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ELECTROMAGNETIC COMPATIBILITY EVALUATION OF SEVEN ELECTRONIC BRAKE SYSTEMS

J.W. Adams
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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary
Sidney Harman, Under Secretary
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CONTENTS

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The seven brake systems are referred to as units A through G. No unit was perfect in all respects. Unit D showed no failure under any test condition, but did have an indicator failure under three conditions. Unit B had 16 failure indications and 8 valve-clicks without failure indication. Units A, C, E, F, and G each indicated numerous failures at levels an order of magnitude below the criteria level.

Key Words: Electromagnetic compatibility; electronic brakes; susceptibility.

1. Background

In order to comply with the Federal Motor Vehicle Safety Standard 121 (FMVSS-121), truck manufacturers have elected to use electronic antilock devices in their braking systems. The work reported here was performed at the request of the National Highway Traffic Safety Administration (NHTSA) to determine whether those systems are susceptible to electromagnetic interference (EMI) and to attempt to detect failure modes under worst-case conditions. Failures due to EMI are difficult to either predict or determine after the fact due to the extreme mobility of vehicles and sources and their complex interactions.

2. Electromagnetic Field Strength Criteria

The same criteria curve is shown on each of seven figures, Figures 1 through 7. The curve is based on worst-case field strength conditions in the sense that worst case occurs in the immediate proximity of a radio transmitter where both electric (E) and magnetic (H) fields are orders of magnitude higher than at distances several wavelengths away from the transmitter. These worst-case levels have been measured previously by NBS with support from NHTSA and reported elsewhere [1].

In summary of this previous work, electric field strength levels in and around vehicles with on-board transmitters range mostly between 10 and 300 volts per meter, while field strength levels in and around vehicles adjacent to vehicles with transmitters range from 5 to 100 volts per meter. Field strength levels in and around vehicles adjacent to fixed, high-power transmitters are generally less than those reported above with the exception of some AM broadcast stations. These levels are sometimes higher than those reported above.

In this referenced work, no near-field measurements have been made above 500 MHz, but the extrapolation used above 500 MHz is predicted from theory [2]. There are plans to make these measurements subsequently.

The criteria curve is actually somewhat lower than suggested in this previous work. This is subject to interpretation and judgment. The basis for using a lower curve is primarily based on the following factors. First, the ANSI C-95.1-1974 Standard and Occupational Safety and Health Standard, 29CFR1910.97, for personnel hazards requires levels for individuals to be less than 200 volts per meter when averaged over any six-minute period. This averaging (of power density or E^2) allows much higher field strength levels for time periods short compared to six minutes. If people are exposed to fields of more than 200 volts per meter when around vehicles, then legal power levels need be reduced in the future so that neither people nor vehicles are exposed to fields greater than 200 volts per meter. Nevertheless, present legal power limits produce fields considerably in excess of 200 volts per meter around vehicles. Finally, if filtering and shielding are adequate to protect a unit against fields of 200 volts per meter, this is normally sufficient to protect it against even higher fields. If there is insufficient filtering and shielding, as is the case in several of these units, failures show up at levels far below the criteria level.

At present, the portion of the spectrum of greatest concern is between 10 MHz and 500 MHz, since there are more mobile transmitters in this range than any other, and electromagnetic energy is coupled more efficiently in this frequency range than any other for objects of vehicle-size dimensions.

3. Test Procedures

Each unit was tested in at least two different TEM cells [3]. This was necessary in order to achieve the desired field strength levels over the 10 kHz to 1 GHz frequency range. Failure detection depended principally on reaction of the failure-indication system. A stethoscope was used to detect audible clicks by the air valves when the unit was inside the large TEM cell. The factors that must be considered are as follows.

a. The power available and the spacing between the center septum and the bottom of the TEM cell determine the unperturbed field strength level E_o inside the cell. This may be calculated from

$$E_o = \sqrt{PZ_o}/d$$

where P is net power into the cell, Z_o is the characteristic impedance of the cell, and d is the spacing between the septum and the floor of the cell.

b. The unit under test perturbs the fields at all frequencies. This is a spatial variation around the unit, and maximum to minimum may vary by a factor of 2 or 3 to 1.

c. At resonant frequencies of the unit under test, the field is greatly changed, usually by a factor of 10 to 1 over the unperturbed levels.

