Department of Theoretical Electrical Engineering

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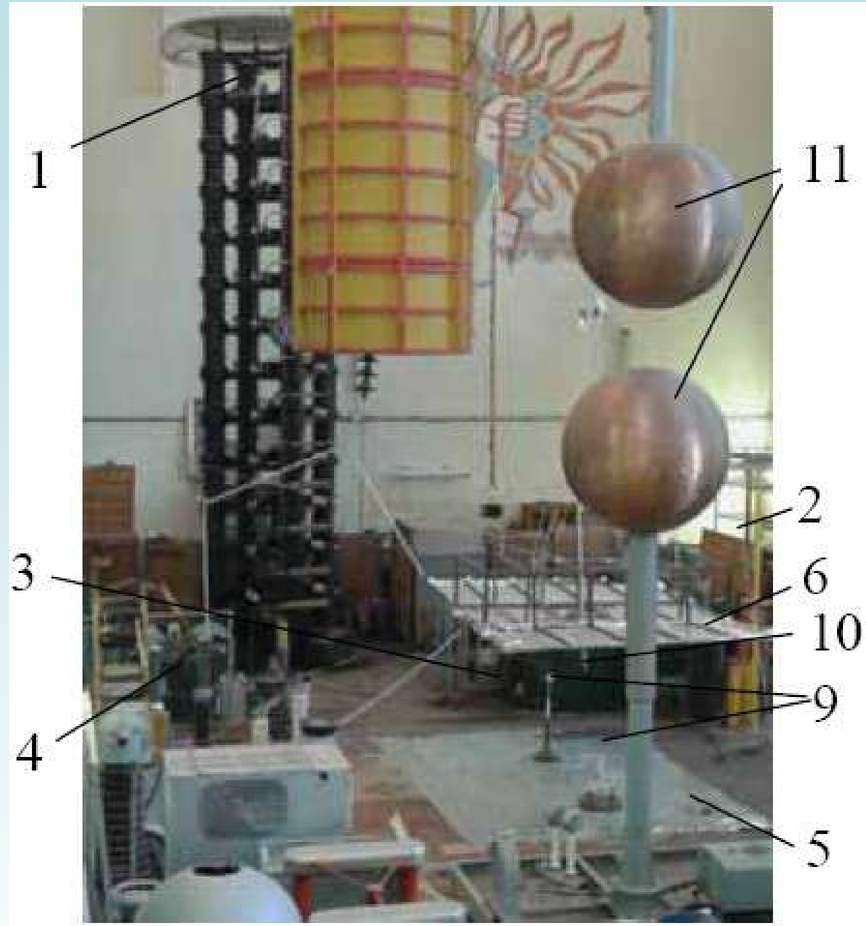
Some themes of possible research work

1. Modeling of the probability distribution of lightning attachment in the territory of extended objects for selection the optimum means of lightning protection.
2. Mathematical and physical modelling of electrical physical processes at electrical breakdown of long air gaps.
3. Formation of powerful electromagnetic pulses in the nonlinear active dielectric, ferromagnetic and composite media.

Directions of existing researches in the areas of mathematical and physical modeling of electrical physical processes in different media

1. Lightning attachment and corona discharges
2. Electromagnetic waves propagation in nonlinear ferroelectric - ferromagnetic media
3. Conductive screens
4. Groundings of high voltage objects in emergency regimes
5. Electromagnetic fields influence on human’s body and UAVs
6. High voltage discharges in solid polymeric insulation

Investigations of high-voltage discharges in high voltage laboratory

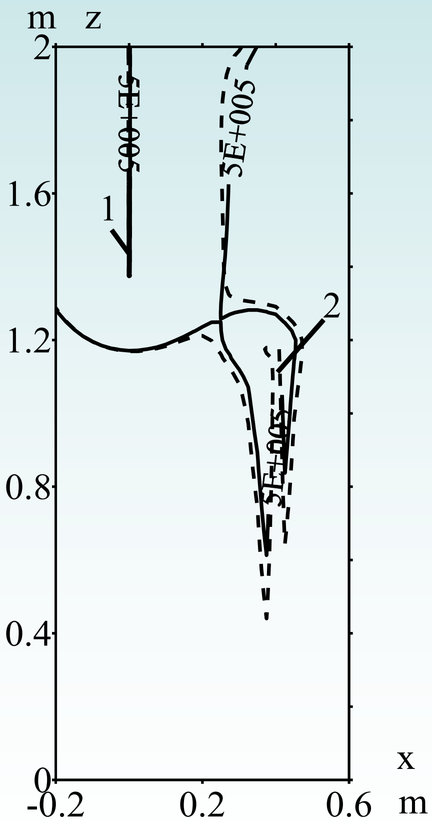


1 is impulse HV generator; 2 is voltage divider; 3 is field-forming system; 4 is DC generator; 5 is grounded plane; 6 is potential plane; 9 is tops of the grounded electrodes; 10 is high-voltage electrode, 11 is ball measurement spark gap

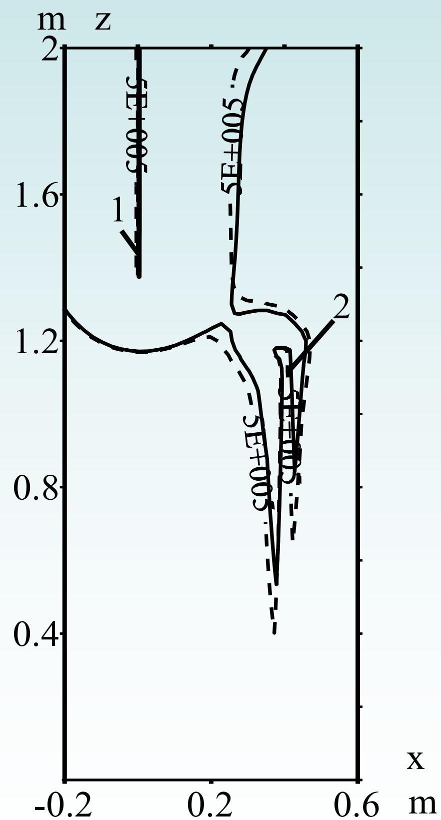
4

Calculated lines of equal eclectic field strength in the cross-section of rods' axes (E_+ =5 kV/cm)

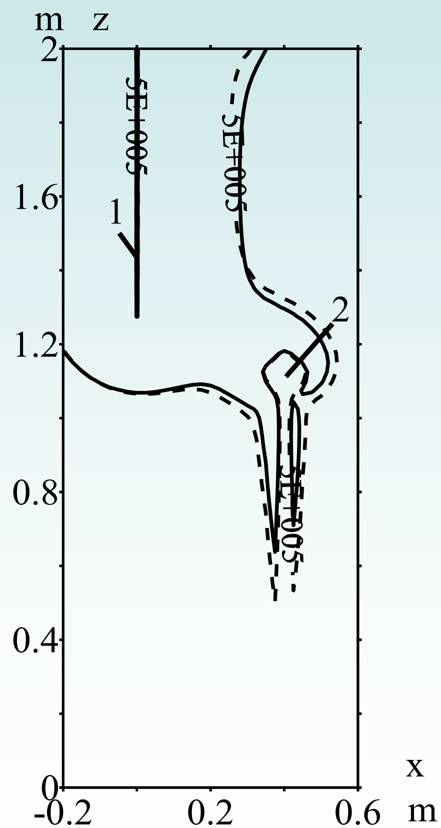
the grounded electrode tip has the shape of a cone with a radius of rounding of 0.015 m because corona presence



the grounded electrode tip has the shape of a sphere with 0.045 m diameter



the grounded electrode tip has the shape of a sphere with 0.125 m diameter

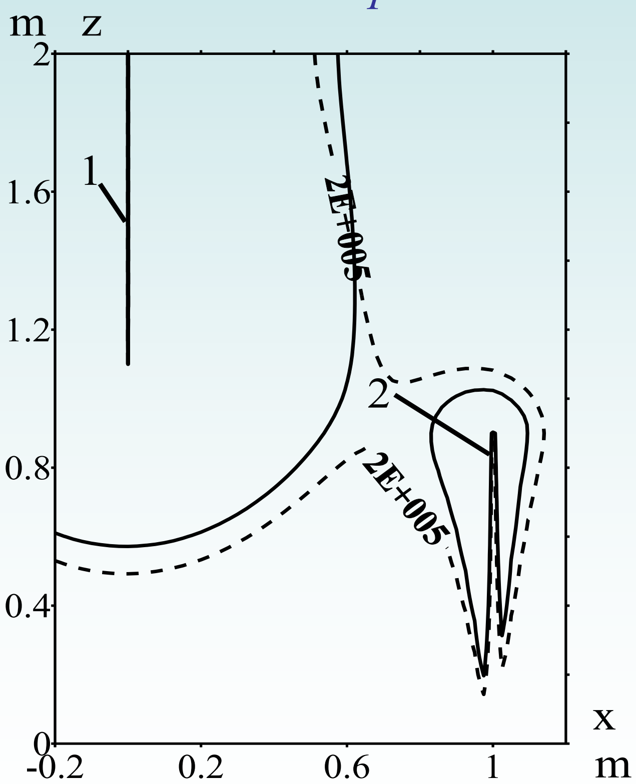


h=1.2 m, d=0.44 m, U=750 kV, 1 is high voltage electrode, 2 is grounded electrode

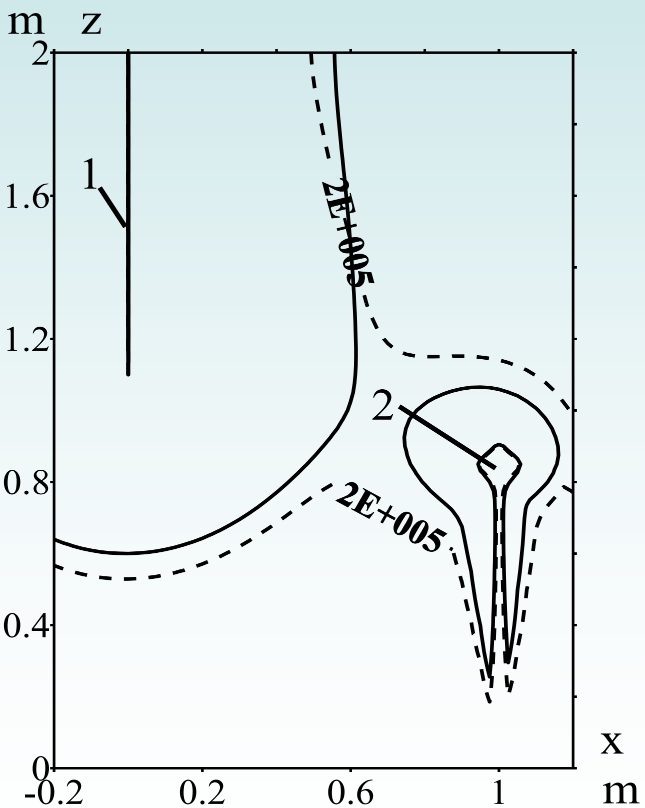
Calculated lines of equal eclectic field strength in the cross-section of rods' axes (E_+=2 kV/cm)

h=0.93 m, d=1.01 m, U_{imp}=862.5 kV ______ – *U_{con}=-120 kV*, ----- – *U_{con}=-200 kV*

the grounded electrode tip has the shape of a cone with a radius of rounding of 0.015 m because corona presence

