLIDE

MOUNT MCKINLEY BUILDING

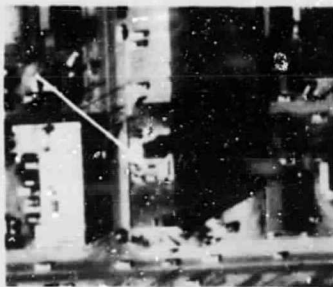


A



B

CORDOVA BUILDING



C



D

FIRST FEDERAL SAVINGS AND LOAN BUILDING



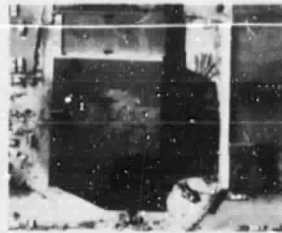
E



F

FIGURE 20 DAMAGE VISIBLE ONLY ON OBLIQUE PHOTOGRAPHY

J. C. PENNEY'S

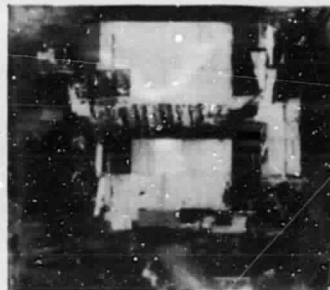


A

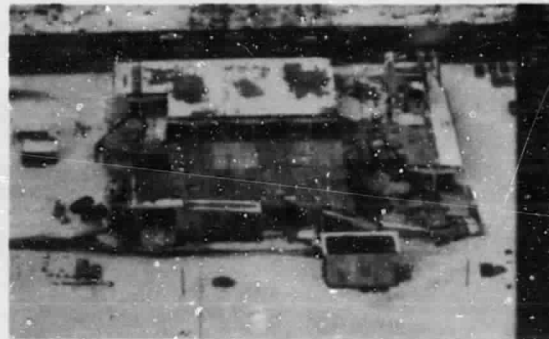


B

CHRYSLER CENTER



C



D

FIGURE 21 VERTICAL/OBLIQUE COMBINATION FOR DAMAGE ASSESSMENT

to a more complete assessment of damage; and Figure 22 illustrates a type of damage not readily discernible either on vertical or oblique photography. Ground truth information states that all four gantry cranes jumped their tracks and suffered damage to their undercarriages and counterweight arms. The only indication of damage to the cranes is the ground crack and the apparent misalignment of one crane with the longitudinal axis of the pier as shown by the arrow in A of Figure 22.

4.9.2.2 Damage to Transportation Routes

A preliminary screening of the USAF Powerhouse photography revealed that there was extensive damage to the highway and railroad nets in the Anchorage area. Causes of damage appeared to include landslides, slumping and avalanches.

A detailed analysis was conducted of the transportation routes in the Portage region and in the easternmost part of the Cook inlet. This area was selected because the damage to both roadbeds and bridges appeared to be quite severe and because fault traces were interpretable in the upper reaches of the Placid River Valley, which the Alaska railroad follows between Anchorage and Seward.

The aims of the analysis were twofold: to identify the magnitude and extent of damage in the area and to determine the primary causes of the damage.

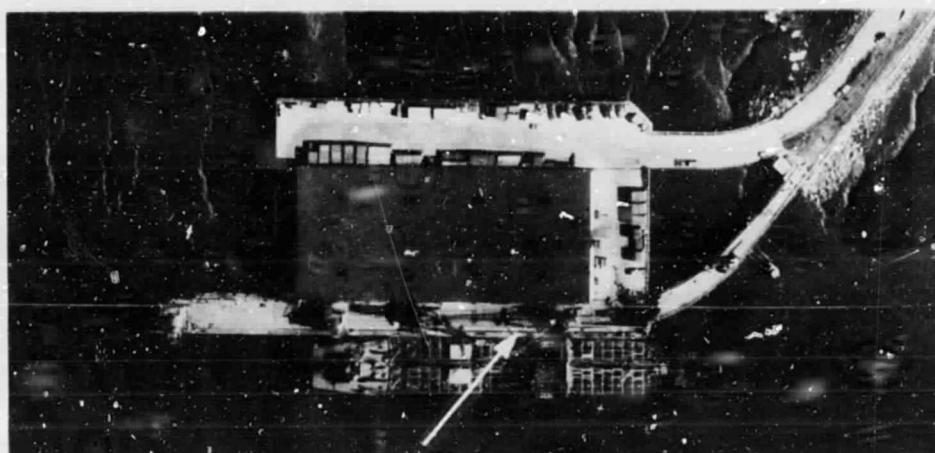
The procedures followed in the interpretation were to trace all the visible fractures, offsets and associated symptoms of earthquakes. In addition, all damaged roadbeds and bridges were identified. Figure 23 is a mosaic on which fissures and damage are identified and annotated.