d. Each system was tested in at least two different geometrical arrangements. For rigid systems, orientation of the unit under test causes variations since the field is a vector quantity. For "flexible" systems in which several components are connected by flexible metallic cables, there seems to be no favored orientation for maximum coupling of energy. What is important at frequencies up to 100 MHz, is the total length of the maximum dimension of the system under test. The larger this dimension, the larger is the ratio of physical length to electrical wavelength, and the amount of energy coupled is correspondingly greater. Thus, lower susceptibility levels would be expected when a large TEM cell (d = 1.5 m) is used than when a small TEM cell (d = 0.8 m) is used. Above 100 MHz (sometimes 200 MHz), the susceptibility levels are about the same for both size cells, since the physical dimension of the cables is a multiple of half wavelengths, just as it is in the larger TEM cell.

e. The field strength level (E_o) shown on the plots of data are those calculated from net power and separation distance of septum to floor of the TEM cell. The levels measured with an isotropic probe are normally within $0.5E_o$ to $3E_o$, usually higher. This means that even though the field strength level was some particular value without the unit being tested present , the fields are perturbed by the unit, and vary from $.5E_o$ to $3E_o$ at various locations around the unit. If the unit is at a resonant frequency, fields may be an order of magnitude or more higher.

Both electric and magnetic fields were present in the TEM cell during tests since the cell was resistively terminated.

4. Results

In the figures, one for each unit, "X" represents indication of a failure as indicated by activation of the light in the failure indication system, regardless of any other system response. An "+" indicates an audible response from the air valve (from one to multiple clicks) that was not signalled by the failure indication light. An "■" indicates a false indication of failure due to a glow of the failure indication light caused by direct rf heating of the light. Failures that were recorded at field strength levels above the criteria level may be discussed and evaluated at a later time, but will not be discussed further in this report. All units performed satisfactorily before and after the EMI tests.

Unit A had six failures at levels an order of magnitude below the criteria level, and a multiplicity of failures below the criteria level. It had two possible failures (370 MHz and 480 MHz) not indicated by the visual warning system.

Unit B had about two dozen failures at levels below the criteria curve. Several of these were potential failures indicated by audible response of the air valve and not indicated by the visual failure indicator.

Unit C had innumerable failures at levels an order of magnitude below the criteria level. This unit had a unique potential failure mode. The air valve switched several (2 to 8) times over 2 to 10 seconds when an applied field was abruptly discontinued. This simulates release of a microphone key on a mobile transmitter. The failure warning light indicated a failure at the end of the clicks.

The only problem with unit D was with the antilock failure indication subsystem. The failure indication subsystem gave false indications at three frequencies. These were due to direct rf heating of the warning light and a light-switching module was burned out at about 120 volts per meter at 48 MHz.

Units E, F, and G had a multiplicity of failures below the criterial level; each unit had several failures an order of magnitude below the criteria level. There is inherent shielding provided by metal cases, but there is apparently insufficient filtering of the cables.

5. References

[1] Adams, J. W., Kanda, M., Shafer, J., and Wu, Y., Near-field electric field strength levels of EM environments applicable to automotive systems, IEEE EMC Symposium, Aug. 2-4, 1977, Seattle, Washington.

[2] Reference data for radio engineers, ITT, International Standard Book Number: 0-672-21218-8, Library of Congress Catalog Card Number: 75-28960, 1975.

[3] Crawford, M. L., Generation of standard EM fields using TEM transmission cells, IEEE Trans. on Electromagnetic Compatibility, Vol. EMC-16, No. 4, November 1974.

