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RESULTS OF RFI TESTING OF SAFEGUARD FLEXIBLE TUNNEL SECTION

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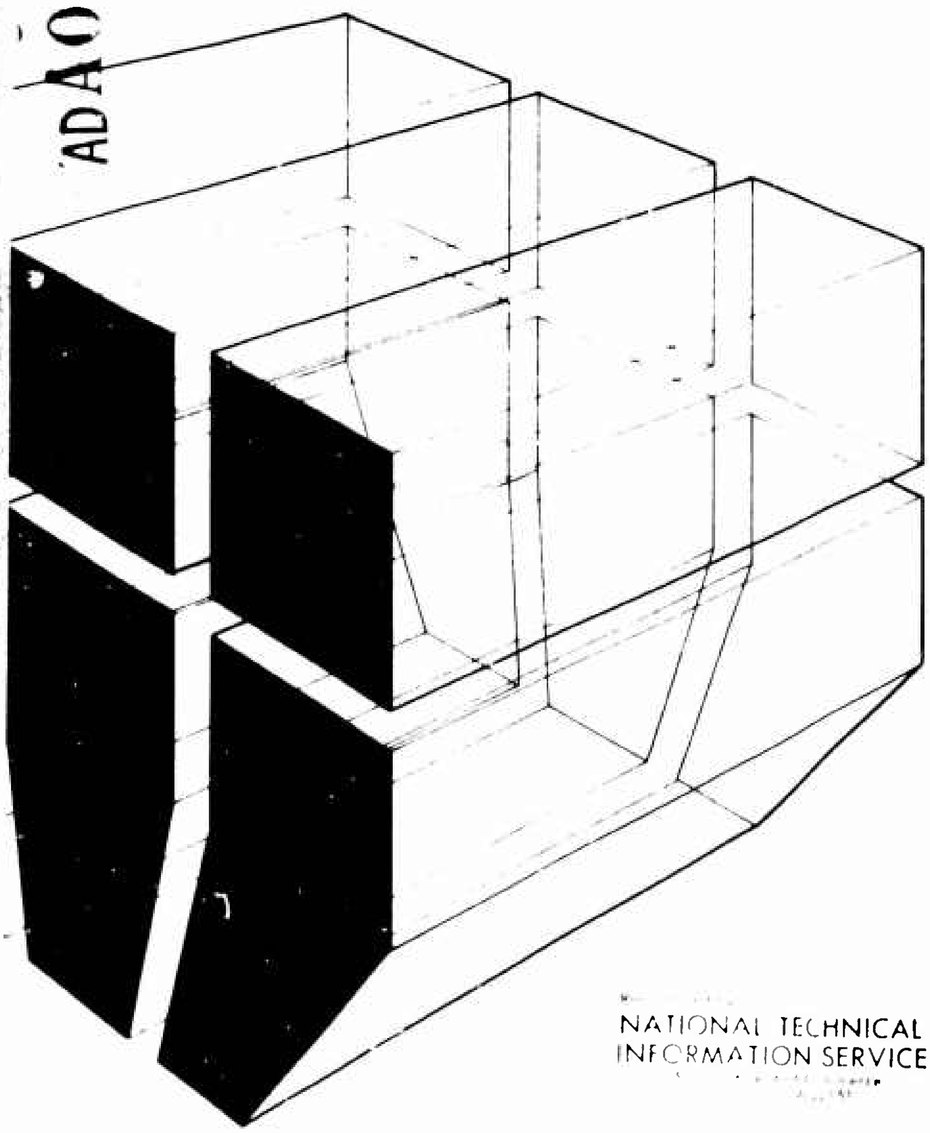

by
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CERL

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This report discusses results of the RFI shielding-effectiveness testing of a portion of the flexible tunnel section used for joining the equipment tunnels to the liner plate of the SAFEGUARD shielded enclosures.

Test results are presented for several modifications to the tunnel section, including the mounting configuration to be used on site. These results indicate that, for most configurations, the shielding effectiveness of the tunnel section does meet the SAFEGUARD EMP specifications. Thus, the choice of

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Block 20 continued.

configuration and material can be selected for construction convenience.

FOREWORD

This investigation was conducted for the U. S. Army Engineer Division, Huntsville (HND), under HND IAO 71-121, dated 30 June 1971, with Amendment 1, 1 December 1971, and Amendment 2, 10 May 1972. The work was performed by the Facilities Engineering and Construction Division (FE) of the Construction Engineering Research Laboratory (CERL).

Appreciation is expressed to Dr. Verdeyen, M. J. Pollock, and E. Spier of CERL for their assistance in the conduct of this investigation; to F. Smith (HND) for his helpful suggestions; and to C. Russell and the Ralph M. Parsons Company for supplying the tunnel section to be tested and for suggesting applicable modifications.

COL M. D. Remus is the Commander and Director of CERL, Dr. L. R. Shaffer is the Deputy Director, and Mr. E. A. Lotz is the Chief of FE.

