

Title:

A SURVEY OF NON-U.S. NUCLEAR ELECTROMAGNETIC PULSE
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A SURVEY OF NON-U.S. NUCLEAR ELECTROMAGNETIC PULSE (EMP) SIMULATORS

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Abstract

This paper, an update of papers presented in 1984 and 1995, describes the large number and diverse variety of EMP simulators that exist outside the United States [1,2]. The end of the Cold War has provided the opportunity to learn of new simulators and to compare their characteristics as well as the test methods employed in them. While similarities exist with EMP simulators developed in the U.S. and other western countries, in some cases the simulators developed by researchers of the former Soviet Union and other Warsaw Pact nations provide some very interesting differences in approach.

As is the case with U.S. EMP simulators, no one perfect EMP simulator exists. Baum has classified non-source-region EMP simulators in three categories: guided-wave, dipole, and hybrid [3,4]. This paper describes several examples that fall into these three categories as well as a unique source-region simulator in Russia that does not. All designs have inherent limitations; thus the large variety that exists. Some analysis and extrapolation of results must always be done. The ideal of a simple "zap" test to prove a system hard to EMP is just that -- an unachievable ideal.

I. Introduction

The author had the good fortune of being involved in the development of most of the EMP simulators located in the U.S. and other non-communist countries during the period of the Cold War. Since the end of the era of the nuclear arms race, he has enjoyed the opportunity of becoming acquainted with many of his colleagues from the former Soviet Union and China and to see first-hand several of the EMP simulators in their countries. Similarities exist with western EMP simulators — researchers from both sides of the former Iron Curtain have said on more than one occasion while seeing the other's facilities for the first time that "Maxwell's equations are the same in both places." However, in some cases the simulators de-

veloped in countries of the former Soviet Union and Warsaw Pact nations provide some very interesting differences in approach.

This paper reviews EMP simulators located outside the United States in terms of their characteristics, capabilities, and limitations. The paper concentrates on those simulators designed to simulate the nuclear EMP outside of the source region and in particular those that simulate the electromagnetic environment caused by a high-altitude nuclear explosion (HEMP). However, information is provided on a few source-region EMP (SREMP) simulators designed to reproduce portions of the electromagnetic environment associated with a nuclear burst on or near the surface of the earth.

II. Guided-Wave Simulators

Guided-wave simulators use metal plates driven by one or more high voltage generators to propagate a nominally TEM wave through a region frequently called the "working volume." The test object is located in this working volume. This class of simulator is used primarily to simulate the free-space environment produced by a high-altitude nuclear burst. Most existing guided-wave simulators produce a vertical electric field (and horizontal magnetic field) because in this case the earth can be used as one of the conducting plates.

This most ubiquitous of EMP simulators is highly efficient in its use of pulsed power. For example, a 1-MV Marx generator can provide high fidelity fields with strengths of >100 kV/m over objects as long as 6 meters. These fields usually have the "double-exponential" shape characteristic of a high-altitude EMP. Guided-wave structures can propagate pulses with sub-nanosecond risetimes if the generator is capable of producing them. Simulator impedances and field distributions can be calculated readily, and the fields can be made uniform over a large volume of space.

Guided-wave simulators are the best choice for testing missiles and aircraft in simulated in-flight configurations. For good simulation fidelity the test object dimensions should not exceed 60 percent of the plate spacing. While they often are used to test ground vehicles (e.g., jeeps, tanks, trains), this is not a high-fidelity simulation because it does not provide the ground reflection needed for assessing the EMP coupling characteristics of systems situated on the earth's surface. In general, guided-wave simulators are not transportable; the test object usually must be brought to the simulator.

Several guided-wave simulators outside the U.S., particularly those in the former Soviet Union, have generators that produce very long pulses (microseconds to milliseconds) to provide some information on system response to an endoatmospheric nuclear burst albeit absent the ionizing radiation and associated conductivity that would exist in a true SREMP environment.

Guided-wave simulators come in two basic types: those with symmetrically tapered input and output feed sections usually attached to a parallel plate section (Table I) and those with a single feed section attached to a sparse, distributed, resistive load, usually without an intervening parallel-plate section (Table II).