The following is a summary of the damage assessment interpretations:

- . Earthquake damage to the transportation net was severe. Neither the main highway nor the railroad were useable at the time the photography was taken.
- . Extensive earth moving and repair would be required to put road and railroad routes back into operation.
- . Severe damage to railroad trestles of wood construction could often only be inferred from reference to the pattern of the tension cracks in the vicinity.
- . No direct evidence of tectonic movement could be found.



A



B

FIGURE 22 UNDISCERNIBLE DAMAGE

- . Damage in the Placid River Valley was attributable to settling and slumping of the unconsolidated sediments. Lurching and slumping resulted in rail-road misalignments and in heaving and fracturing of the paved roads. The force of the earth tremors did not directly cause the collapse of bridges except where structures were of concrete deck construction.

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5. CONCLUSIONS

The principal conclusions to be drawn from the analysis are as follows:

5.1 Sensor Capabilities

- A. Accurate and complete identification of structural type and composition, or damage to structures, is primarily a function of image quality. Good resolution, acuity, and tonal rendition are the most important of image parameters.
- B. Panchromatic black-and-white photography can provide almost all the information needed for the analysis of structure and function.
- C. Although color infrared and thermal infrared imagery were not found to significantly enhance the ability of a photo interpreter to extract additional characteristic detail regarding man-made features, color IR has been found, in this as well as in several other studies, to be the best single sensor for the location of chemical and biological water pollution. It is also superior in detecting vegetation under stress of drought, disease, insect infestation, and radiation. Similarly, thermal IR is unsurpassed in detecting thermal pollution, the on-off activity states of heat producers, and in pin-pointing hot spots of fires in areas obscured by smoke. In addition, it would probably play a principal, or at least corroboratory, role in locating the ground zero points of nuclear weapon detonations.
- D. In areas where fine detail is required for the interpretation of structure, composition or subtle damage, oblique photography is a useful supplement to vertical photography.
- E. The conclusions outlined in A, B, C, and D, above, were derived from analysis of the sensor records provided for the present study. Enlarging upon these results by those obtained in other studies, it can be concluded that, in a mission whose principal objective is the acquisition of a maximum of detailed information, the primary sensor should be

color IR, with thermal IR as the secondary. The present study tended to emphasize the importance of black-and-white simply because this was the sensor having the best quality and largest scale. Color IR of an equivalent scale taken under similar conditions, would have an information content equal or superior to that of the black-and-white and would, in addition, be capable of detecting water pollution and crop stress, both important informational requirements of the OEP. The thermal IR, although only marginally useful in the present study, has amply demonstrated its capabilities in many others, as suggested in C, above. (See Section 6, paragraph A for the recommendation based on this conclusion.)

5.2

General

- A. Analysis of photography flown by the Army a few days after the Alaska earthquake revealed quite dramatically the necessity for timeliness in both the acquisition and the reduction of data acquired for damage analysis. This photography very clearly showed many areas of damage that were undetected on the original Powerhouse imagery, taken five weeks after the earthquake, since by then much of the damage had been repaired, much of the rubble cleared, and several of the damaged buildings razed and their foundations graded.

Therefore it is concluded that if damage assessment is to be accomplished in a timely and accurate manner it is imperative that some form of photographic data base be available, the more current and complete the better. The more extensive the disaster (such as that resulting from a nuclear strike or major natural disaster), the more critical the need for pre-event coverage.

For example, a preliminary interpretation of the Valdez and Seward areas (Alaska) completely overlooked the destruction of the port facilities, because the piers at both locations had vanished in a submarine landslide, leaving no evidence that the facilities had previously existed. The damage was discovered only after a comparison was made with pre-earthquake photography.