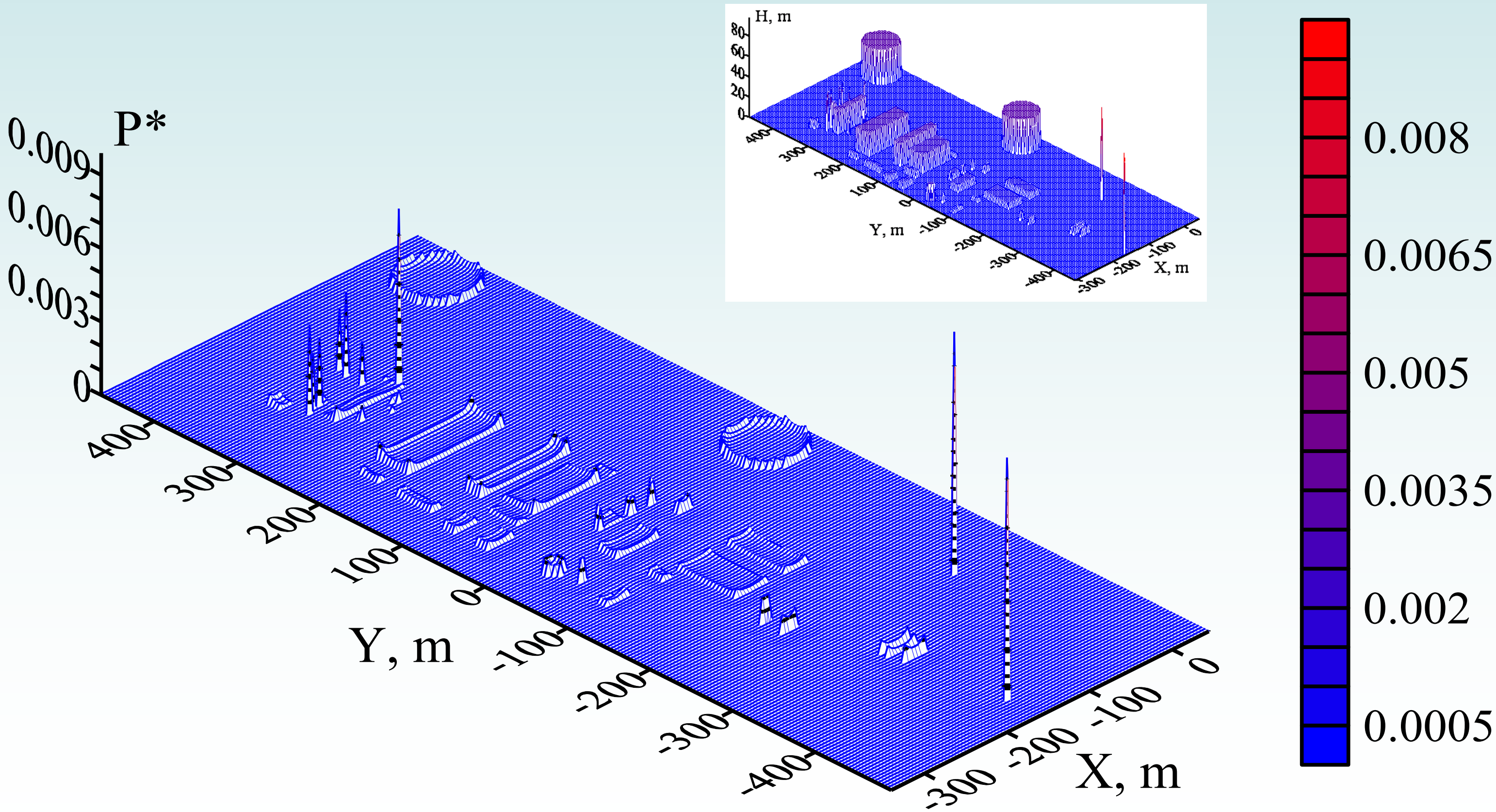


the grounded electrode tip has the shape of a sphere with 0.125 m diameter

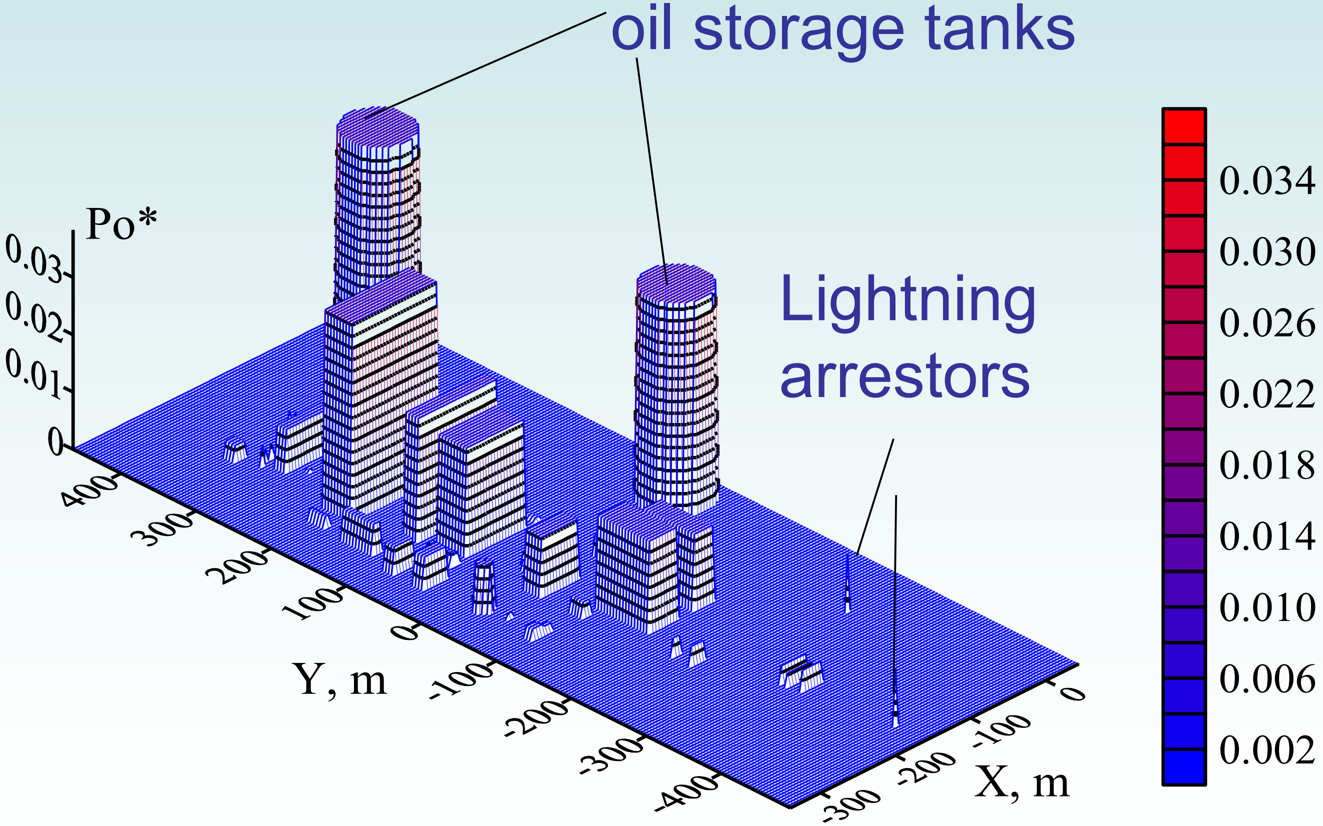


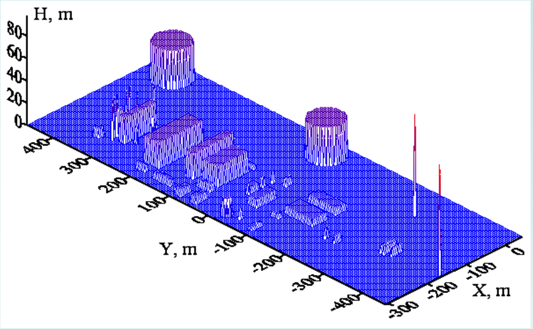
1 is high voltage electrode, 2 is grounded electrode

Calculated distribution of $P^*=P/S_\Sigma$, where P is a coefficient proportional to the number of lightning strokes to k–th cell; S_Σ is the area of an investigated facility, which equals to $150 \times 120 m^2$ for the illustrated example

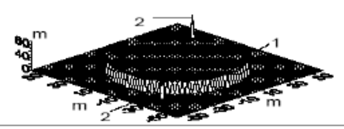
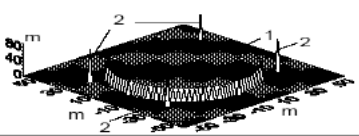
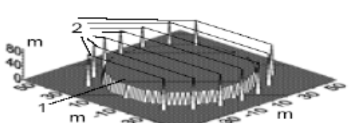


Calculated distribution of probability of the number of lightning strokes (oil storage facility)

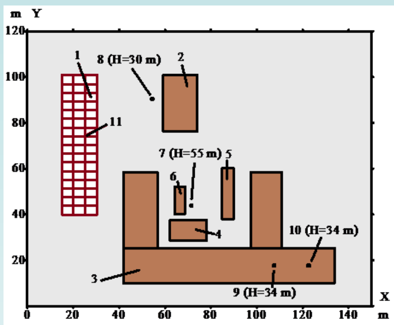


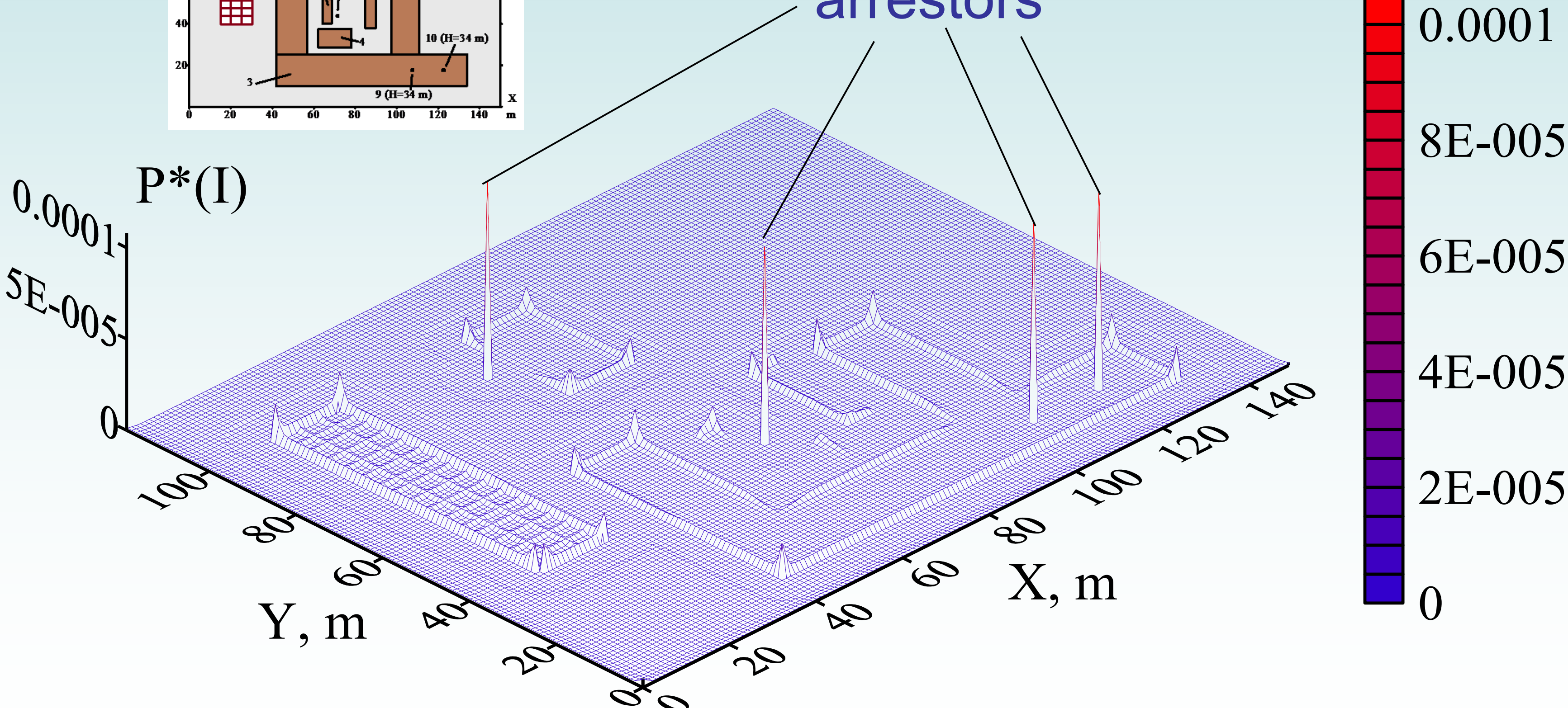


K - calculated predicted number of years in which a lightning may strike to the oil storage tank when different lightning protection systems are used. C – catenary wire system; N_m=5

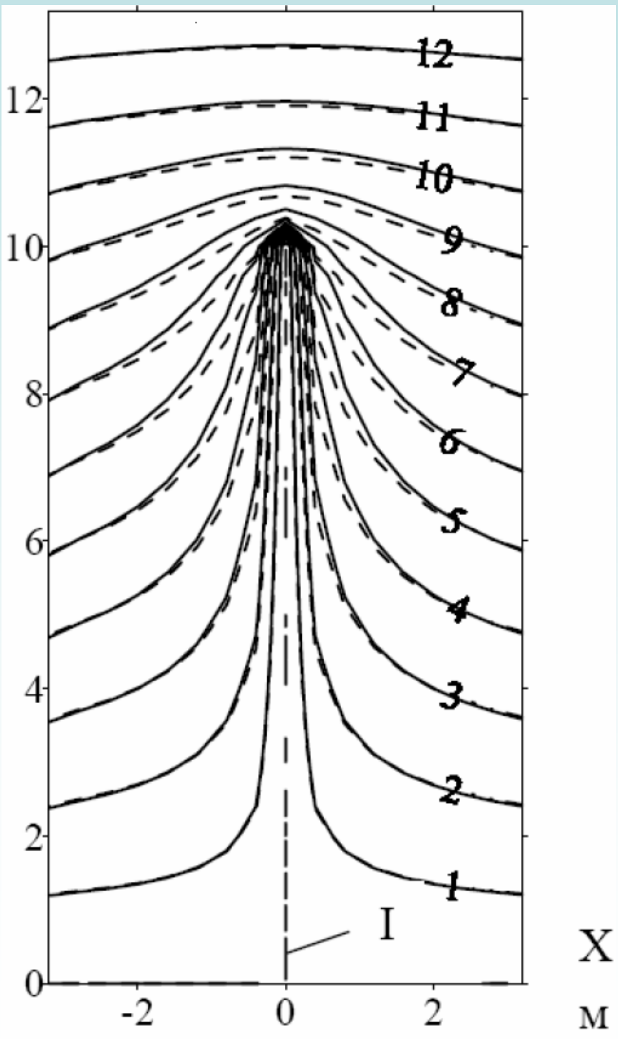
N	Number of lightning air terminals	Type of lightning protection	Height of lightning air terminals, m	K, years
1	without LAT	-	-	1.2
2	existing LAT	LAT	two LATs (91m, 98m) located aside the tanks	1.3
3	1	LAT	60	1.5
4	1	LAT	90	1.6
5	1	LAT	120	1.6
6	2 	LAT	90	2.2
7	4 	LAT	90	3.9
8	14	LAT	60	8.5
9	14 	LAT	90	8.6
10	7 	C	50	~20

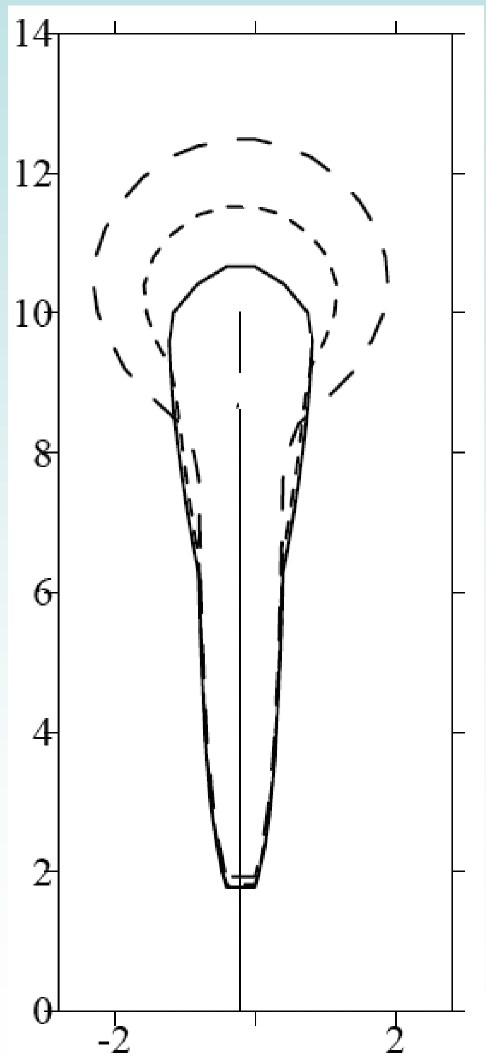
Calculated distribution of probability of the number of lightning strokes (high voltage substation)

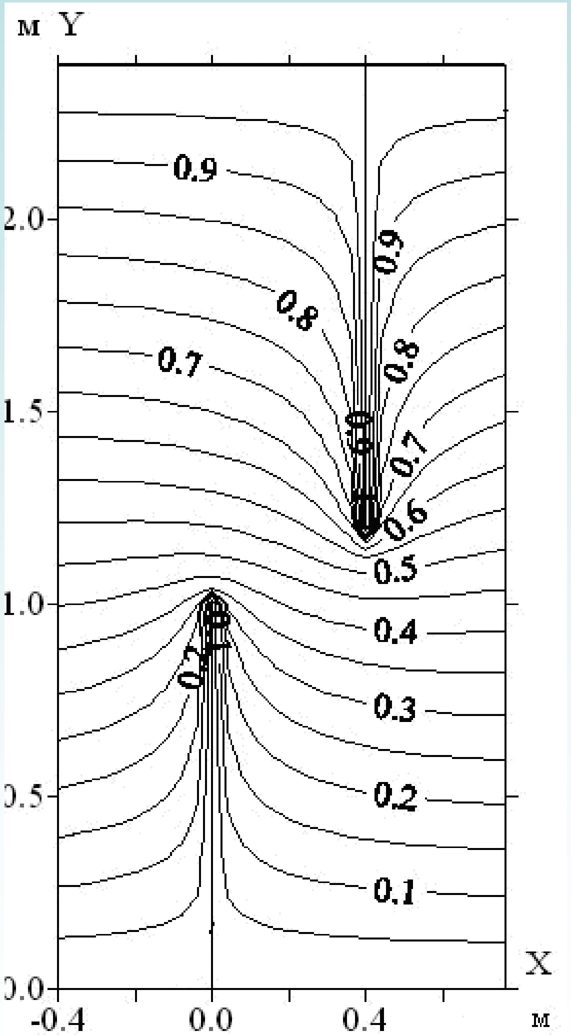




Examples of 3D electric fields calculation around lightning rods and lightning leaders



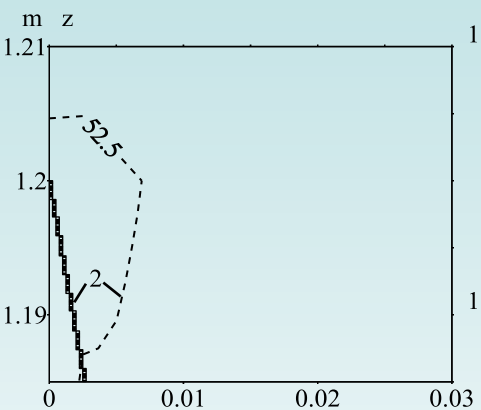




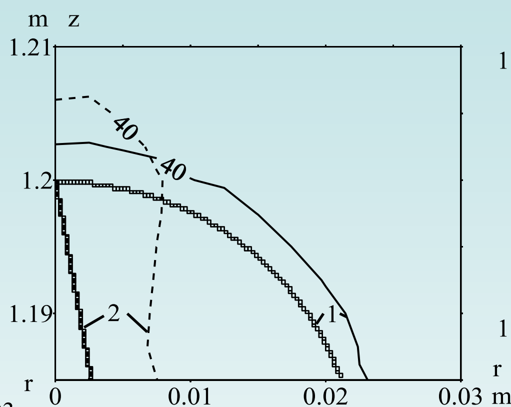
Experimental investigations of corona discharges on the tips of grounded rods