Two very large guided-wave simulator complexes are operated by the Ministry of Defense in Russia: one at the Central Institute of Physics and Technology (CIPT) at Sergiev Posad near Moscow [5] and one at the Science Research Center near St. Petersburg [6,7]. Each of the Russian complexes includes two large guided-wave simulators driven by a centrally located pulse generator. The very large cylindrical housing for the multi-megavolt air-insulated Marx generator adjacent to another large dielectric structure housing the pulse shaping circuitry (e.g., "peaking capacitor") are distinguishing characteristic of these facilities (Figure 1).

Figure 1 IEMP-6 Simulator Complex Located in Sergiev Posad, Russia

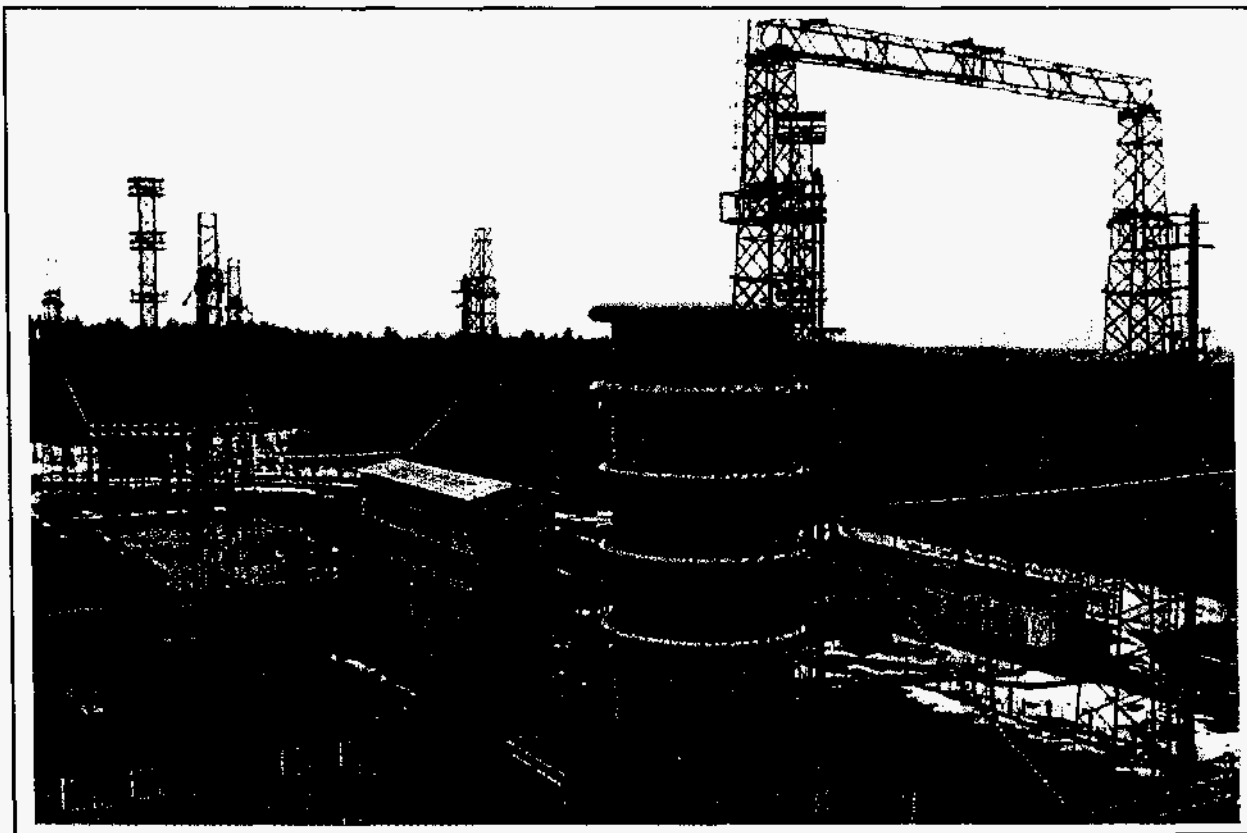


Table I Guided-Wave EMP Simulators with Point Termination

Simulator Characteristic	EMIS-II	DM-1200	IEMP-6	Pulse-M	SEMP-12-1	SEMP-12-3
Location	The Hague, Netherlands	Beijing, China	Sergiev Posad, Russia	St. Petersburg, Russia	St. Petersburg, Russia	St. Petersburg, Russia
Peak Output Voltage (MV)	0.5	1.2	6	0.6	2.4	2.4
Risetime (ns)	10	10	5-10	5	Air ≥ 200 Earth ≥ 200	Air ≥ 15 Earth ≥ 20
Duration (ns)	?	200	500	150	Air $< 6 \times 10^6$ Earth < 500	Air < 400 Earth < 100
Peak Electric Field (kV/m)	~50	120	100	100	Air < 200 Earth < 50	Air < 200 Earth < 30
Length (m)	?	54	~100	15	70	187
Plate Spacing (m)	~10	8.4	15	5	5-15	10
Wave-guide Impedance (Ohms)	?	180	?	150	130	110
Initial Operational Capability (IOC)	70s	early 80s	mid-70s	Early 90s	late 80s	late 80s
Status	?	?	2	2	2	2

Table II Guided-Wave EMP Simulators with Distributed Termination

Simulator Characteristic	SIEM- 2	DIESES	SAPIENS	INSIEME	Rafael	VEPES	SSR	CNET	ERU- 2M
Location	Mimizan, France	Munster, Germany	Linköping, Sweden	Pisa, Italy	Haifa, Israel	Spiez, Switzer- land	Gramat, France	Lannion, France	Sergiev Posad, Russia
Peak Output Voltage (MV)	2.8	1	1	1	2	0.8	2	0.8	2
Risetime (ns)	10	1-9	4	4	<5	7	1-5	2.5	2-20
Duration (ns)	250	1600	?	?	?	?	?	23-200	10-500
Peak Electric Field (kV/m)	>100	>100	>100	>100	>200	>100	>100	>100	>100
Length (m)	180	120	?	120	130	~15	106	50	~40
