1. Introduction

Test installations according to MIL-STD 461 / RS105 are used to test the radiated susceptibility to transient electromagnetic field, especially due to high altitude nuclear explosions (NEMP or HEMP). They mainly consist of a fast rise time / high voltage pulse generator connected to a radiating structure. These test installations are large and must be installed outside in most cases. For that reason, the radiated electromagnetic field (EMF) pulse could interfere with sensitive electronic systems located in the vicinity. The influence on the health of personnel working or living close to the test installation has also to be considered.

This technical note will establish the peak electric field around the NEMP test installations and will try to compare the results to standards or guidelines. This document relates to guided wave (vertical polarisation) and hybrid (horizontal polarisation) simulators.

2. Specifications of the RS105 pulse

The figure 1 gives the specifications of the RS105 impulse. It only represents the early time part of the complete HEMP phenomenon. The duration of the impulse is 23 ± 5 ns, the rise time is 2.3 ± 0.5 ns and the minimum amplitude of the field is 50 kV/m. The waveform and spectrum of the field are shown in the figure 1. It can be noted that the main part of the energy is below some tens of MHz.

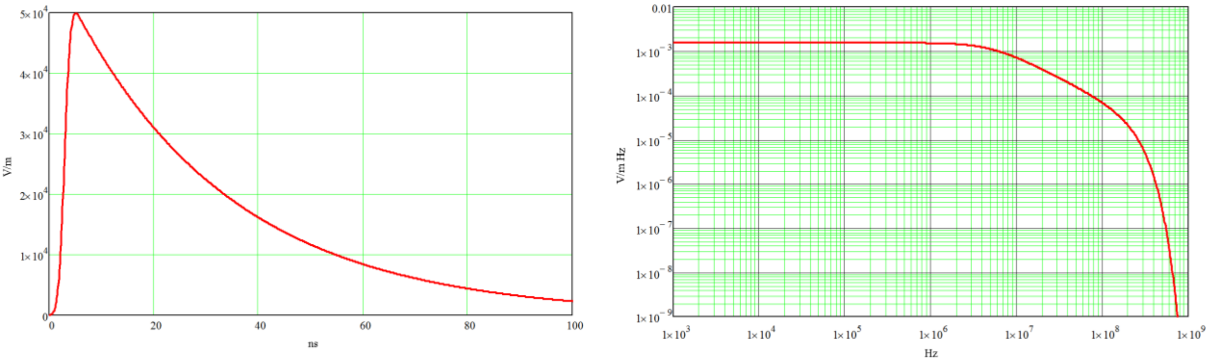

Figure 1: Waveform and spectrum of the RS105 impulse

3. Limitation concerning the health protection

3.1 Normalization

There are no standard specifying extensive limits for single electromagnetic pulse. The ICNIRP[1] defines limits for electric, magnetic and electromagnetic field but for continuous waves only, in the frequency domain. The ICNIRP document is essentially based on the exposure limitation based on the absorption of energy from electromagnetic fields, in the high frequency domain. With continuous wave, the situation is quite clear and the limits are well defined.

These ICNIRP guidelines for limiting exposure have been developed following a thorough review of all published scientific literature. Only proven effects were used as the basis for the proposed exposure restrictions. Induction of illnesses such as cancer from long-term EMF exposure was not considered to be established, and so these

[1] ICNIRP: International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz).

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guidelines are based on short-term, immediate health effects such as stimulation of peripheral nerves and muscles, shocks and burns caused by touching conducting objects, and tissue temperatures increases resulting from absorption of energy during exposure to EMF.

In pulse mode, very few studies are available. It is harder to evaluate the risk due to the multiplication of various factors characterising the pulse: duration, rise time, repetition rate, nature of the pulse (unipolar, bipolar), etc. A short and unique pulse has obviously not the same influence on a biological organism as long and repetitive pulses. Therefore the only value which can be given is based on the note 5 of the table 6 (reference levels for occupational exposure) of the ICNIRP guideline. This note says: "*For frequencies exceeding 10 MHz it is suggested that … the field strength does not exceed 32 times the field strength exposure levels given in the table*". Because the limit for continuous wave is 61 V/m, the result of the calculation for pulsed fields is roughly 2 kV/m.

