Tartu University
Department of Environmental Physics

MEASUREMENTS OF NANOMETER PARTICLE SIZE FRACTION CONCENTRATIONS

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HANNES TAMMET

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CONTENT

INTRODUCTION

The measurements are made during a two-week research visit by Hannes Tammet to Laboratoire de Physique des Décharges (LPD) according to an invitation by Prof. Max Goldman. The period of the visit was from 9 May until 19 May 1995. The research program was including two tasks proposed by Prof. Goldman:

1. Measurement of nanometer particles under HV transmission lines with aim to check hypotheses about generation of the particles when an intensive corona discharge is present on the HV line and the grass canopy under the line is exposed to a strong AC electrical field.

2. Measurement of nanometer particles generated by the corona discharge in a laboratory experiment with aim to confirm the phenomenon of the particle generation and determine the size of the particles.

The measurements reported in the present document are not complete and they should be considered as a part of the complex data. The data about location of field measurement site, the HV lines, the meteorological and air chemical background are recorded by Bernhard Kreissl. The complete data set can be assembled when joining the presented below field measurement data to the data by Kreissl. Similarly, the presented data of laboratory measurements should be joined with the data about dimensions, electrical, ventilation, and chemical regime of laboratory corona discharge reactor by Marie-Pierre Panaget.

The present paper is not a complete scientific report and it should be considered as a working document representing a stage of continuing co-operated research.

INSTRUMENTATION

The measurements were performed using the air ion and nanometer particle electrical mobility and size spectrometer UT-9105 designed by H. Tammet and manufactured in Tartu University. The main unit of the spectrometer includes a second order differential mobility analyzer with flat measuring condenser. The measuring condenser has two simultaneous measurement electrodes: one for higher and the second for lower mobilities. Additionally, the mobility is controlled by the condenser voltage that is scanned to cover the mobility range from 0.004 to 0.5 $cm^2/(V\ s)$ during the one-minute measuring cycle when measuring the particles, or 0.04 to 5 $cm^2/(V\ s)$ when measuring the small atmospheric ions. In the occasion of particle measurement, the main unit is completed by an additional particle charging unit, where the unipolar negative small ions are generated and some amounts of the initially neutral or positive particles are negatively charged as a result of diffusion of ions to particles. The ratio of charged particle number to the total particle number after passing the charging unit was calculated according the theory and numerical results by Hoppel and Frick [Aerosol Sci. Technology **5**:1-21, 1986 and Aerosol Sci. Technology **12**:471-496, 1990] depending on the particle size. The instrument is counting only the charged particles and the total number of particles was restored by the measurement program (see Appendix 1) dividing the measured number to the above ratio. As a result, the total number of particles was recorded independent of their charge. The particle mobilities were converted to the size according the model by Tammet (J. Aerosol Sci. **26**:459-475, 1995).

A notebook computer “Compaq Contura Aero” was used to control the spectrometer, process and record the data. The spectrometer and sensor (temperature, flow rate, air pressure) output signals were conditioned for the computer input by the analog-digital converter UT-

9201 build in Tartu University. The data were recorded as ASCII text files in form shown in the Appendix 2. All equipment could be powered or by a car battery or from 220 V network. As the 220 V power was available everywhere in measurement sites, it was used in all measurements described below.

A sophisticated procedure of signal modulation by means of the controlled input gate was used to suppress the systematic errors and errors caused by the zero level drift of the electrometric amplifier. The measurement control and recording program is attached to the report as Appendix 1. Although all mobilities are scanned during about one minute, as a minimum five one-minute scans is needed to get correct results. Increase in the measurement time follows in decrease in the measurement errors. All measurements were made in the regime of seven or five minute measurement time. The measurement error can be reduced afterwards when averaging the results over several records.

The corona discharge reactor and everything else used in the experiments was the equipment of LPD.

FIELD MEASUREMENTS

The measuring site was prepared and preparatory measurements were started at 10 May. The eleven measurements made in first day have only technical value. They were analyzed after the measurement and used when choosing the optimum measurement regime for following days.

The basic measurements were performed on May 11, 12 and 15. The instrument was placed open on a small cable reel used as a support. Four locations were used:

1. *Standard location*. The instrument is straight under the 400 kV AC line in place where the height of the HV line is minimal. The air input is about 33 cm over the solid ground that is the same as about 10-15 cm over the grass canopy. The air flow through the spectrometer (less than 150 ccm/s) is not disturbing the natural movement of the air. During some part of the measurements a wind-shielding board of the same height as the instrumentation was used. It was not identified any essential change in average measurement results when using the wind shield. The effect of the wind shield was suppressing of the random errors caused by fluctuations of air flow through measuring condenser when exposed to fluctuating wind. During one subperiod a carton box was placed over the instrument to protect the instrument from rain. This period is indicated in the data table (see Appendix 3).

2. *Shifted location*. The shifted location was about 60 m away from the HV line in the place with the similar character of the ground and plantation. Unfortunately, the direction of the wind was from the HV line to the measurement site. It would be necessary to make measurements under the HV line and in some distance windward from the line over the similar ground as below the line. This was not possible because the wind was blowing all days or from the side where the character of the ground was essentially different as under the line and where the measurement was technically obstructed.

3. *Elevated location*. This is the same as standard location, but the instrument is elevated by 90 cm so that the air inlet is about 1 m above the grass canopy.

4. *Tent location*. During a rainy period the instrument was placed in a tent. The tent was located about 10 m leeward from the HV-line and the instrument was placed in distance about 50 cm from the open door of the tent.

11 May from 15:05 until 15:45 the small ion concentration in the standard location was measured. The concentration of both negative and positive ions was about 50 ions per ccm that is about ten times less than average in the undisturbed natural air.

The nanometer particles have been recorded:

11 May from 17:04 until 17:58 in standard location,

11 May from 18:45 until 20:55 in shifted location,

12 May from 14:27 until 16:21 in standard location,

12 May from 17:20 until 19:09 in tent location,

15 May from 14:18 until 15:55 in standard location,

15 May from 16:11 until 17:00 in elevated location,

15 May from 17:22 until 18:27 in standard location.

Some short periods between actual measurements were used for checking of the instrument zero level and noise.

