LIGHNING THREAT TO ABOVE GROUND AND BELOW GROUND STRUCTURES

MODELING AND TESTING

~~300~~ 3 trillion FFT computations to simulate 4μs of 179.

RICHARD COLLIER

RSC LIGHTNING PROTECTION ANALYSIS AND TESTING

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16244 GRANGE ROAD
P.O. BOX 459
PAONIA CO 81428
970-527-3784

LIGHNING THREAT TO ABOVE GROUND AND BELOW GROUND STRUCTURES

A. DIRECT THREAT

RESISTIVE HEATING OF CRITICAL ASSET ELEMENTS
- [E.G. HUMANS . EXPLOSIVES, ELECTRICAL CIRCUITS]
- DUE TO DIRECT ATTACHMENT OF LIGHTNING CURRENT
- [INCLUDING POSSIBLE LIGHTNING SIDE FLASH AND/OR CURRENT SPLITS AT VARIOUS CONDUCTING JUNCTIONS]

B. INDIRECT THREAT

RESISTIVE HEATING OF CRITICAL ASSET ELEMENTS
- DUE TO INDIRECT SECONDARY CURRENTS INDUCED BY TIME VARYING ELECTRIC AND MAGNETIC FIELDS IN THE LIGHTNING ENVIRONMENT [ACTION AT A DISTANCE]
- [INCLUDES POSSIBLE CAPACITIVE BREAKDOWN NEAR CLOSELY SPACED CONDUCTIVE ELEMENTS]

C. RESONANCE COUPLING

RESONANCE COUPLING TO CRITICAL ASSETS IN THE LIGHTNING SPECTRAL RANGE – UP TO 20 OR 30 MHZ.
-LONGER TERM HEATING OF CRITICAL ELEMENTS OVER SUCCESSIVE RESONANCE CYCLES

LIGHNING THREAT TO ABOVE GROUND AND BELOW GROUND STRUCTURES

TEST METHODS

A. ROCKET TRIGGERED LIGHTNING

EXAMPLES:

GAINSVILLE FLORIDA: ABOVE GROUND STRUCTURES
FT. McCLELLAN: UNDERGROUND STORAGE BUNKERS

B. HIGH VOLTAGE MARX GENERATORS

EXAMPLES:

FLORIDA: SPACE SHUTTLE LAUNCH PAD
UTAH THIOKOL: SOLID ROCKET RAILCAR COVERS
PITTSFIELD: LABORATORY SCALE MODELS

C. LOW LEVEL RF CURRENT INJECTION

SINGLE FREQUENCY AT VARIOUS INJECTION POINTS -SWEPT OVER THE SPECTRAL RANGE OF LIGHTNING STRIKES UP TO 30 MHZ – MONITORED AT TEST POINTS -MANY EXAMPLES OF ABOVE GOUND AND BELOW GROUND STRUCTURES AND FACILITIES

RADIO FREQUENCY (RF) TESTING – EXAMPLES

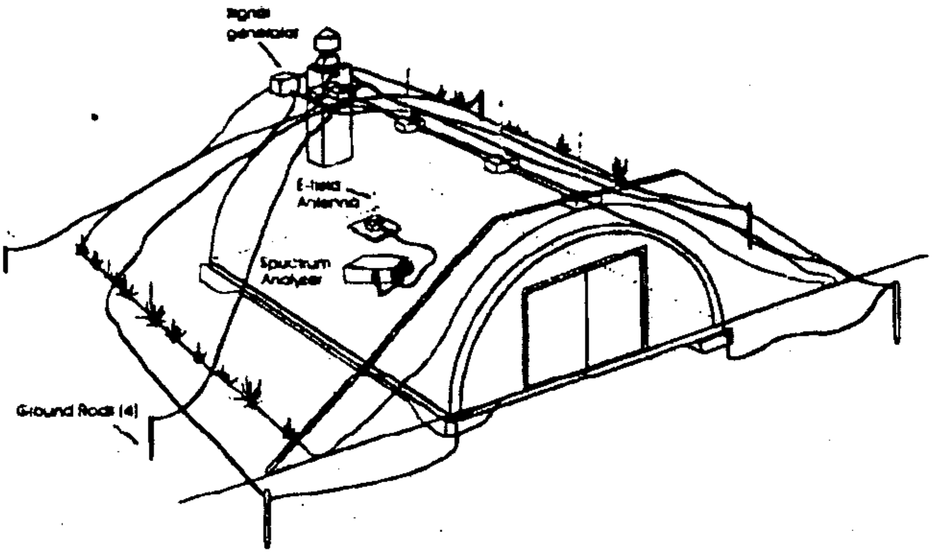
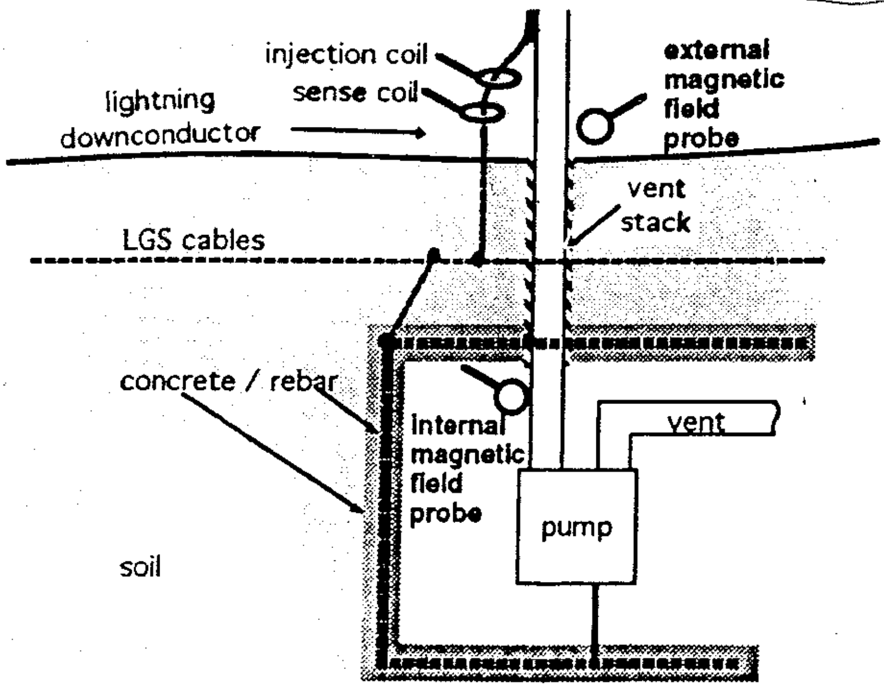


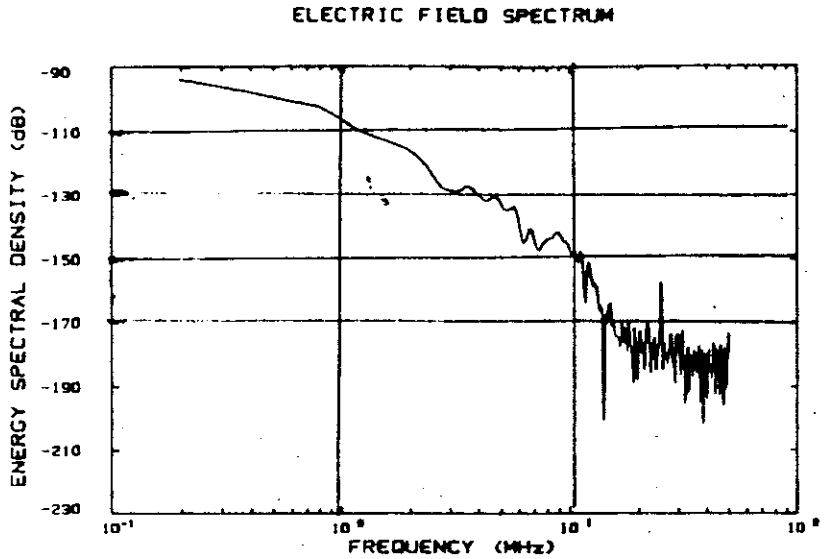
Figure 2. Typical equipment layout during transfer impedance testing.