Remarks: The ICNIRP guideline is only dealing with pulses of sine wave, for instance radar pulses. Pure pulses like double exponential pulses are not discussed in these guidelines. In addition, no mention of the repetition rate is given.

3.2 Comparison with ESD

Due to the fact that no standard gives definitive limitation for health protection during NEMP tests, it is interesting to compare the NEMP field with the field produced around a person when he produces an electrostatic discharge (ESD). When a charged person touches a metallic object, a high current pulse flows in its body and an electric field is produced around it. The rise time is lower than 1 ns and the duration could be some tens of ns which is similar to the NEMP pulse. The charging voltage before the pulse can reach 8 kV. We have carried out measurements of the electric field around the body due to its discharge which show local electric field of almost 10 kV/m (see figure 2). The standard IEC 61000-4-2:2008 gives an example with very similar amplitude (figure D.1). It must be mentioned that this type of "natural" phenomenon does not induce any known illnesses.

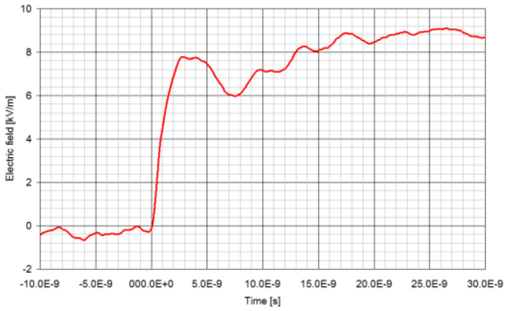

Figure 2: Electric field around a person charged with 8 kV

4. Limitation concerning the electronic equipment

Electronic equipment placed in the vicinity of the test installation can be disturbed or destroyed by the radiated pulse. Additionally to the field strength (which depends on the distance to the line) the level of disturbance depends on the susceptibility of the electronic device.

Very few studies are dealing with immunity of common electronic equipment to NEMP pulses. In addition, no common civilian standard documents are referring to pulsed radiated field tests. For instance domestic appliances and computers are not tested to pulsed fields. It is then almost impossible to establish a limit of immunity to this type of disturbances. Some electronic equipment can be disturbed with low pulsed fields due to poor internal design even if other similar devices can be very robust.

The only civilian standard which indirectly mentions an immunity test to pulsed radiated fields is the standard IEC 61000-4-2 (ESD). The indirect discharge test, described for instance in the paragraph 7.2.2, can produce local electric fields of 10 – 40 kV/m.

The comprehensive experience which is the result of many tests of various electronic systems in our EMC test labs shows that very few devices are disturbed by these pulsed electric fields.

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5. Calculation of the field

5.1 Results for a small bounded wave simulator

The bounded wave (or guided wave) test installations produce electric field in vertical polarisation. This test is described in the standard MIL-std-461/RS105, for instance. The peak electric field in the vicinity of an RS105 test system of 1.8 m height has been calculated with the software SemcadX by Speag. The below graph shows the top view of the peak field strength on an horizontal plane located at 1 m over the ground, with a peak electrical field of 50 kV/m at the EUT location.