Photo of the experimental setup in the high-voltage laboratory of NTU "KhPI"

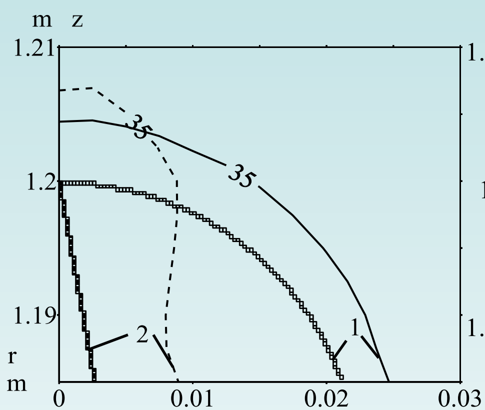
Calculation of the distribution of lines of equal EF strength ($E^*=E_{cr}\cdot D/|U_{con}|$) at application to the upper plane voltages (U_{con}) of different levels



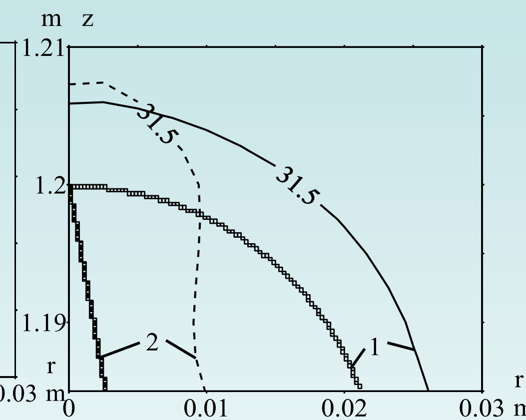
U_{con}=-120 kV



U_{con}=-160 kV



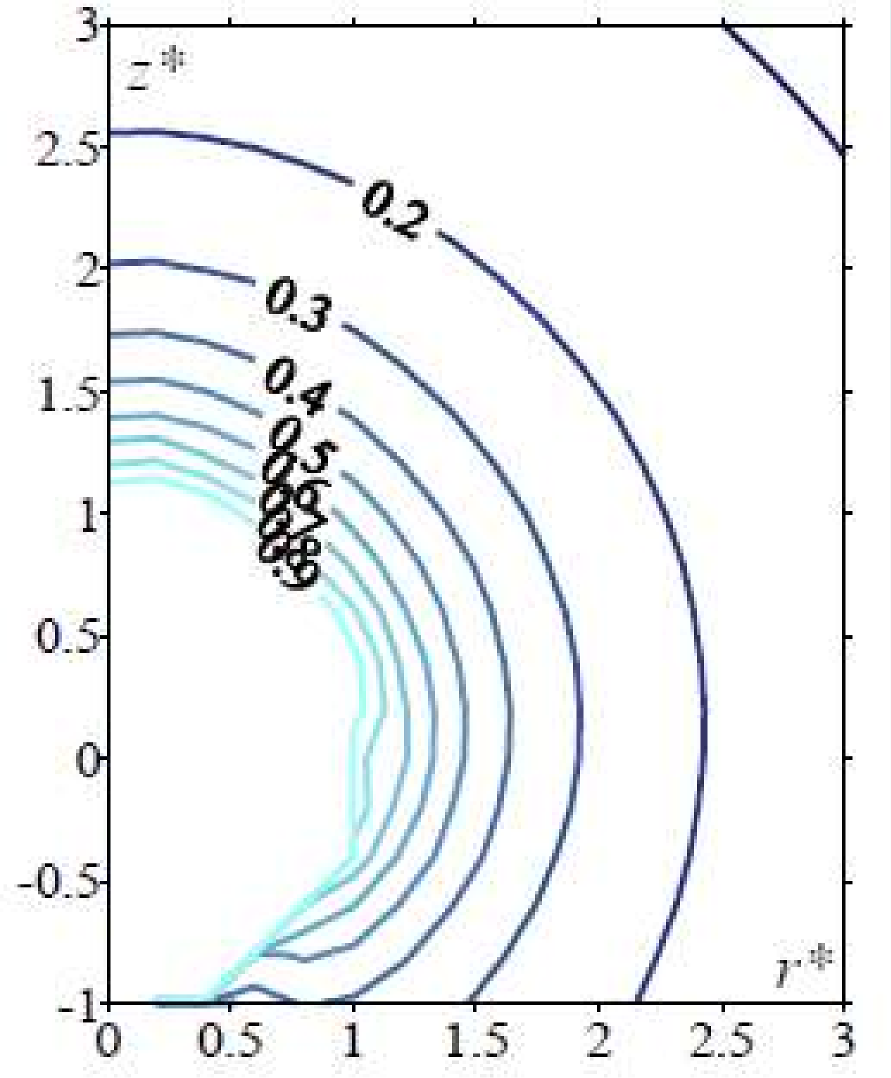
U_{con}=-180 kV



U_{con}=-200 kV

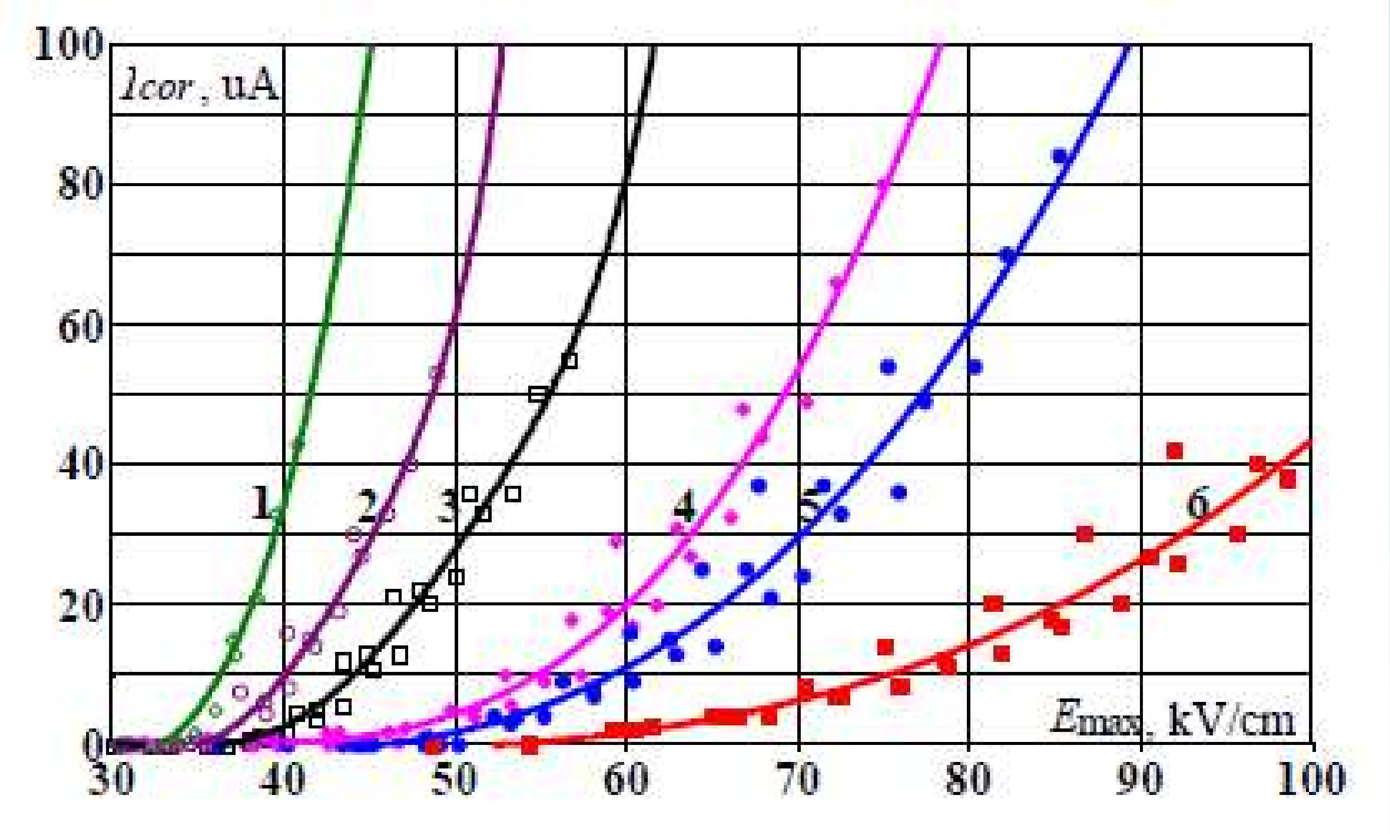
1, 2 are zones in which the EF strength exceeds critical level (30 kV/cm) at a certain level of the applied voltage U_{con} for a tip of the grounded electrode in the form of a cone (1) and a sphere (2)

Calculated values of the spatial distribution of EF, using EF contours E*=const in the coordinates r* and z* around the tip of an electrode with R =0.0125 m and h =1.2 m



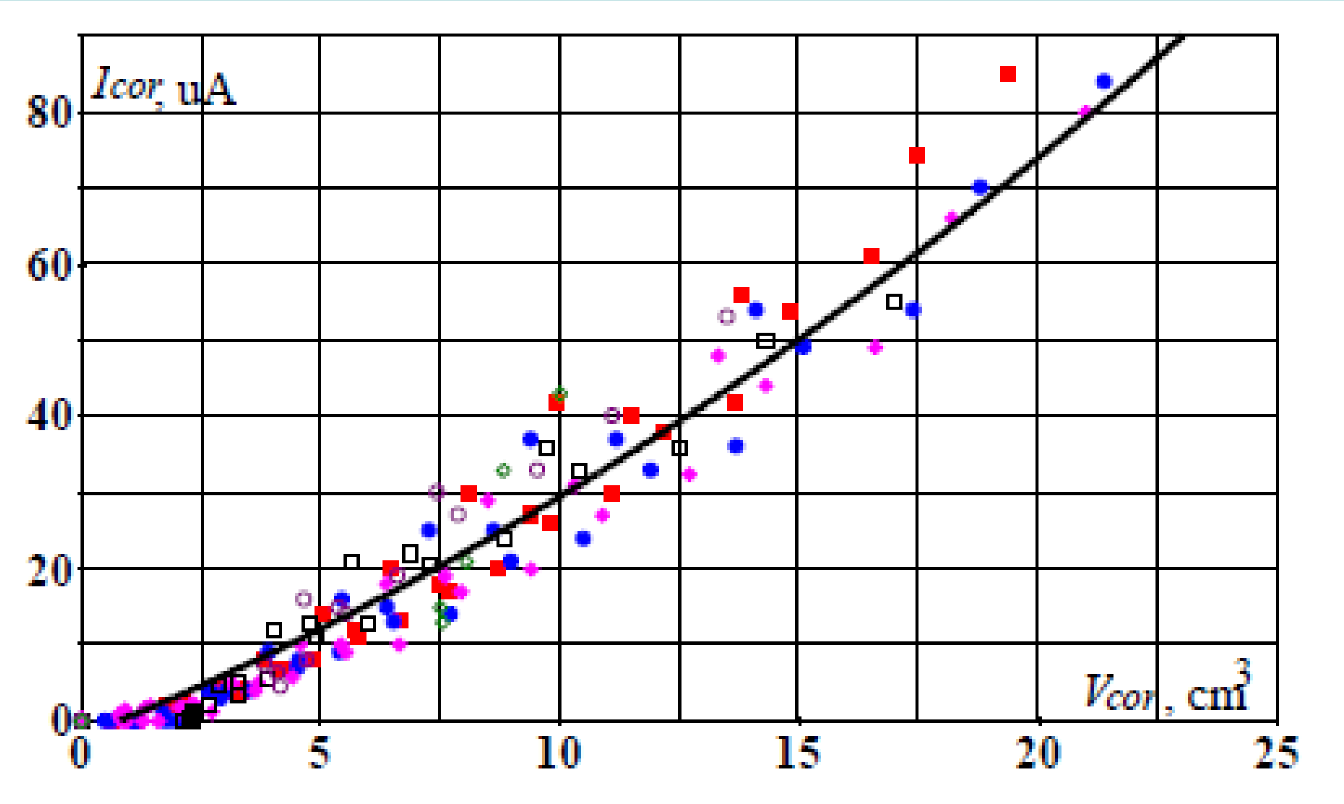
r = r/R;*
z=[z - (H - R)]/R;*
E_{max} is calculated maximum level of electric strength of the rod's tip

Results of physical and mathematical modeling of the corona current dependence (I_{cor}) on the values of maximum electric field strength on the grounded rods tips (E_{max}) for different radii of curvature of their tips



1 - R =0,019 m; 2 - R =0,015 m; 3 – R=0,0125 m; 4 - R = 0,009 m;
5 - R = 0,00775 m; 6 – R=0,0055 m

Results of physical and mathematical modeling of the corona current dependence (*Icor*) on the volume of the zone in which the EF strength is equal or greater than the critical breakdown voltage for air (30 kV/cm) at different radii of curvature of their tips, their different height and different levels of the applied DC voltage



◇ - *R=0,019 m;* ○ - *R =0,015 m;* □ - *R=0,0125 m;*
◆ - *R = 0,009 m;* ● - *R=0,00775 m;* ■ - *R=0,0055 m*

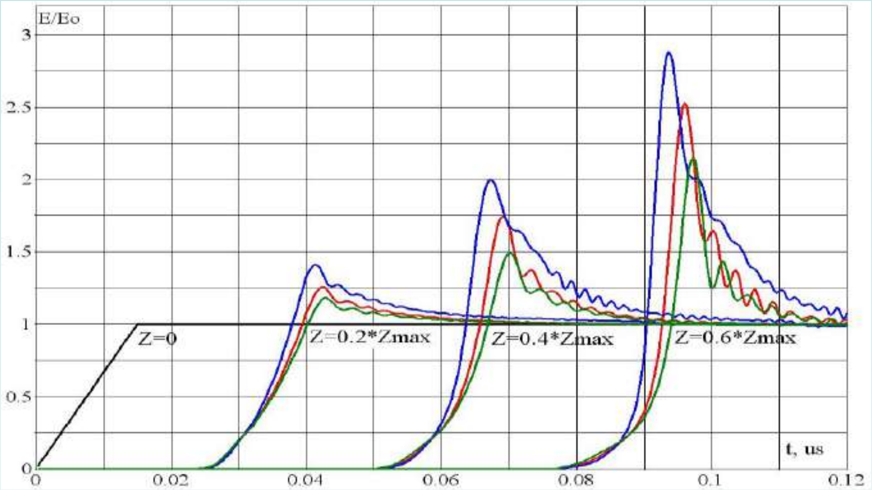
Electromagnetic shock waves (EMSW)

Pulses' front distortions in nonlinear medium:

$$\frac{\partial E}{\partial z} = -\frac{\partial B}{\partial t}, \qquad D = D(E)$$