GLOBAL TESTING – SHIELDING EFFECTIVENESS
EXTERNAL VOLTAGE INJECTION

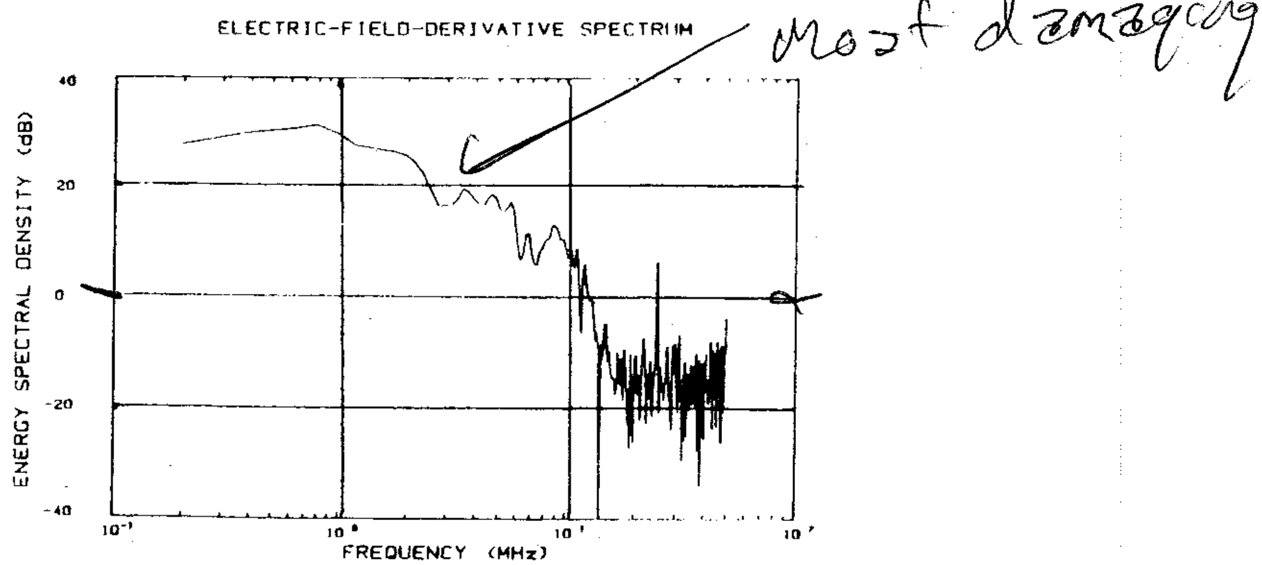


LOCAL TESTING – PENETRATION/BOND CURRENTS
EXTERNAL (OR INTERNAL) CURRENT INJECTION

RF TEST FREQUENCY RANGE
LIGHTNING PULSE SPECTRAL DISTRIBUTION



SPECTRAL DISTRIBUTION for LIGHTNING CURRENT (I)^2 – DETERMINES INTERNAL MAGNETIC FIELDS

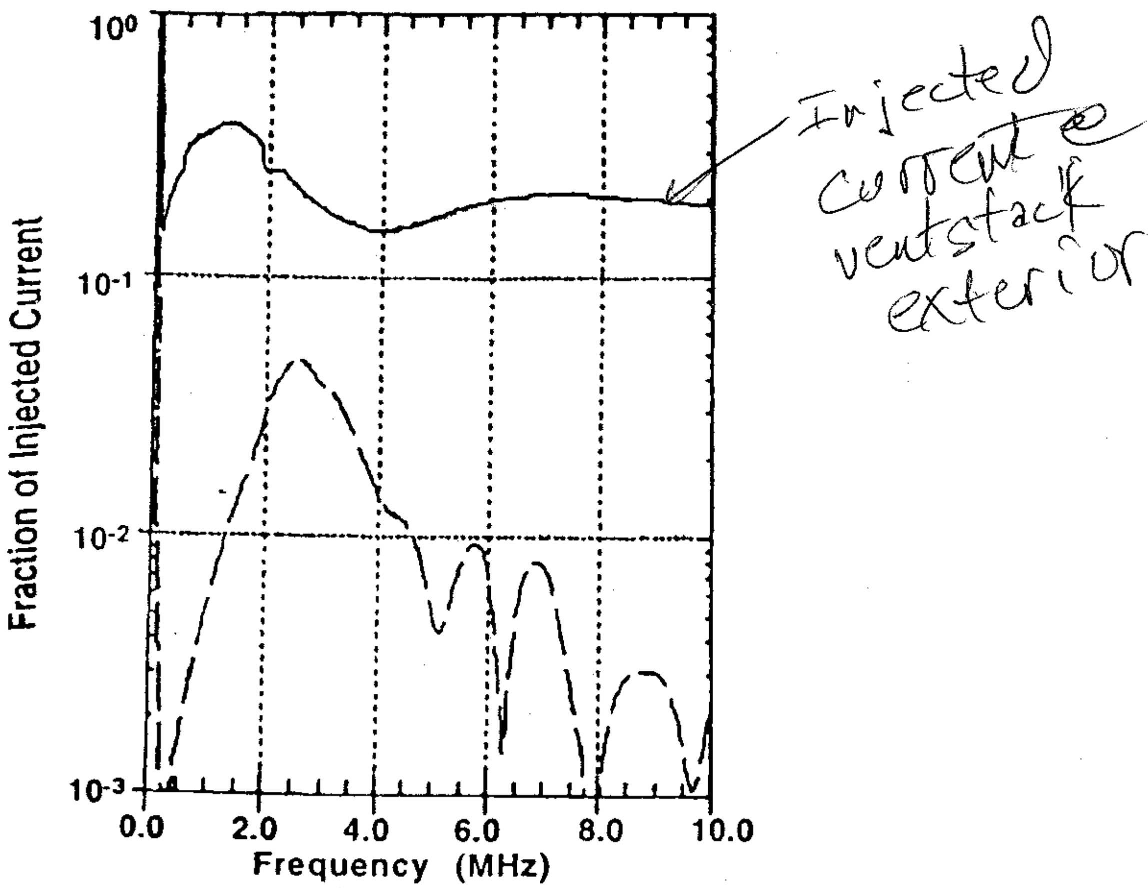


SPECTRAL DISTRIBUTION for CURRENT DERIVATIVE (dI/dt)^2 – DETERMINES INTERNAL ELECTRIC FIELDS

FROM: "Lightning Electromagnetic Radiation Field Spectra in the Interval From 0.2 to 20 MHz", J. C. Willett, et al, Journal of Geophysical Research Vol. 95 D12 pp. 20,367 – 20, 387 Nov. 20, 1990 (Graphs for a typical first return stroke, Fig A1; I is approximately. proportional to external Electric Field)

RESIDUAL HAZARD - CURRENTS ON BONDED PENETRATIONS:

RF PENETRATION TESTING (CONTINUED):



EXAMPLE RF PENETRATION TEST RESULTS FOR A VENT STACK BONDED TO A CONCRETE REBAR STRUCTURE

SOLID LINE - CURRENT ON VENT STACK EXTERIOR
DASHED LINE - CURRENT ON VENT STACK INTERIOR
(CURRENTS EXPRESSED AS FRACTIONS OF THE RF INJECTION CURRENT ON THE LPS)

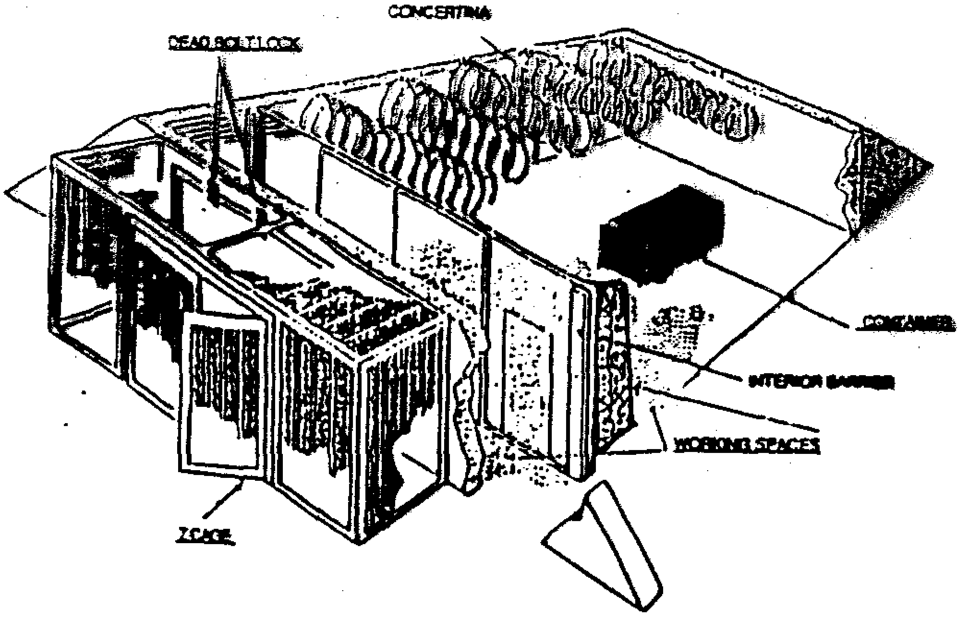


Figure B.2 Earth Covered Storage Igloo -- Lightning Strike Model

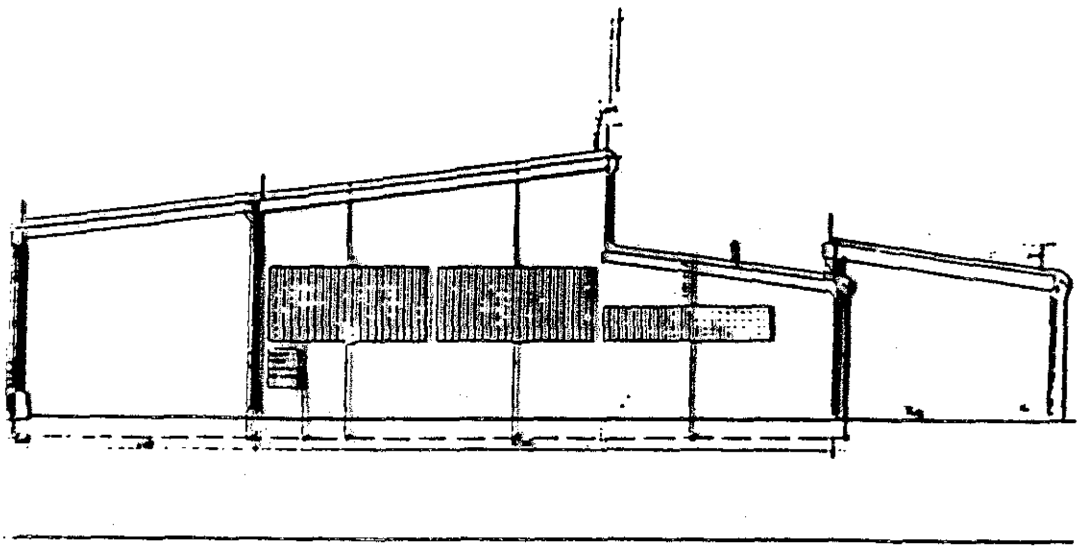


Figure B.3 Building - Right Side View With Window Screens and Lightning Protection System