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RESULTS OF RFI TESTING OF SAFEGUARD
FLEXIBLE TUNNEL SECTION

1 INTRODUCTION

Problem. The Huntsville Engineering Division (HND) has requested that CERL determine the shielding effectiveness of a piece of the flexible tunnel section used in connecting equipment tunnels to shielded enclosures at the Grand Forks, ND, SAFEGUARD site.

Background. A considerable effort has been made to protect SAFEGUARD sites from damage due to the effects of the nuclear electromagnetic pulse (NEMP) that accompanies most nuclear detonations. As part of the SAFEGUARD NEMP protection, large volumes of the structures that house critical electronic equipment have been completely enclosed in a steel shell. This shield is designed to attenuate NEMP fields to a level that the SAFEGUARD electronic equipment can tolerate without degradation in performance. Where two of the shielded structures have to be interconnected, a shielded equipment tunnel, which maintains the NEMP-shielding integrity, is used. This equipment tunnel is connected to the shielded structure with a specially designed flexible tunnel section that provides NEMP shielding while shock-isolating the tunnel from the shielded structure. In this manner, different ground motions can be absorbed without rupturing the NEMP shield.

This flexible tunnel section is a possible point of shielding degradation and, as such, must be tested to determine its level of shielding effectiveness. The results of this testing will be part of the information required by HND, SAFEGUARD System Command (SAFSCOM), and the Weapons System Contractor (WSC) to evaluate the overall SAFEGUARD site NEMP-shielding effectiveness; determine the level of NEMP signals that the electronic equipment must be able to withstand; and decide if a full-threat level site test of the NEMP shield is necessary.

Scope. The scope of this investigation was to determine the shielding effectiveness of a test sample of flexible tunnel section supplied to CERL by the Ralph M. Parsons Company, Los Angeles, CA. The shielding effectiveness was determined by means of tests based on procedures

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outlined in IEEE Standard 299 and MIL-STD-285.[1] The tests were conducted at CERL by the Electro-Mechanical Branch of the Facilities Engineering and Construction Division.

2 TEST PROCEDURE

Test Facility. The shielding-effectiveness tests were conducted by mounting the piece of flexible tunnel section over a hole in an 11-gauge steel test panel. The hole was cut to the same size as the tunnel section. This test panel was designed to mount on the access port of a shielded enclosure. The shielded enclosure was an 11-gauge steel box with welded seams and a 4-ft by 4-ft access port to which test panels could be mounted. The shielding effectiveness of this enclosure was measured over the frequency range 10 kHz to 10 GHz when a plain 11-gauge steel plate is mounted on the access port. The results of this measurement are presented in Chapter 4. Figure 1 shows this shielded enclosure without a test panel mounted on the access port and Figure 2 shows the shielded enclosure with a test panel mounted.

Test Sample. The test sample was prepared by the Ralph M. Parsons Company and consisted of an 11-in. by 24-in. piece of the flexible tunnel section mounted on a 1/4-in.-thick steel backing plate. The backing plate was 18 in. wide and 36 in. long and included a 6-in. by 22-in. slot over which the flexible tunnel section material was centered. The sample as received at CERL is shown in Figure 3.

The flexible part of the test consisted of three layers. The two inner layers were square-mesh, steel-wire cloth and the external layer was copper foil. The wire cloth consisted of an 11 wire/in. mesh using 0.047-in. diameter wire made of low-carbon steel of ASTM grade C-1030. The copper foil was 0.004 in. thick. A cross-sectional view of the flexible section is shown in Figure 4. The long edges of the flexible section were bolted to the steel backing plate as shown in Figure 5. The top and bottom of the flexible section were silver-soldered to 14-in. long sections of 3-in. by 3-in. by 1/8-in. angle iron which in turn were MIG-welded to the backing plate. The welded angle irons prevented any measurable RF energy leakage at the top or bottom of the test sample.

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[1] *Recommended Practice for Measurement of Shielding Effectiveness of High-Performance Shielding Enclosures*, IEEE Standard 299 (Institute of Electrical and Electronics Engineers, Inc., 1969); *Method of Military Standard Attenuation Measurements for Electromagnetic Shielding of Enclosures Used for Electronic Test Purposes*, MIL-STD-285 (Department of Defense, June 1956).

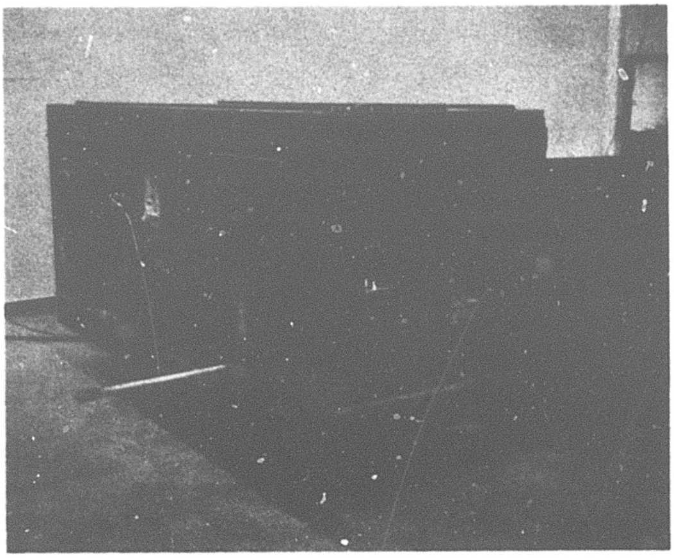


Figure 1. Shielded enclosure without test panel mounted.