Figure 3: example of a guided wave simulator

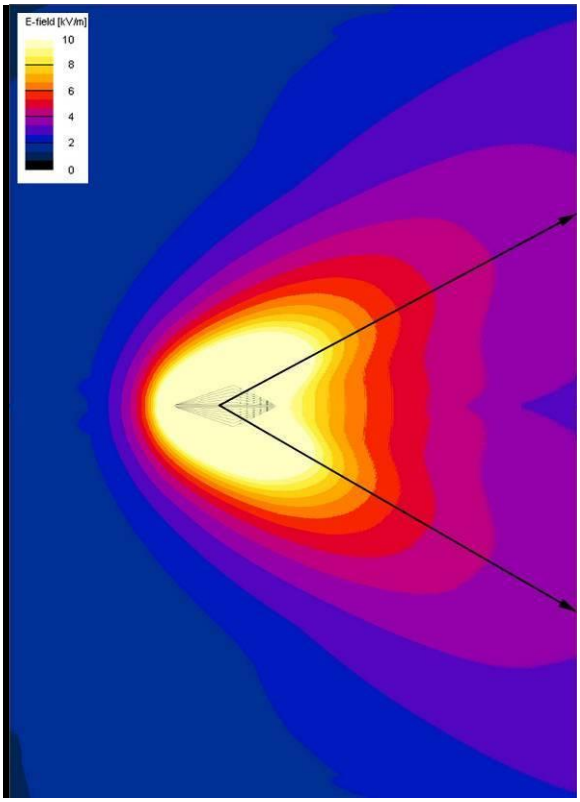

Figure 4: peak electric field map, top view (calculation area is 35 x 50 m). The direction where the electric field is the highest is represented by arrows.

Remark: some additional simulations have shown that the peak electric field mapping is almost not varying from the ground level up to the top of the antenna (1.8 m high). Therefore far from the antenna, the level of the peak electric field is independent on the height over ground, up to the maximum height of the line. Above this height, the field is decreasing.

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The peak electric field along that line is shown in the figure 4. The distance for which the value of 2 kV/m is reached in the worst case direction is 35 m (respectively 7 m for 10 kV/m).

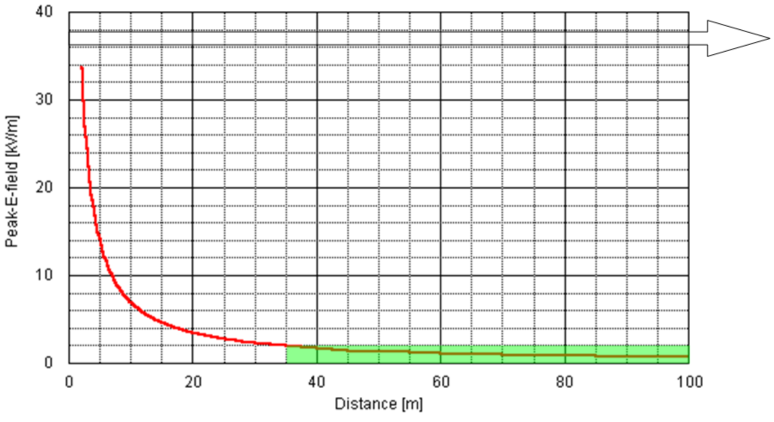

Figure 5: evolution of the peak electric field along the worst case direction (arrows, see figure 4)

5.2 Results for the other RS105 test installations

The simulated values of the chapter 4 can be linearly extrapolated to larger installations. The following table gives the values for the distances for which the peak electric field becomes lower than 10 kV/m and 2 kV/m, in the worst case direction (arrows) and successively behind the generator. The height corresponds to the highest part of the transmission line.

Height of the line [m]	*Worst case direction [m]*		*Behind the generator [m]*	
	10 kV/m	*2 kV/m*	*10 kV/m*	*2 kV/m*
1.8	7	35	4.5	8
2.7	10	52	6.7	12
3.6	14	70	9	16
5.4	20	104	13.4	24
7.2	28	140	18	32
18	70	350	45	80

5.3 Results for the hybrid test installations

Hybrid simulators produce electric field in horizontal polarisation. The figure given below shows an example of this type of test installation.