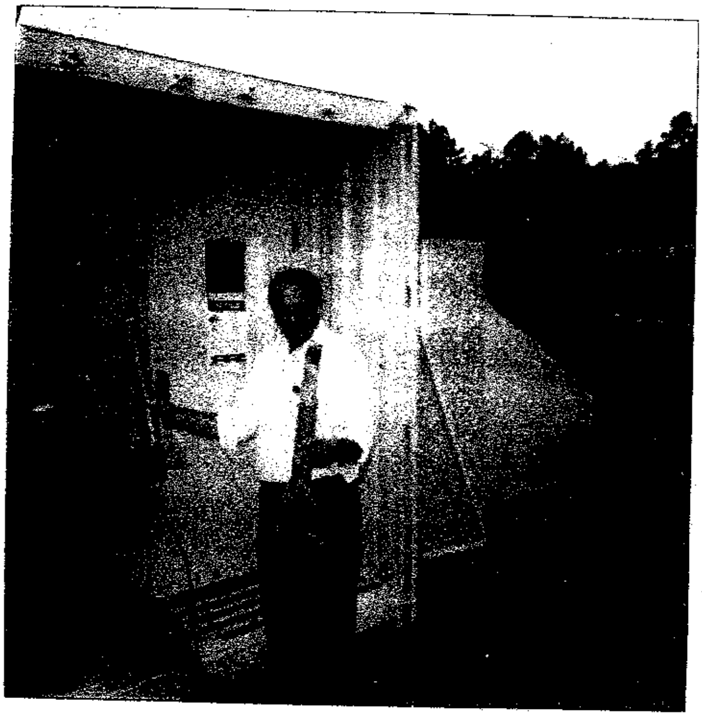
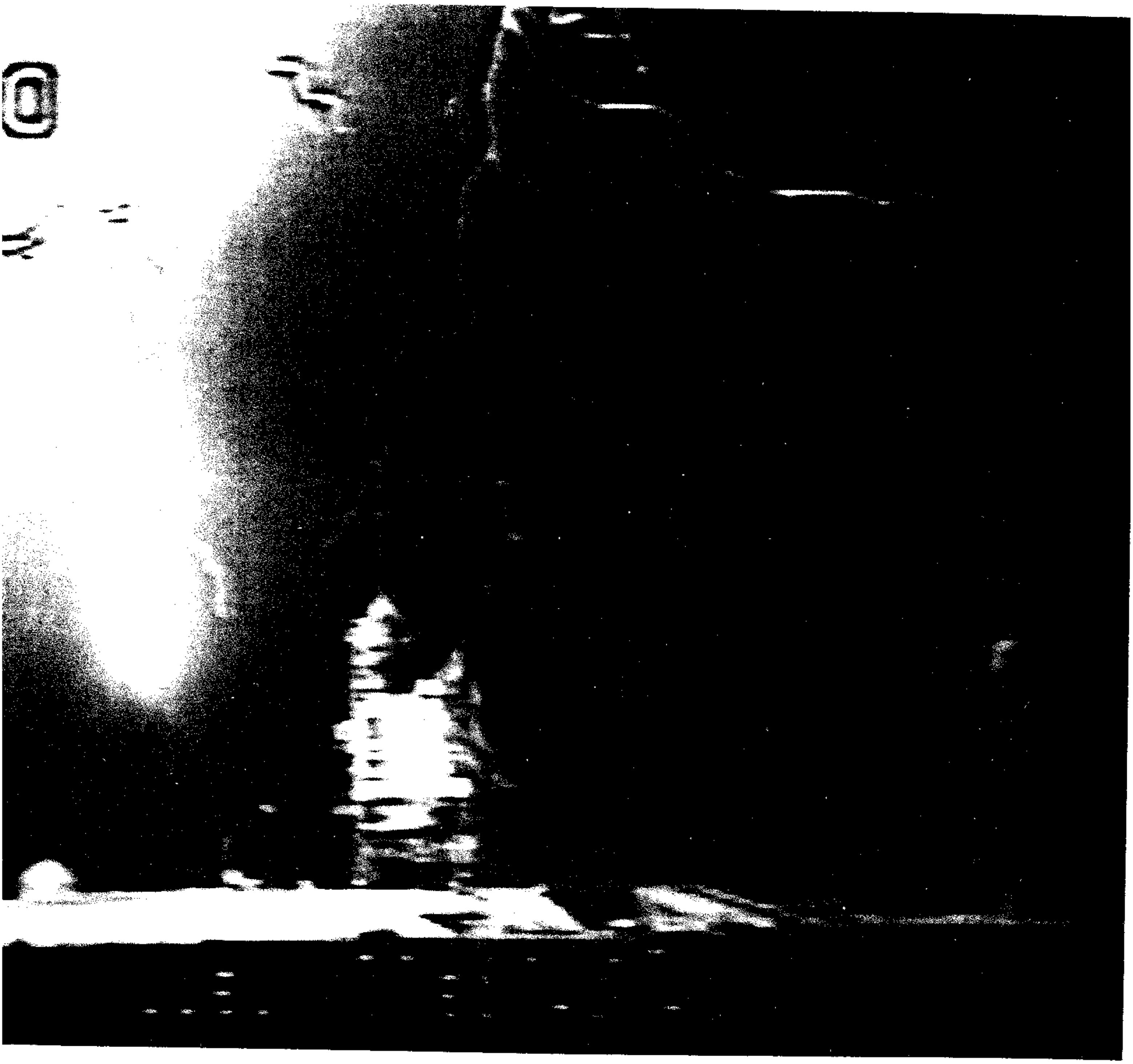
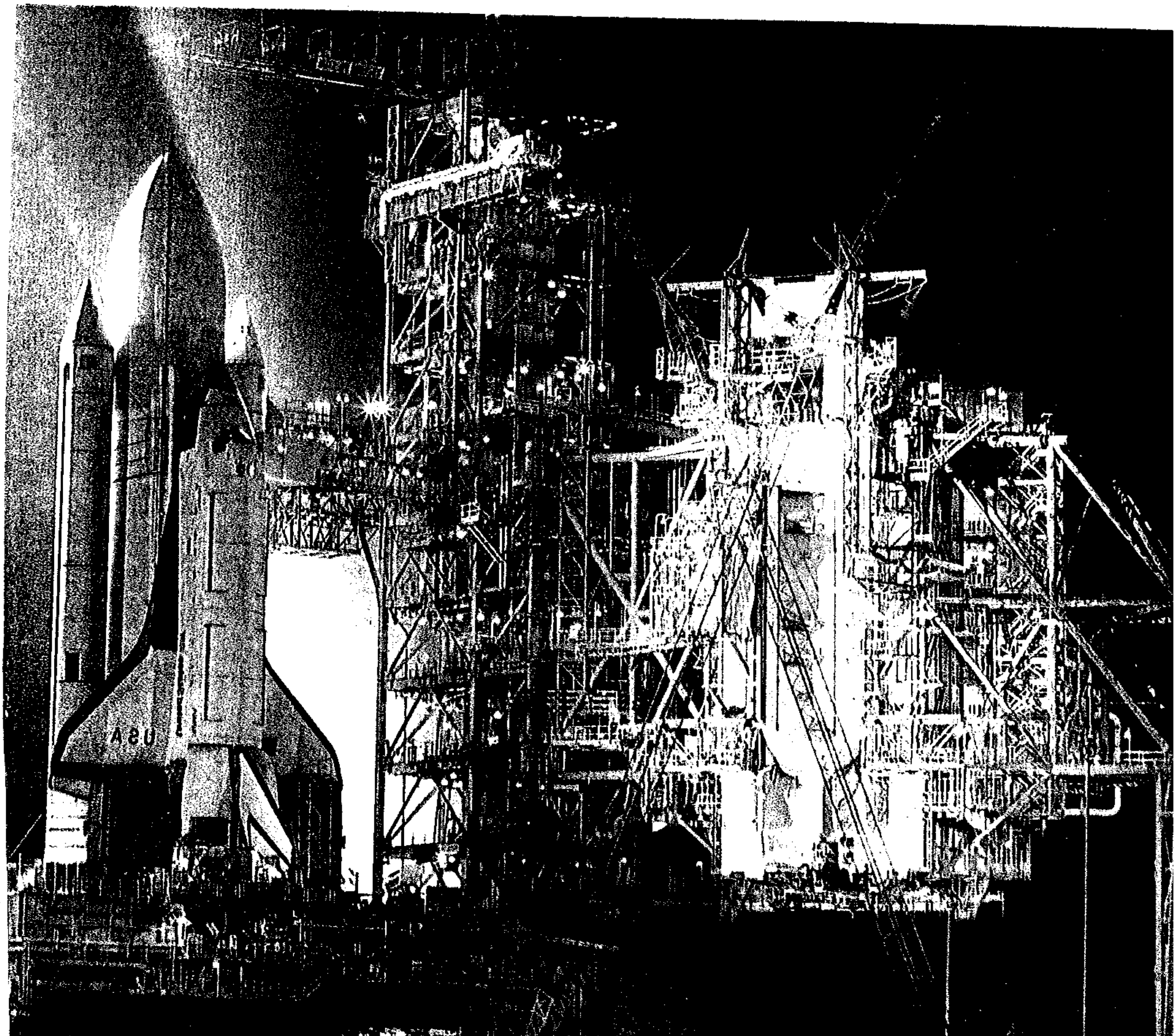
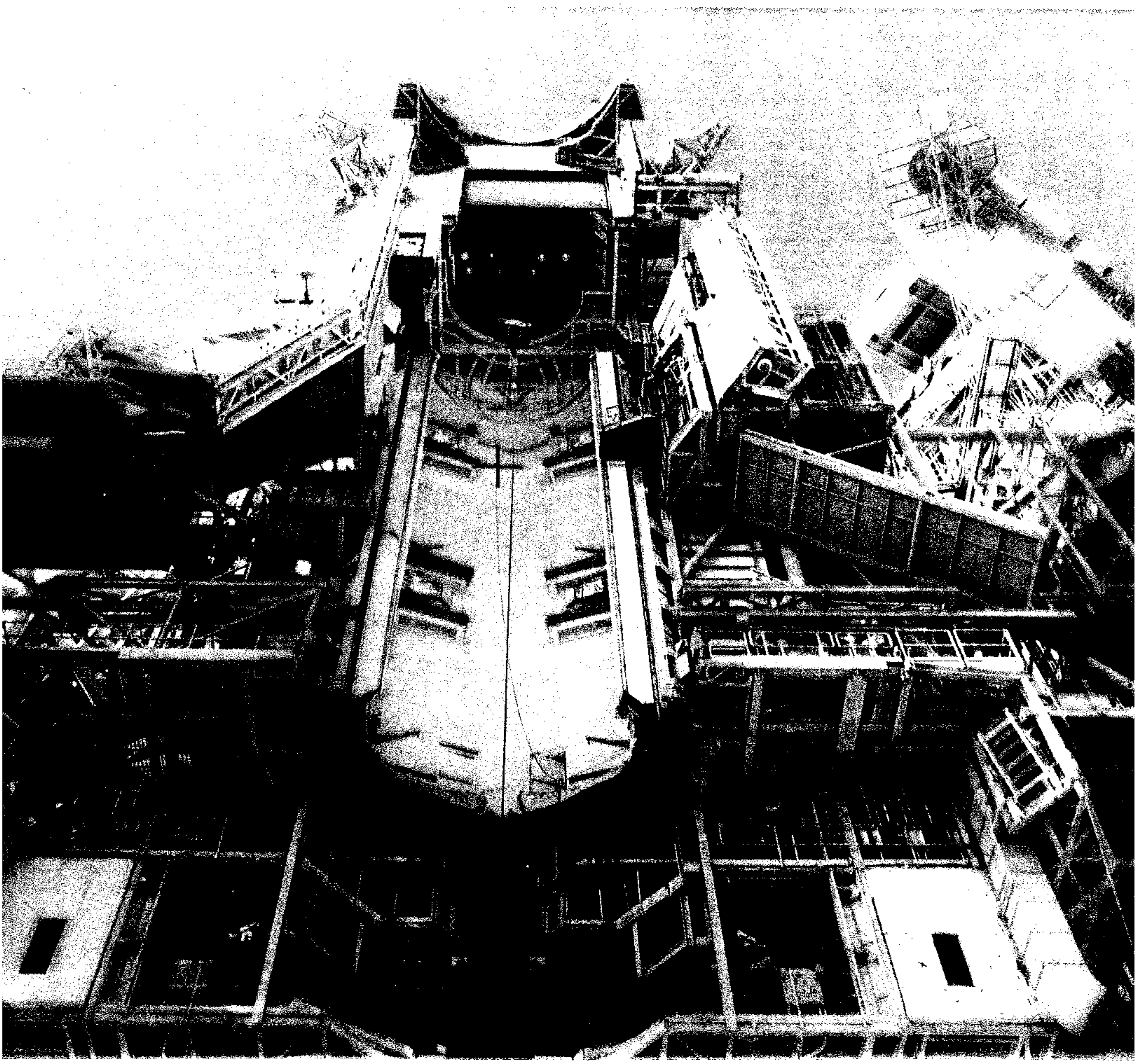