UNIT A

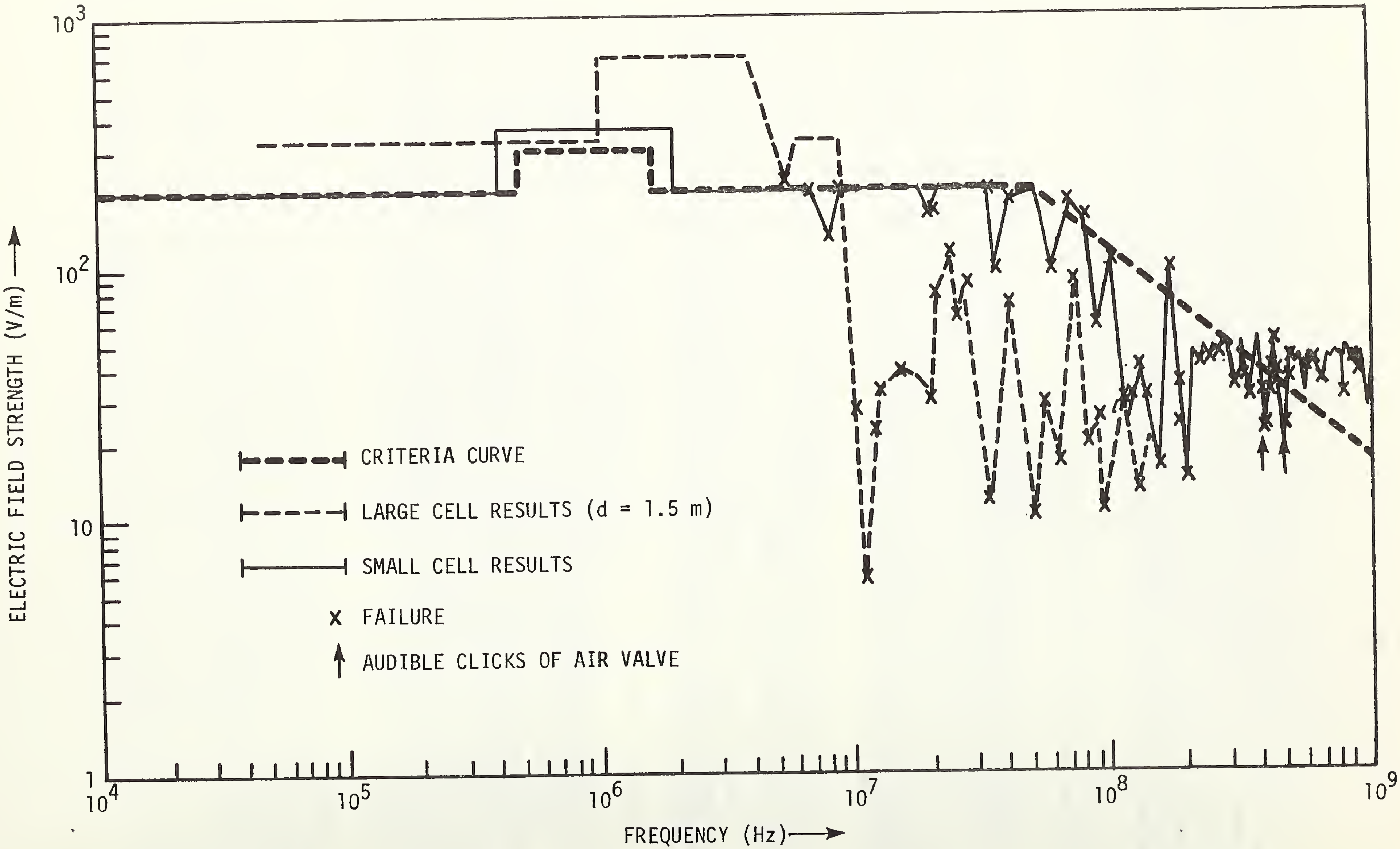

Figure 1. Susceptibility curves for Unit A.