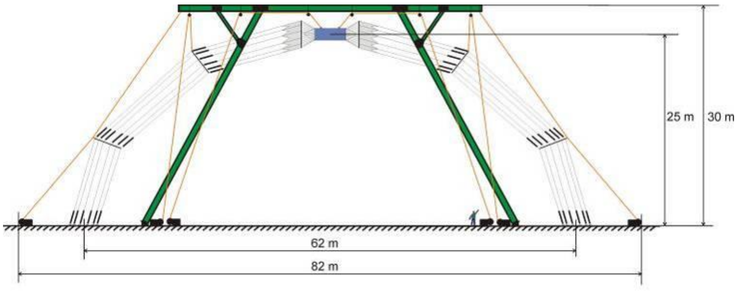

Figure 6: example of a hybrid simulator

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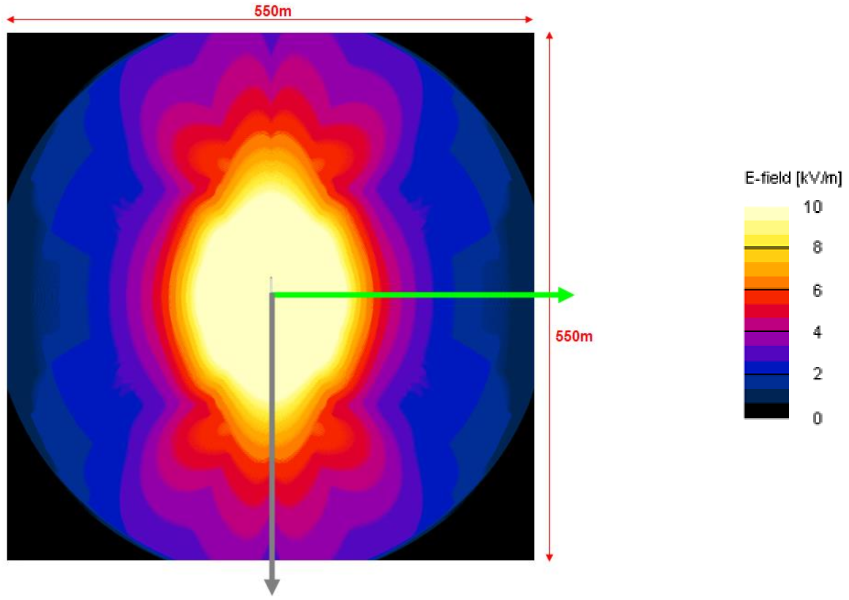

Figure 7: peak E-field amplitude decay in 2D for a height of 20 m above ground plane, for the installation described in figure 6.

Based on the above numerical simulations, the peak E-field decay up to 1 km from the antenna axis at 20 m height is now shown in the following graphs in linear and logarithmic scale. It corresponds to the E-field values along both the green and grey arrows of the figure 7. At a distance of about 100 m from the antenna, the peak E-field is following a 1/x decay.

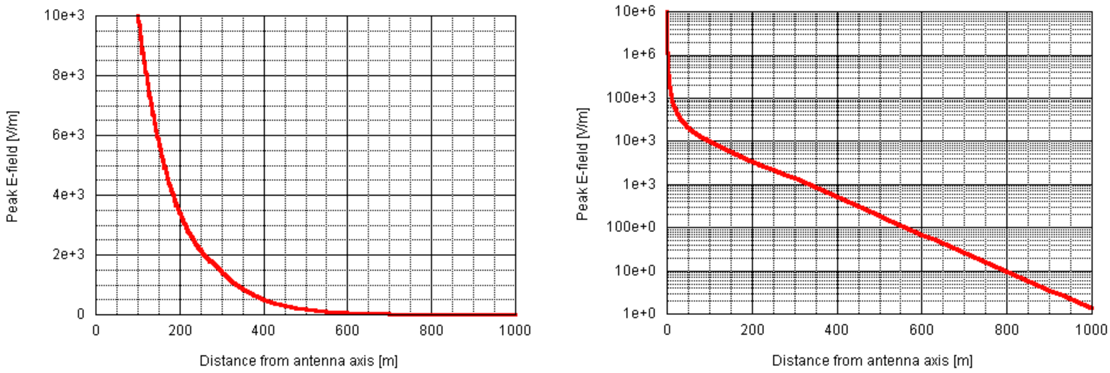

Figure 8: peak E-field amplitude decay along the green arrow in linear and logarithmic scale.