Figure 4.1 Spent Rockets and Launchers for Triggered Lightning Experiments







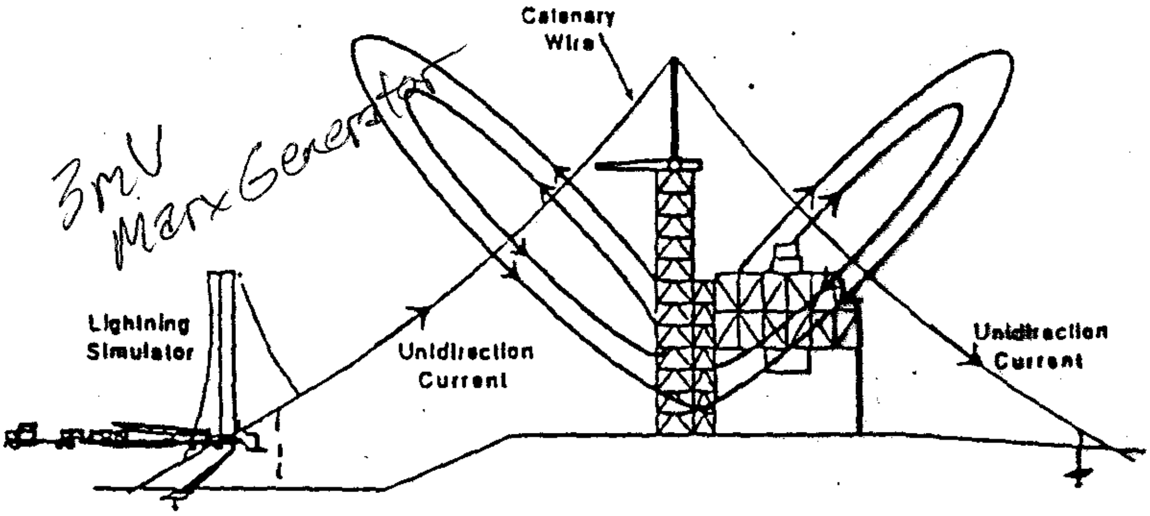


Figure 2. Test Configuration

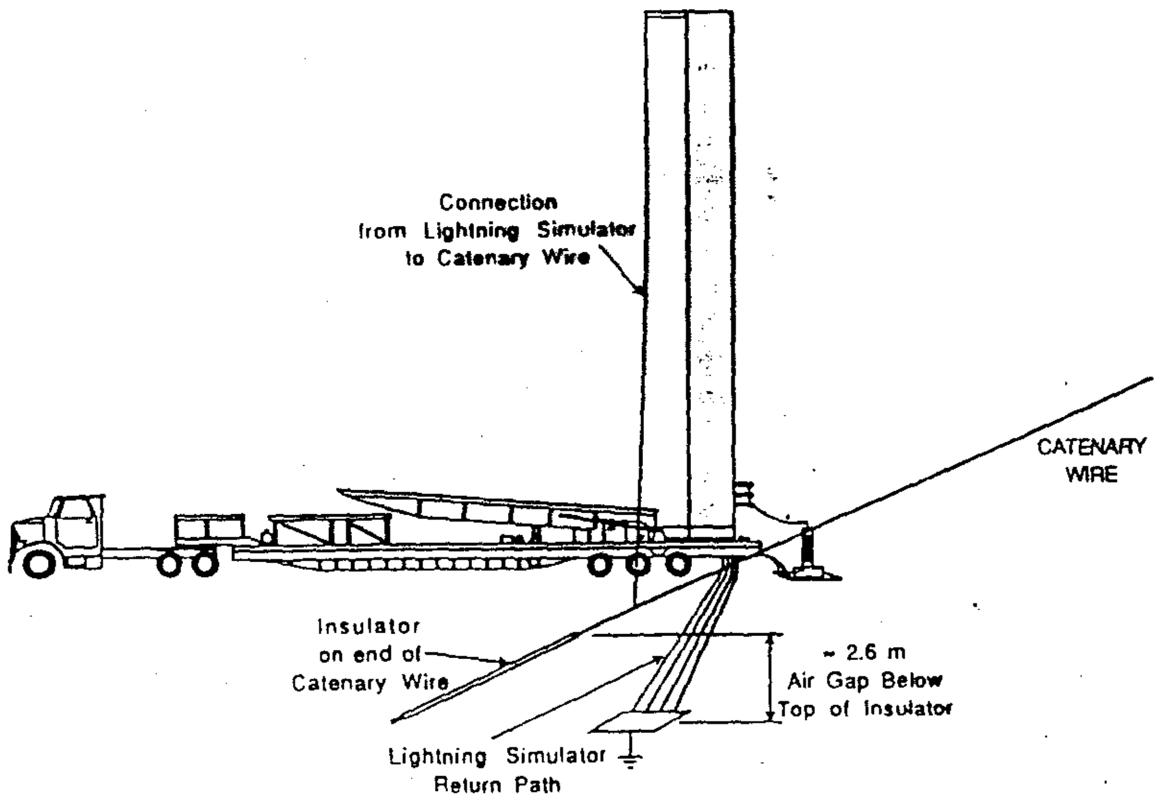
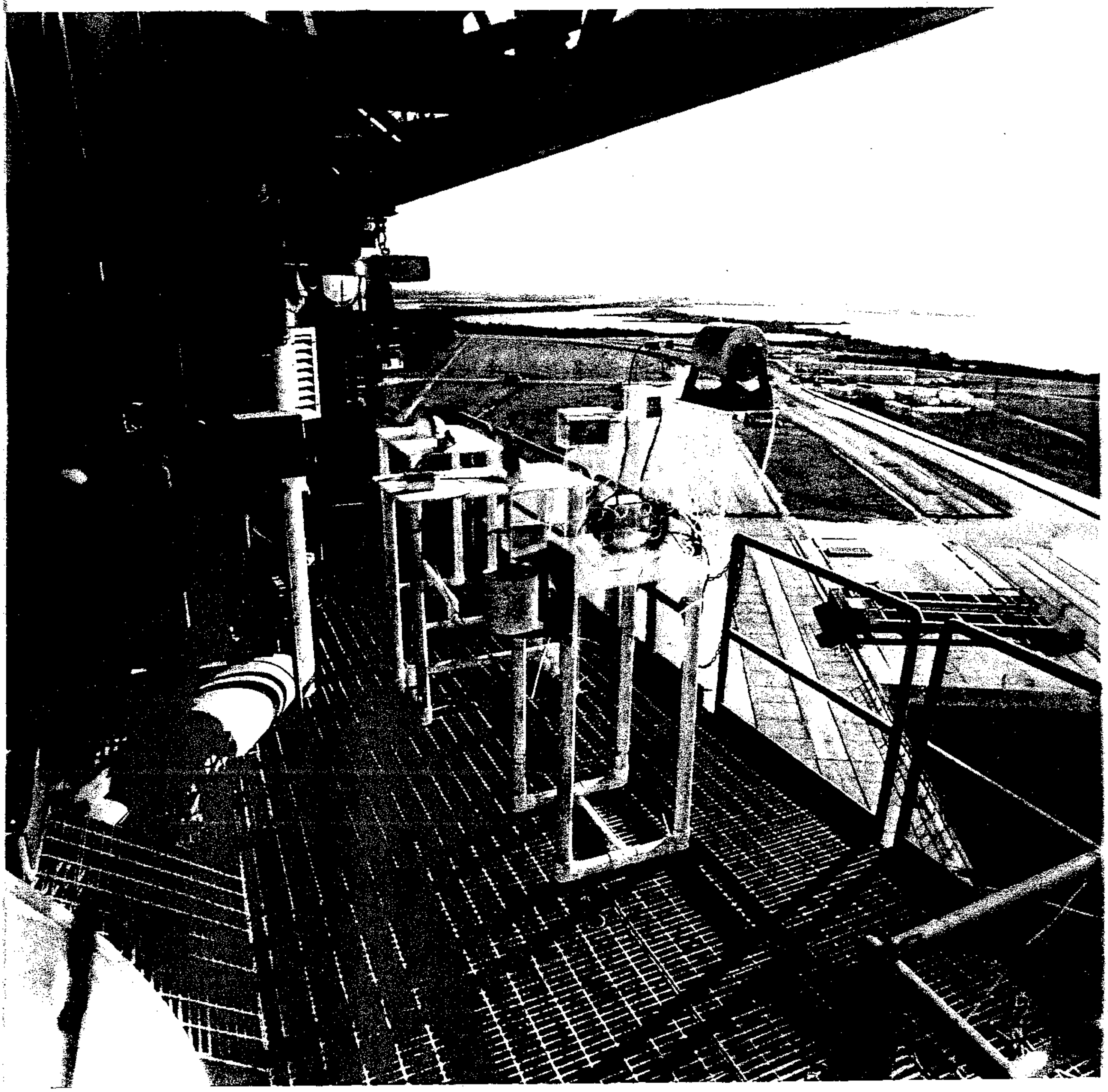
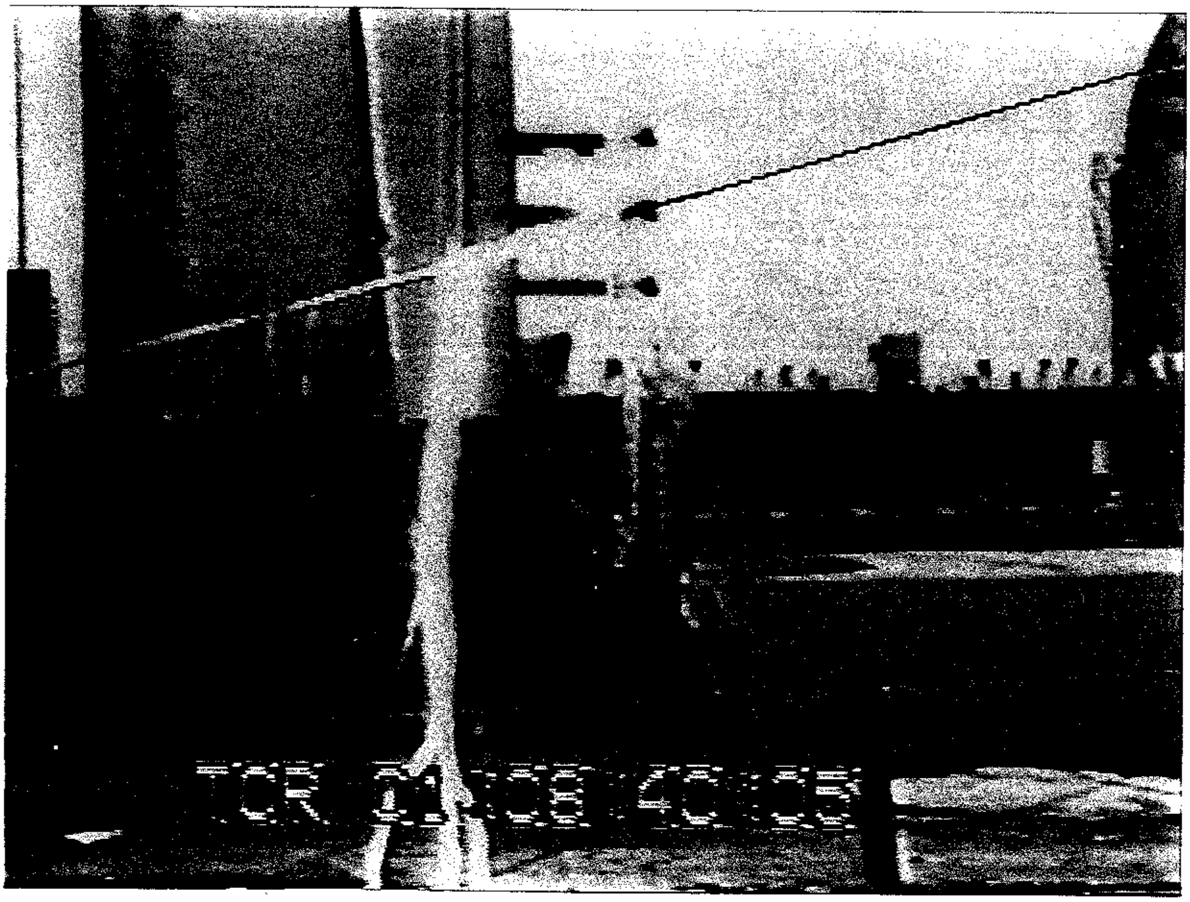


Figure 4-1. Simulator--Catenary Wire Configuration




TCR

The field components in each cell are calculated numerically via the finite difference form of Maxwell's Equations [3].