Similarly, an adequate assessment of damage to the residential areas of Anchorage could not be made in areas where numerous single-family dwellings had vanished in earthslides. Some slides were so extensive that neither the previous road net nor the number and location of the houses could be reconstructed without the aid of comparative imagery.

A nationwide data base, consisting of a central facility and several strategically located regional facilities, would prove invaluable in the event of large-scale man-made or natural emergencies. In addition, the pre-emergency value of such an installation would be inestimable in planning economic or cultural improvement efforts and in resource management.

- B. All of the analyses conducted - both in the Alaska and New Orleans areas - consumed substantial amounts of time.⁴ It is abundantly clear that if assessments had to be made under constraint of limited time, significant losses in accuracy and completeness of information would be experienced. For example, only gross estimates of building composition - structure, function and damage effects would be feasible. However, such estimates would be satisfactory for assessment of "severe" or "moderate" levels of damage.

⁴Four specialists required a total of 605 man hours for the analysis of the data and the preparation of the pencil draft copy of this report.

6. RECOMMENDATIONS

Based upon the results of the analyses and on the conclusions derived therefrom, the following recommendations are advanced:

6.1 Data Acquisition

- A. It is recommended that a mission be flown with color IR and thermal IR as the primary and secondary sensors, respectively. (See Section 5, paragraph E.) The multiband camera should also be employed, both as a back-up system to the color IR and for the purpose of further analysing its capabilities, the results of which were inconclusive in this study. The mission should be conducted over an area for which prior ground truth has demonstrated the existence of a variety of spectral signatures in the form of distinctively colored smoke plumes, stock piles, industrial roof staining, waste deposits, water pollution effluents and other visible industrial spectral effects. The selected flight line(s) should be flown at two levels - one at approximately 1,000 feet (or at the lowest altitude at which can be maintained a V/H ratio that will not degrade the imagery); and the other at the highest altitude of which the aircraft is capable. The high altitude is requested in order to more fully determine the elements of OEP information that can be acquired at small scale. (Assuming a focal length of six inches and an upper altitude of fifty thousand feet, the two scales would be 1:2,000 and 1:100,000.) If obliquity of view is required, it should be at an angle of from 45 to 60 degrees, and the offset of the flight line should be calculated and positioned accordingly. Sun angle, although less important than the other flight parameters, should ideally be at about 45 degrees, or, in time, halfway between local sunrise and local noon.

It is expected, on the basis of this study, that required ground truth data will be of a kind that is either time-invariant, such as the composition of roof material, or is monitored and recorded on a regular basis, such as the height of fuel in POL tanks. Therefore, ground data can be acquired after

the flight on an ad hoc basis as the imagery analysis dictates.

- B. It is suggested that, in addition to the continuing examination and analysis of unclassified multi-sensor recordings, consideration be given to the application of classified imagery capabilities of the Defense Department and other Government agencies. The first step in implementing this recommendation would be to screen, select, and catalog the pertinent imagery at Government facilities and then transfer this data to contractor facilities, where analysis would be accomplished.
- C. Because of the unique microwave reflectance of water, it is further suggested that the use of side-looking radar for the assessment of flood damage be investigated. Side-looking radar can record vast areas of inundated terrain in a relatively short time and accurately depict the high water mark. The all-weather capability of this sensor makes its application to flood area assessment especially advantageous, since flooding and inclement weather are usually concomitant phenomena. In addition, since SLR, due to its small scale, all-weather capacity, and smoke penetration capability, can provide the most timely data of any airborne sensor, its application to OEP requirements should be explored.
- D. More consideration should be given to the collection and use of reconnaissance imagery over areas of natural and man-made disasters, such as floods, earthquakes, hurricanes, possible riots, etc. Such an acquisition program should be planned as a contingency operation, in which aircraft missions would be ordered as needed, on short notice.
- E. To best satisfy OEP reconnaissance requirements for damage assessment, it is recommended that either

a trimetrogon⁵ or panoramic⁶ photographic system be utilized. It is felt that a system affording ground resolutions of about four or five feet would satisfy the most stringent of information requirements. (For broader, less detailed, analyses resolutions up to 75 feet, such as obtained by some SLR systems, or up to 150 feet, as proposed for the Earth Resources Satellite, could be tolerated.)