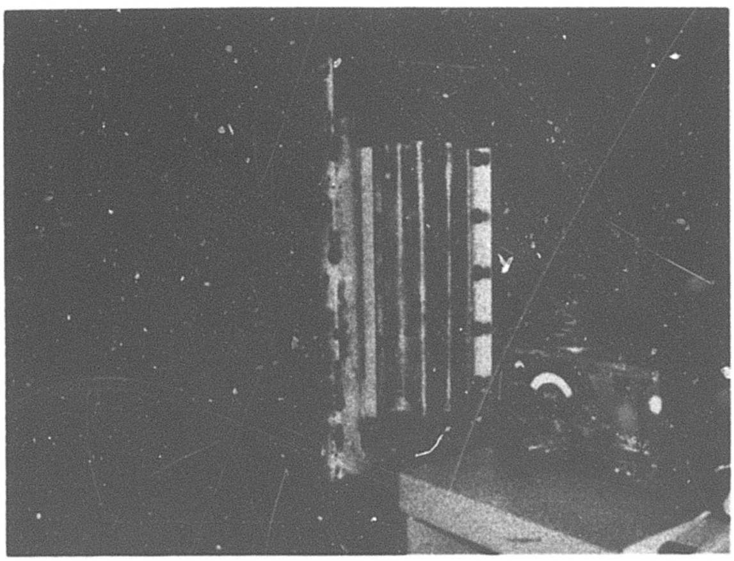
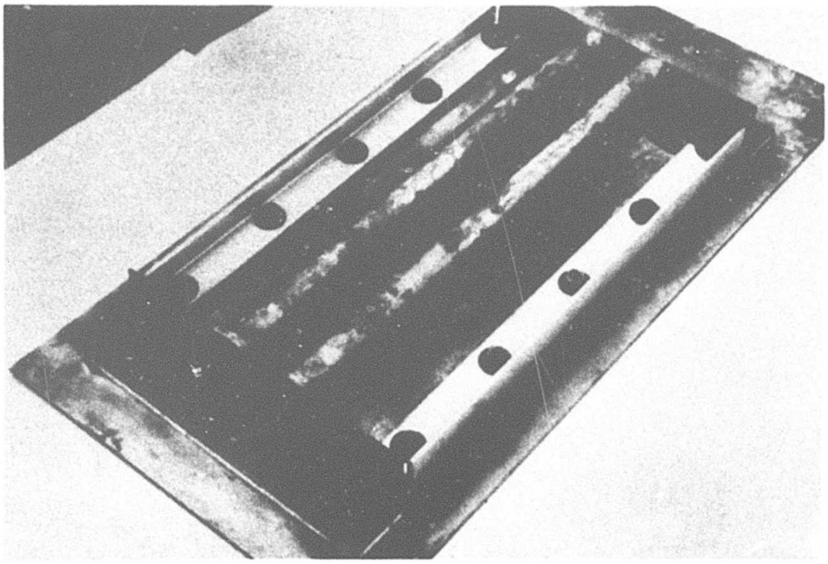
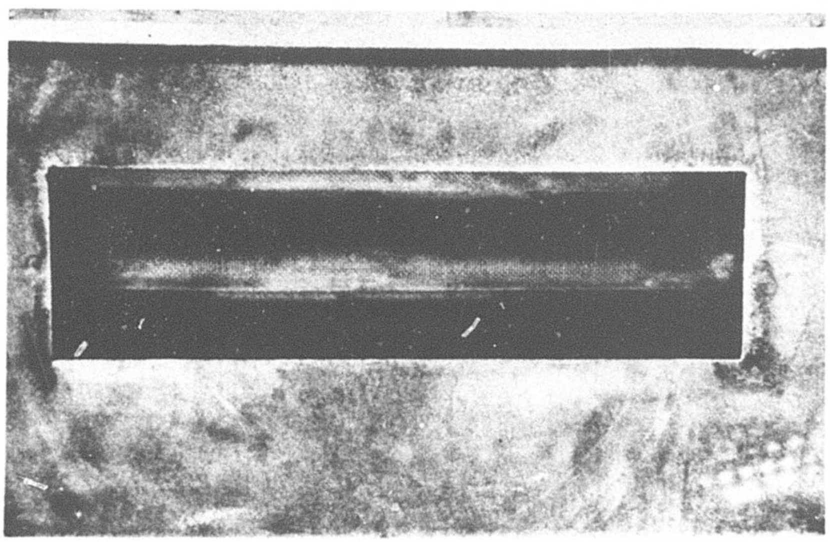


Figure 2. Tunnel section test sample mounted on shielded enclosure.



(a) Front view



(b) Rear view

Figure 3. Tunnel section as received from Ralph M. Parsons Company.