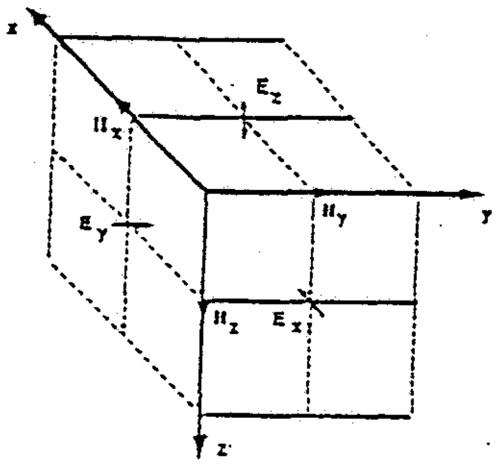


Figure 2.1 Staggered Spatial Grid

MAXWELL'S EQUATIONS

$$\mu\frac{\partial H}{\partial t} + \nabla \times E = M \tag{2.1}$$

$$\varepsilon\frac{\partial E}{\partial t} + \sigma E - \nabla \times H = -J \tag{2.2}$$

$$\nabla \cdot E = \frac{\rho}{\varepsilon} \tag{2.3}$$

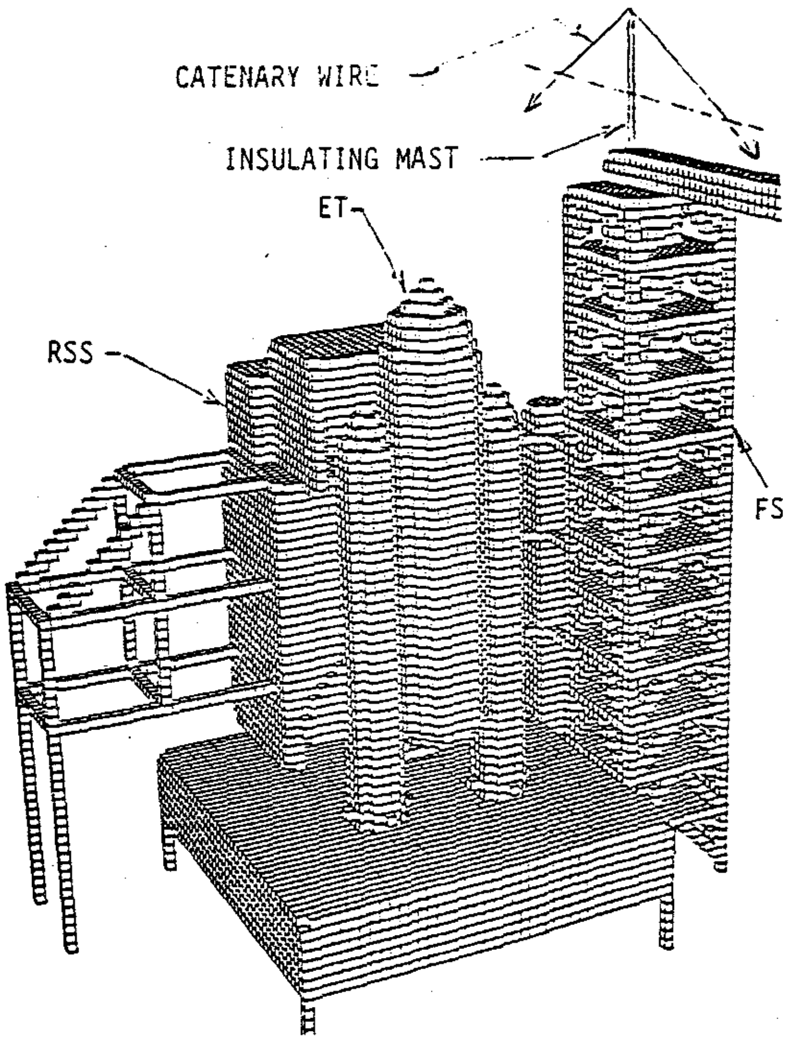
$$\nabla \cdot H = 0 \tag{2.4}$$

The vector components of equations 2.1 and 2.2 describing the time advance of magnetic and electric fields respectively are shown in Figure 2.2 together with the centered finite difference formulation of these equations. It is seen that besides being stagered in space, the electric and magnetic fields are also staggered in time. The numbers MX, MY and MZ are the numbers of cells in the X, Y and Z directions respectively.

The time step (increment) for this finite difference solution of Maxwell's Equations is determined by the Courant criterion, which may be viewed as requiring that the speed of numerical propagation be greater than the fastest physical wave speed, in this case the speed of light in air. Specifically, the Courant condition is:

$$\Delta t \leq \frac{1}{c\sqrt{\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} + \frac{1}{\Delta z^2}}} \tag{2.5}$$

where Δt is the time step, Δx, Δy, and Δz are the three cartesian spatial increments and c is the speed of light in the air. For the external coupling problem Δt is 1.8×10^{-9} sec and for the internal coupling problems Δt .45 to is $.9 \times 10^{-9}$ sec. The smallest spatial increments control the time