LABORATORY MEASUREMENTS

Measurements of nanometer particle generation by corona discharge in a laboratory reactor were performed from 16 May until 18 May. The air generator and corona discharge reactor were prepared by M.-P. Panaget.

In all measurements the clean and dry synthetic air supplied from a gas bottle was used. The flow rate was controlled and its value was 7.3 l/min in all experiments.

The water vapour was added to the air when bubbling the air in a humidifier through a water-filled vessel. The water in the humidifier was not equipped with temperature stabilizer. In the beginning of the experiment the temperature of the water was equal to the room temperature but as a result of evaporation, the temperature decreased afterwards. It follows the effect, that the humidity increased quickly after switching the air flow through the humidifier and decreased later a little with decrease of the water temperature. To keep the humidity in high level, a makeshift heater was coupled with the container of the water in some experiments. The humidity of air was measured by a capacitive sensor in the output flow of the particle spectrometer. The sensor was not connected to the computer and the values of the relative humidity were recorded manually.

The air was flowing from the bottle through the rotameter and the humidifier to a big reactor (volume about 10 l) where a wire-to-plane corona discharge gap was installed. The air was flowing out from the reactor through a teflon tube to the inlet of the nanometer particle spectrometer. The inner diameter of the tube was about 5 mm and the length about 30 cm. The air flow was maintained by the pressure in the bottle and any air pump was not used.

The particle production by positive corona, negative corona and AC corona in conditions of various humidity was tested in the measurements. In some AC corona measurements a thin polypropylene film was placed on the plain electrode. The schedule of the experiments was as follows:

16 May from 11:00 until 12:16 reconnaissance measurements,

16 May from 14:38 until 15:24 checking of the initial electrical charges of particles,

16 May from 15:45 until 16:45 16 test of the effect of negative corona by humidity about 80%,

17 May from 11:08 until 13:07 study of the effect of negative corona in conditions of varied humidity,

17 May from 13:51 until 15:07 study of the effect of positive corona in conditions of varied humidity,

18 May from 13:06 until 18:14 study of the effect of AC corona with and without polypropylene film in conditions of varied humidity.

DATA

All data are saved in ASCII text logfiles exactly as they are displayed on the computer screen during the measurements. Some fragments of original and averaged logfiles are presented as examples in Appendix 2. The primary results are stored in the third column of every table as the fraction concentrations of the charged particles. The total concentration of particles (fourth column) is a secondary result calculated on the basis of the third column data, Hoppel-Frick model, and empirical calibration of the charging unit.

The logfiles consist lot of information unnecessary in the present research and these files are not convenient in the further analysis, where only fourth column of every new table is used. Therefore, a compact table of particle fraction concentration data was compiled as a result of processing all logfiles. Some logged data corresponding to ion measurements and measurements of technical importance are omitted in the compact table. The compact table is presented as Appendix 3 and as an ASCII text file.

DISCUSSION OF FIELD MEASUREMENTS

A first question was, is there a corona discharge on tops of grass leaves or not? The corona discharge is producing small air ions and these ions should be measurable in the air immediately above the grass canopy. According the measurement 11 May from 15:14 until 15:45 the concentrations as positive as negative small ions (mobility greater than 0.5 $cm^2V^{-1}s^{-1}$) was about 50 ions of one polarity per ccm. The typical value of small ion concentration in natural conditions is about 500 ions per ccm. It follows that the small ion concentration under the HV line is not enhanced as it should be in occasion of corona on the grass but essentially reduced. In occasion of the concentration about 50 ions per ccm, the the vertical ion current density magnitude order is estimated 1 pA/m^2 that is the same as natural atmospheric electric vertical current. It could be concluded that there was no corona discharge on grass leaves during the measurement of 11 May.

The reduction of the small ion concentration under a HV line is an unexpected result and the measurement is yielding an essentially new knowledge. A question was posed after the measurement, how to explain the effect of reduction of small ion concentration. The first hypothesis is that the strong AC electric field is causing enhanced sedimentation of small ions produced by natural ionizing radiations. When neglecting the turbulent mixing of the air, the electric field with order of magnitude 1 kV/m would be required to reduce the small ion concentration until the measured values. A turbulent mixing of the air is counteracting the reduction of the ion concentration. Therefore, the real electric field required to achieve the observed effect, is expected to be several times higher as 1 kV/m.

The measurement of small ion concentration and mobility distribution under a HV line is obstructed by low values of the ion concentration. The ion current in the instrument is close to the electrometric amplifier noise. An averaging of the signals over long time is needed to suppress the noise. The essential information could be obtained my measuring the vertical profile of the small ion concentration and by simultaneous measurement of electric field, vertical current, and coefficient of vertical turbulent diffusion. However, the main aim of the field measurements was to learn the nanometer particles in air and the available time resources were not sufficient to undertake the detailed research of small ions.

The measurements of nanometer particles had no full success. The reason was unfavourable wind direction during all measurement days. An initial idea was to make comparative measurements straight under the HV line and in another location shifted windward from the HV line. The ground surface was homogeneous only in one side of the HV line but the wind was blowing all days from the other side.

The results presented in the Appendix 3 do not allow to draw any definite conclusion about possible enhancement or peculiarities of nanometer particle production under HV line. The nanometer particle average concentration in all measurements is high and the particles are fine when compared with averages for natural environment. However, the deviation from natural average is not big and it fits in the limits of natural variations. It is known, that the nanometer particle generation in nature is enhanced in regions of active vegetation and the actual measurement site was located in a region of active vegetation. A specific source of air pollution that could have some effect on the measurement results was a highway located about one kilometer windward. Due to the short measurement period, it was not possible to learn the dependence of particle concentrations on the wind direction. Therefore, the considerations above are only free speculations.