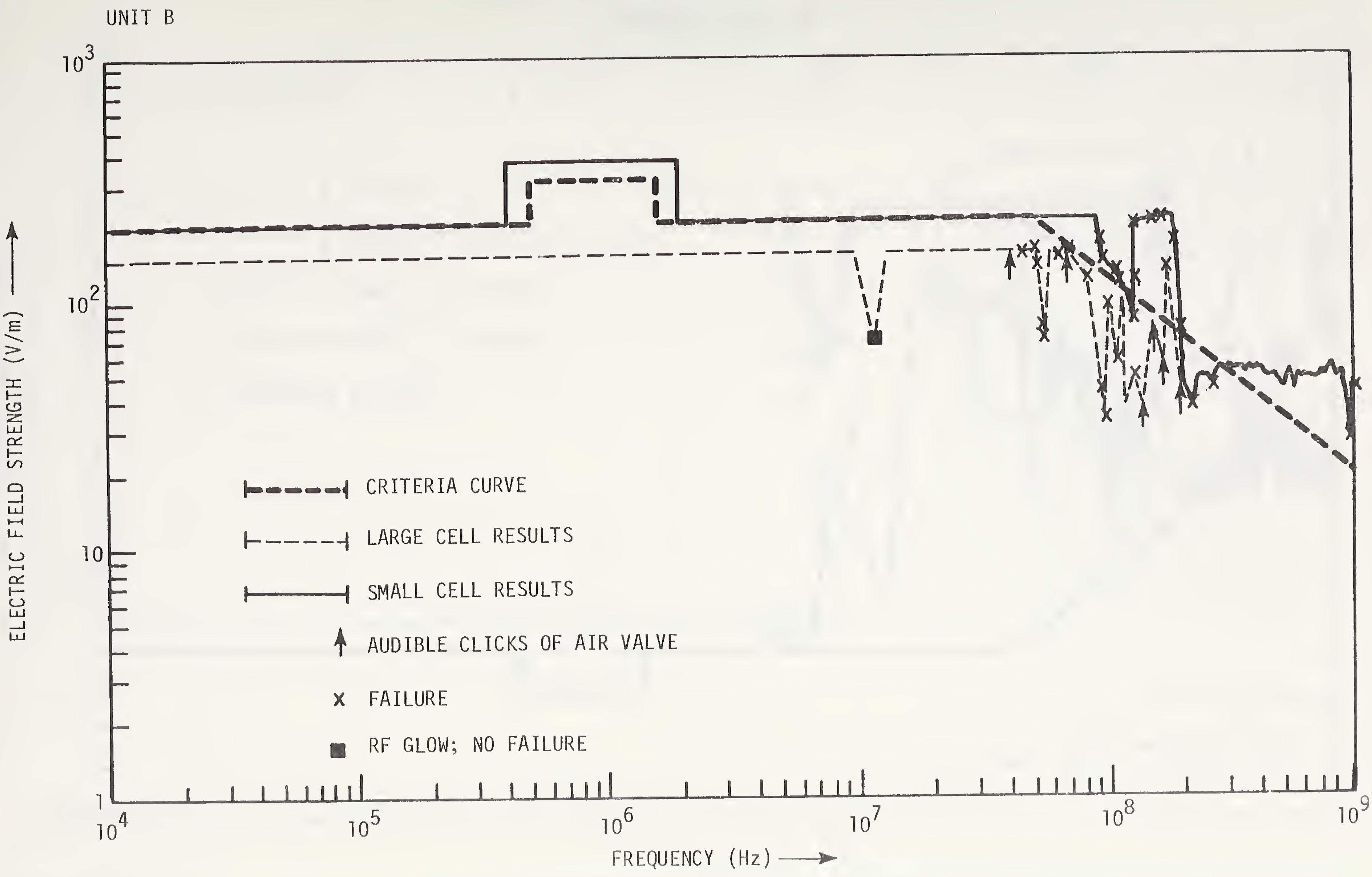

Figure 2. Susceptibility curves for Unit B.