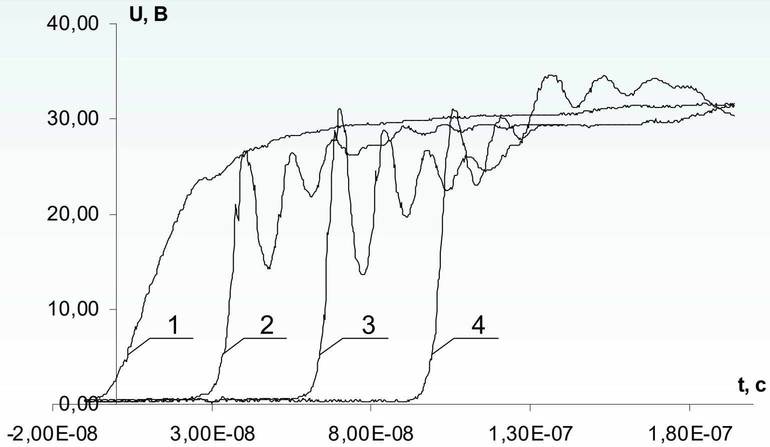
$$\frac{\partial H}{\partial z} = -\frac{\partial D}{\partial t}, \qquad B = B(H)$$

$$V = \sqrt{\frac{1}{\varepsilon\varepsilon_0\mu\mu_0}} = c\sqrt{\frac{1}{\varepsilon\mu}}$$



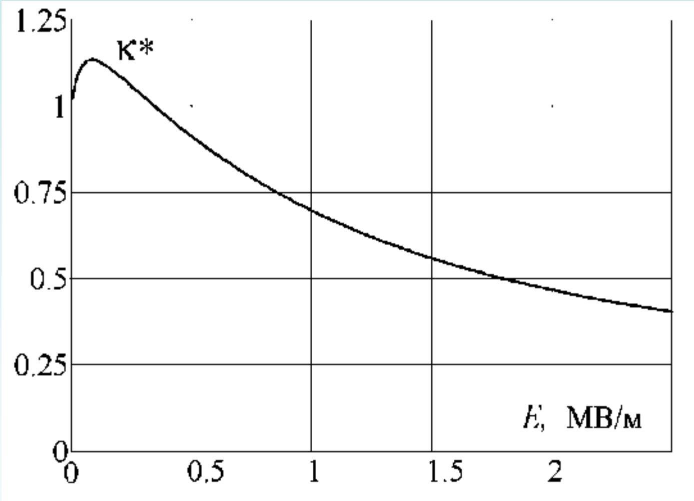
Physics of shock waves formation:

- Dissipation of energy due to magnetization or polarization
- Dependence of phase velocity of EM wave propagation on field strength



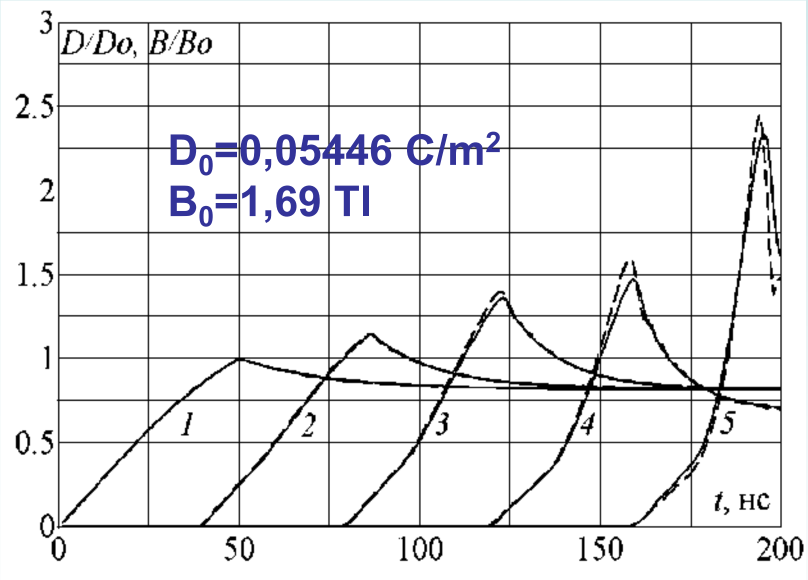
Shock electromagnetic waves formation in layered nonlinear ferroelectric-ferromagnetic media

Dependence of the normalized coefficient *k* *, proportional to the relative dielectric permittivity and magnetic permeability



Composite medium consists of alternating layers of ferroelectric (three 0.5 mm thick layers, ε = 3600k *, μ = 1) and magneto-dielectric (two 0.075 mm thick layers, ε = 360, μ = 10k *)

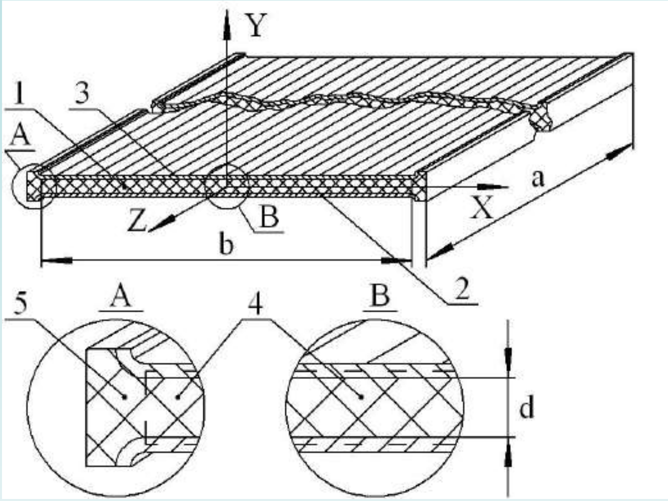
Results of electric and magnetic induction calculation in different cross sections of the forming line at electromagnetic wave propagation



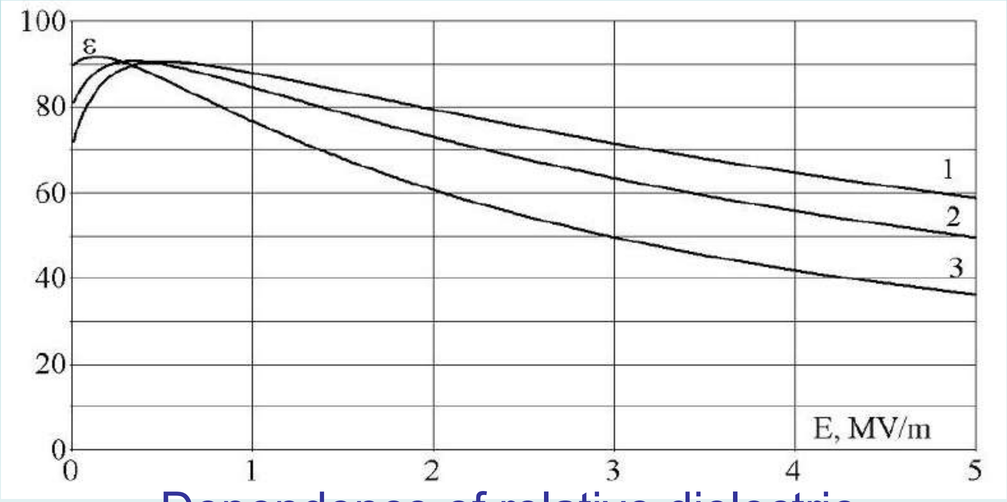
1 – Z=0; 2 – Z=0,2·Z_{max}; 3 – Z=0,4·Z_{max}; 4 – Z=0,6·Z_{max}; 5 – Z=0,6·Z_{max}, Z_{max} – forming line length

——— – D(t)   - - - - – B(t)

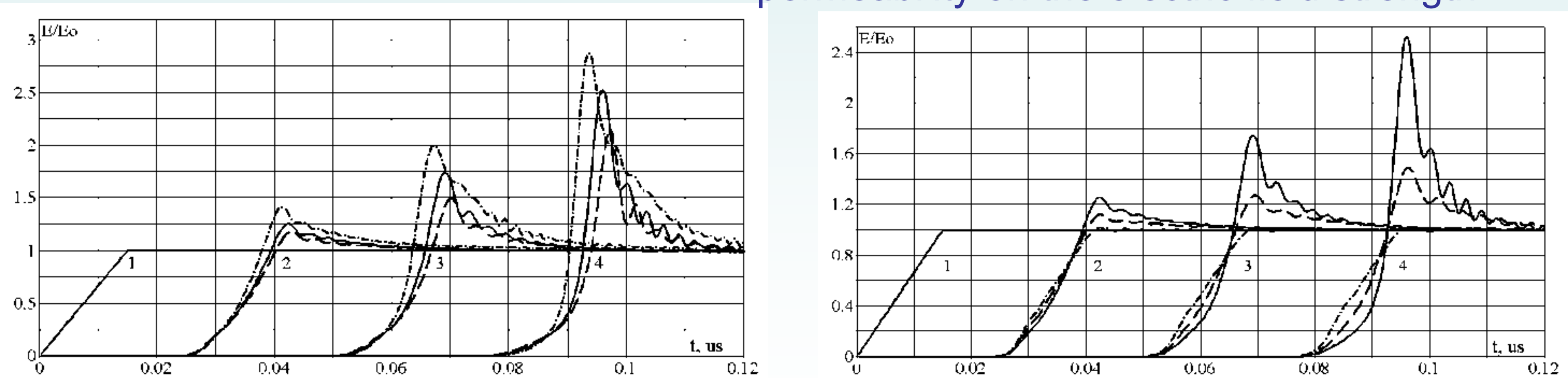
Mathematical modeling of shock wave formation and propagation in nonlinear dielectric media



Forming line (FL)



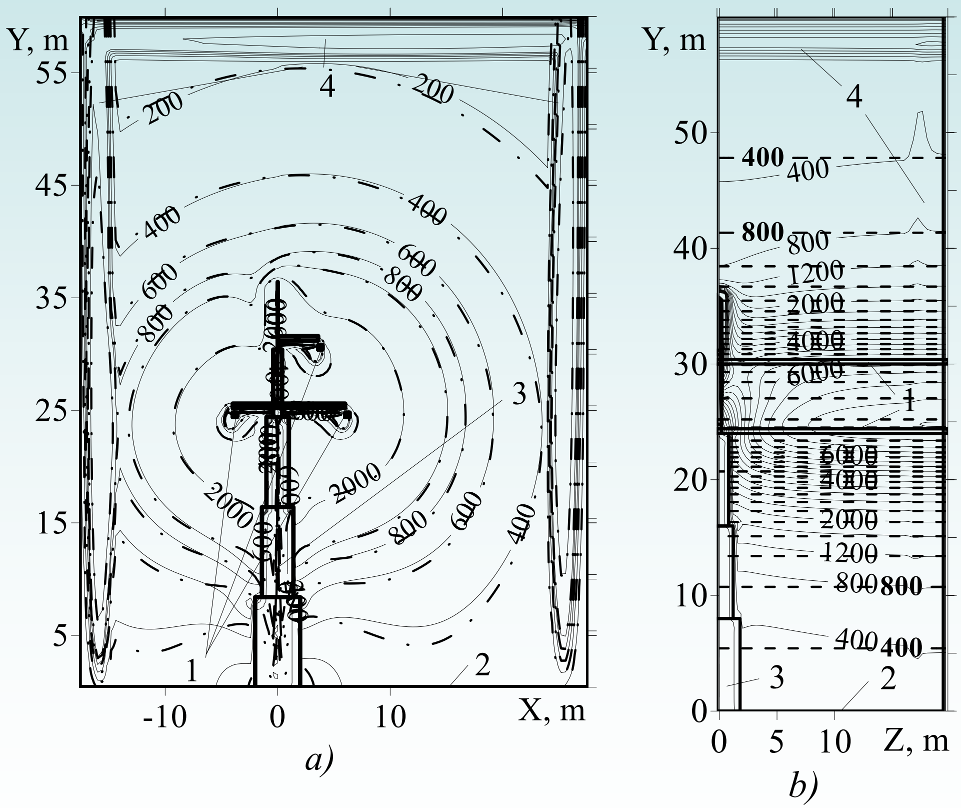
Dependence of relative dielectric permeability on the electric field strength



Calculated profiles of electric field strength in different FL cross-sections for different degrees of dielectric permeability nonlinearity

Calculated distributions of the lines of equal EF strength (V/m)

Triangle layout of TL lines



Horizontal layout of TL lines in an UAV presence

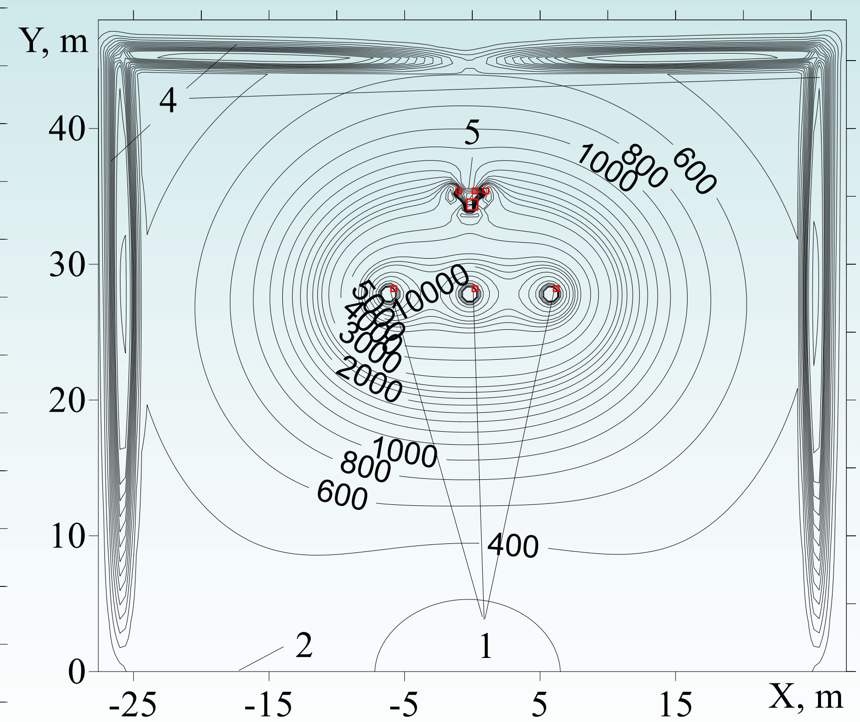
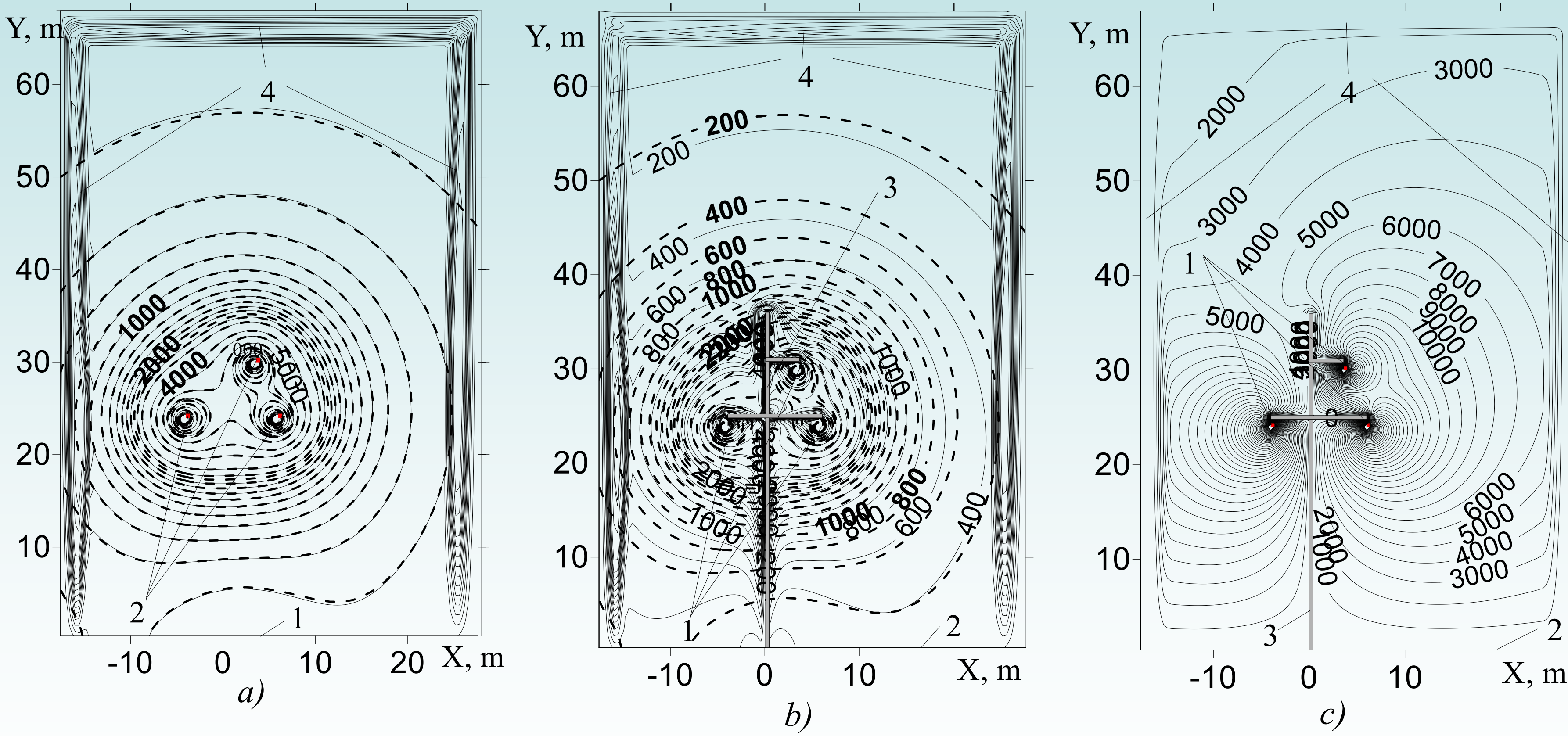