The essential measurement results are illustrated by Figures 1-4.

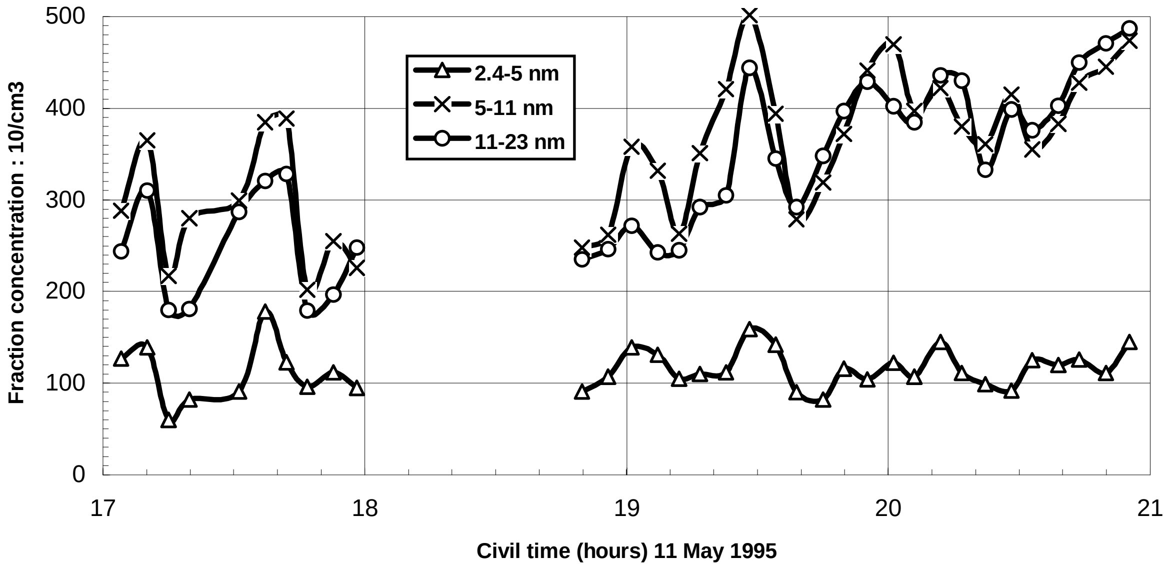

Figure 1. Measurements straight under a HV line (time 17:04–17:58)
and 60 m away from the line (time 18:50–20:55)

Figure 1 is demonstrating the time variation of three joint fractions of nanometer particles straight under the HV line (time 17:04–17:58) and 60 m away from the line (time 18:50-20:58). The natural variability of the particle concentration is quite big and the difference between the first and second time period still remains in limits of natural variations. The relatively high concentration of particles below 10 nm could be explained by natural processes over the field with active vegetation. The main factor of short-time variability of the concentration is obviously the variability of the wind velocity and turbulent vertical exchange of the near-ground air. The correlation with the wind records is a subject of interest and it could be learned later after joining the data bases of particle measurements and simultaneous meteorological measurements.

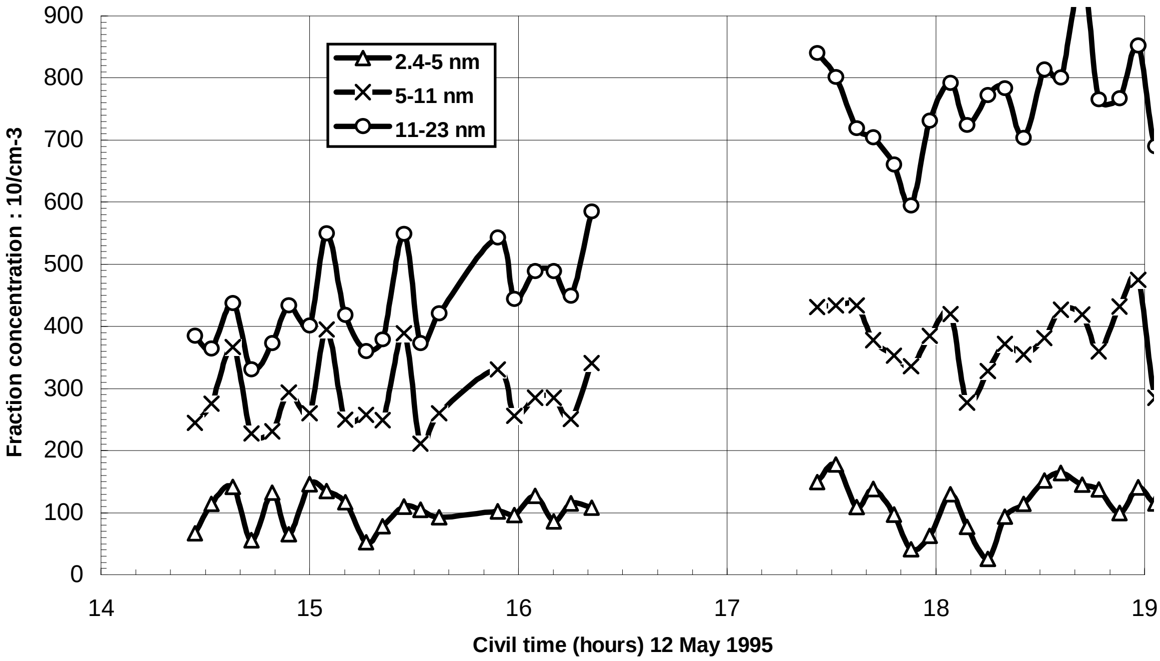

Figure 2. Measurements straight under a HV line
without rain (time 14:27–15:05), during light rain (time 15:10–16:21) and
in tent about 10 m away from the line during light rain (time 17:26–19:03)

The essence of measurements of 12 May is depicted on Figure 2. The character of variations in aerosol fraction concentrations is nearly the same as in measurements of 11 May. The difference is enhanced concentration of particles with diameter above 11 nm. The size distribution observed at 12 May is similar to long-time averages of natural aerosol measurements. The particles of size greater than 11 nm have long age and they are generated in large area measured in many kilometers windward from the measurement site. When the measurements of two days are compared, the measurements of 11 May might be considered as a little exceptional as they are characterized by unusually low average size of particles.