UNIT C

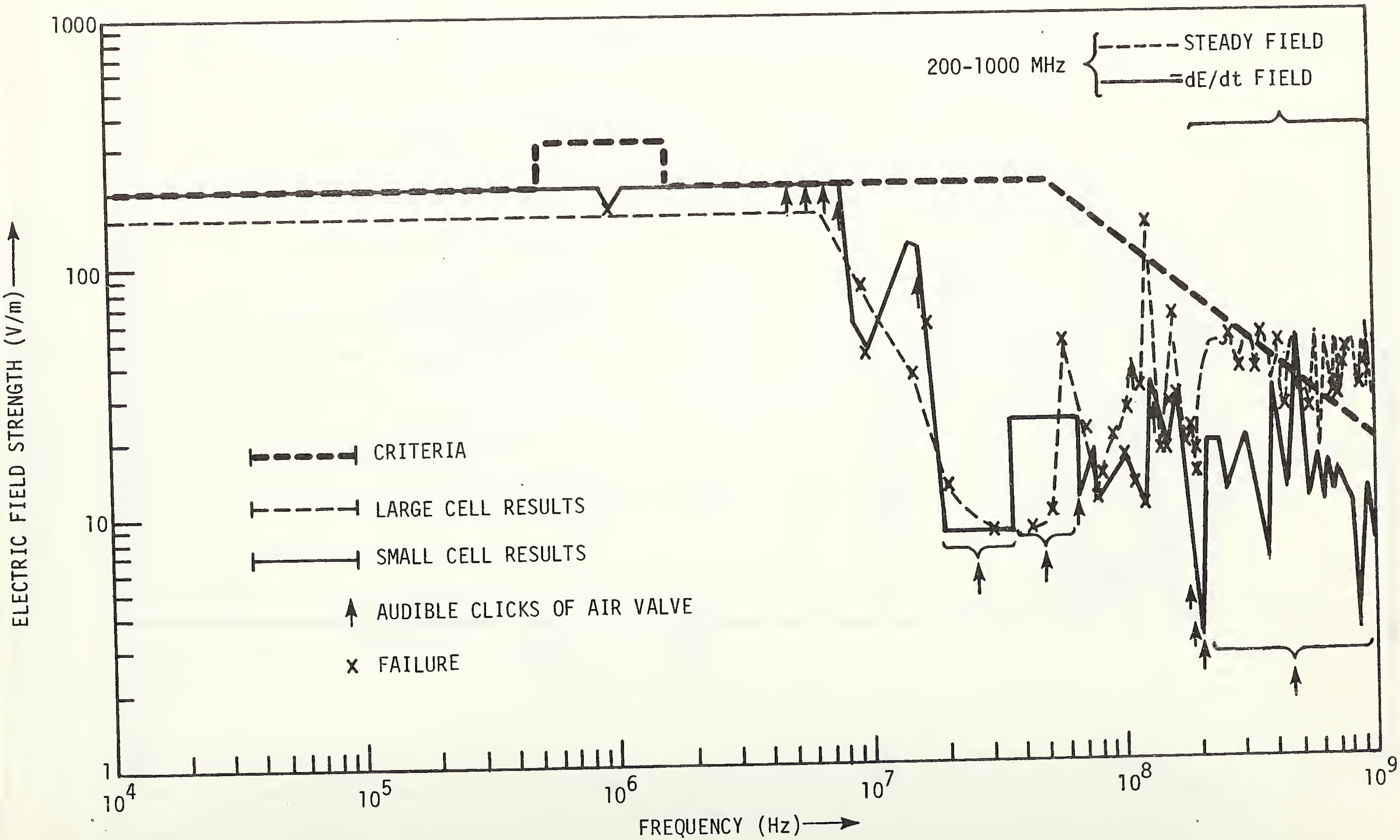

Figure 3. Susceptibility curves for Unit C.