Fig. 6

Calculated electric field distributions in the vicinity of power transmission lines (TLs) with towers in the cross-sections perpendicular to the TL lines

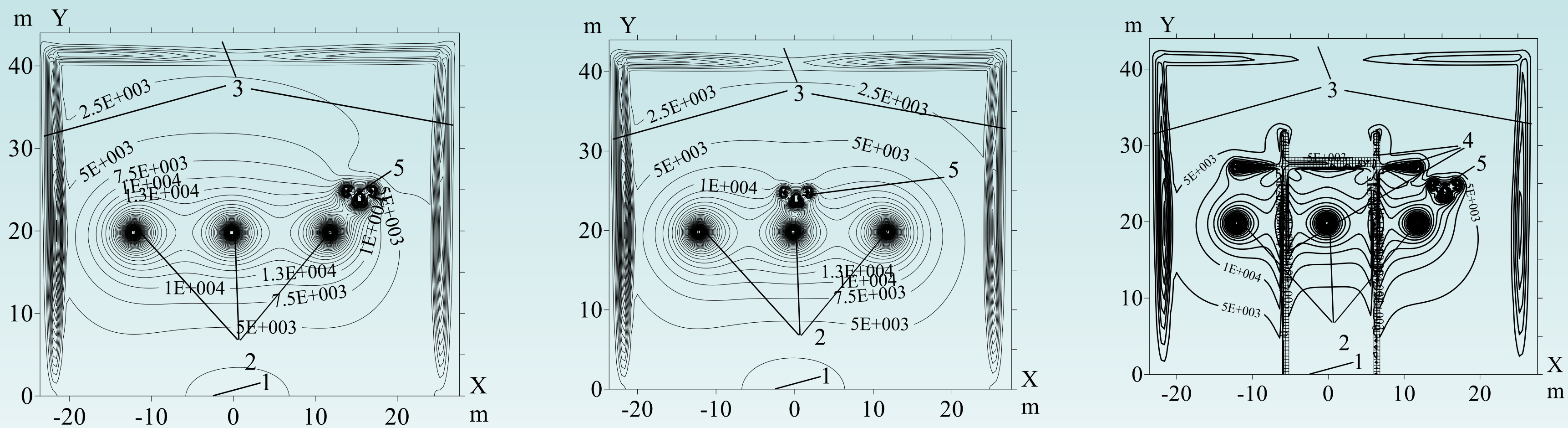
Calculated distributions of lines of equal EF strength (V/m)

Calculated distributions of equipotential lines (V)

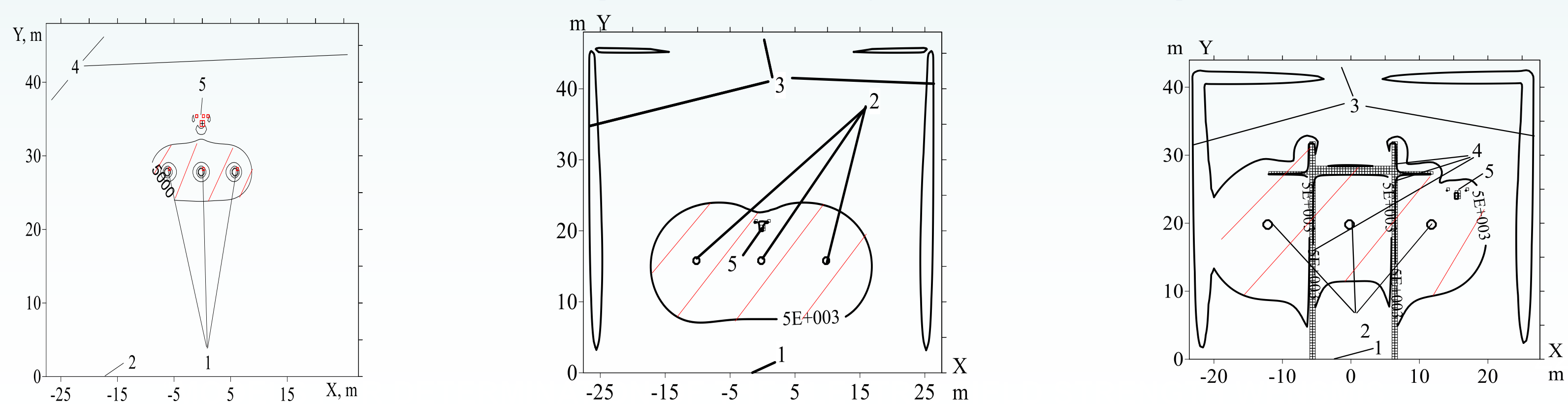


1 is the earth, 2 are TL lines, 3 is a TL tower, 4 are UPML. Analytical solutions for the cases for any objects absence in the TL zone are shown by dashed lines

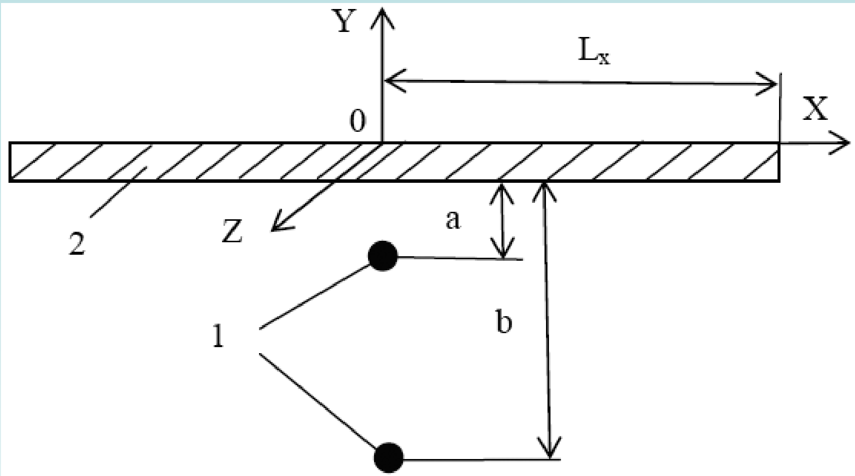
Examples of mathematical modeling of the electric field distributions in the vicinity of high-voltage power lines in presence of the UAVs

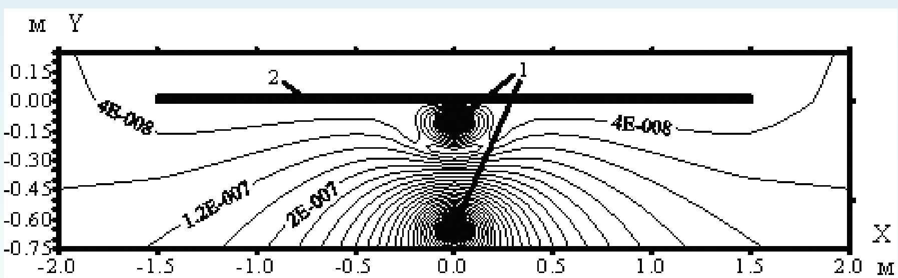


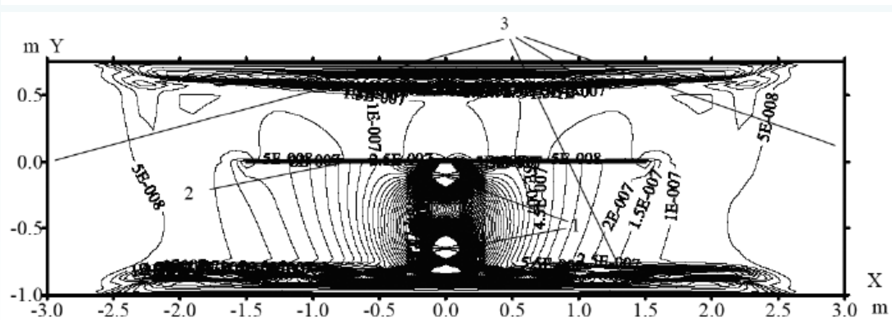
The areas dangerous for the electronic equipment of the UAVs (shown by red lines)

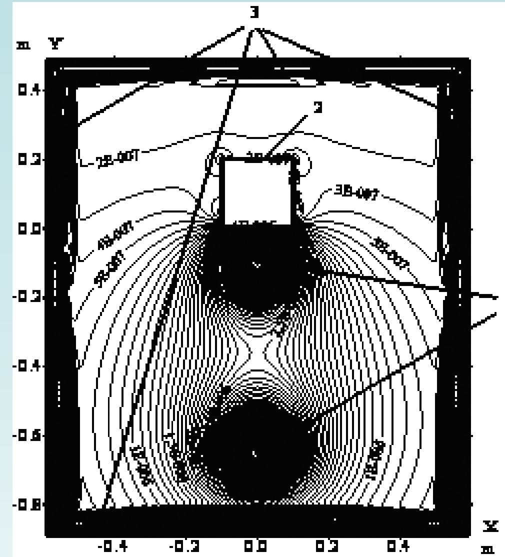


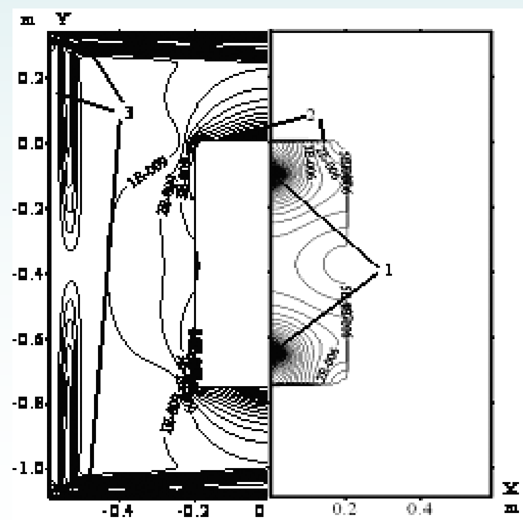
Calculations of magnetic fields at conductive screens application



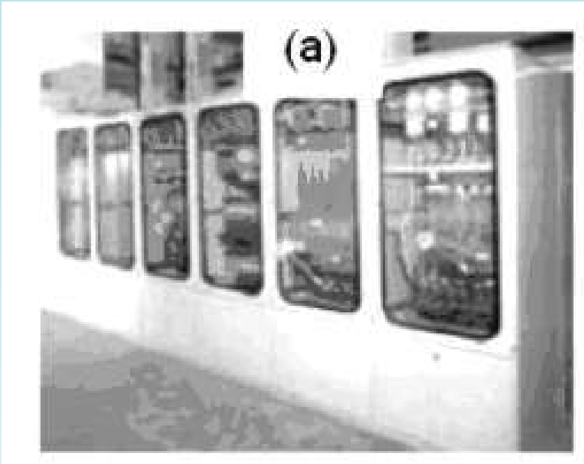


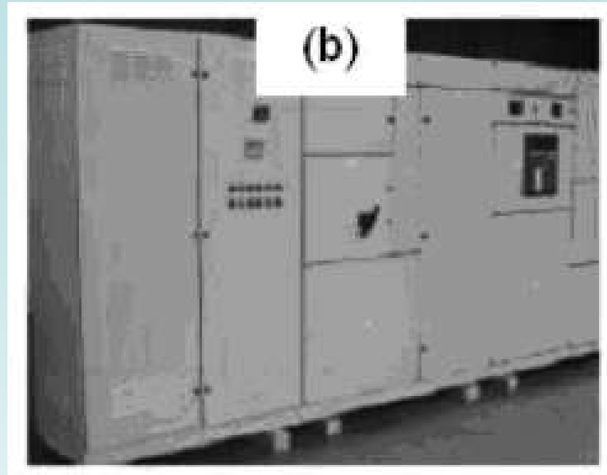


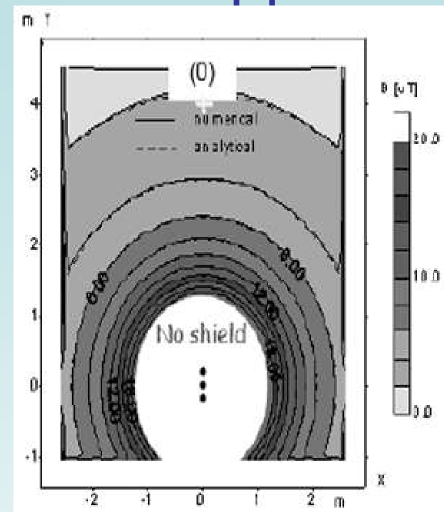


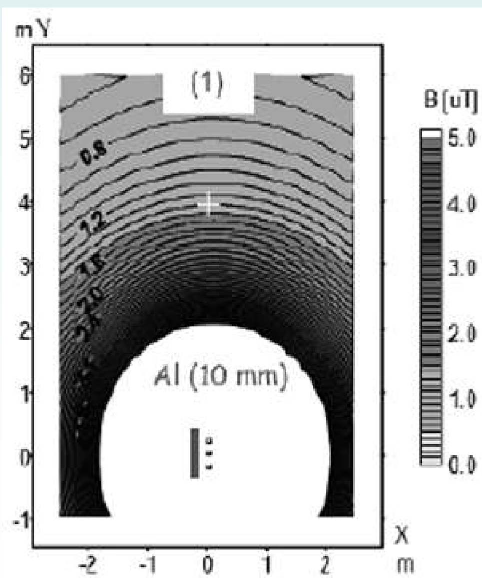


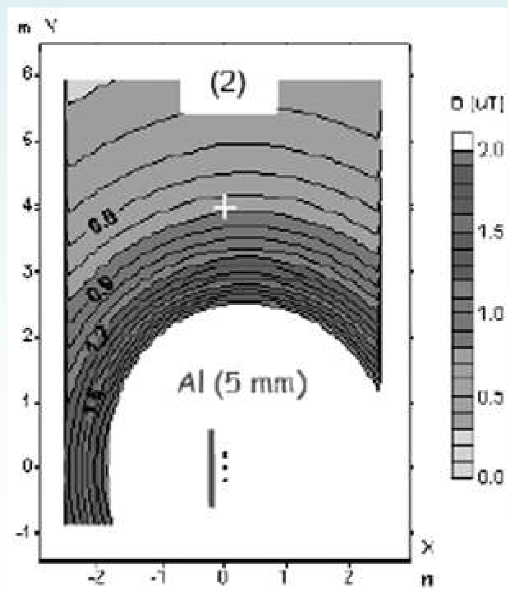
Calculations of magnetic fields at conductive screens application