The average size distributions for both days are depicted in Figure 3.

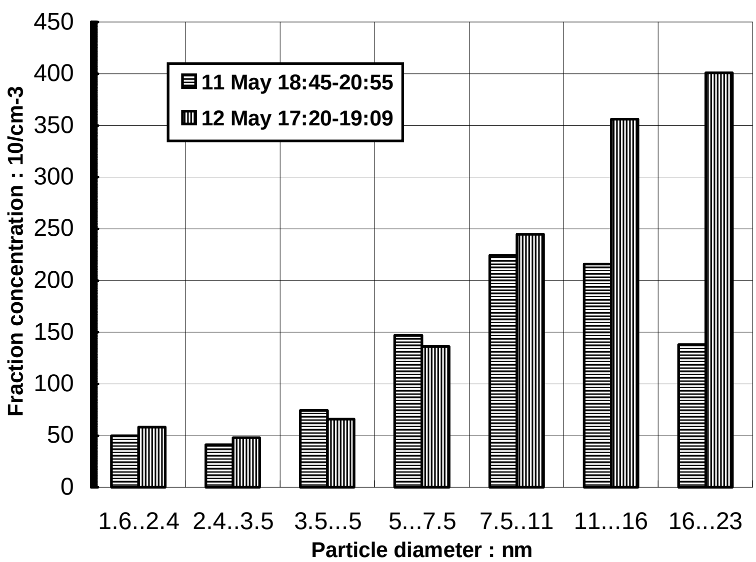

Figure 3. Average size distributions of nanometer particles
according to the measurements of 11 and 12 May 1995.

A factor of special attention at 12 May is the rain. However, the intensity of rain was very low and no big shifts in aerosol concentration was not produced. It seems, that the concentration of bigger particles was increasing by the rain at the same time as the concentration of finest particles remains unaltered. However, the amount of the measurements is too small to draw any reliable conclusion. The analysis of the data could be repeated and the conclusions could be revised after joining the data of simultaneous meteorological measurements (humidity and rain intensity).

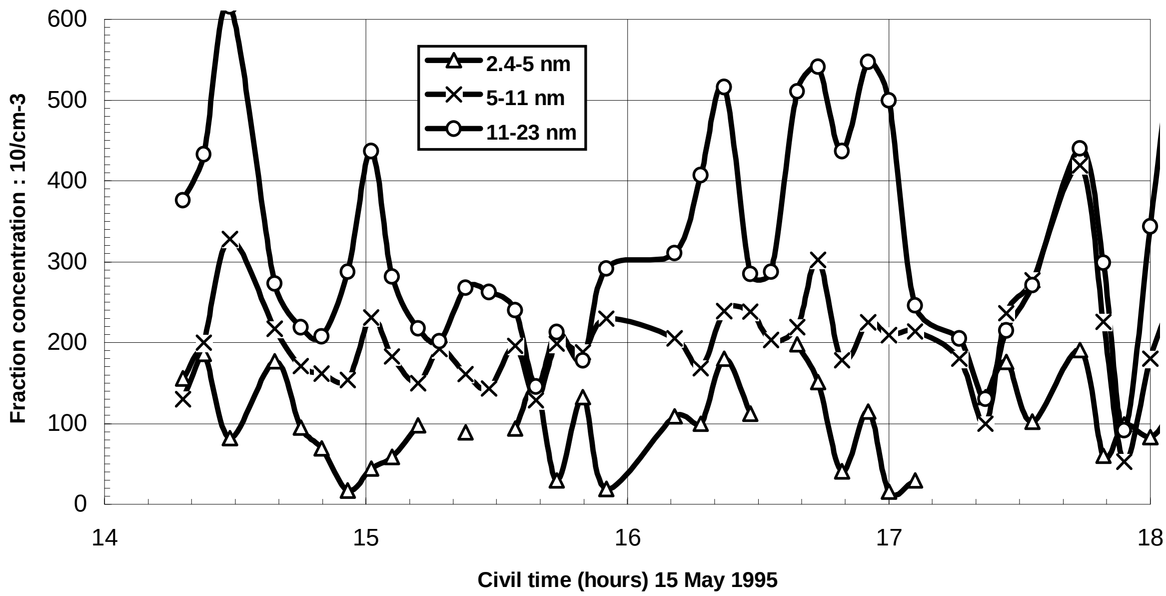

Figure 4. Measurements straight under a HV line
about 10 cm over the grass canopy (time 14:18–15:55 and 17:16–18:05)
and about 100 cm over the grass canopy (time 16:11–17:06).

An experiment to study the vertical profile of the particle concentration directly under the line was performed at 15 May. The essence of results is depicted in Figure 4.

A peculiarity of the measurements of 15 May is enhanced technical noise of finest particle concentration. Therefore, the lower curve in Figure 4 is not reliable and essential part of variations in this curve is originated not by the particle concentration variations rather by the instrumental noise. The role of instrumental noise is decreasing by size and not perturbing the measurements of bigger particles.

The average concentration of bigger nanometer particles is a little enhanced during the measurements in the elevated location of the instrument. However, the deviation is small when compared with the natural time variability of the particle concentration and therefore we cannot draw any reliable conclusion.

An essential technical recommendation based on the performed measurements is: two simultaneously working aerosol spectrometers are required for reliable detection of the local peculiarities of aerosol production near HV lines.

DISCUSSION OF LABORATORY MEASUREMENTS

The prior knowledge obtained by former measurements in LPD (M. Goldman, J.-P. Borra, M.-P. Panaget et al.) was that the corona discharge in clean air is producing very fine particles. The particle production was detected only in humid air. It was known that the AC corona over a polymer-coated plain is forming microscopic nodules on the polymer surface and this process could be considered as an initial stage of airborne particle generation. The present measurements were posed with the aim to confirm the prior knowledge and to study the size distribution of generated particles.