Maximum Height (m)	33	22	?	22	20	~3	15	5.6	~20
Waveguide Impedance (Ohms)	90	90	90	100	90	90	90	140	100
Initial Operational Capability (IOC)	1979	1981	late 80s	early 90s	1989	early 90s	mid-80s	1996	mid-90s
Status	4	2	2	2	2	2	2	2	2

In the case of the St. Petersburg complex, one of the simulators is used for high-altitude EMP environments and one for source-region EMP environments [7]. This complex specializes in evaluating the effects of EMP on buried structures. These simulators include a capability for testing objects either on or buried beneath the earth's surface. In SEMP-12-3 an underground transmission line, which consists of two

rows of vertical electrodes positioned at a relative distance of 50 meters, is connected to the transition sections leading to the pulse generator section and the matched restive load. The other transmission line (SEMP-12-1) is driven by a collection of pulsed voltage and current generators providing very long pulse durations for SREMP simulation.

* 1 - Under development; 2 - Operational; 3 - Stand-by; 4 - Dismantled or no longer in use; ? - Unknown.

The IEMP-6 facility near Sergiev Posad (Figure 1) is very similar in appearance to the one at St. Petersburg, but important differences exist. For example, the lower plate of the transmission line is on, not below, the earth's surface. However, like SEMP-12-1 at St. Petersburg, the IEMP-6 provides some SREMP simulation capability by the use of large-dimension rectangular coils in the vertical planes outside the working volume driven by pulsed current sources to produce late-time, long-duration magnetic fields in the simulator. Many different types of military systems are tested in this simulator complex. The simulator in the foreground in Figure 1 is being upgraded for 1-3 ns risetime performance.

Although the simulators have an output transition section, the terminations in the Russian simulators do not really form a "point." Instead a rectangular array of resistive elements absorbs the electromagnetic wave after it has passed through the simulator working volume.