- F. An effort should be made to maximize the benefits that could be provided by a satellite such as the proposed Earth Resources Technological Satellite. Such a reconnaissance system would provide the means for meeting three important OEP requirements: 1) timeliness, since it would be collecting data within a few days, at most, of the occurrence of an emergency; 2) repetitive coverage, enabling image analysts to observe and project rates of recovery; and 3) provision of a data base. However, since it is not known how well the elements of information required by OEP will be imaged at the proposed ERTS resolution range of from 100 to 200 feet, it is suggested that an empirical-hypothetical study be undertaken to determine this. The study would be conducted in three phases: 1) the first phase would define the elements of information required for several levels of emergency analysis, from the more specific to the more general; 2) the second would involve the detailed analysis of existing Gemini, Apollo, and other available photography to determine how well the necessary elements are imaged, with alteration of resolution to simulate ERTS imagery; and 3) the third phase would extrapolate all empirical data to that expected from the ERT satellite.

⁵Trimetrogon photography is produced by an array of three cameras, one pointing vertically downward and the other two pointing at angles of 63° from the vertical, at right angles to the flight line. The two oblique photographs overlap the vertical.

⁶Panoramic photography is taken by a camera having a rotating prism that scans through an arc of 180° or less, normal to the flight line.

6.2 Data Handling Center

On the basis of the conclusion reached in Section 5.2, paragraph A, it is suggested that consideration be given to the establishment of a data base and data handling center. The base should be in multi-sensor imagery form, with large-scale topographic maps available for supporting use. Data should be in an easily retrievable form, miniaturized, and comprehensive. An investigation should be made as to the exact form of the base, the storage and retrieval interfaces, and the possibility of expanding the amount of information through the inclusion of tax maps and other data, from which dollar estimates of damage could be rapidly made.

The data handling center, of which the data base would constitute the heart and nucleus of growth, would have a general function and form as follows:

A. Center Requirements

The data center would contain the personnel and equipment needed to index, process, store, retrieve, interpret, prepare user products, reproduce, and disseminate sensor records, as required to satisfy specific OEP requirements and to assist, in addition, regional and national planning efforts.

B. Receipt and Indexing of Records

The data center would receive sensor records on magnetic tape or in unprocessed film format. It would also receive navigational data or, in the case of data acquired from a space platform, satellite tracking data and ephemerides.

C. Initial Processing

Facilities would be required for processing records to provide both archival quality imagery and imagery for initial screening and evaluation.

D. Storage and Retrieval (Imagery Data Base)

All sensor records and corollary information would be filed by an unambiguous index number for rapid retrieval and would be appropriately cross indexed and coded to facilitate selection and location.

E. Interpretation and Analysis

Specific assessments would be made, as applicable, of either the susceptibility of the imaged resource to damage or of the extent and intensity of damage incurred.

F. Product Preparation

This function would include mensuration, photogrammetric reduction, densitometric and colorometric reduction, mosaic assembly, drafting, etc., as necessary to supply information of the kind, and in the format, most convenient to the user. (Probably the most important products would be those in computer compatible form, for use in updating the computer damage predictions. See Section 6.3, Paragraph A.)

G. Reproduction

This facility would include the capability of producing copies of original records and of processed photography in a range of scales and formats.

H. Dissemination

In addition to the products developed in the center and original or processed sensor data, there would also be dissemination of assessment bits of information, such as indexes, study reports, imagery, graphics, etc., as appropriate to the users.

Figure 24 shows the flow of data through the data handling center.

6.3 Aids to Data Handling and Reduction

- A. It is suggested that a coordinated effort be made to convert analyzed and evaluated reconnaissance data into a format compatible with the National Resource Analysis Center's existing (or modified) computer simulation programs. The initial result of such an integration of data would be to provide more realistic scenarios and simulations of post-emergency conditions, with its ultimate significance being a developed capacity of the computer to accept data from real-life reconnaissance data reduction efforts for actual situational analysis.