A short preliminary measurement was performed at 16 May 14:38-15:24 to check the electrical charges of the particles by entering the particle spectrometer. The problem is of methodological importance because the measurement program is correctly processing the data only if the deviation of initial charge distribution of the particles from a steady bipolar distribution is not very big. The result was that most of the particles are initially neutral when entering the aerosol spectrometer and the computer program (Appendix 1) can be used for particle measurement without restrictions. Probably, the initially charged particles are sedimented already in the corona reactor and the teflon tube and only the neutral particles are able to reach the spectrometer.

The particle relative size distribution was similar in all experiments. An example is presented in Figure 5. Mainly the finest nanometer particles are generated in the reactor. Most of them have diameter below 3 nm that is typical detection limit of best condensation nucleus counters. Therefore, the electrical mobility technique has no alternatives when studying the generation of particles in corona reactors.

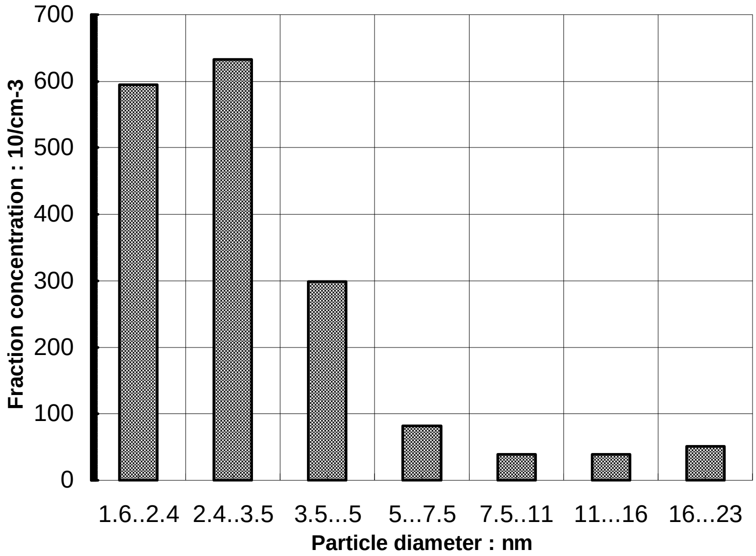

Figure 5. The size distribution of particles generated in the corona discharge reactor. Experiment of 18 May 1995, 16:59-18:14.

The first experiments performed with aim to determine the limit of relative humidity when the particle generation is starting, were unsuccessful. In the dry air no particles were detected. After switching on the humidifier, a big amount of nanometer particles was generated during about ten minutes. Later, the particle concentration was nearly exponentially decreasing independent on variations of the humidity. The effect was qualitatively the same as for negative, positive and AC corona. All attempts to get repeatable results when controlling the corona current and humidity were unsuccessful.

A regularity in particle generation was identified only in the experiments of 18 May. The experiment can be followed according the data table (Appendix 3) where all events are marked. An essence of results is depicted in Figure 6. The measurements were started after adding of some amount of the fresh bidistilled water into the air humidifier at 13:28. The plain electrode was coated with polypropylene film and the AC corona (about 200 μA) was turned on. In the period of 14:00-14:05 the corona current was temporarily turned off and the particle concentration fell down more than ten times (see Appendix 3) showing that there are practically no particles generated in the reactor without corona. When the corona was turned on again, the particle concentration continued decrease without a visible reason. At 14:50 the heating of the water in the humidifier was turned on to increase the humidity. It follows in a small temporary increase in particle generation about 15:10 and quick decrease during the next ten minutes. From 15:27 until 16:48 various experiments were made (the corona wire was replaced and the polymer film was replaced twice, see Appendix 3) but any effect in particle generation was not achieved. About 16:50 some amount of fresh bidistilled water was added to the humidifier and humidifier was switched onto the same regime (without heating) as at 13:28. The result was impressive: the same process of humidity variation has started again as after 13:28. About 17:26 the humidifier was temporarily turned off for few minutes and the polymer film was removed from the reactor. The particle generation power of the reactor was partially restored after the short period when the air flow through the humidifier was stopped. Later, the process was continuing in the same way as in the experiment with polymer film.

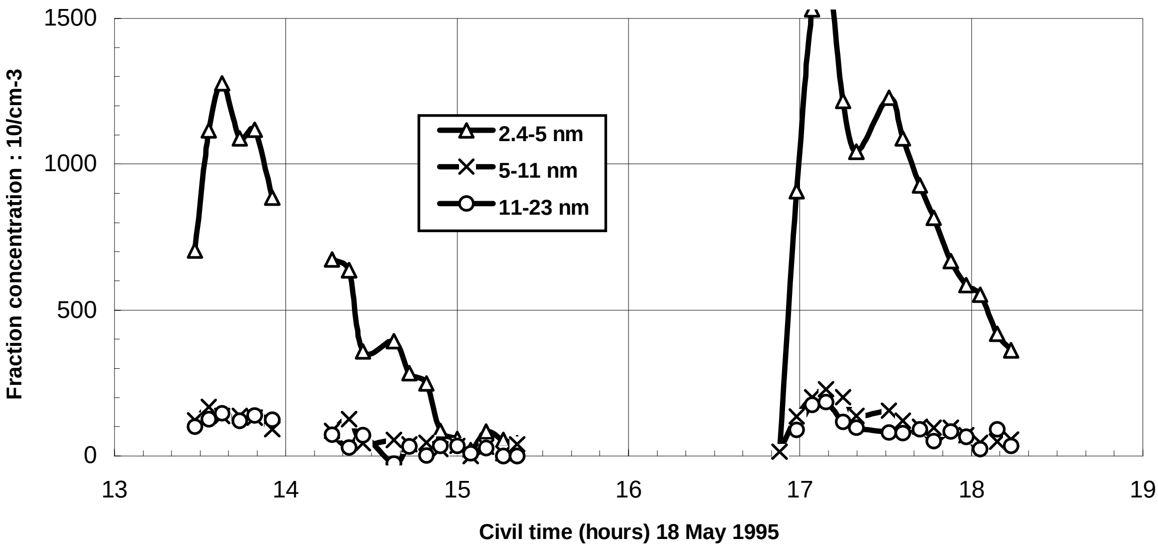

Figure 6. Time variation of aerosol particle concentration in the corona discharge reactor. Water in humidifier is not heated, RH ≈ 50%.