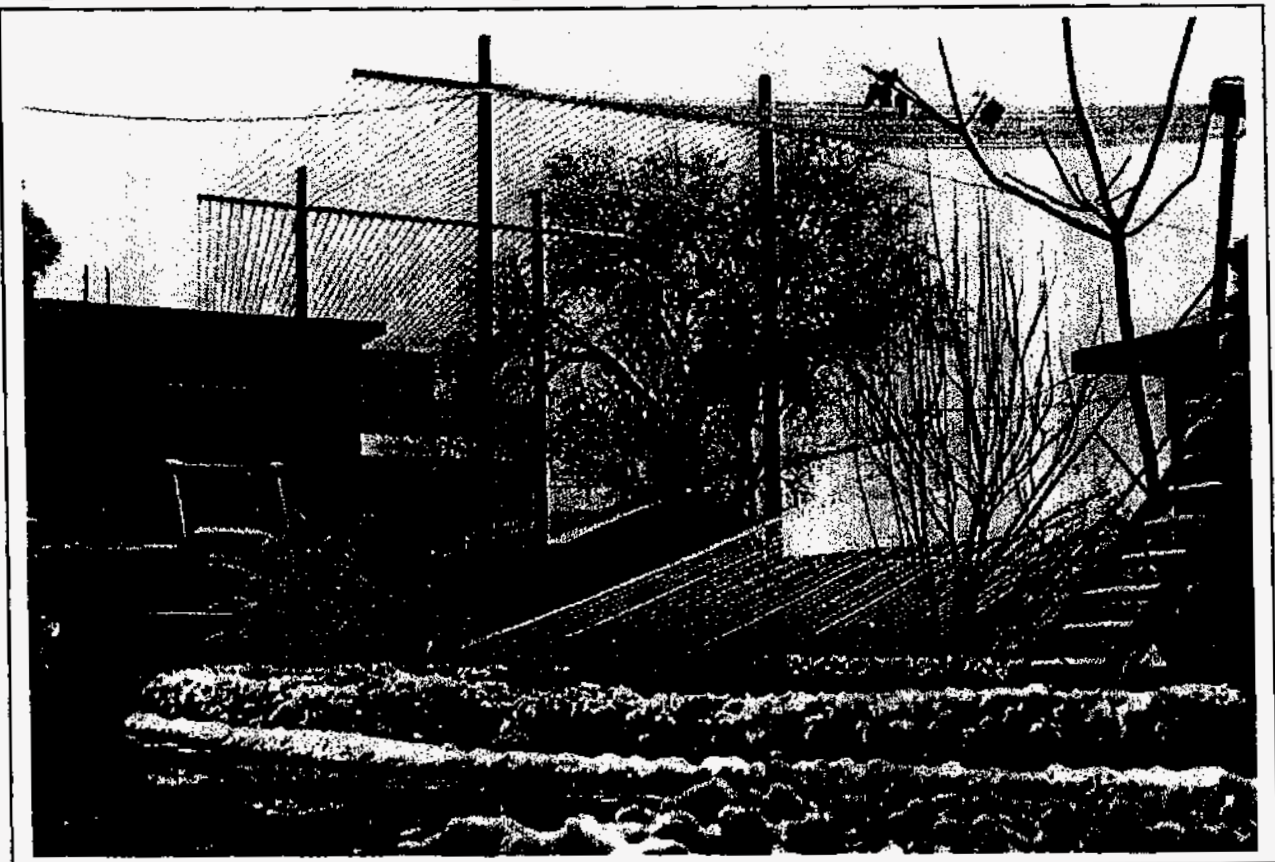
A similar, antecedent complex that exists at the small town of Andreavka near Kharkov in Ukraine was developed and is operated by the Institute "Molniya" (lightning). As this name implies, both the Russian

and Ukrainian complexes are used for studying the effects of lightning as well as EMP on systems.

China has a small guided-wave EMP simulator, the DM-1200 (Figure 2), that is similar in basic geometry to the ARES system located in Albuquerque, New Mexico. Note, however, that the lower plate of the transmission line is not connected to the earth in the transition sections as in the case of ARES. The 1.2-MV Marx generator is located in the building on the left in Figure 2. The DM-1200 was developed and is operated by the Beijing Institute of Electronic Systems Engineering (BIESE) of the Ministry of Aerospace.

The "bend" in the top plate at the transition from conical to parallel geometry in traditional guided-wave EMP simulators produces reflections that limit the unperturbed fields to the forward portion of the parallel plate section in this type simulator [8]. This bend and its twin at the output transition (see Figure 2 below) also produce higher-order mode effects particularly limiting the usefulness of these simulators in continuous-wave (CW) mode.