In order to use the shielded enclosure to evaluate the shielding effectiveness of the sample, it was necessary to mount the piece of tunnel section to a 4-ft by 4-ft 11-gauge steel test panel that could be attached to the access port of the shielded enclosure. The test panel used had a 7-in. by 28-in. slot over which the 6-in. by 22-in. slot of the original sample was centered--thus providing an aperture through which to measure electromagnetic-energy leakage. Attachment of the 1/4-in. backing plate of the sample to the 11-gauge test panel was made by a MIG fillet weld around the periphery of the backing plate. The completed test sample mounted on the test chamber is shown in Figure 2.

After testing of this configuration, the test sample was modified and additional testing was done after each modification. The first modification consisted of providing fillet welds between the backing plate and the metal piece to which the wire mesh was attached, and around the top and bottom of the nuts used on the Nelson studs. This modification insured that all edges of the steel-wire cloth were either welded or silver-soldered, thus reducing possibilities for RF leakage other than through the flexible materials themselves. After this configuration was tested, the copper foil was removed and the sample was retested to evaluate the steel-wire cloth alone. Finally, the copper foil that had been removed was replaced with a layer of copper screen and a final testing of the sample was made. The copper screen was a 20 by 20 per in. mesh with a copper wire diameter of 0.16 in.

Instrumentation Setup. As stated earlier, the shielding effectiveness testing of the sample of flexible tunnel was based on procedures outlined in IEEE Standard 299 and MIL-STD-285,[2] though some modification of the IEEE-recommended antenna spacings for 450 MHz and 1 GHz was necessary due to the dimensional constraints of the shielded enclosure. The specified test setup involved placing an RF transmitter and transmitting antenna inside the test chamber and an RF receiver and receiving antenna outside the test chamber, so that the test sample when mounted on the chamber was directly between the two antennas, as shown in Figure 6. Transmitter frequency determined which of three types of antennas was used. These included 12-in. loop antennas, 1/4-wave dipole antennas, and horn antennas. The orientation of each of these antennas with respect to the test sample is shown in Figure 7.

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[2] *Recommended Practice for Measurement of Shielding Effectiveness of High-Performance Shielding Enclosures*, IEEE Standard 299 (Institute of Electrical and Electronics Engineers, Inc., 1969); *Method of Military Standard Attenuation Measurements for Electromagnetic Shielding of Enclosures Used for Electronic Test Purposes*, MIL-STD-285 (Department of Defense, June 1956).

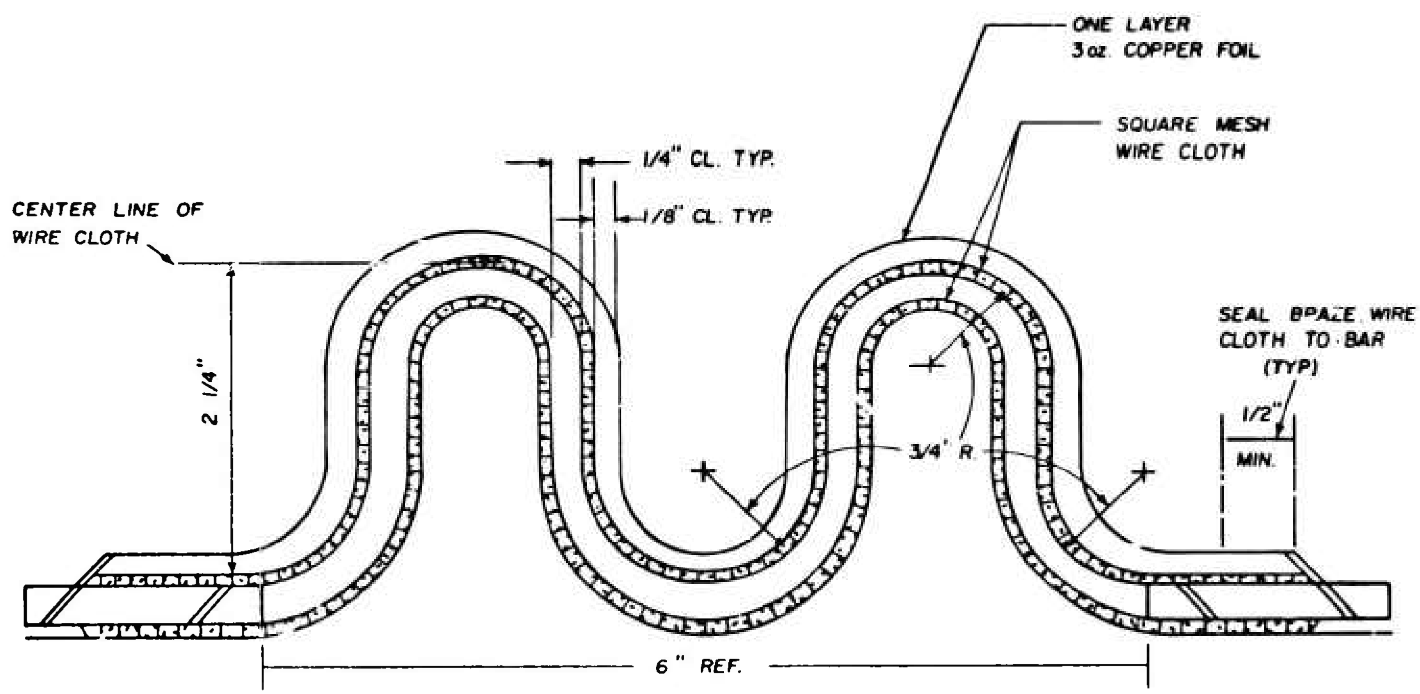

Figure 4. Flexible tunnel cross section.