The processes of nearly exponential decrease of the particle generation have occurred after every adding of the water into the humidifier and only in these occasions. The time of decrease of the particle concentration was shorter in experiments where the water was heated. An example of the process in occasion of the warm water is shown in Figure 7.

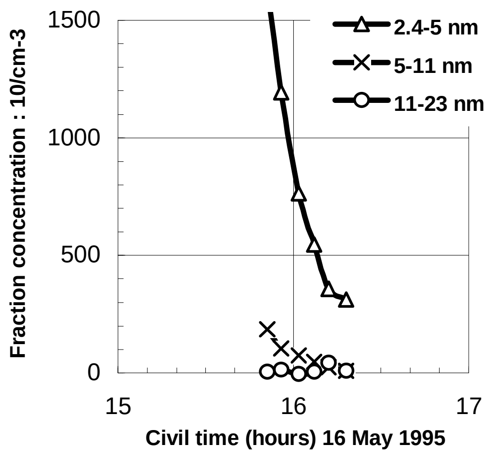

Figure 7. Time variation of aerosol particle concentration in the corona discharge reactor. Water in humidifier is heated, RH ≈ 80%.

Some preliminary conclusions from the experiments are:

- The humidifier without corona discharge does not generate the particles.
- The particle generation occurs only after adding some fresh water into the humidifier.
- The decay time of the particle generation is depending on the temperature of the water.
- The expected effects of polarity of the corona discharge and the polymer film on the particle generation were not visible in the performed experiments.

A hypothesis can be posed that the bidistilled water contains a volatile admixture (the standard distillation process is not cleaning water from volatile admixtures). The admixture reacts with the corona products (ozone?) and forms an involatile compound that could be the substance of the detected nanometer particles. The performed experiments are not sufficient to draw conclusions about the mechanism of the reactions and about a possible role of ions in these reactions. In the further research, the first task could be to learn the chemical composition of the water used in the humidifier. A gas chromatograph can be recommended as the instrument for analysis of volatile admixtures in the water.

ACKNOWLEDGEMENTS

The measurements are performed as co-operation between Laboratoire de Physique des Décharges and Tartu University. The present measurement project was initiated by Prof. Max Goldman and supported by CNRS and SUPELEC. The facilities of experiments were prepared by Bernhard Kreissl and Marie-Pierre Panaget. The field measurements were performed together with Bernhard Kreissl and the laboratory experiments together with Marie-Pierre Panaget. The discussions with Max Goldman, Alice Goldman and Svein Reidar Sigmond were the source of ideas and suggestions for research.