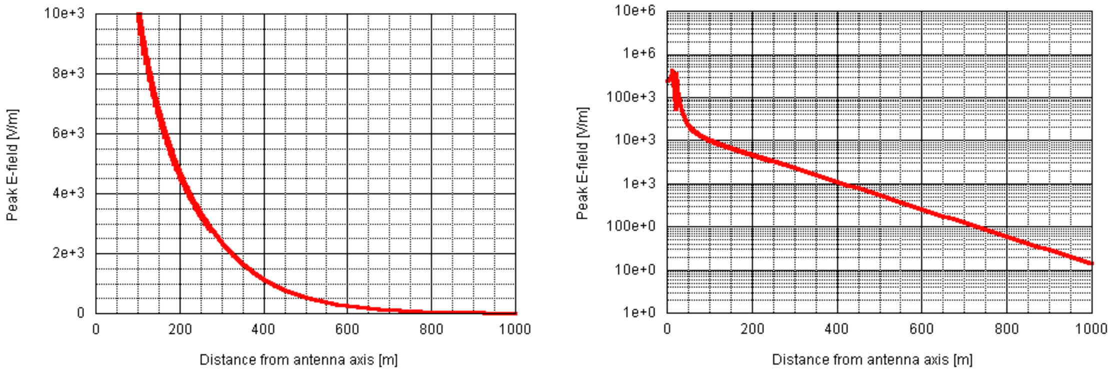

Figure 9: peak E-field amplitude decay along the grey arrow in linear and logarithmic scale.

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6. Special case of the field decay toward the sky

The preceding chapter gave the results for the peak electric field present around bounded wave antennas, which is valid for people, systems or building located on the surface of the earth. In some cases, the electric field decay toward the sky might also be a concern, for the safety of aircrafts potentially flying over the antenna region for instance. Therefore it might also be desired to get an approximation of the generated peak electric field toward the sky. This analysis is done in this chapter for the case of the bounded wave antenna.

6.1 Results for a small bounded wave simulator

The simulation is performed on a RS105 test system of 1.8 m height with a peak electrical field of 50 kV/m at the EUT location. The below graph shows the side view of the peak field strength on a vertical plane located at 1.25 m from the antenna axis.