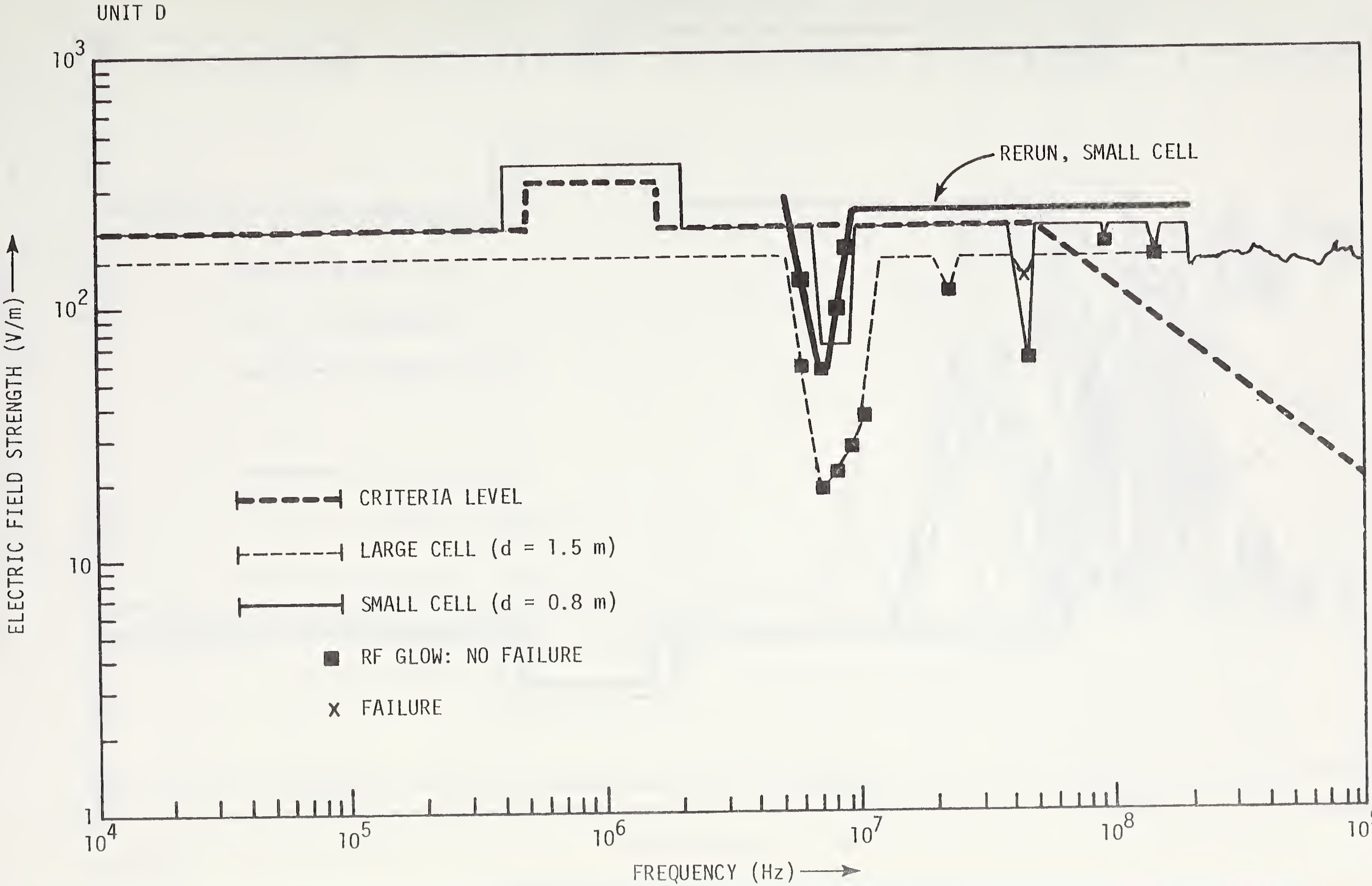

Figure 4. Susceptibility curves for Unit D.