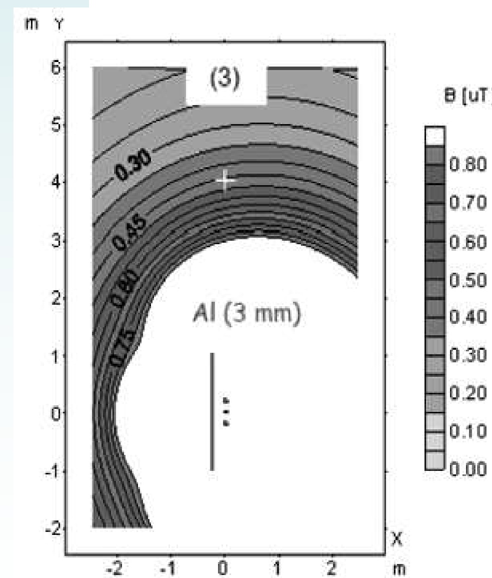




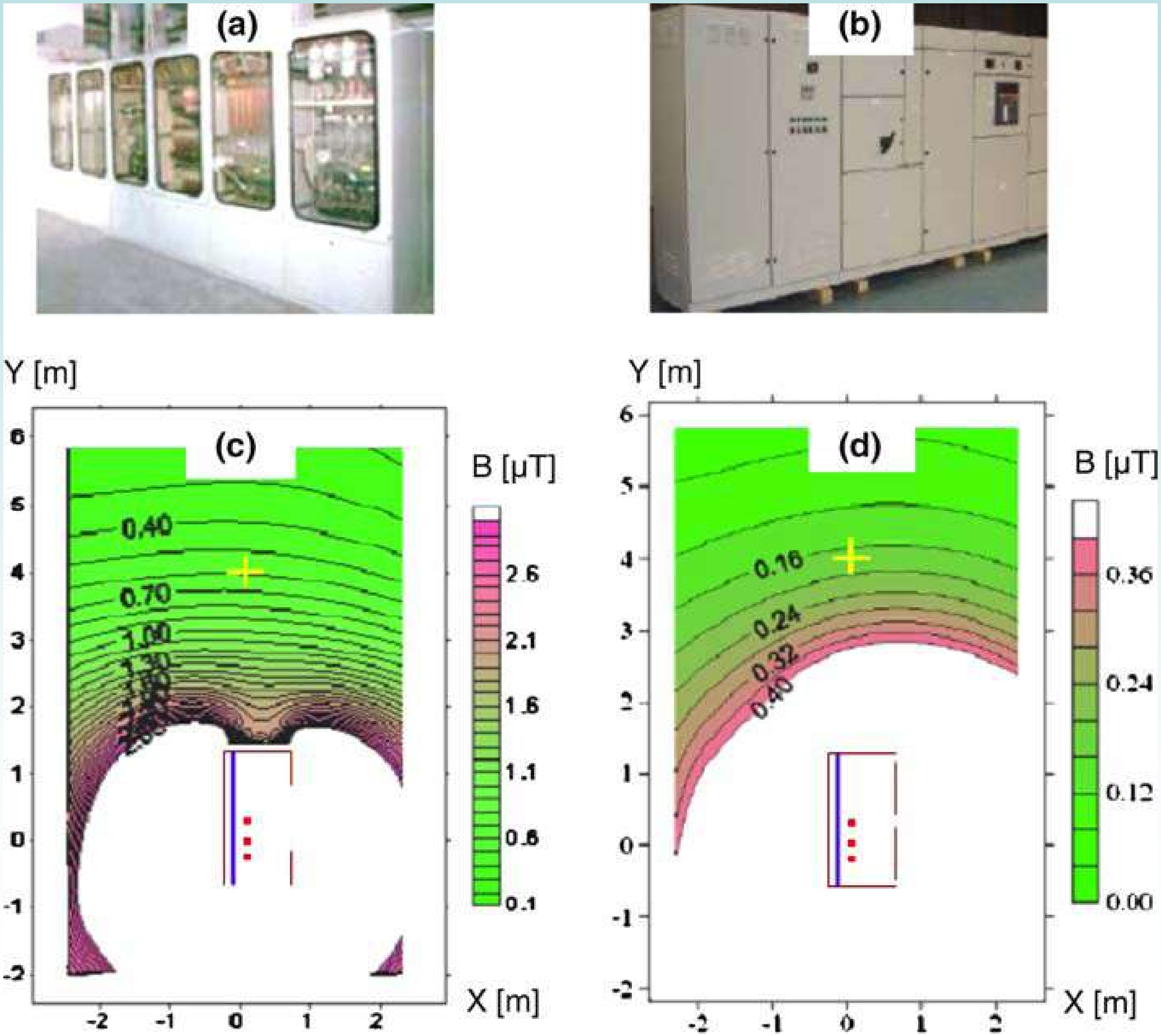




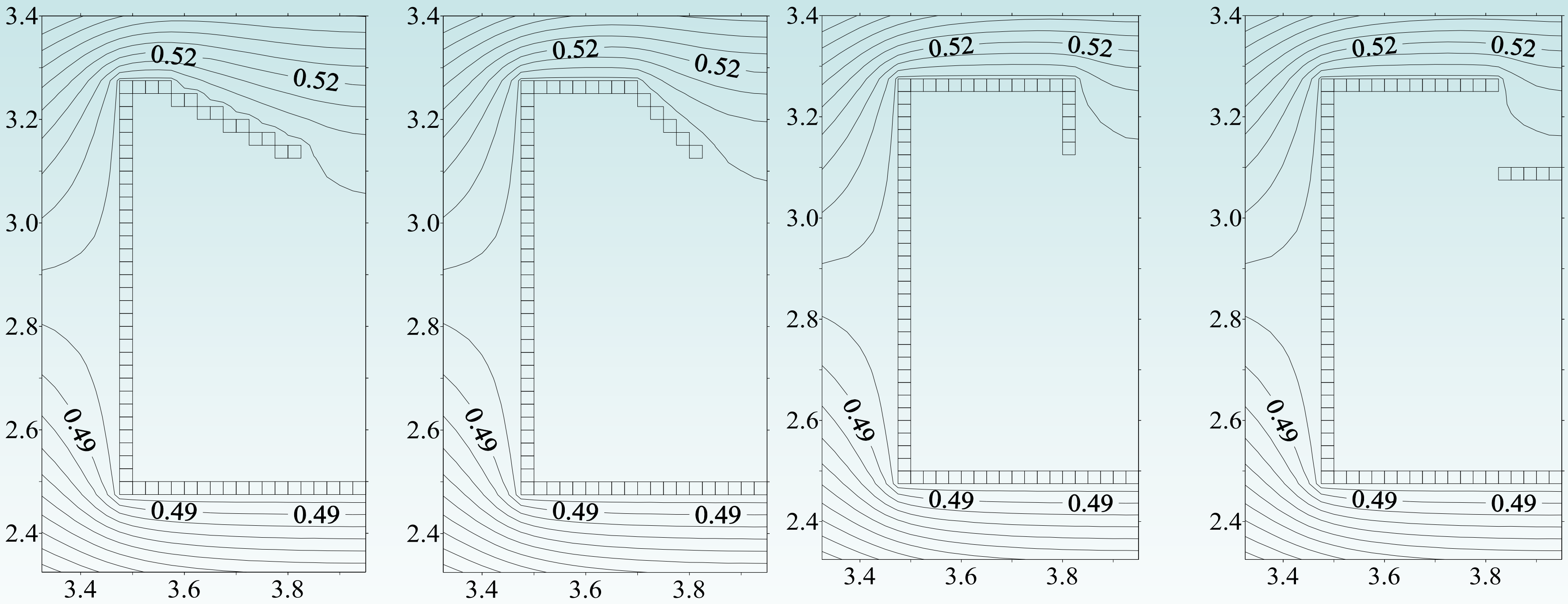




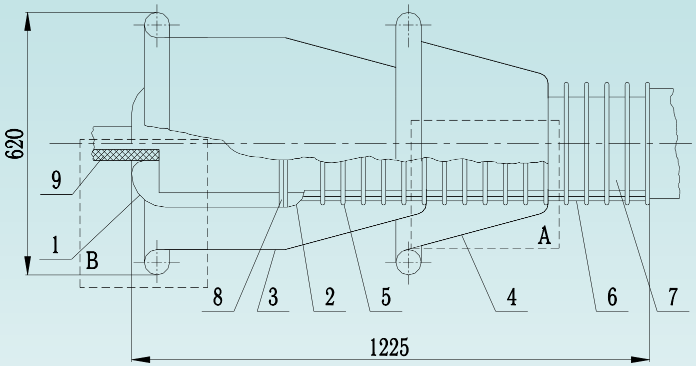
Calculations of magnetic fields at conductive screens application

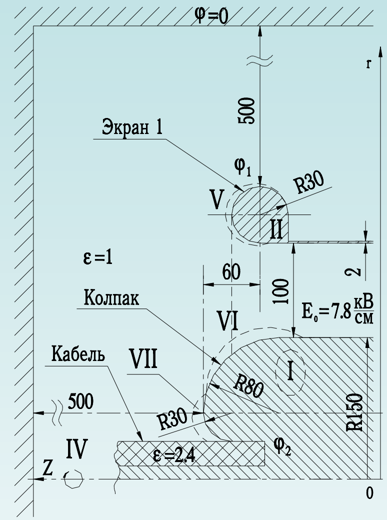


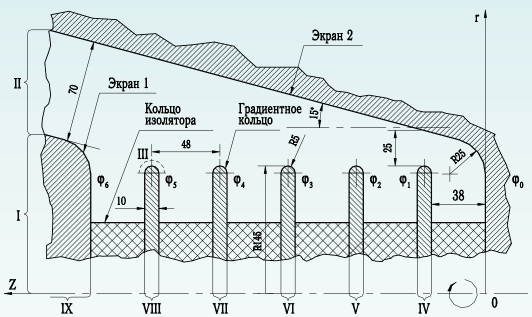
Calculated distributions of the lines of equal potentials in the cross-section Z=const of the screens with different aperture shape

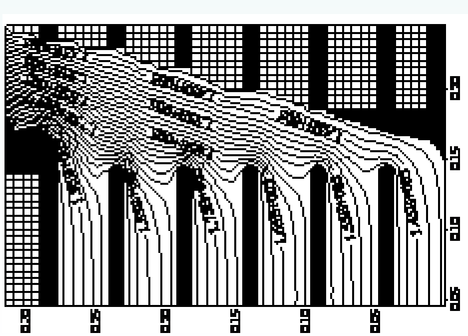


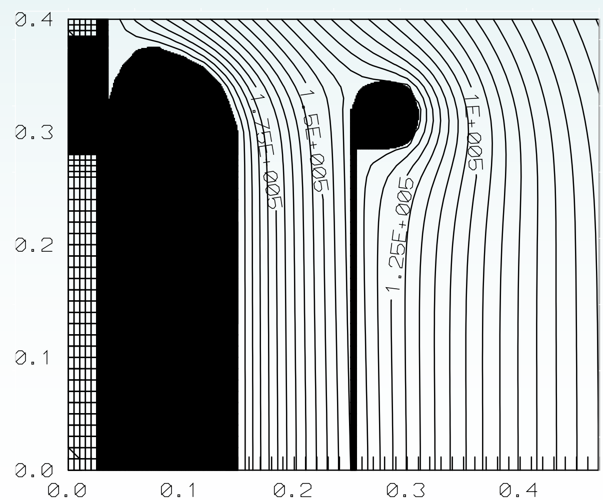
Distribution of the lines of equal potentials in the cross-section Z=const of the accelerator protective screens



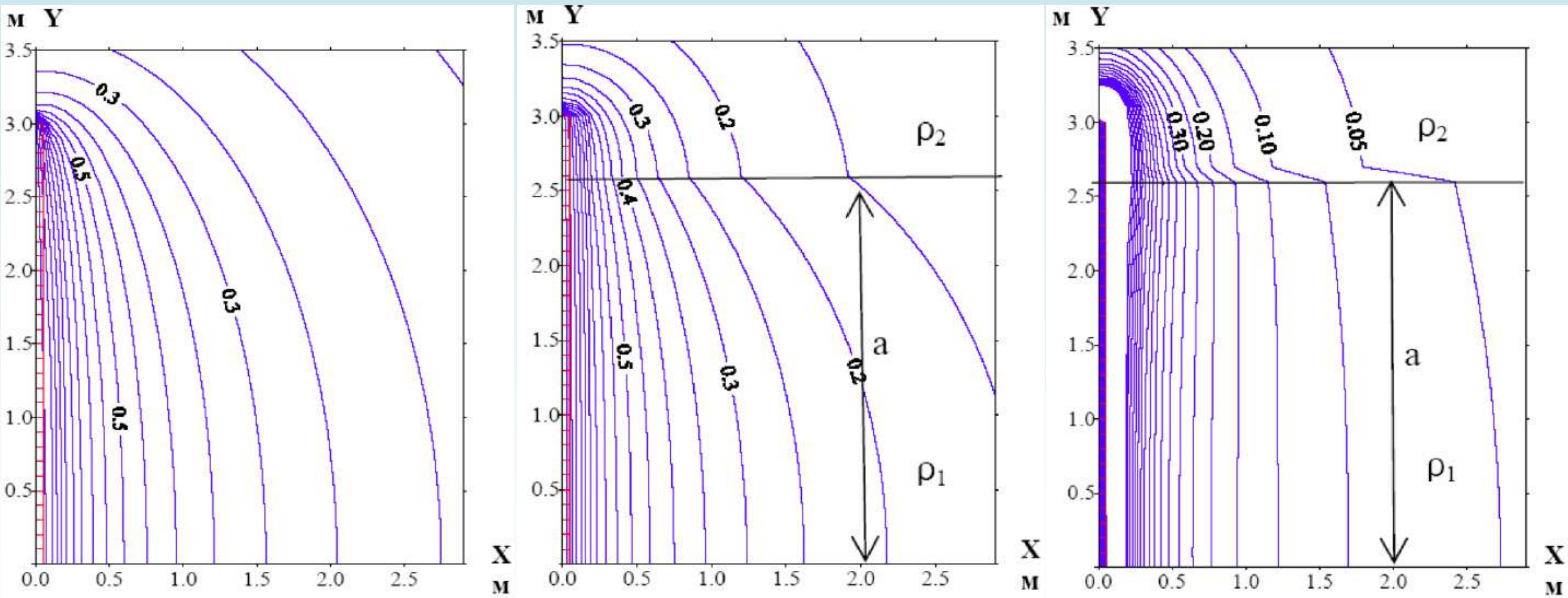






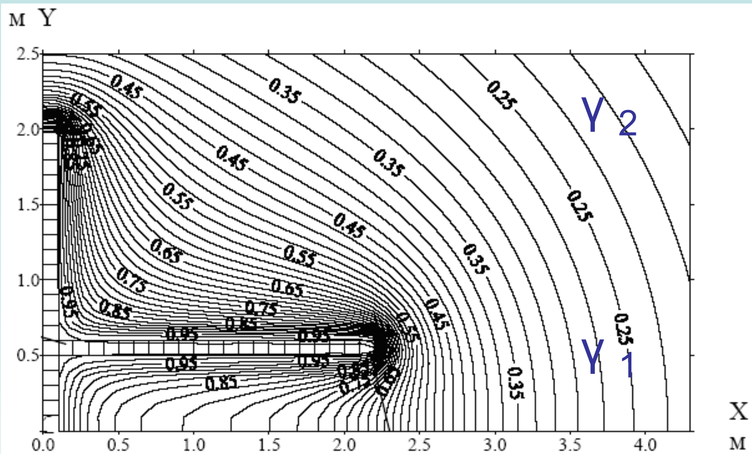


Calculated distribution of the lines of equal potentials around a grounding rod in homogeneous and heterogeneous soil