Figure 2 DM-1200 EMP Simulator in Beijing, China



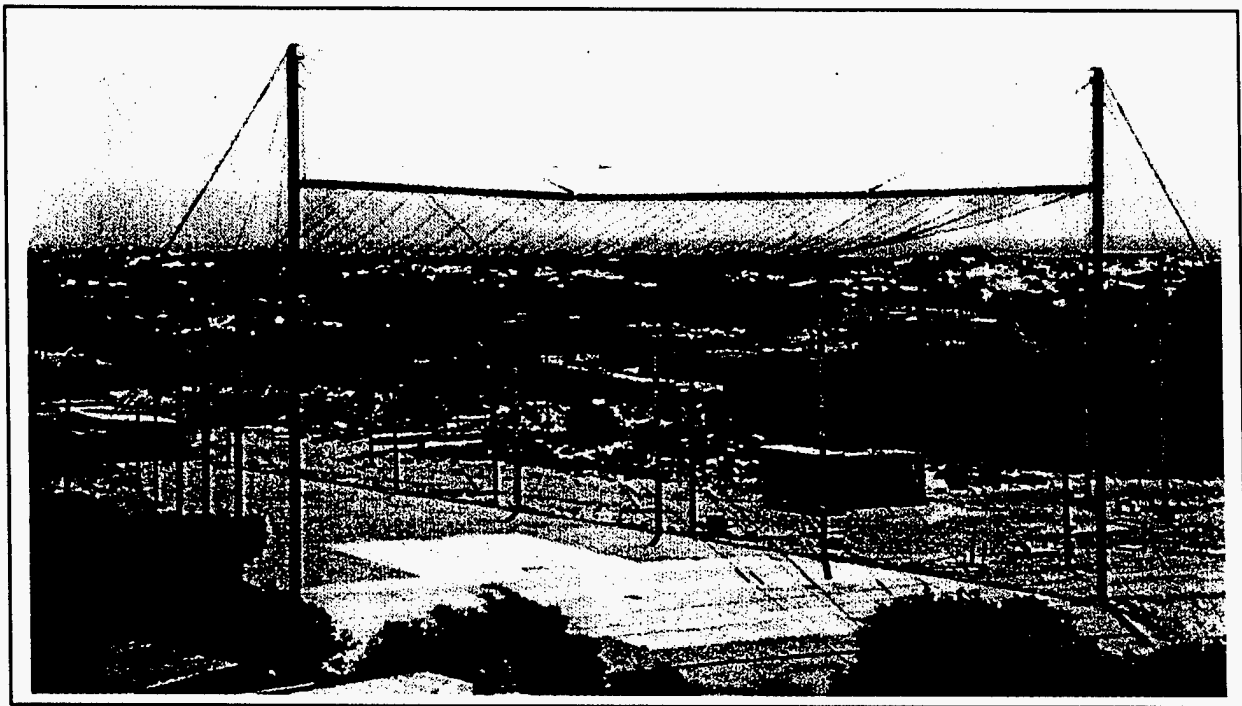


Figure 3 Rafael Guided-wave EMP Simulator in Haifa, Israel

SIEM-2, built in France in the late 1970s for testing strategic missiles, was the first of a class of simpler geometry guided-wave simulators with improved high frequency performance over traditional symmetrical geometries (Table II). These simulators basically use just the input conic section of in the traditional-geometry simulators. This configuration sometimes is referred to as a "horn" simulator. The large, but sparse, distributed resistive termination used in these simulators (Figure 3) allows the high-frequency components of the pulse to radiate out the end of the simulator rather than being trapped as standing waves in the transmission line. Simulators with this basic geometry exist in Germany, Sweden, Switzerland, Italy, Israel, and Poland.

The conical geometry of the input section that transitions from the relatively small dimensions where the wave is launched to the large dimensions of the working volume produces a spherical wave rather than the desired plane wave. This causes different parts of the test object to experience the arrival of the wave at somewhat different times and introduces non-vertical components to the electric field. In traditional simulator designs, this problem has been controlled by keeping the transition angle small (typically 15 degrees) which makes the simulator dimensions large.