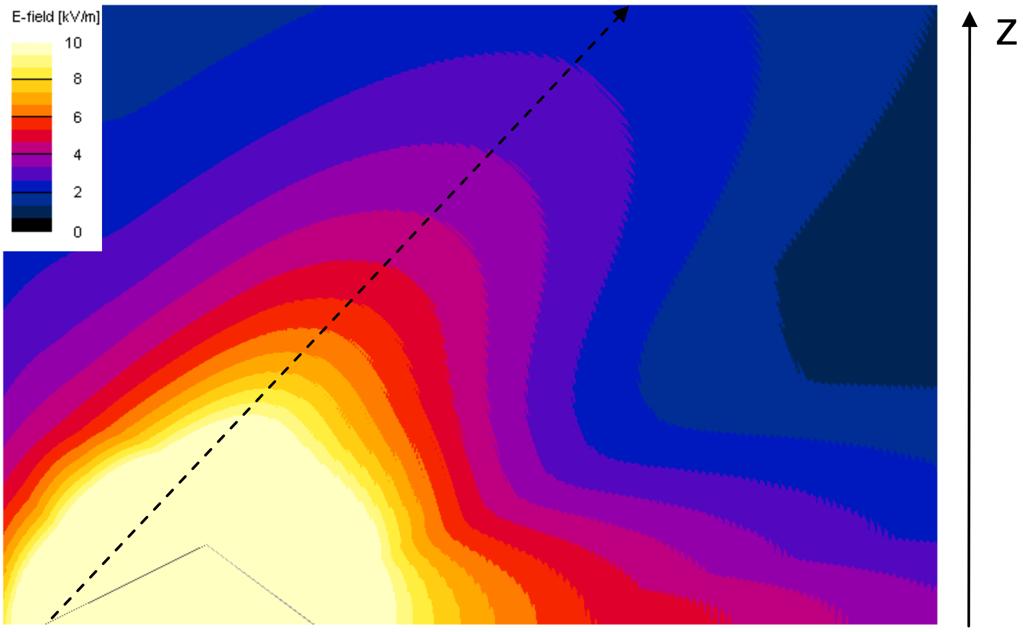

Figure 10: peak electric field map, side view (calculation area is 21 x 14 m). The direction where the electric field toward the sky is the highest is represented by the dashed arrow. The solid arrow on the left represents the z axis, along which the maximum electric field for each altitude of figure 11 is plotted.

Remark: The dashed arrow of figure 10 is pointing toward the point which has the maximum peak electric field at the altitude of 14 m. This gives the worst-case scenario. Beyond that point, the electric field decay is extrapolated with the help of a fitting function.

For practical reason it is not useful to show the field along the dashed line, because it has no indication of the altitude, which is the interesting parameter of this research.

Therefore the figure 11 shows the maximum peak electric field for each altitude, but along an axis strictly perpendicular to the ground, which is a more meaningful definition.

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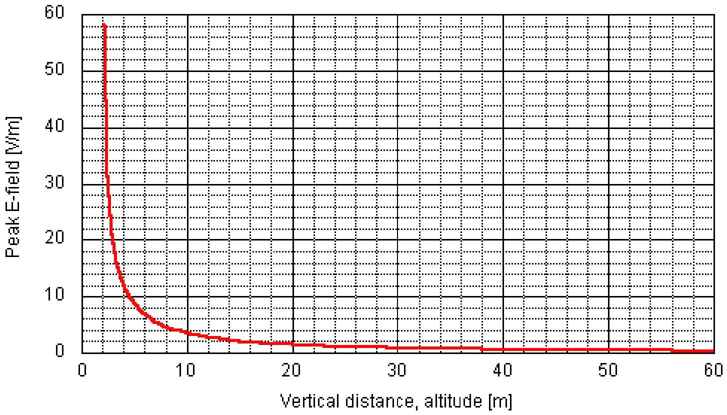

Figure 11: evolution of the maximum peak electric field in the vertical direction along the Z axis of figure 10.

6.2 Results for the other RS105 test installations

The simulated values of the chapter 5 can be linearly extrapolated to larger installations. The following table gives the values of the altitudes for which the maximum peak electric field becomes lower than 10 kV/m and 2 kV/m. The height corresponds to the highest part of the transmission line.

Height of the line [m]	*Altitude [m]*	
	10 kV/m	*2 kV/m*
1.8	4.5	16
2.7	6.8	24
3.6	9	32
5.4	13.6	48
7.2	18	64
18	45	160

6.3 Results for the hybrid test installations

The same field evaluation at high altitude is performed for the hybrid simulator of figure 5.