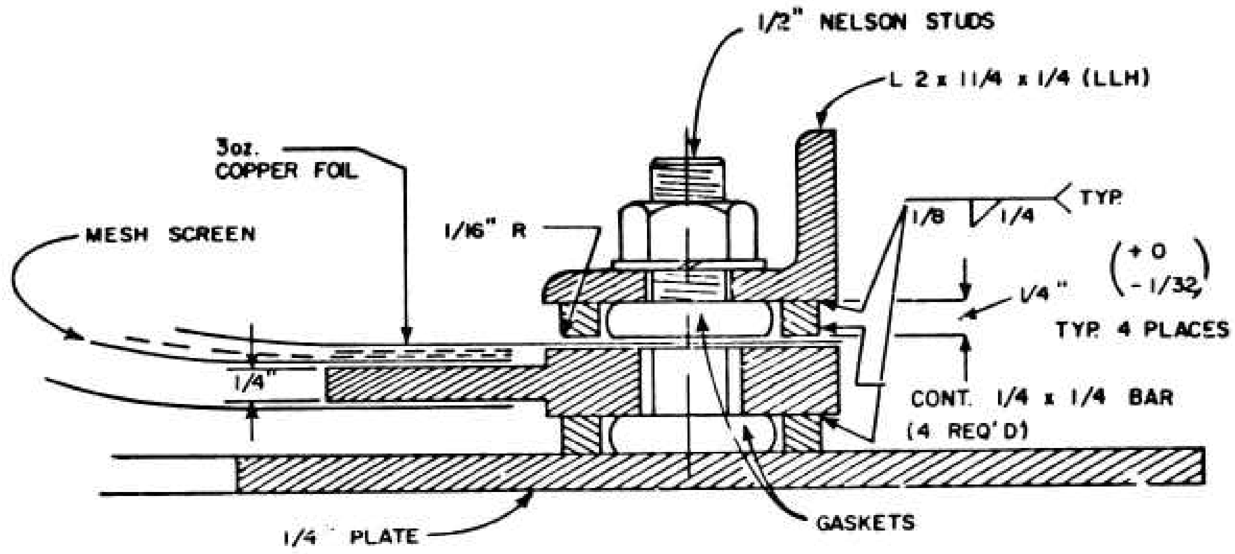

Figure 5. Tunnel section mounting.

Figure 6. Shielding-effectiveness measurement test setup without test panel.