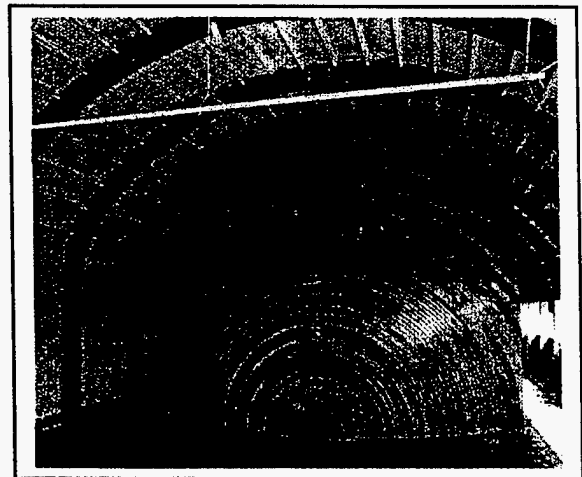


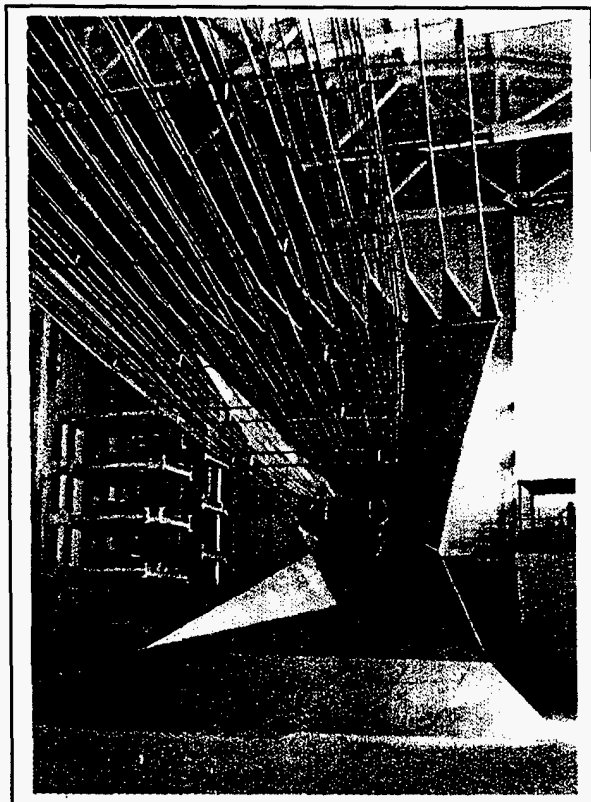
Figure 4 Dielectric Lens in CNET EMP Simulator Located in Lannion, France

A different approach has been taken in a new simulator built by France Telecom/CNET in Lannion, France [9]. In this simulator, the electromagnetic wave passes through a large lens made from plywood (Figure 4). The effect of the lens is to refract and slow down the electromagnetic waves while traversing the dielectric material. In this way, the spherical wave is transformed into a planar one, because the shape of the lens slows down waves traveling along the direction of the simulator axis more than waves diverging from the simulator axis. The authors of the paper presented at AMEREM 96 claim very good

field characteristics (e.g., homogeneity, risetime, planarity) in the simulator working volume beyond the lens.

The indoor ERU-2M simulator at Sergiev Posad, Russia (Figure 5) is significantly different than those described above because it employs a 3-plate transmission line. The 2-MV pulse generator is much more compact than those typically found in the simulators of the former Soviet Union and produces a 2-ns risetime field in the simulator working volume.

Figure 5 ERU-2M Simulator Located in Sergiev Posad, Russia



In addition to those listed in Tables I and II, guided-wave simulators exist or formerly were used in the United Kingdom, India, Poland, and the former East Germany. Egypt is soliciting bids for a small simulator at the present time.

III. Dipole Simulators

Ideally, the test object is far away from the source of a freely propagating TEM wave for this class of EMP simulator; practically this is seldom quite the case. These simulators can be mobile or fixed. They can radiate very fast risetime pulses, and the fields produced are analytically tractable.

Only a few examples of this class of simulator exist outside the United States. All are equivalent dipoles over a conducting surface; i.e., vertical dipoles. In this configuration they produce vertically polarized fields and a single angle of incidence. Since these are radiating antennas, they are not as efficient at converting pulse-power energy into fields as are guided-wave simulators. Dipoles also suffer from a deficiency in low frequency energy because they cannot radiate at DC and their physical size must be held to practical limits.

Most of these antennas are resistively loaded to prevent reflection of the currents when they reach the top of the cone [10]. Some information about coupling to an in-flight aircraft can be extracted from the test data, but the effects of the conducting ground must be considered in the analysis. Low frequencies are enhanced by employing a large antenna, large pulser capacitance, and very large shunt resistance to ground. The fields can be predicted accurately by analytical methods. Baum's model predicts the temporal and spatial distribution of the fields very well.