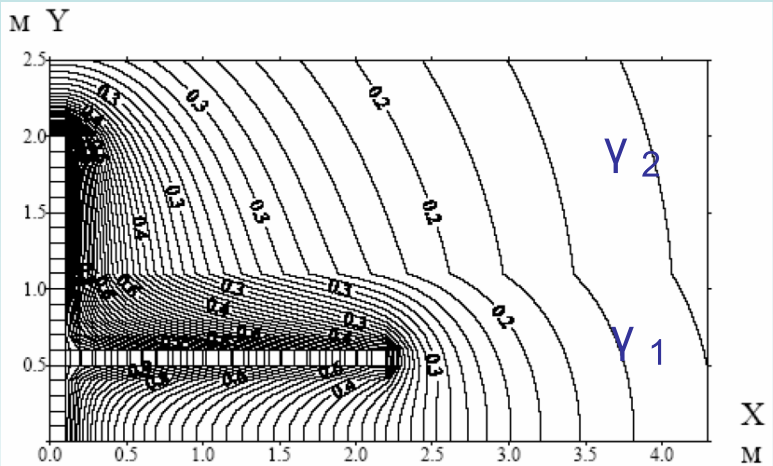


$\gamma_1 = \gamma_2$ $\gamma_1 > \gamma_2$ $\gamma_1 < \gamma_2$

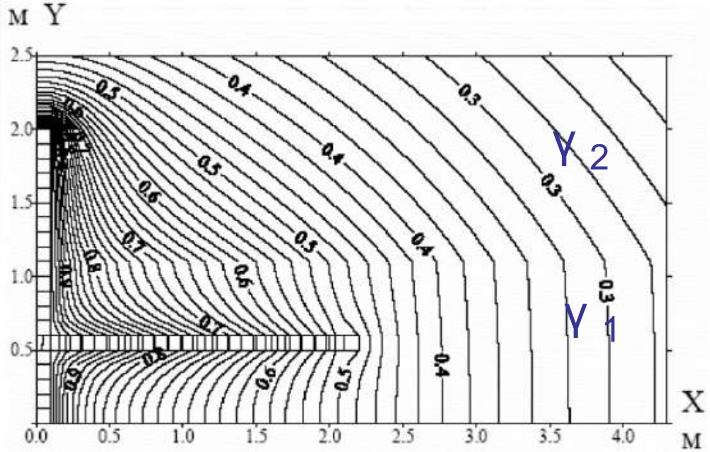
Calculated distribution of the lines of equal potentials around a grounding rod in homogeneous and heterogeneous soil



$\gamma_1 = \gamma_2$

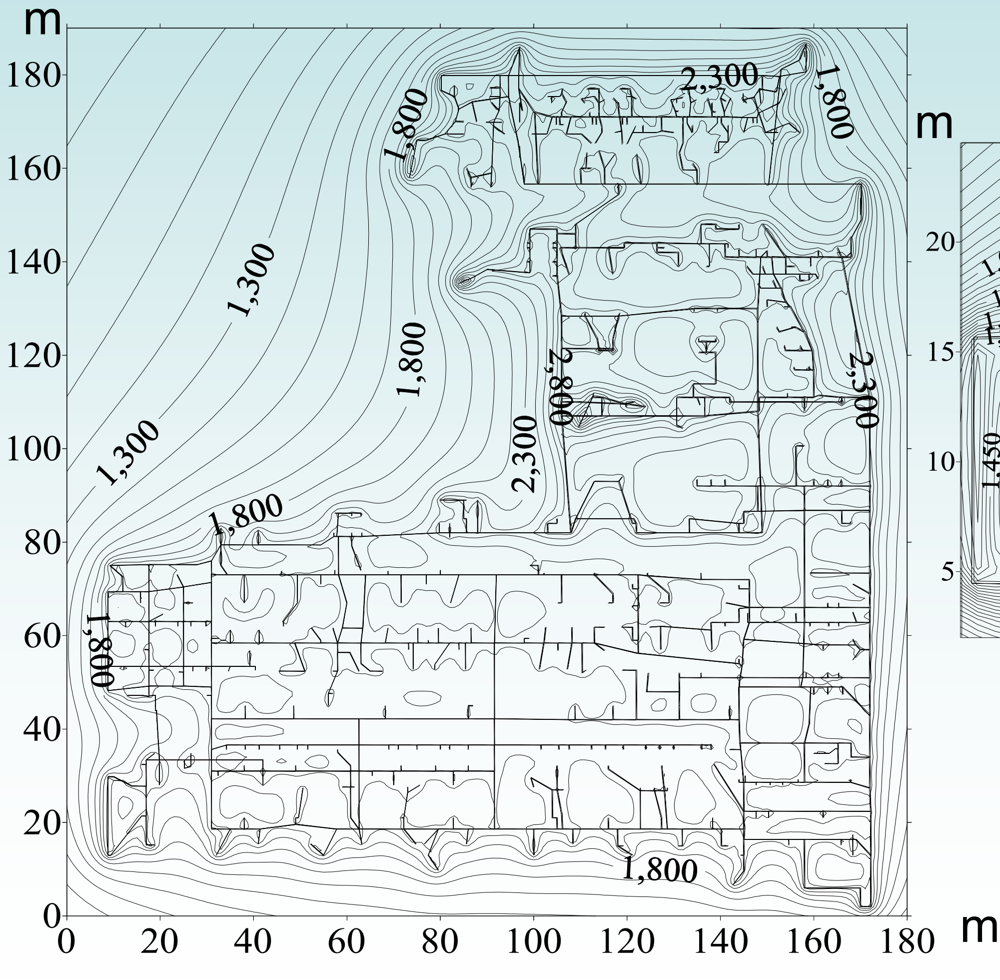


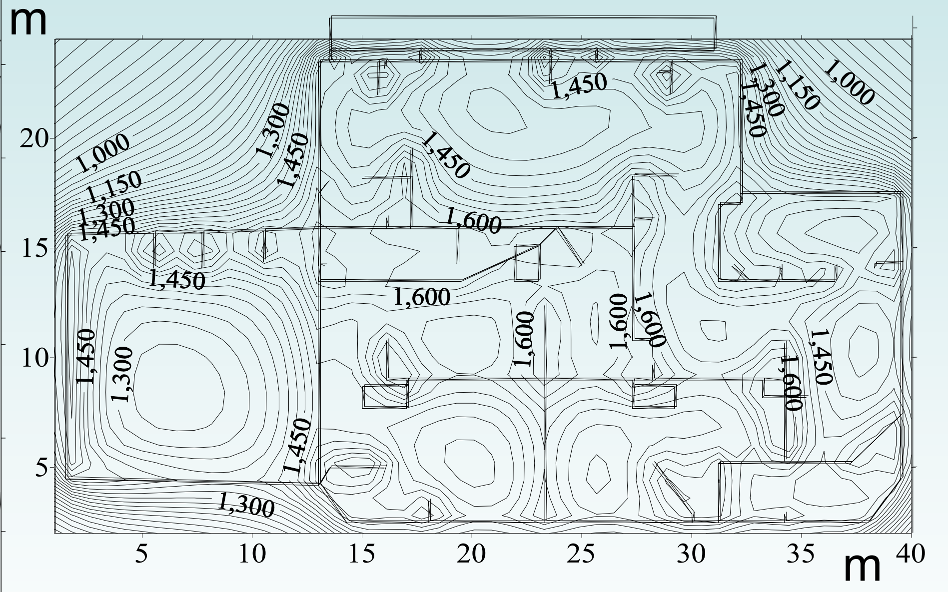
$\gamma_1 > \gamma_2$



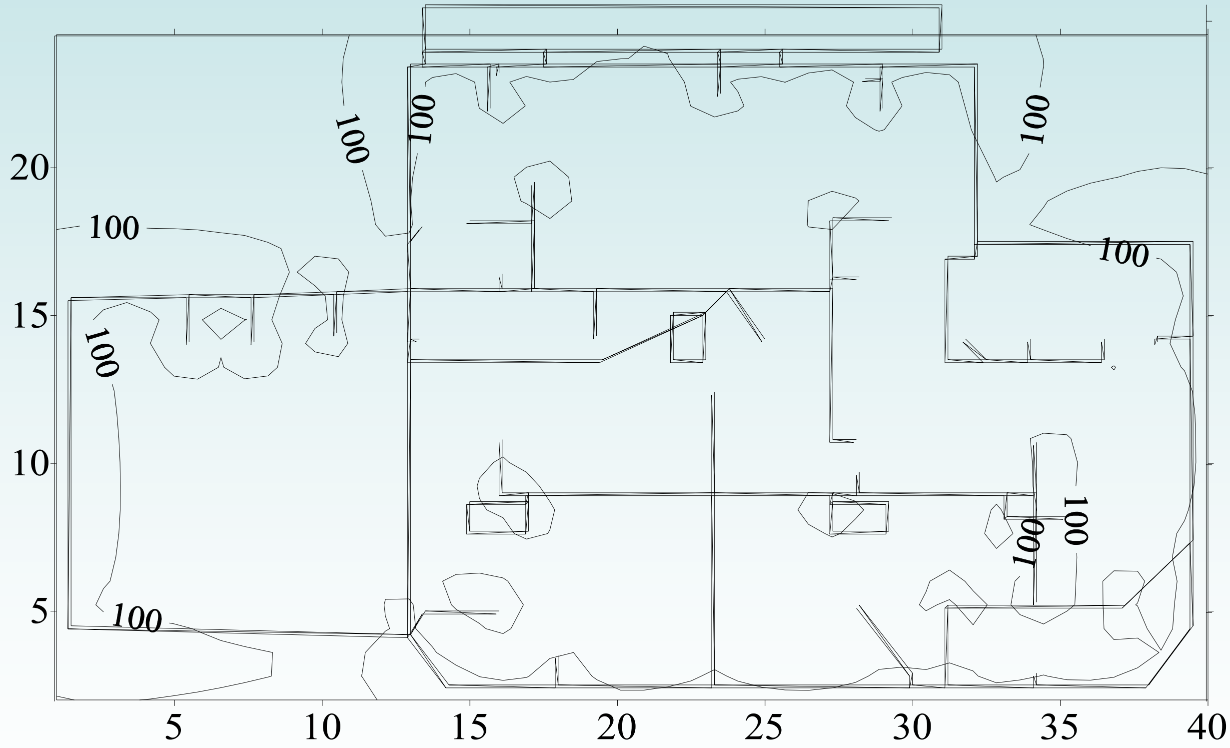
$\gamma_1 < \gamma_2$

Calculated distributions of the lines of equal potentials (V) on the surface of the ground (m) above the defense grounding of high voltage substations in short circuit regimes

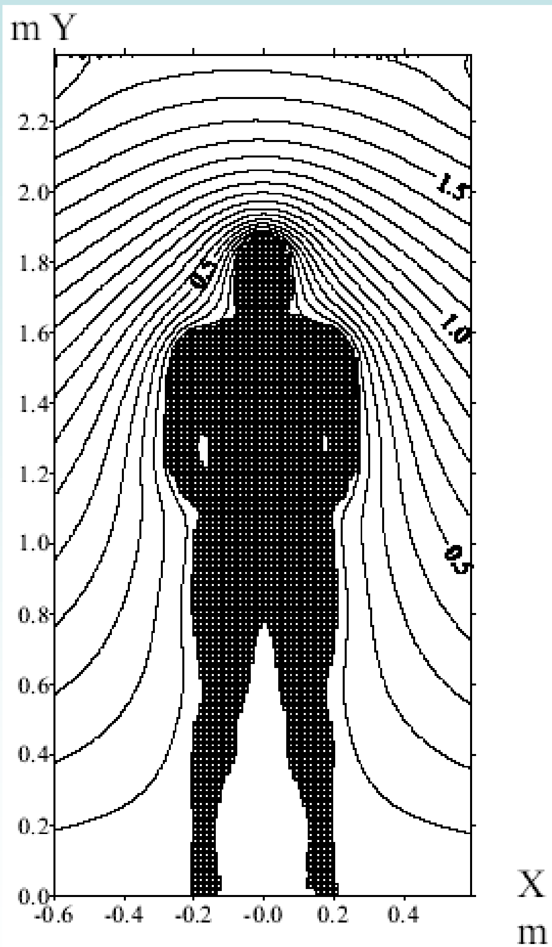


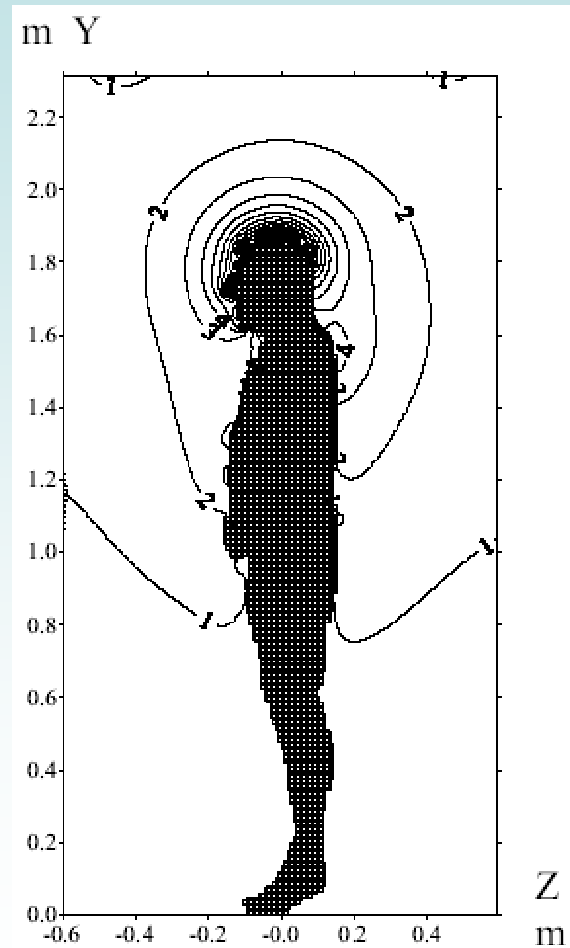


Zones where maximum level of pace voltage on the surface of the ground is equal or more than 100 V/m in short circuit regime