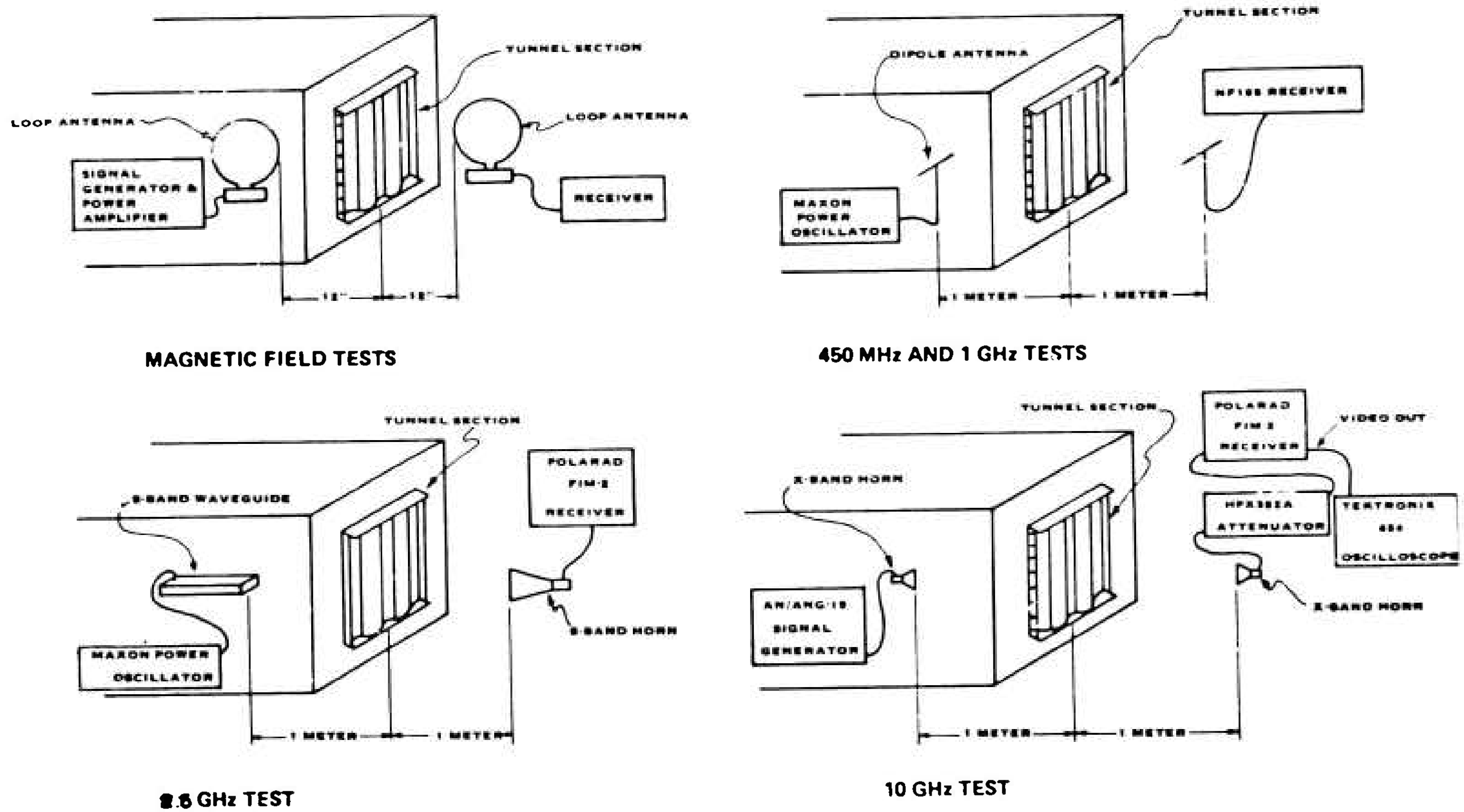

Figure 7. Tunnel section shielding-effectiveness measurement setups.

Frequencies at which the tests were conducted include 10 kHz, 40 kHz, 200 kHz, 1 MHz, 28 MHz, 450 MHz, 1 GHz, 2.55 GHz, and 10 GHz. The receivers, transmitters, and antennas that were used at each of these frequencies are listed in Figure 8. This equipment was used for both shielding-effectiveness measurements and evaluation of the test chamber.

Measurement Techniques. In this investigation, shielding-effectiveness measurements were made using the equipment listed in Figure 8 and the test setup described earlier. The power level detected by the receiver with and without the test panel in place, for a constant known value of transmitter power, was measured. Then, defining P_r as the reference power level detected without the test panel in place and P_a as the attenuated power level detected with the test panel in place, the shielding effectiveness, SE, can be defined as decibels (dB) as

$$SE\ (dB) = 10 \log_{10} \frac{P_r}{P_a} \ . \qquad \text{[Eq 1]}$$

The measurement of shielding effectiveness by this technique is limited by the output power of the transmitter, the sensitivity of the receiver, and the efficiency and coupling losses of the antennas. Table 1 gives the experimentally determined values for the upper limit of the shielding-effectiveness measurements for the equipment listed in Figure 8, and the antenna placements of Figure 6. This table defines the dynamic range of the shielding-effectiveness measurements presented herein.

The easiest method for obtaining P_r and P_a was to place an attenuator between the receiver and the receiving antenna. By adjusting the attenuator for the same receiver reading with and without the test panel in place, the values of P_r and P_a relative to some base power level could be obtained. Since only the relative values of P_r and P_a are needed in Eq 1, the shielding effectiveness can be calculated without regard to receiver calibration. Thus, only the attenuator needs to be calibrated. Since most attenuators are calibrated in dB, the shielding effectiveness can be found directly from the attenuator settings by simply subtracting the attenuator reading with the test panel in place from the reading without the test panel in place. This procedure was used to obtain the results presented in this report.

In general, the shielding-effectiveness measurements were made by radiating a continuous-wave (CW) signal and detecting the signal with a field-intensity meter tuned to the transmitter frequency. The 10-GHz measurement, however, was made by radiating a pulsed CW signal and observing the video output of the field-intensity meter on an oscilloscope. This technique considerably increased the dynamic range of the

10 kHz and 40 kHz

Hewlett Packard 202D Signal Generator
MB Electronics 2250 Power Amplifier
CERL Loop Antenna (radiating)
Stoddard NM-12AT Field Intensity Meter
Empire LP-105 Loop Antenna (receiving)

200 kHz

Hewlett Packard 606 Signal Generator
Electronic Navigation Industries 310L Amplifier
CERL Matched Loop Antenna (radiating)
Stoddard NM-12AT Field Intensity Meter
Empire LP-105 Loop Antenna (receiving)

1 MHz and 28 MHz

Hewlett Packard 606 Signal Generator
Electronic Navigation Industries 310L Amplifier
CERL Matched Loop Antennaes (radiating)
Empire NF105 Field Intensity Meter, TA Tuning Head
Empire LP-105 Loop Antenna (receiving)
Hewlett Packard 355D Attenuator
Hewlett Packard 355C Attenuator

450 MHz + GHz

Maxson 1141A Power Oscillator
CERL Dipole Antenna (radiating)
Empire NF105 Field Intensity Meter, T-3 Tuning Head
Empire DM-105-T3 Dipole Antenna (receiving)

2.5 GHz

Maxson 1141A Power Oscillator
S-Band Waveguide (radiating)
Polarad FIM-2 Receiver
S-Band Horn
PRD Electronics 1211 Isolator

10 GHz

AN/ASG-19 Signal Generator
X-Band Waveguide (radiating)
Polarad FIM-2 Receiver
X-Band Horn (receiving)
Hewlett Packard X382A Attenuator
Tektronix 454 Oscilloscope

Figure 8. Equipment used for tunnel section shielding-effectiveness measurements.