Table III Vertical Dipole EMP Simulators

Simulator	EMIS III	ORION-V
Characteristic		
Location	The Hague, Netherlands	Sergiev Posad, Russia
Peak Output Voltage (MV)	0.5	?
Risetime (ns)	<5	5
Peak Electric Field (kV/m @ stated meters)	?	50-100
Height (m)	?	30
Cone Impedance (Ohms)	75	?
Initial Operational Capability (IOC).	early 80s	TBD
Status	2	1

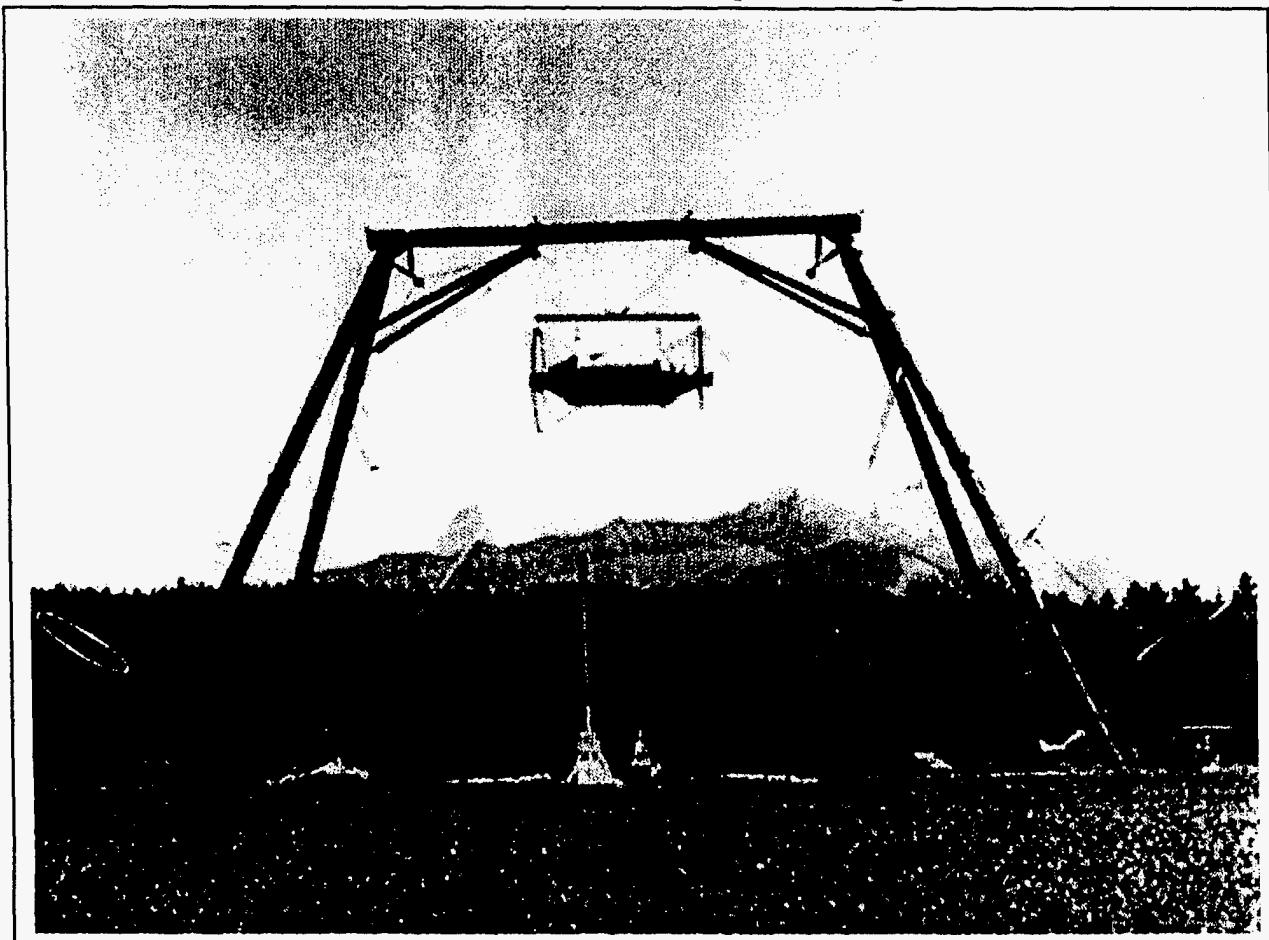
IV. Hybrid Simulators

This class of EMP simulators simulates the plane wave and its ground reflection by combining properties of both radiating and static simulators. Hybrid simulators provide the best available approximation to the environment that would be experienced by a ground-based system exposed to an EMP from a high-altitude nuclear detonation.