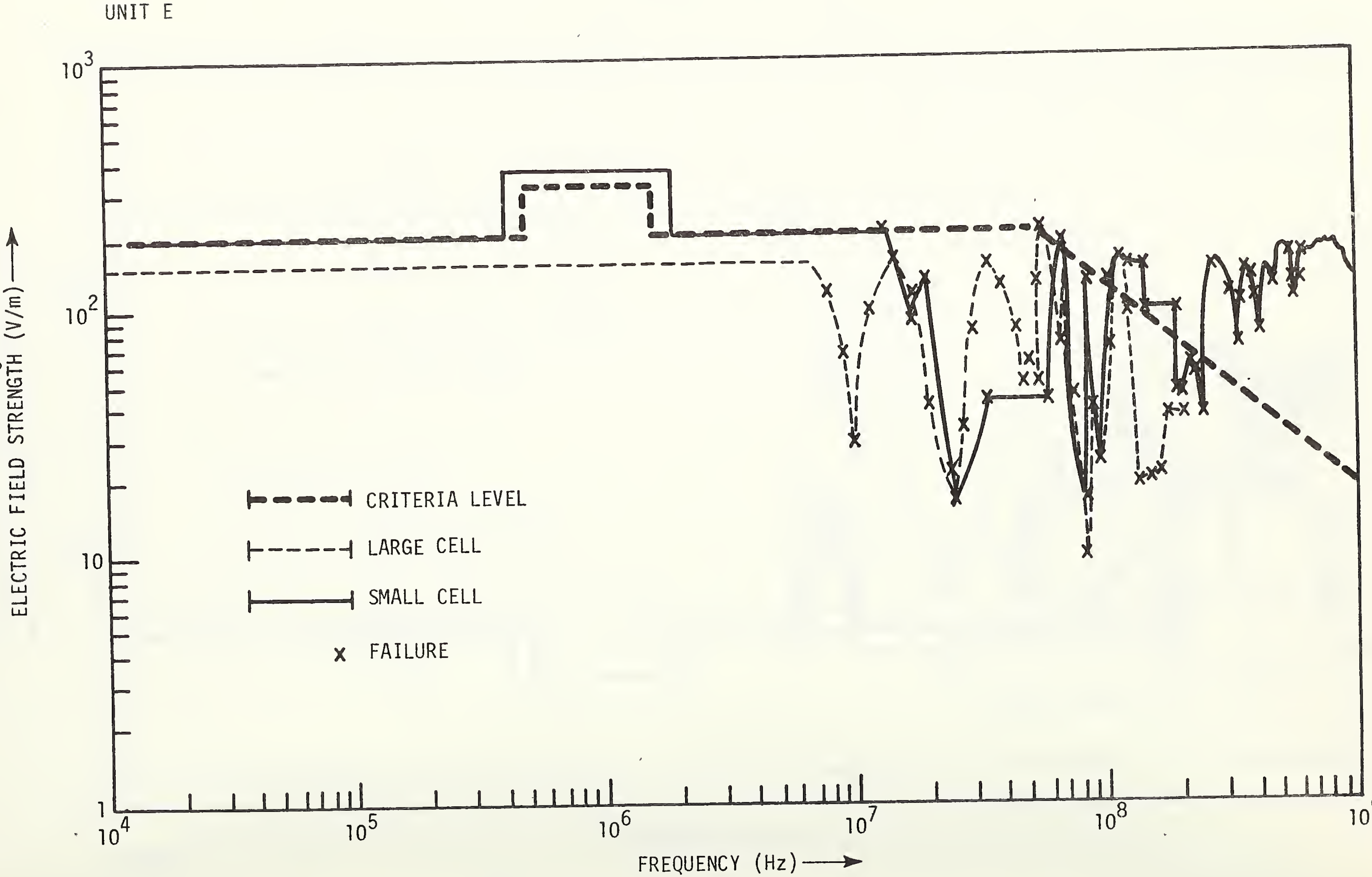

Figure 5. Susceptibility curves for Unit E.

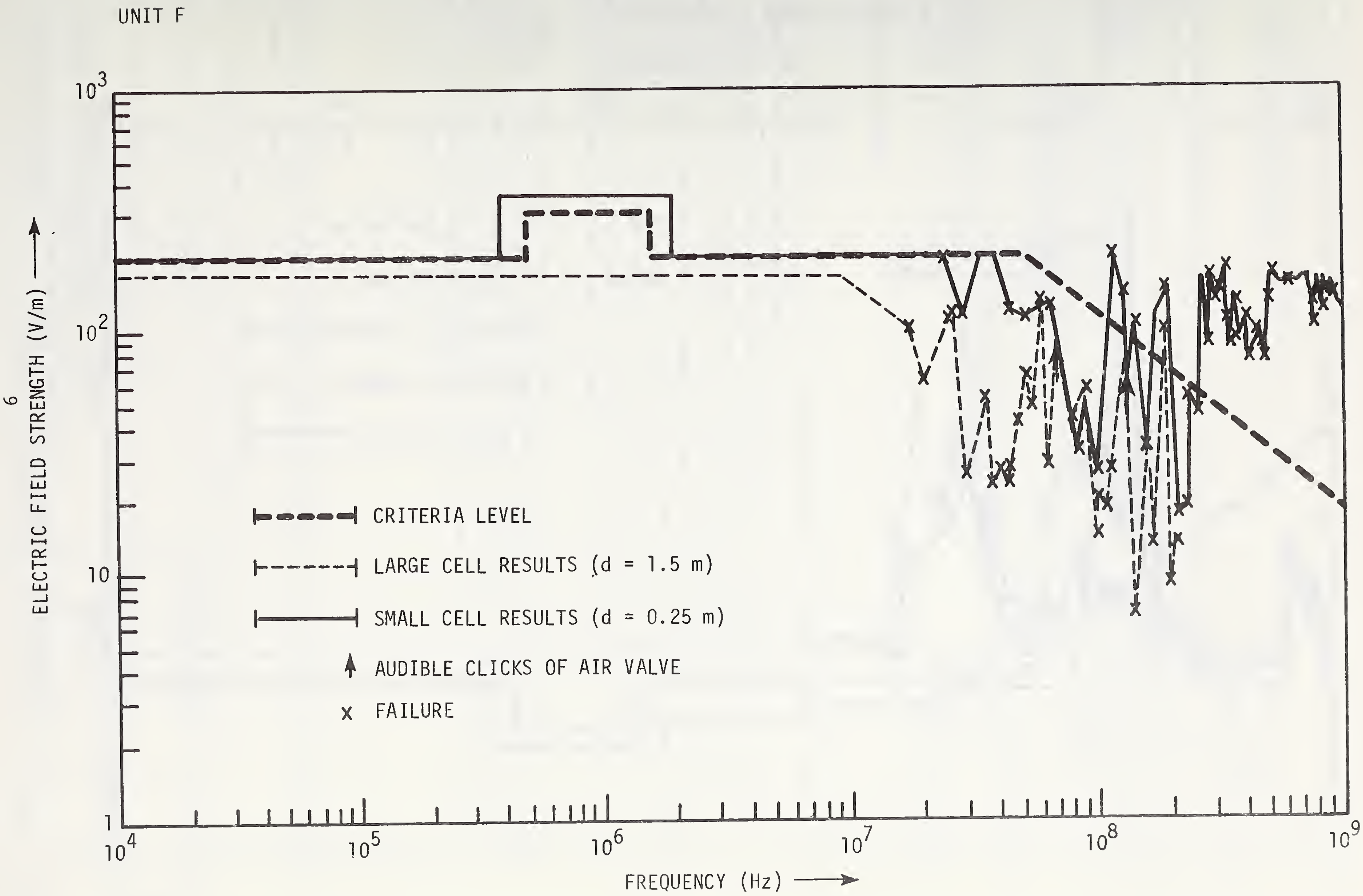

Figure 6. Susceptibility curves for Unit F.