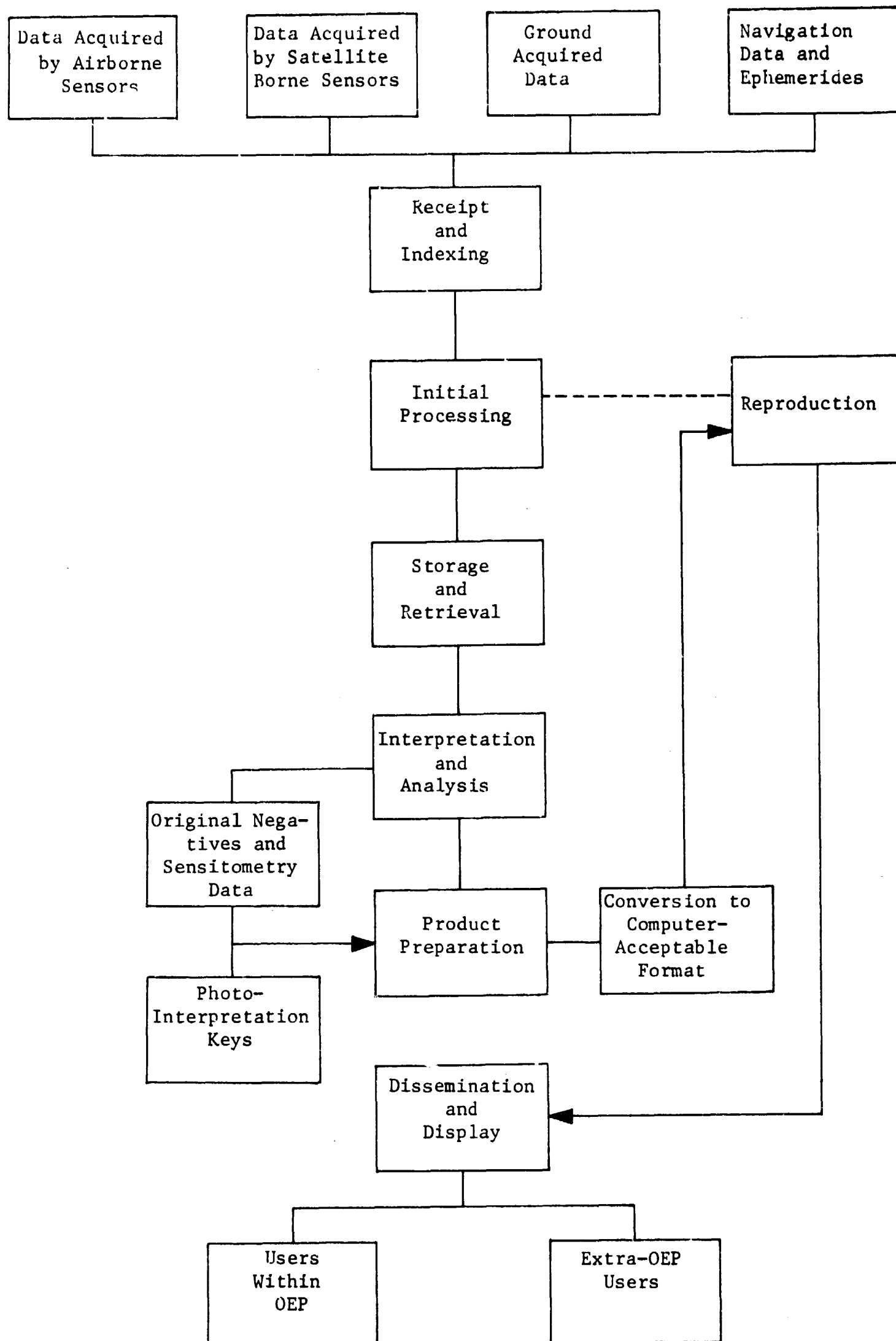


FIGURE 24 DATA FLOW THROUGH DATA HANDLING CENTER

- B. It is recommended that photointerpretation keys be produced both on damage assessment and structural analysis. These would replace the obsolete keys currently available. An investigation should be conducted to determine the information requirements of the OEP regarding the assessment and reporting of all kinds of disasters. These requirements would then serve as the guideline for the content, scope, and format of the keys.
- C. More consideration should be given to the receipt and use of original negatives, sensitometry data, and the computational constraints on measuring modulation transfer functions, in order to better quantify results.