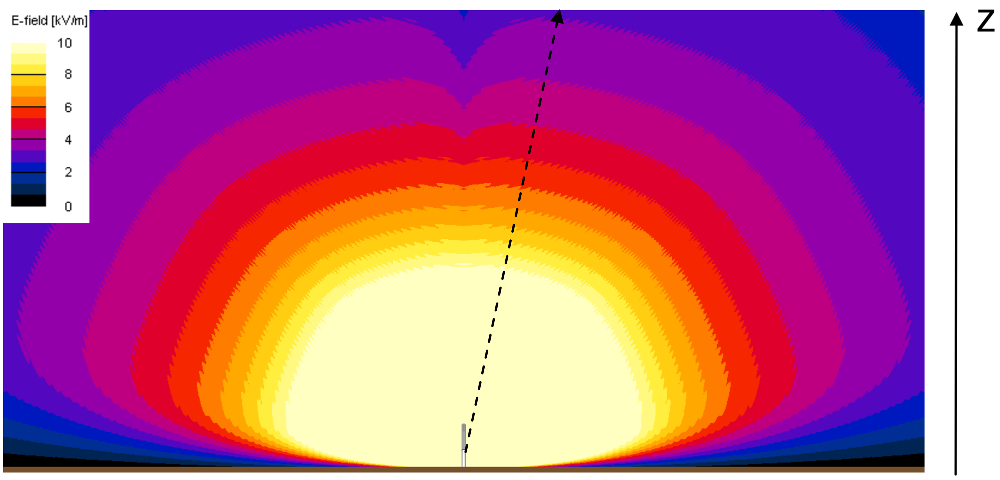

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Figure 12: peak electric field map, side view (calculation area is 550 x 275 m). The direction where the electric field toward the sky is the highest is represented by the dashed arrow. The solid arrow on the left represents the z axis, along which the maximum electric field for each altitude of figure 13 is plotted.

The figure 13 shows the maximum peak electric field for each altitude along an axis strictly perpendicular to the ground. For altitudes higher than 275 m, the electric field decay is extrapolated with the help of a fitting function.

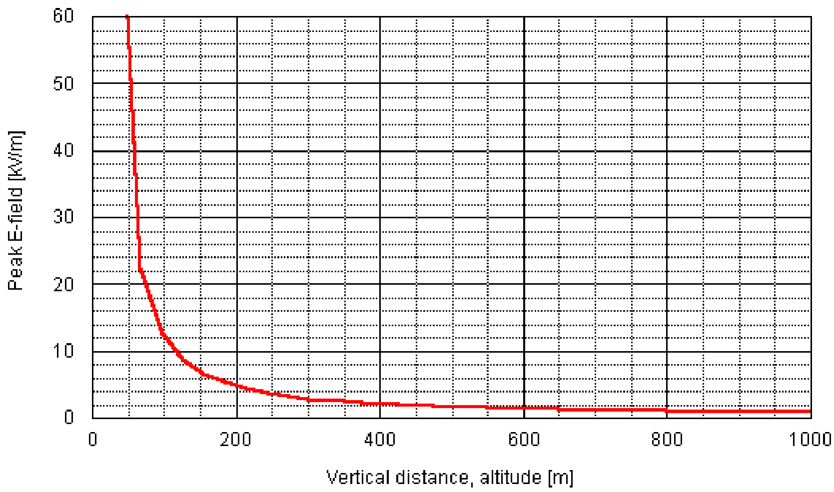

Figure 13: evolution of the max. peak electric field in the vertical direction along the Z axis of figure 12.

7. Conclusions

No standard specifies any limitation of the peak pulsed electric field neither for personnel nor for equipment placed in the vicinity. As an indication, simple extrapolations with the ICNIRP guidelines give a quite severe value of 2 kV/m. But the ICNIRP guidelines actually concern only the frequency domain and not pure pulses.

It is interesting to analyse the ESD natural phenomenon. Humans can stand ESD which provoke electric field of 10 kV/m around their body, without illnesses. Therefore we suggest that a conservative of 10 kV/m limit can be taken for the protection of personnel working in the vicinity of NEMP installation instead of the ICNIRP guideline values.

Concerning the susceptibility of electronic equipment placed in the vicinity of the test installation, tests made according to IEC 61000-4-2 (indirect ESD) have shown that few devices are disturbed (or destroyed) under an equivalent peak electric field of 10 kV/m. Therefore a field limit of 10 kV/m can also be taken into account for the estimation of minimum safety distance to electronic equipment. Exception: sensitive measurement equipment like spectrum analysers, oscilloscopes, receivers which have to be specially protected against this type of disturbances. Finally it cannot be excluded that some sensitive devices or poorly designed pieces of equipment could be disturbed below 10 kV/m. The number of devices which can be disturbed is statistically decreasing with the distance.

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