Table 1

Dynamic Range of CERL Shielding-Effectiveness
Measurement Equipment

Frequency	Dynamic Range (dB)
10 kHz	101
40 kHz	104
200 kHz	118
1 MHz	107
28 MHz	108
450 MHz	116
1 GHz	94
2.55 GHz	83
10 GHz	83

measurement over that obtainable by the reading on the field-intensity meter. Extended dynamic range measurements were made in some cases by modulating the radiated signal and using it as a reference for a phase-sensitive detector. The audio output from the field-intensity receiver was then synchronously detected by multiplying it with the reference signal and integrating the result over a period of time to obtain a signal-to-noise improvement and a subsequent increase in dynamic range.

Several tests were run to validate the testing procedure. These tests were made on the shielded enclosure using a blank 11-gauge steel test panel in place of the test sample. Then, using the method described earlier, the shielding effectiveness of the blank test panel was measured. With the exception of 10 kHz and 40 kHz, the shielding effectiveness of the blank panel was greater than the dynamic range of the equipment. The decline in shielding effectiveness at the lower frequencies was due to leakage through the steel-wool gasket between the test panel and access port. The results of these measurements are given in the next chapter.

Although the test results presented in this report were made with the antenna spacings shown in Figure 6, measurements made at other antenna spacings showed that spacing had no effect on the value of the shielding effectiveness measured, except for a change in the dynamic range due to the change in antenna-coupling efficiency. Orientation of the antenna and polarization of the electric field, however, had a considerable effect on the measured value of shielding effectiveness. For this reason, some shielding-effectiveness measurements were made for both vertical and horizontal electric field polarizations.

Before making the test-panel measurements, a final check was made to insure that mounting the test panel did not affect the transmitter output power due to possible antenna loading. This was checked by using a Tektronix P-6021 current probe and 454 oscilloscope to monitor the antenna current with and without the test panel in place. This was done for the test frequencies of 30 MHz and below, where loop antennas that allowed for use of the current probe were used. For these frequencies, the presence of the test panel had no effect on the antenna current. There were indications that the test panel was loading the antenna at 450 MHz, which is near the resonant frequency of the chamber. Therefore, measurements at these frequencies may be somewhat inaccurate, though the accuracy is probably not off by more than 10 dB.

3 TEST RESULTS

Shielding-effectiveness measurements made during this study consisted of reference tests, testing of the tunnel section sample as received, and testing of the tunnel section sample with various modifications.

The reference tests involved determination of the dynamic range of the measurement equipment; the shielding effectiveness of the shielded enclosure with a blank test panel; and the shielding effectiveness of a test panel with a 6-in. by 22-in. slot--the placement and size of which is approximately the same as the slot in the test panel on which the tunnel section sample was mounted.

The dynamic range of the test equipment was determined by subtracting the receiver noise level, with no radiated signal, from the receiver (and attenuator) readings with the transmitter radiating directly into the receiving antenna. The antennas were positioned as shown in Figure 6 with no shielding (test panel) between them. Following these measurements and using the same equipment setup, shielding-effectiveness measurements were made with a blank test panel and then the slotted test panel (containing the 6-in. by 22-in. slot) mounted in place of the test sample. In this way the shielding effectiveness of the test chamber and the contribution of the end panel and backing plate used to support the test sample could be determined. The results of these measurements are presented in Table 2.

Tunnel section tests were made on the samples described in Chapter 2. These tests included: the tunnel section as received, the tunnel section with the edges of the mounting brackets and the mounting bolts welded, the welded tunnel section with the copper foil outer layer removed, and the welded tunnel section with a copper mesh replacing the layer of copper foil.

The initial testing was done as described in MIL-STD-285,[3] which calls for measurements using vertical electric fields for loop antennas, horizontal electric fields for dipole antennas, and both horizontal and vertical electric fields for horn antennas. These types of measurements were made for the blank panel, the tunnel section as originally received, and with the mounting bracket welded. After these tests were completed, it was discovered that there was a considerable difference between the measurements for horizontal and vertical polarization of the electric field (Table 2); therefore, the remaining tests were made for both polarizations.

There was no requirement for testing at 1 GHz, but because the equipment was available for 1-GHz testing when the original sample was being tested the measurement was made and included in Table 2. The

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[3] *Method of Military Standard Attenuation Measurements for Electromagnetic Shielding of Enclosures Used for Electronic Test Purposes*, MIL-STD-285 (Department of Defense, June 1956).