(a) LAUNCH PAD OVERVIEW

(b) CUTAWAY SHOWING ORBITER

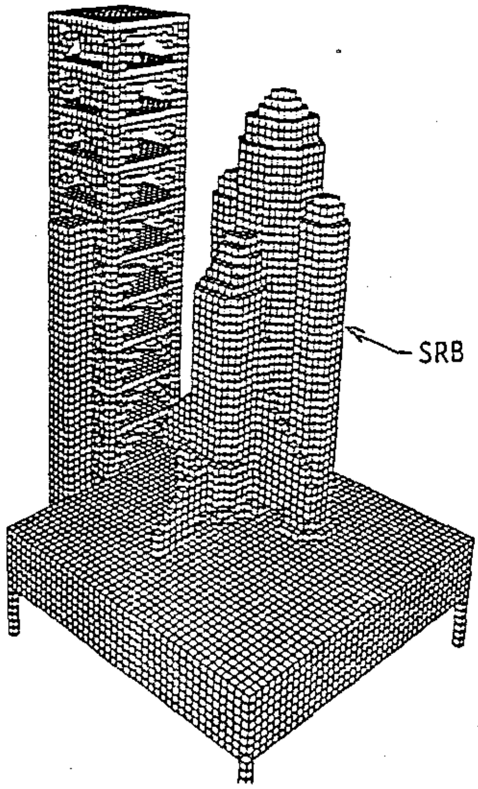
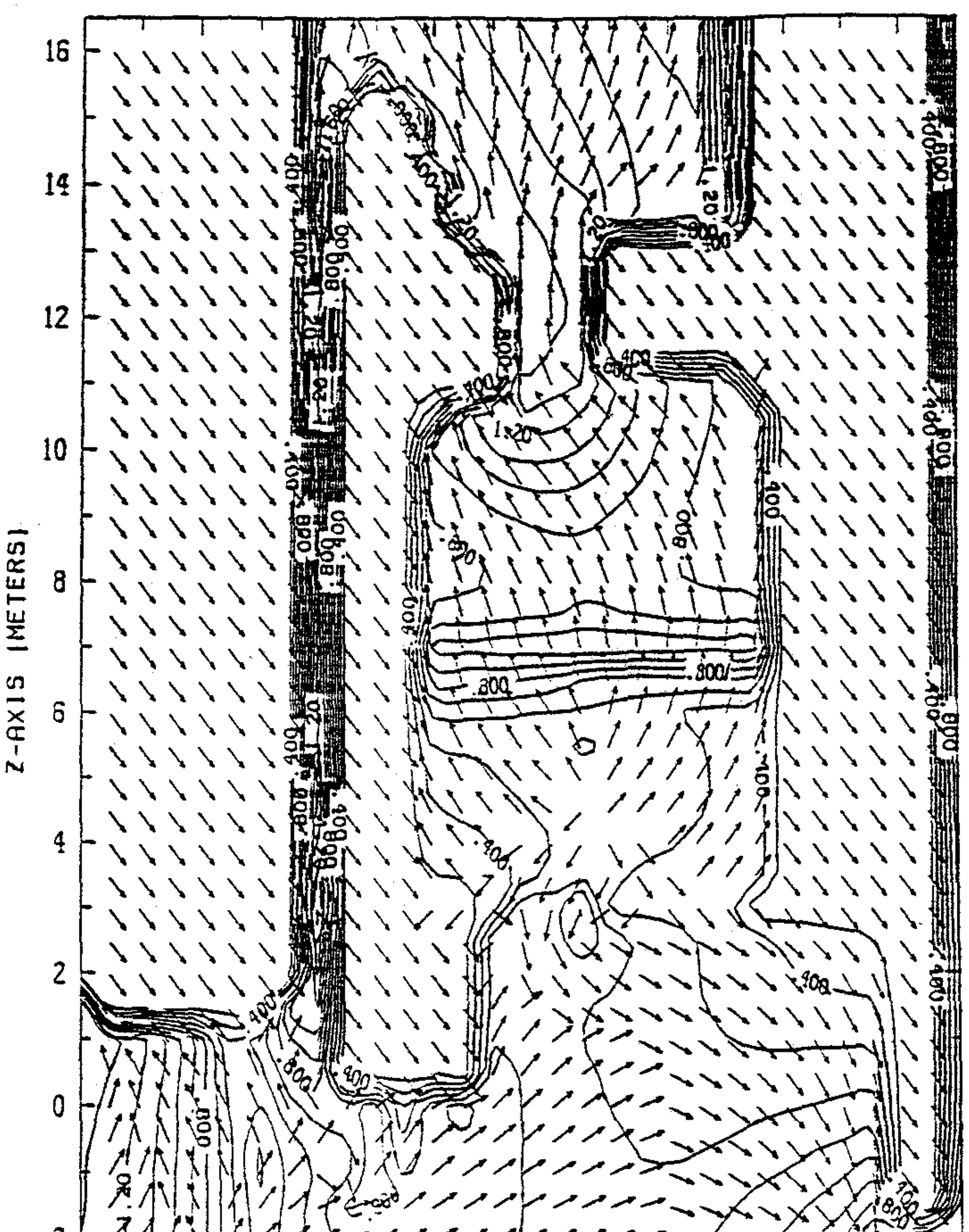
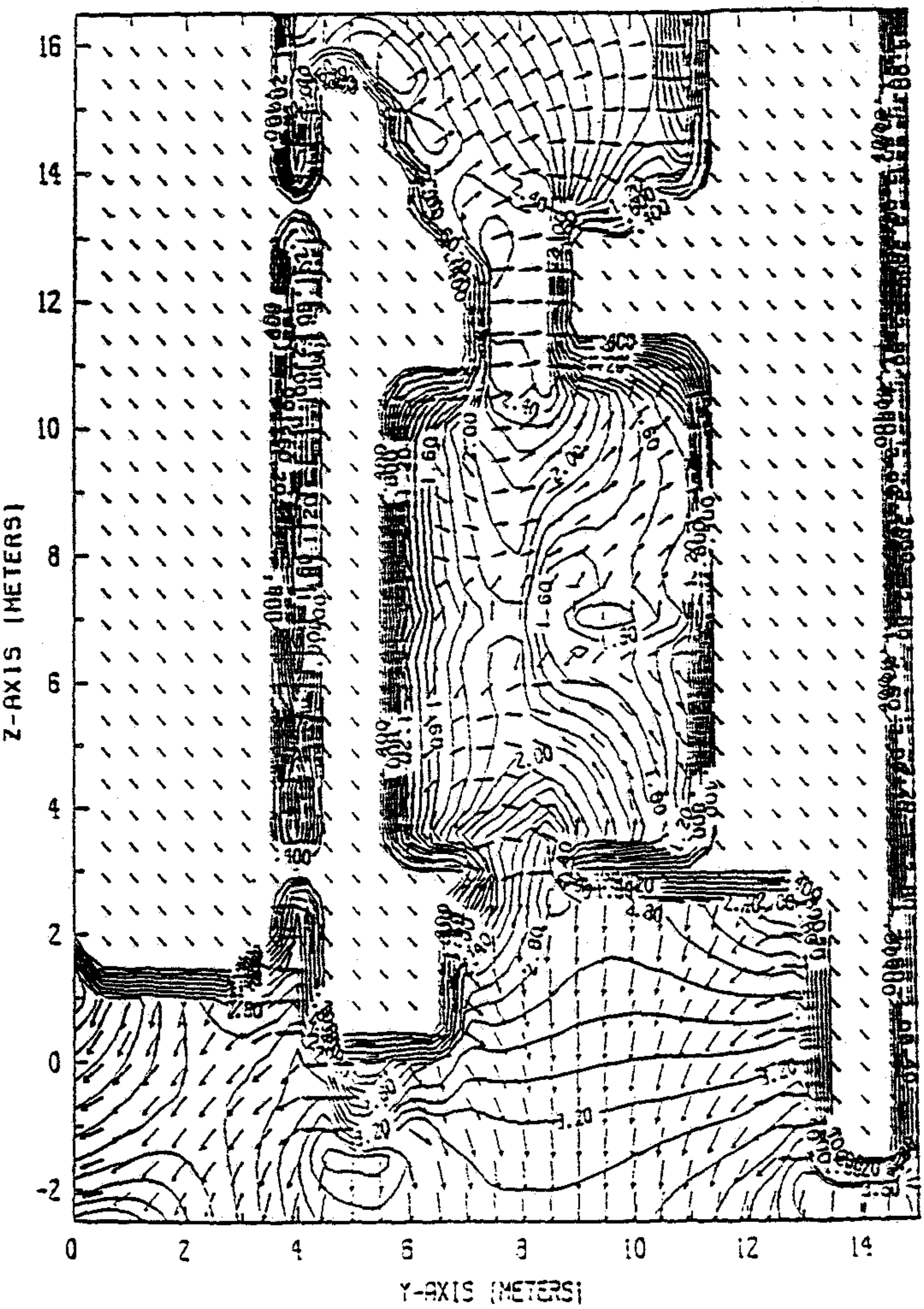