Appendix 1

COMPUTER MEASURING PROGRAM

(Turbo Pascal)

```
Program UT9105E; {2 second modulation}

{$M 65520,0,65520}

Uses DOS, CRT;

Function UT9201 : word;
   Begin ASM
      {ettevalmistus}          cli
      {kella programmeerimine}  mov al,64;  out 97,al
                                mov al,176; out 67,al
                                mov al,255; out 66,al
                                out 66,al
      {ADM avamine}             mov dx,890 {pordi aadress}
                                mov al,1;   out dx,al
      {kella kaivitus}          mov al,65;  out 97,al
      {ADM signaali ootamine}   mov dx,889 {pordi aadress}
                            @1: in al,dx
                                and al,128
                                jz @1
      {kella lugemine}          mov al,64;  out 97,al
                                in al,66;   mov bl,al
                                in al,66;   mov bh,al
                                mov @Result,bx
      {ADM sulgemine}           mov dx,890 {pordi aadress}
                                mov al,3;   out dx,al
      {lopp}                    sti
         END; {of ASM}
   End;

{Null = 49975, -max = null - 18510, +max = null + 15555}

Type UT9201output = array [1..16] of word;

Procedure Measure (channels : integer; var result : UT9201output);
   Var i : integer;
   Begin
   port [890] := 2; {reset on}
   delay (1);       {paus 1 ms}
   port [890] := 3; {reset off}
   for i := 1 to channels do begin
      delay (25);   {25 ms puhul on max-ylekostvusviga < 1,
                     15 ms => 1.5, 10 ms => 3.5, 5 ms => 7,
                     + pingel on max-viga nimetatust 1/3}
      result [i] := UT9201;
   end;
   End;

Function MechMob                                    { air     nitrogen}
      {velocity/force} (GasMass         {u},    {28.96    28.02    }
      {   m/(fN s)   }  Polarizability  {nm3}, { 0.00171  0.00174}
                        VisCon1         {nm},   { 0.3036   0.2996 }
                        VisCon2         {K},    {44       40      }
                        VisCon3,                { 0.8      0.7    }
                        Pressure        {mb},
                        Temperature     {K},
                        ParticleDensity {g/cm3},
                        ParticleCharge  {e},
                        MassDiameter    {nm} : real) : real;
   function Omega11 (x : real) : real;  {ê(1,1)* (T*) for ì-4 potential}
      var p, q : real;                  {elastic-specular collisions}
      begin
      if x > 1 then Omega11 := 1 + 0.106 / x + 0.263 / exp ((4/3) * ln (x))
      else begin p := sqrt (x); q := sqrt (p);
           Omega11 := 1.4691 / p + 0.059 - 0.341 / q + 0.181 * x * q end;
      end;
   const a = 1.2; b = 0.5;  c = 1;
       ExtraDistance = 0.115 {nm}; TransitionDiameter = 2.48 {nm};
   var GasDiameter, MeanVelocity, Viscosity, FreePath, DipolEffect,
       DeltaTemperature, CheckMark, ParticleMass, CollisionDistance,
       Kn, Omega, s, x, y : real;
   begin
      Viscosity  {æPaús} := 0.02713 * sqrt (GasMass * Temperature) /
         sqr (VisCon1 * (1 + exp (VisCon3 * ln (VisCon2 / Temperature))));
      MeanVelocity {m/s} := 145.5 * sqrt (Temperature / GasMass);
      FreePath  {nm} := (166251 * Viscosity * Temperature) /
                                (GasMass * Pressure * MeanVelocity);
      ParticleMass {u} := 315.3 * ParticleDensity *
                                 exp (3 * ln (MassDiameter));
      DeltaTemperature := Temperature;
      repeat
         CheckMark := DeltaTemperature;
         GasDiameter {nm} := VisCon1 *
            (1 + exp (VisCon3 * ln (VisCon2 / DeltaTemperature)));
         CollisionDistance {nm} := MassDiameter / 2 + ExtraDistance +
                                   GasDiameter / 2;
         DipolEffect := 8355 * ParticleCharge * Polarizability /
                        sqr (sqr (CollisionDistance));
         DeltaTemperature := Temperature + DipolEffect;
      until abs (CheckMark - DeltaTemperature) < 0.01;
      if ParticleCharge = 0 then Omega := 1
         else Omega := Omega11 (Temperature / DipolEffect);
```

```
      Kn := FreePath / CollisionDistance;
      if Kn < 0.03 {underflow safe} then y := 0 else y := exp (-c / Kn);
      x := (273.15 / DeltaTemperature) *
           exp (3 * ln (TransitionDiameter / MassDiameter));
      if      x > 30 {overflow safe} then s := 1
      else if x < 0.001 then {underflow safe} s := 1 + (2.25 / (a + b) - 1)
      else s := 1 + exp (x) * sqr (x / (exp (x) - 1)) * (2.25 / (a + b) - 1);
      MechMob :=
         ((2.25 / (a + b)) / (Omega + s - 1)) *
         sqrt (1 + GasMass / ParticleMass) *
         (1 + Kn * (A + B * y)) /
         (6 * PI * Viscosity * CollisionDistance);
   end;
   {Electrical mobility = 1.602 * ParticleCharge * Mobility}
   {     cmý/(Vús)                        e        m/(fNús)}

CONST Nsec = 23; {Doubleseconds, 4 + 15 + 2*23 = 65 second period}
      DiaLimit = 1; {for calculating of neutral particle concentrations}
      K0 : array [1..2] of real = (0.0275, 0.0110);
           {for F = U, open gate 5 or gates 4+5+6}
      Factor = 0.182; {ratio of G peak to flowrate}
      GigaOhm : array [1..2] of real = (324, 338);
      VoltPerDigit : array [1..8] of real =
                    (19145E-8, 18975E-8, 6567E-8, 6560E-8,
                      6563E-8,  6567E-8, 6590E-8, 6569E-8);
      NtF = 1E9; {red ionizer 60 V}
      TransferCorrection = 1.0;

VAR Gate, Relay, Polarity, Bridge, {spectrometer controls}
    OldPolarity : byte;
    HotCelsius, ADCzero, PowerVolt,
    Celsius,  Millibar,  FlowRate,
    CelsiusS, MillibarS, FlowRateS,
    Gain, Nt : real;
    Signal : array [1..2] of real;
    Data2, Data1, Data,
    Mobility, Spectrum : array [1..2, 0..99] of real;
    UpperMob, UpperDia, Fraction, Total : array [0..55] of real;
    Nfr, kNt, TabNum : integer;
    Directory : string;
    FileName : string [12];
    Date : string;
    Time : array [1..2] of string;
    Stop, Break, Manual : boolean;
    Gates, Nmin, Synchro : integer; {1 or 3}

Function Diameter (K : real) : real; {nm}
    Var c, d, B, test : real;
                    n : integer;
    Begin
    c := 300; n := 0; B := 0.624 * K;
    repeat
       n := n + 1;
       d := (0.6 + sqrt (0.36 + 200 * c * B)) / (c * B) - 0.3;