Table 2

Shielding-Effectiveness Measurements

	Reference Tests				Tunnel Section Tests Edges Welded					
Frequency	Dynamic Range	Blank Panel	Slot Panel H*	Slot Panel V*	As Received	With Copper Foil	With Copper Foil Removed H	With Copper Foil Removed V	With Copper Foil Replaced by Copper Mesh H	With Copper Foil Replaced by Copper Mesh V
10 kHz	101	80	11	22	72.5	80	48	64	62	71
40 kHz	104	101	9.5	23	78.5	101	57	78	77.5	86
200 kHz	118	118+	9.5	24.5	77.5	118+	72	96	91.5	118+
1 MHz	107	107+ 134**	10	23	89 88 †		84	107	107+	107+
28 MHz	108	108+	11	25	100		108+	108+	126+ ††	126+ ††
450 MHz	112	112+	16	13	100		112+	86	112+	108
1 GHz	94	94+			94+					
2.55 GHz	83	83+	0	2	83+		83+	83+	83+	83+
10 GHz	83	83+			83+ 100 dB+ **					

* H designates a horizontal antenna orientation, V, a vertical orientation.

** Extended range measurement.

† The extended range technique was used on the tunnel section to obtain a comparison with conventional measurements.

†† The greater dynamic range is obtained by retuning the transmitting antenna.

10-GHz transmitter failed after testing the welded sample and a replacement could not be obtained before publication of this report. Therefore, no 10-GHz measurements were made for the last two modifications.

The results listed in Table 2 that are followed by a plus sign are readings that exceed the equipment dynamic range; that is, there was no detectable signal at that frequency with the test panel in place. In addition, there has been no attempt to use correction factors for those measurements that were close to or below the noise level. The correction factor can be greater than 10 dB for signals that are less than 1 dB above the noise level. Therefore, the values in Table 2 are conservative.

When measurements at 10 kHz and 40 kHz are near the value for the blank panel, they are somewhat dependent on the condition of the gasket since the roll off in shielding effectiveness for the blank panel is due to leakage through the gasket.

4 CONCLUSIONS

The procedures specified in MIL-STD-285 and IEEE Standard 299[4] are for the testing of the entire area of material between the two antennas and not of any particular point or section on the test sample. Thus, the data presented in this report are for measurements of the shielding effectiveness of the whole test sample--including the flexible material, the mounting assembly, and the backing plate. Naturally, because of the antenna placement, the area directly between the two antennas (in this case, the flexible material) has more effect on the shielding-effectiveness measurement than the peripheral areas (i.e., the backing plate). It is this weighting of the area under test that makes extrapolating the results to different configurations a difficult theoretical problem. For this reason, the flexible tunnel sample duplicated as closely as possible the actual installation configuration that was to be used at the SAFEGUARD site. The width of the test sample and the mounting procedure are the same as would be found at the SAFEGUARD site--only the height had to be shortened (22 in.). The top and bottom of the test sample were soldered to the backing plate to insure that no leakage would occur at these points due to the

[4] *Recommended Practice for Measurement of Shielding Effectiveness of High-Performance Shielding Enclosures*, IEEE Standard 299 (Institute of Electrical and Electronics Engineers, Inc., 1969); *Method of Military Standard Attenuation Measurements for Electromagnetic Shielding of Enclosures Used for Electronic Test Purposes*, MIL-STD-285 (Department of Defense, June 1956).

shortness of the test sample. Thus, it can be stated that, within a reasonable degree of confidence, the results presented in this report are identical to those that would be obtained from conducting this type of test on the flexible tunnel section as installed at the SAFEGUARD site.

Determination of whether the tunnel section and the various modifications are acceptable for use at the SAFEGUARD site is beyond the scope of this project. However, if the acceptable level of shielding effectiveness is chosen to be 70 dB at 200 kHz, 80 dB from 1 MHz to 3 GHz, and 60 dB at 10 GHz, as previously suggested, the tunnel section provided for this study and all the modifications reported (Table 2) would meet the levels listed above. The tunnel section as received, but with the edges welded, is the best performing configuration. The second rated modification with nearly equal shielding performance is replacement of the copper sheet with a copper screen.

With the test sample produced by welding the edges of the original sample, tests were conducted at only the three lowest frequencies. Previous testing had shown that leakage from the unwelded edges was greatest at lower frequencies; thus, when the shielding effectiveness was found to be outside the dynamic range at 200 kHz, no further testing at higher frequencies was conducted since the dynamic range was less than those frequencies. Comparison of the data for this sample and the copper mesh data indicates that this was a valid procedure.

A further point to consider is that all values followed by a plus sign in Table 2 are readings at which no signal could be detected above the receiver noise level. Since a signal 10 dB below the noise level will at least be detectable, it is safe to assume that the shielding effectiveness in these cases is 10 dB better than shown by these values in the table. Based on these results, it is the opinion of this laboratory that a suitable flexible tunnel section assembly can be constructed that will meet the shielding-effectiveness requirements of the SAFEGUARD site.

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Method of Military Standard Attenuation Measurements for Electromagnetic Shielding of Enclosures Used for Electronic Test Purposes, MIL-STD-285 (Department of Defense, June 1956).

Recommended Practice for Measurement of Shielding Effectiveness of High-Performance Shielding Enclosures, IEEE Standard 299 (Institute of Electrical and Electronics Engineers, Inc., 1969).