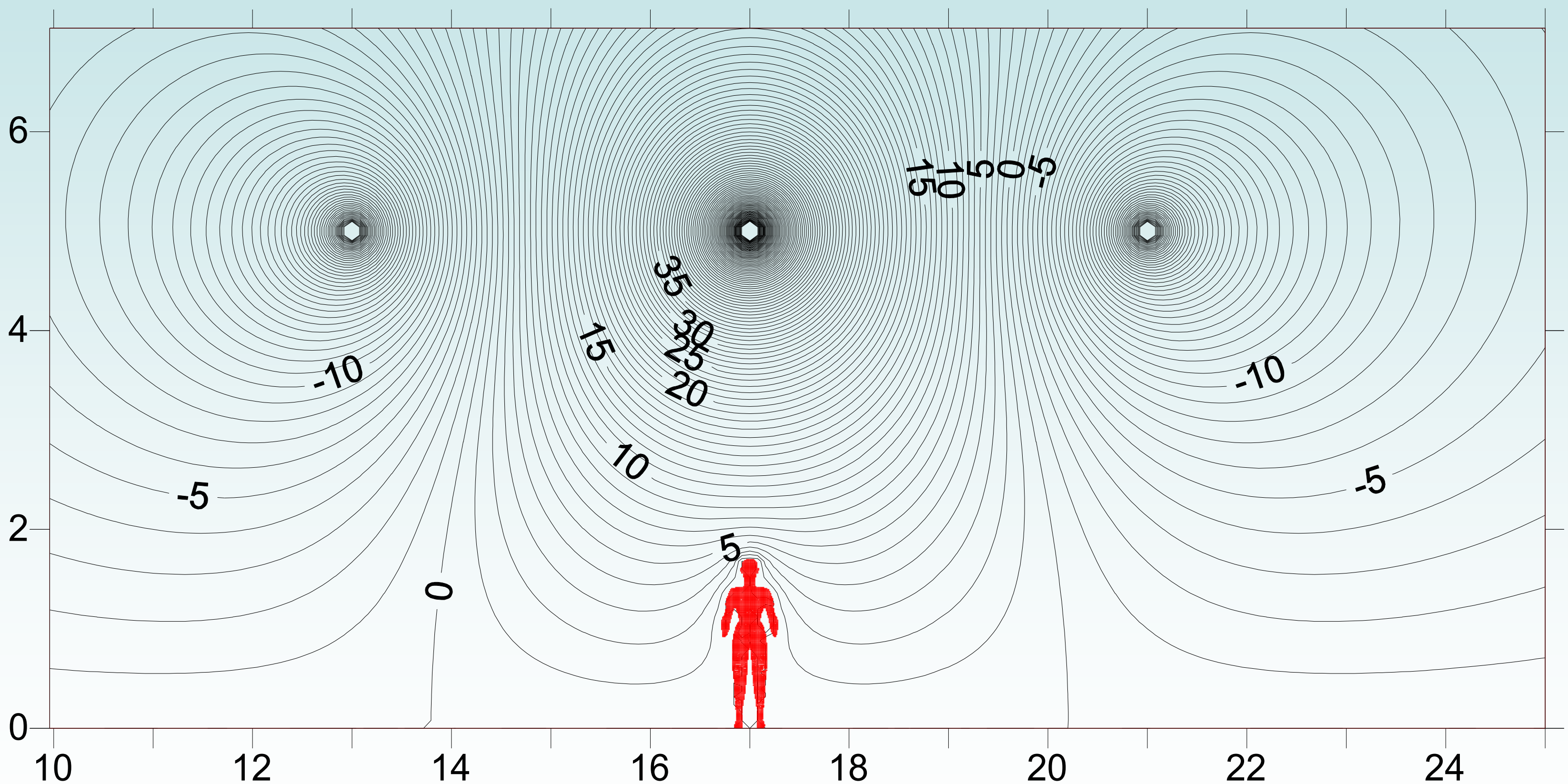


Calculated distribution of the lines of equal potentials (kV) and equal electric field strength (kV/m) around HUGO phantom located in electric field

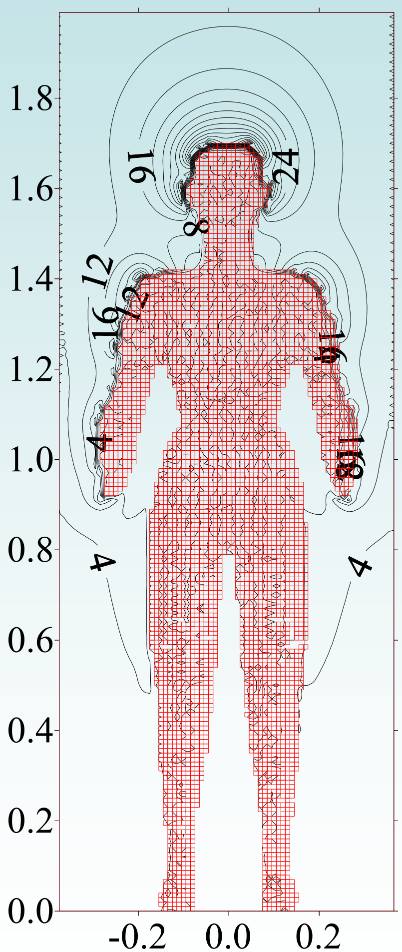


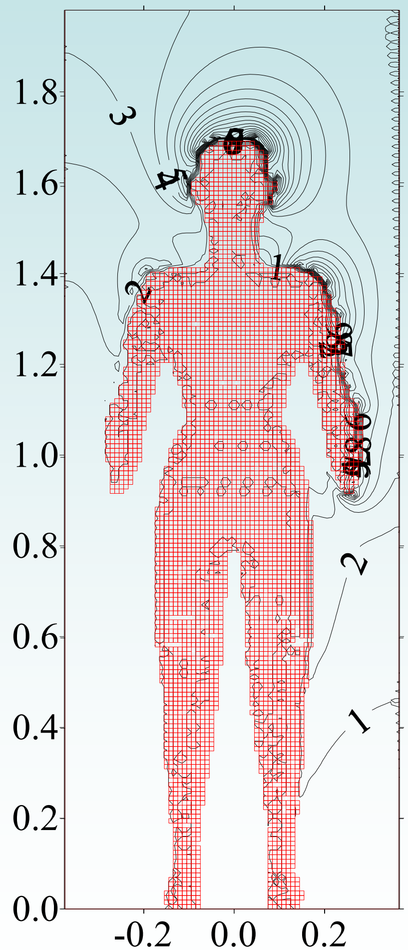


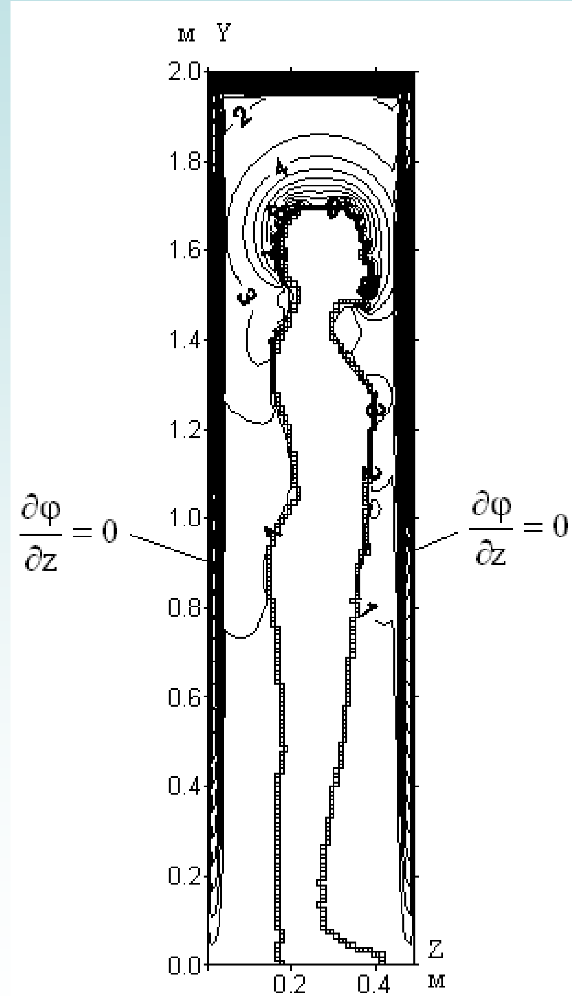
Calculated distribution of the equal potential lines (kV) in the average cross-section Z=const of the human body in the sanitary zone of power transmission line of 110 kV



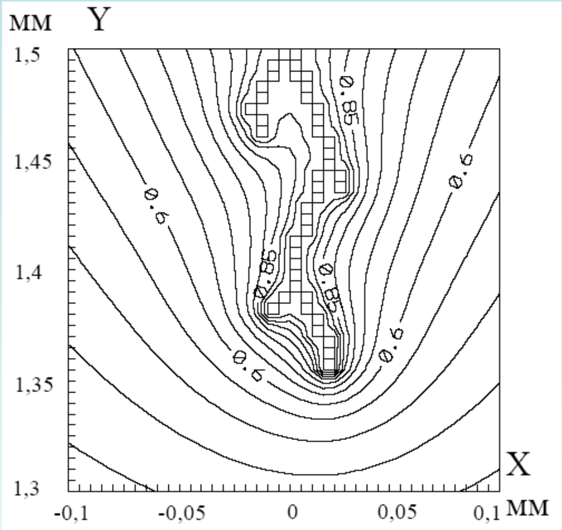
Calculated distribution of the lines of equal electric field strength (kV/m) around a human's body located in electric field

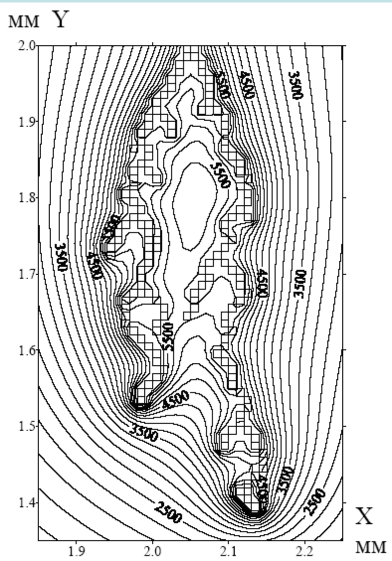


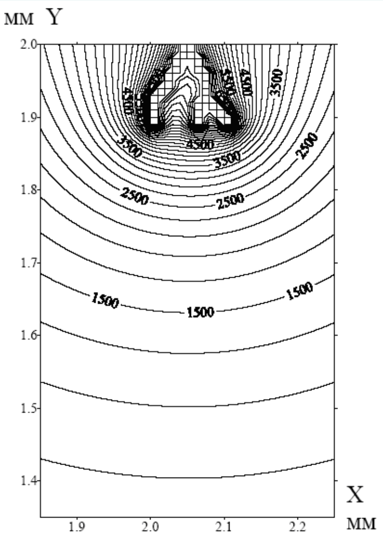


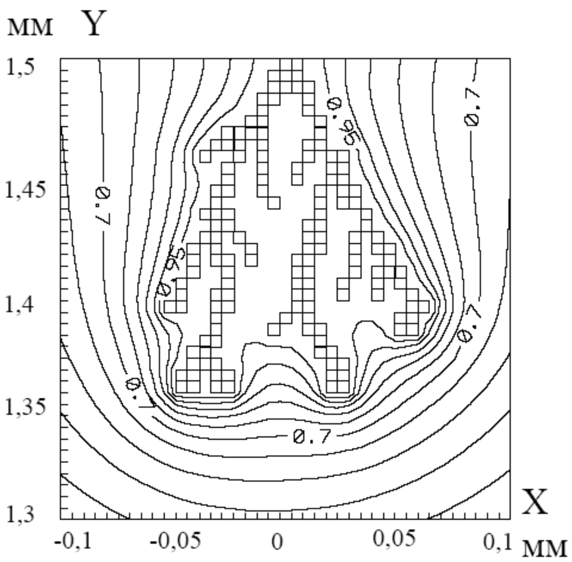


Physical and mathematical modeling of electrical physical processes in polymeric (cable) insulation upon high voltage stress



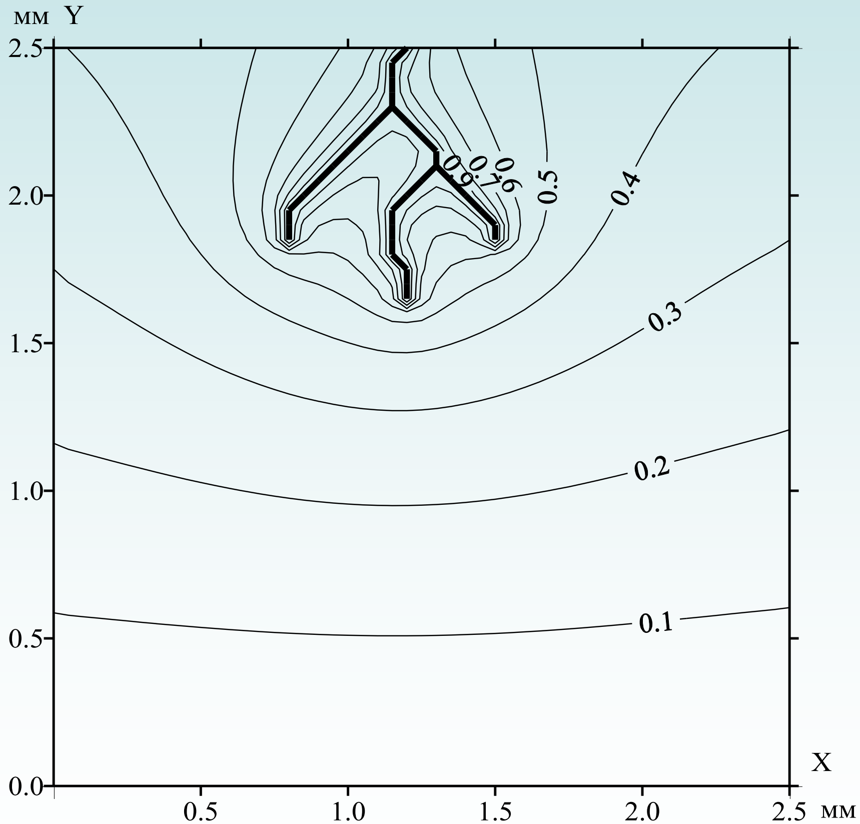




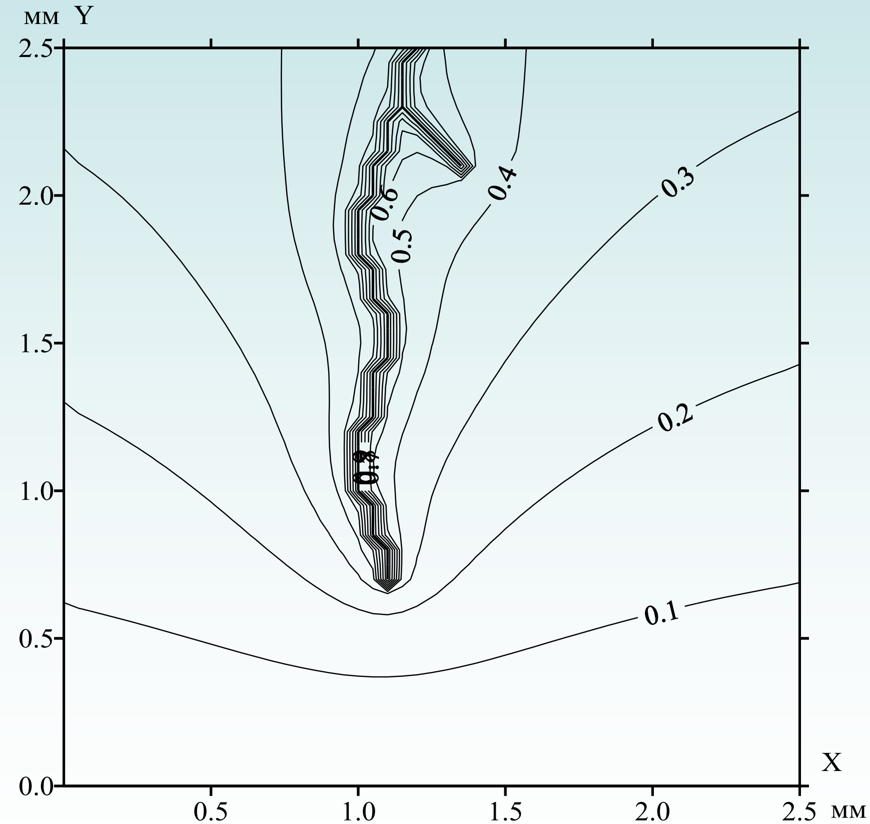


Calculations of electric field distribution in polymeric (cable) insulation upon high voltage stress (lines of equal potentials – kV)

diameter of treeing channels - 10 μm



diameter of treeing channels - 1 μm



Experimental investigation of correlation between treeing shape and PD patterns