Table IV Hybrid EMP Simulators

Characteristic	Simulator	NIETES III	WIS [12]	HPD/ DPH	MEMPS	Rafael	DM- 4000	ORION - H
Location		The Hague, Netherlands	Munster, Germany	Gramat, France	Speiz, Switzer- land	Haifa, Israel	China	Russia
Peak Output Voltage (MV)		0.5	0.3	4	4	0.6	4	?
Risetime (ns)		<5	1-2	1-5	7	<5	?	5
Peak Electric Field (kV/m @ stated meters)		?	~10 @8	~50 @30	80 @20	?	~33 @30	50-100 @?
Height (m)		?	8	30	20	10	?	?
Length (m)		100	30	150	60	30	?	300
Bicone Impedance (Ohms)		75	150	150	150	150	150	?
Initial Operational Capability (IOC).		early 80s	1996	early 80s	mid-80s	1991	TBD	TBD
Status		2	2	2	2	2	1	1

Figure 6 Swiss MEMPS – Mobile EMP Simulator – with the Alps in the Background



Early-time (high-frequency) fields are produced by a small source region, usually a bicone radiator. Late-time (low-frequency) fields are a result of the currents and charges distributed over a large structure that surrounds or is near the test object. Usually, the antenna is sparse and resistively loaded to reduce interactions with the test object and to minimize resonances. Some hybrid simulators are transportable so that they can be taken to fixed installations such as missile silos and C³ facilities. Conceptually, the position of the pulser could be varied in the antenna to change the angle of incidence and the polarization; however, this capability has not been incorporated in an actual system. Because the early-time portion of the wave is radiated by a biconic antenna (an isotropic radiator), the field strengths achievable for a given generator voltage do not match those of a guided-wave system. The limit on pulser output becomes a mechanical-design consideration because the generator must be suspended high above the earth. The early-time bicone is matched to a cylindrical-cross-section antenna. This interface is an abrupt impedance discontinuity that has an appreciable effect on the pulse waveform. This transition is made as smooth as possible using tapered wire mesh sections to minimize the abruptness of the unavoidable impedance discontinuity. The fields produced by these simulators are more complex functions of both space and time than for the other classes of simulators, so a detailed experimental mapping of them is necessary for understanding of the test data [11]. When used to test very large facilities, particularly those with overhead and buried conductors entering them, the simulator cannot adequately excite the complete facility, so a form of direct drive for these points of entry (POEs) usually is used to supplement the field testing. Several simulators exist that employ the elliptically shaped HPD antenna design first developed in the U.S. in the mid-70s. The standard HPD antenna has a diameter of 5 meters and contains discrete resistors uniformly distributed throughout its length to provide the desired ratio of electric and magnetic field amplitudes at low frequencies. The resistors also damp resonances within the structure. France has two simulators identical to U.S. versions of the HPD, and one of the French systems is transportable. Switzerland developed the MEMPS, a smaller pulser/antenna system suspended beneath a fiberglass structure that can be broken down into modules for transport by truck or helicopter (Figure 6). Germany, Sweden, and Israel have non-transportable systems very similar to the MEMPS.

V. Source-Region EMP Simulators

The SEMP-12-1 simulator located at St. Petersburg, Russia, described earlier in the section on guided-

wave EMP simulators, is a source-region and not a HEMP simulator. The IEMP-6 simulator located at Sergiev Posad, Russia and presumably the guided-wave simulators located near Kharkov, Ukraine also are used to simulate source-region as well as high-altitude EMP effects. These simulators are capable of producing very long pulse durations using a combination of pulsed voltage and current sources. Some EMP simulators don't fall into one of Baum's three classes. Perhaps the most unique of these is the CEMP, a new Russian SREMP simulator described by Kuprienko and Worshevsky [7,13]. This unique cylindrical simulator (Figure 7) uses a combination of current loops and electrodes to produce vertical magnetic fields of up to 2,700 A/m with associated horizontal electric fields lasting up to 5 ms in a 250 m³ working volume that can be filled with different media. This simulator was designed to evaluate the effects of EMP on missile silos.

Figure 7 CEMP Simulator Located at St. Petersburg, Russia



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