FIGURE 1. DIAGRAM OF THE ELEMENTS OF THE LAUNCH PAD STRUCTURE AS THEY HAVE BEEN MODELED

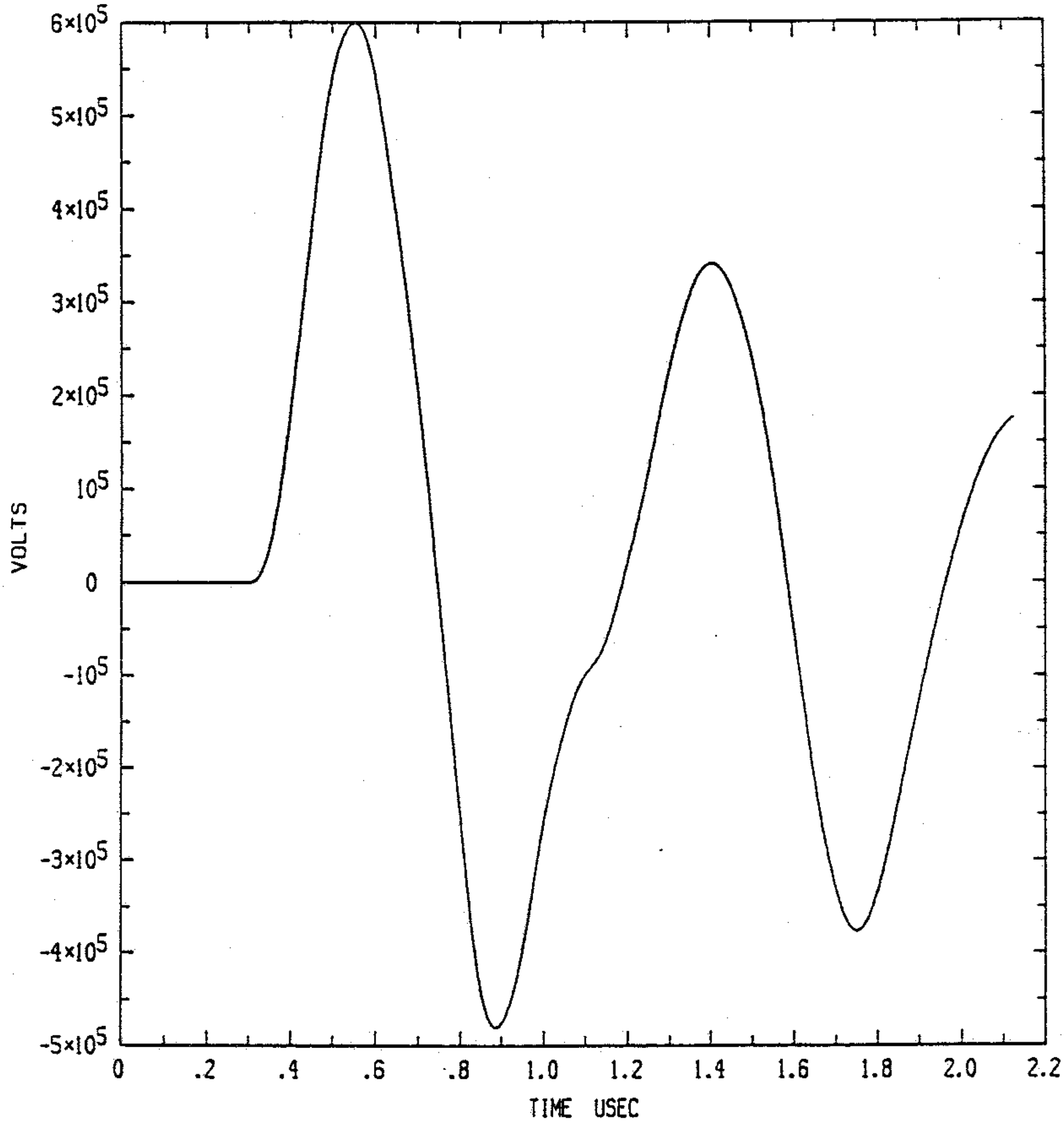
Fig 4.1



log10(H) (H in A/M)
CFW11: I=(H+1)
FIELDS AFTER 720 NSEC
H-FIELD CONTOURS ON A VERTICAL CROSS SECTION OF PCR AND SHUTTLE

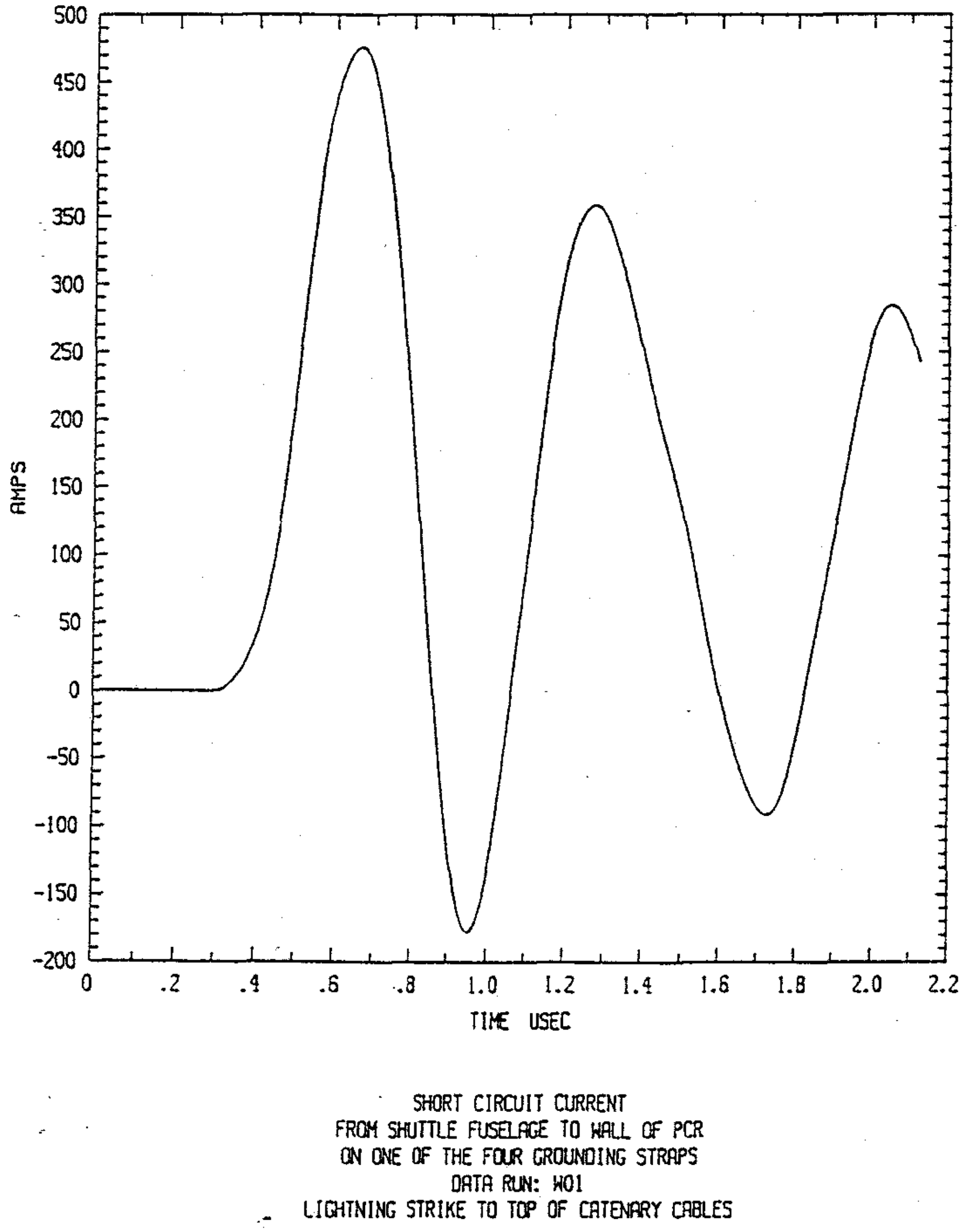


log10(E) (E in V/M)
DFW11: I=(H+1)
FIELDS AFTER 720 NSEC
E-FIELD CONTOURS ON A VERTICAL CROSS SECTION OF PCR AND SHUTTLE

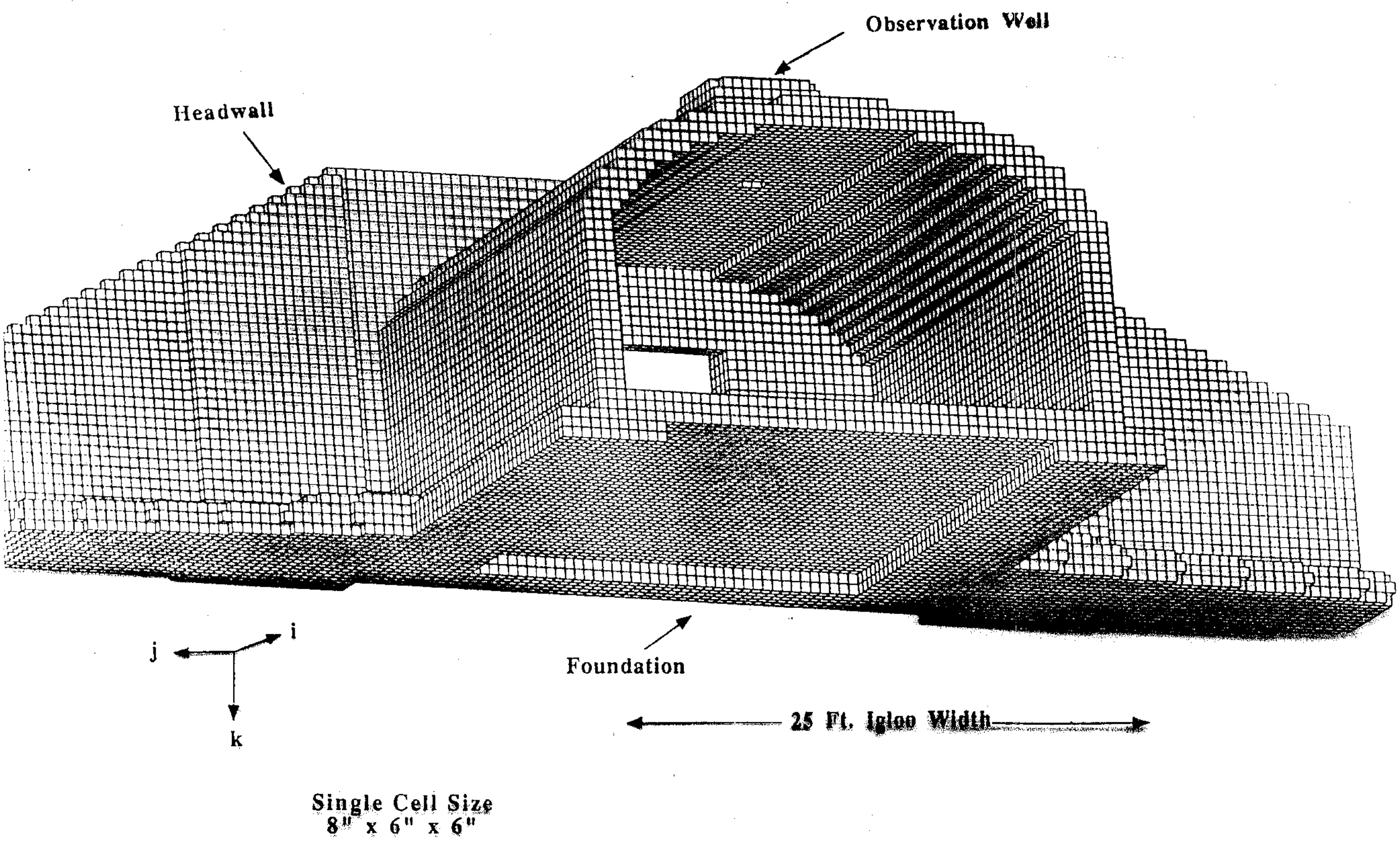


OPEN CIRCUIT VOLTAGE
FROM INSIDE SHUTTLE PAYLOAD BAY
TO INSIDE WALL OF PCR
DATA RUN: D01
LIGHTNING STRIKE TO TOP OF LIQUID FUEL TANK

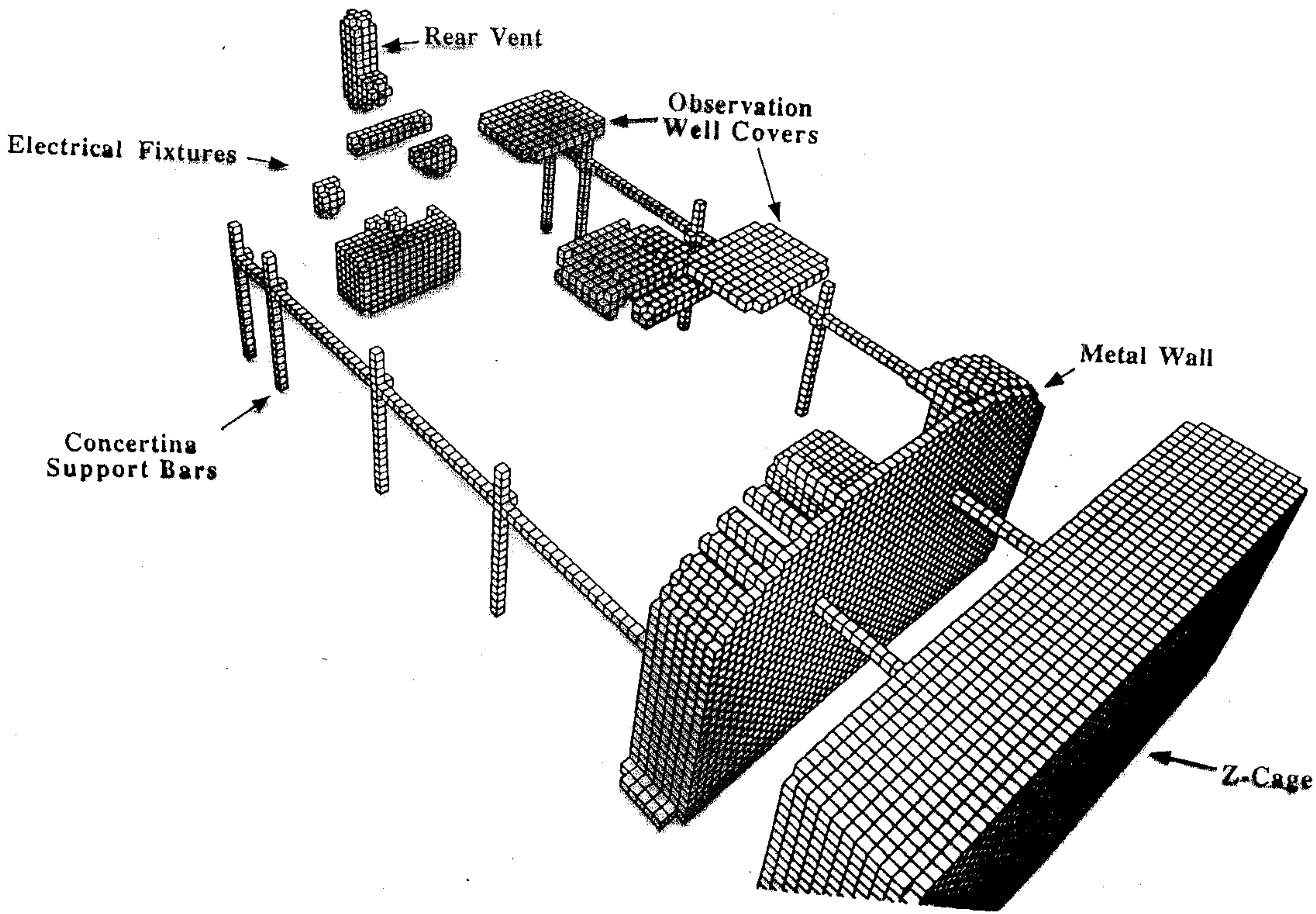
Figure 4.5. Resonant Response of the PCR/FSS/RSS/Shuttle System from an Attachment to the Catenary Wire