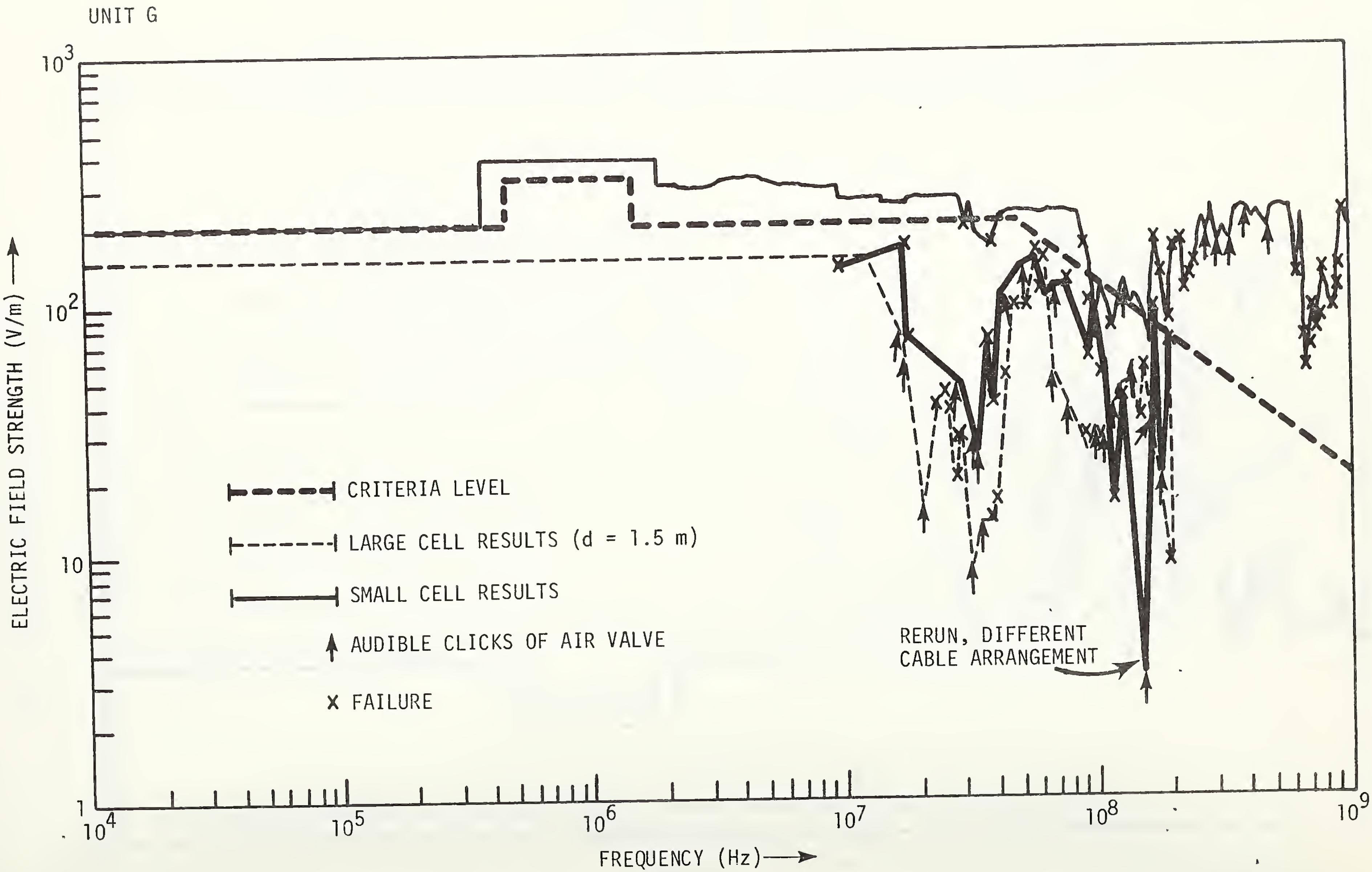

Figure 7. Susceptibility curves for Unit G.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

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17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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