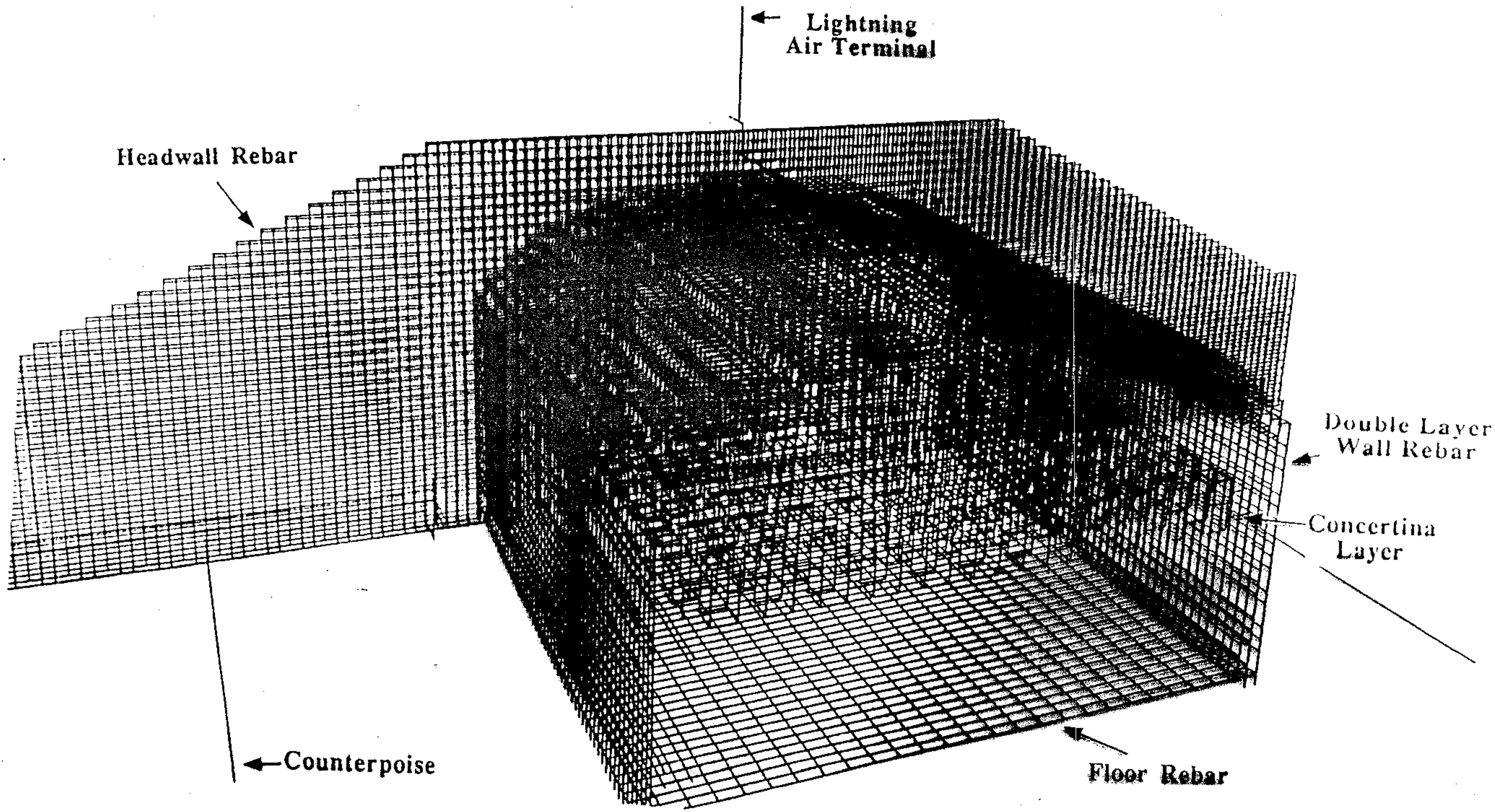
IGLOO CONCRETE



IGLOO METALS



IGLOO REBAR AND WIRING



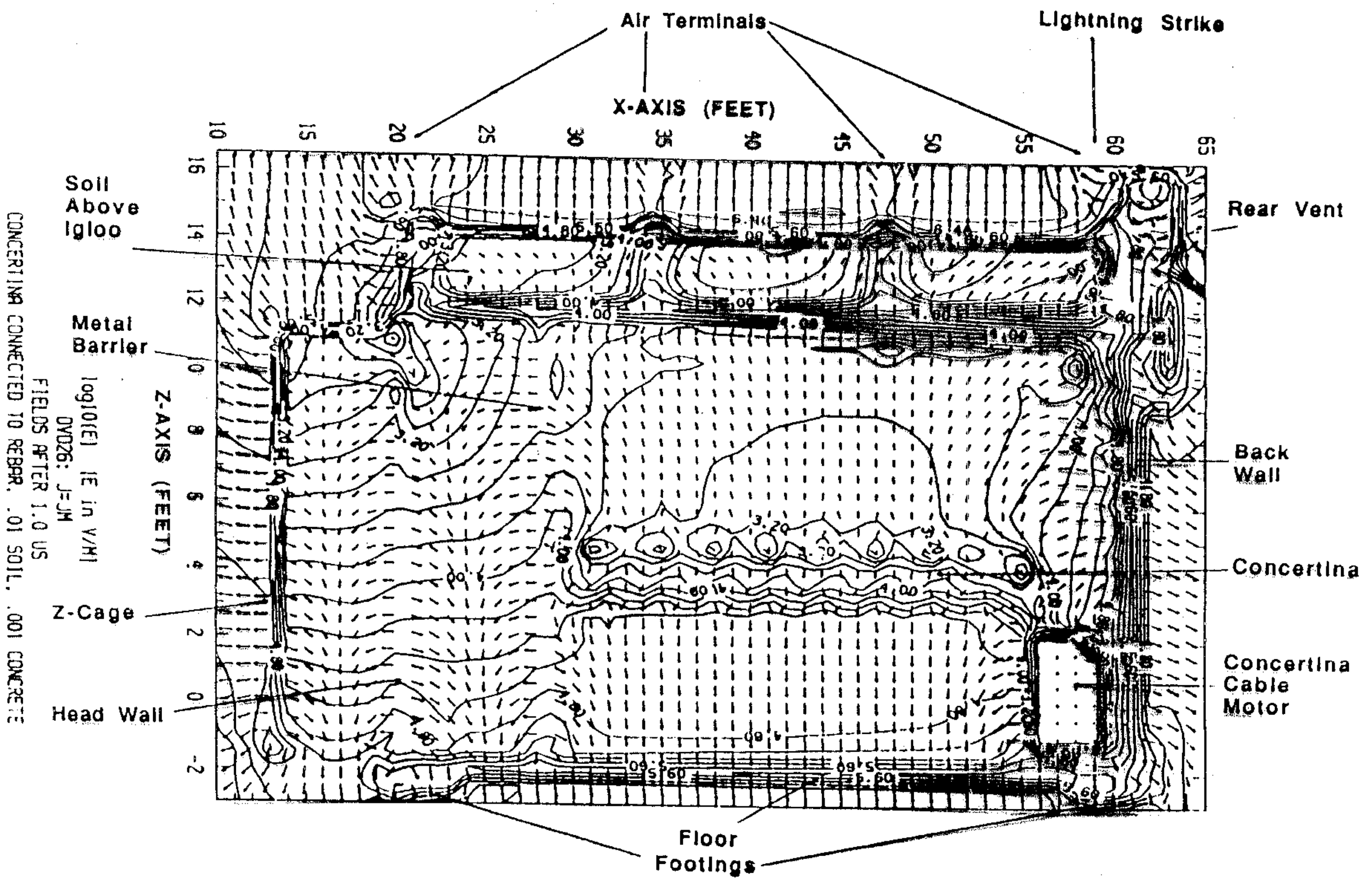
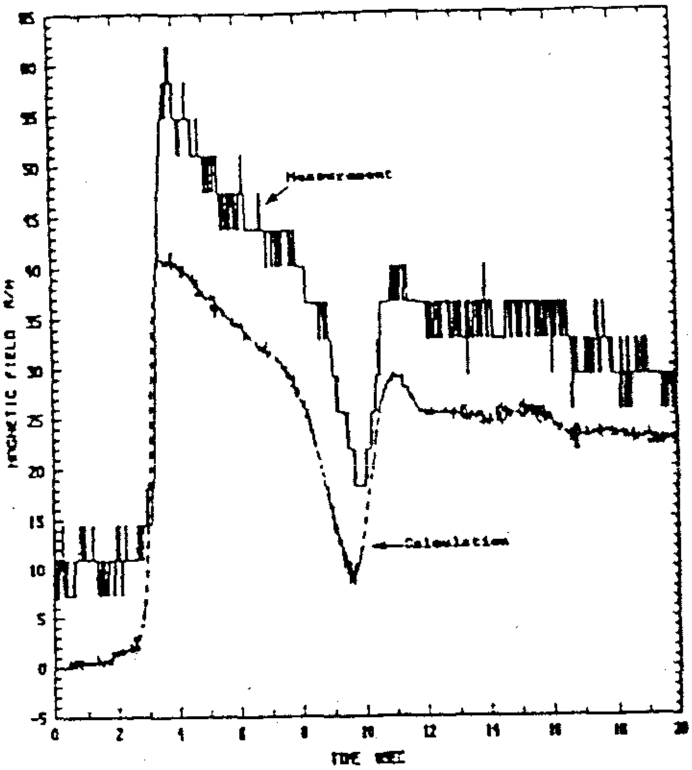
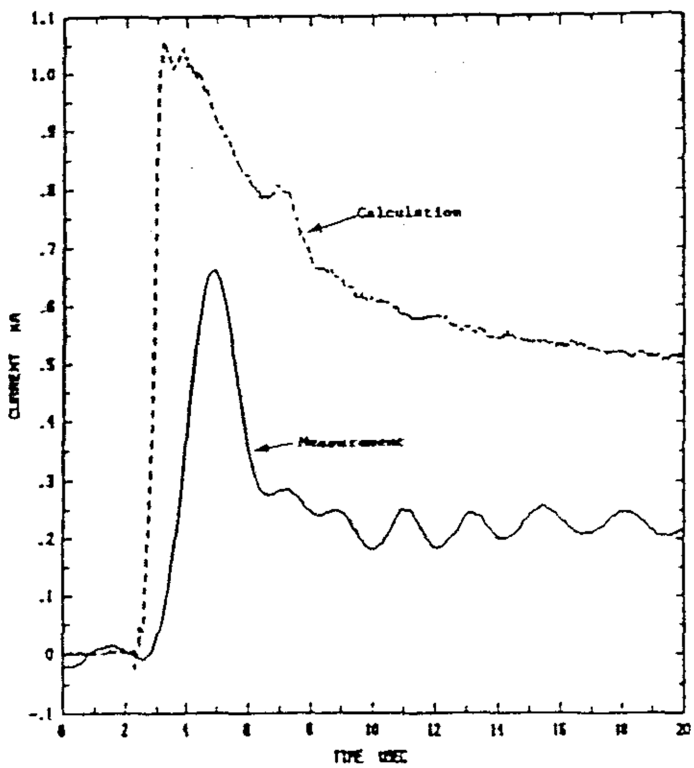


Figure B.8 Electric Field Vector and Magnitude Contour Plot for Vertical Mid-Cross Section of Igloo



(e) Internal Magnetic Field in Vicinity of Right Rear Corner of Igloo



(f) Current on Conductor Between Z-Cage and Counter-Poise

Figure 4.9 (Cont'd.) Comparison of Analysis with Experimental Results for Partialy Buried Concr [7, 8] Igloo Rocket Triggered Lightning Experiment Picatinny Arsenal/Sandia Laboratories