       test := MechMob (28.96, 0.00171, 0.3036, 44, 0.8,
                    Millibar, 273 + Celsius, 2, 1, d);
       c := (1.2 / (d + 0.3) + 200 / sqr (d + 0.3)) / test;
    until (abs (test / B - 1) < 0.001) or (n = 99);
    if n < 99 then Diameter := d else Diameter := 0;
    end;

Procedure Control;
   Begin port [888] := Gate + Relay + Bridge End;
   {GateOpen = 1
     RelayPlus = 2
      RelayMinus = 4
     BridgePowerOn = 8}

Procedure Initialize; {Result = ADCzero}
   Var i : integer; r : UT9201output;
   Begin
   writeln ('INITIALIZATION');
   ADCzero := 0;
   for i := 1 to 25 do begin
      Measure (8, r);
      ADCzero := ADCzero + r [7];
      ADCzero := ADCzero + r [8];
   end;
   ADCzero := ADCzero / 50;
   End;

Procedure RestorePrinter;
   Begin port [888] := 0; port [889] := 7; writeln End;

Procedure GateClosed;     Begin Gate := 0; Control End;
Procedure GateOpen;       Begin Gate := 1; Control End;
Procedure Plus;           Begin Polarity := 2 End;
Procedure Minus;          Begin Polarity := 4 End;
Procedure RelayOff;       Begin Relay := 0; Control End;
Procedure RelayOn;        Begin Relay := Polarity; Control End;
Procedure BridgePowerOff; Begin Bridge := 0; Control End;
Procedure BridgePowerOn;  Begin Bridge := 8; Control End;

Procedure WaitSecond;
   Var h, m, s, t, x : word;
   Begin
   gettime (h, m, s, x);
   repeat gettime (h, m, t, x);
   until t <> s;
   End;
```

```
Procedure MeasureSecond (var times : integer);
   {Result = Signal [1..2] on electrometer, Volt}
   Var h, m, s, t, x,
                a, b,
      la, ha, lb, hb : word;
                   r : UT9201output;
              sa, sb : real;
   Begin
   gettime (h, m, t, x);
   repeat gettime (h, m, s, x) until s <> t;
   repeat gettime (h, m, s, x) until x > 30;
   Measure (2, r); times := 1;
   a := r [1]; b := r [2];
   la := a; ha := a; lb := b; hb := b; sa := a; sb := b;
   repeat
      Measure (2, r); times := times + 1;
      sa := sa + r [1]; sb := sb + r [2];
      if r [1] < la then la := r [1];
      if r [1] > ha then ha := r [1];
      if r [2] < lb then lb := r [2];
      if r [2] > hb then hb := r [2];
      gettime (h, m, t, x);
   until t <> s;
   Gate := 1 - Gate; Control;
   if times < 3 then begin sa := sa / times; sb := sb / times end
   else begin
      sa := ((sa - la) - ha) / (times - 2);
      sb := ((sb - lb) - hb) / (times - 2);
   end;
   Signal [1] := VoltPerDigit [1] * (sa - ADCzero) / Gain;
   Signal [2] := VoltPerDigit [2] * (sb - ADCzero) / Gain;
   End;

Procedure MeasureSensors (seconds : integer);
   {Results: corrected ADCzero, Celsius, HotCelsius,
                    PowerVolt, Millibar, FlowRate}
   Var i, n : integer; r : UT9201output;
       c, h, v, b, x, z : real;
       hh, mm, ss, tt, xx : word;
       q : char;
   Begin
   n := 0; c :=0; h := 0; v := 0; b := 0; x := 0;
   for i := 1 to seconds do begin
      gettime (hh, mm, ss, xx);
      repeat
         Measure (8, r); n := n + 1;
         c := c + r [3]; h := h + r [4];
         v := v + r [5]; b := b + r [6];
         x := x + r [7]; x := x + r [8];
         gettime (hh, mm, tt, xx);
      until tt <> ss;
      if keypressed then begin
         q := readkey;
         Stop := q = 's';
         Break := q = 'x';
      end;
      if Break then exit;
   end;
   ADCzero    := (4 * ADCzero + x / n) / 6; z := n * ADCzero;
      Celsius := VoltPerDigit [3] * 100 * (c - z) / n -0.64;
   HotCelsius := VoltPerDigit [4] * 100 * (h - z) / n;
   PowerVolt  := VoltPerDigit [5] * 23.16 * (v - z) / n;
   Millibar   := VoltPerDigit [6] * 250 * (b - z) / n + 875;
   x := HotCelsius - Celsius;
   if x > 12 then FlowRate := 33 else
   FlowRate := (127000 / (Millibar * exp (0.7 * ln (273 + Celsius))))
            * (100000 / (x * x * x) - 45);
   if FlowRate < 33 then FlowRate := 33;
   Celsius := Celsius - 666 / (FlowRate * sqrt (sqrt (FlowRate)));
   End;

Procedure NewDate (var ymd : string);
   Var a, b, c, d : word;
                s : string [4];
   Begin
   getdate (a, b, c, d);
   str (a, s); ymd := copy (s, 3, 2);
   str (1000 + b, s); ymd := ymd + copy (s, 3, 2);
   str (1000 + c, s); ymd := ymd + copy (s, 3, 2);
   End;

Procedure NewTime (var dm : string);
   Var a, b, c, d : word;
                s : string [4];
   Begin
   gettime (a, b, c, d);
   str (1000 + a, s); dm := copy (s, 3, 2) + ':';
   str (1000 + b, s); dm := dm + copy (s, 3, 2);
   End;

Procedure MeasurePeriod;
   Var i, k, n, ab, first : integer;
                        z : char;
   Begin
   CelsiusS := 0; MillibarS := 0; FlowrateS := 0;
   for ab := 1 to 2 do for i := 1 to Nsec do begin
      Spectrum [ab, i] := 0;
      Data1 [ab, i] := 0; Data [ab, i] := 0;
   end;
```

```
   If Polarity = OldPolarity then first := 1 else first := 0;
   for k := first to Nmin do begin
      GateClosed;
      WaitSecond; RelayOn;
      if Manual then writeln ('CHARGING:', k);
      WaitSecond; BridgepowerOn;
      MeasureSensors (15);
      WaitSecond; RelayOff; BridgePowerOff;
         if k > 0 then begin
            CelsiusS  := CelsiusS  + Celsius;
            MillibarS := MillibarS + Millibar;
            FlowRateS := FlowRateS + FlowRate;
         end;
         if k mod 2 = 0 then GateOpen;
         if Manual then begin
            write ('ADC0 = ', ADCzero:3:0, PowerVolt:8:2, ' V   ',
                    FlowRate:3:0, ' cm3/s   ', Celsius:3:1, ' C  ',
                    Millibar:3:1, ' mb   ');
            if Polarity = 2 then write ('+') else write ('-');
            if k mod 2 = 1 then  write ('closed')
                           else  write ('open');
            writeln (k:4, '/', Nmin);
            writeln ('sec   n    A..    .A.    ..A       B..    .B.    ..B');
         end;
         if k = 2 then begin NewDate (Date); NewTime (Time [1]) end;
      WaitSecond;
      for i := 1 to Nsec do begin
         MeasureSecond (n);
         if Manual then write (i:3, n:4);
         for ab := 1 to 2 do begin
            Data2 [ab, i] := Data1 [ab, i];
            Data1 [ab, i] := Data  [ab, i];
            Data  [ab, i] := Signal [ab];
            if (k = 1) or (k = Nmin) then Signal [ab] := Signal [ab] / 2;
            if k > 0 then Spectrum [ab, i] := Spectrum [ab, i] +
               (1 - 2 * (k mod 2)) * Signal [ab];
            if Manual then write (10000 * Data2 [ab, i] :7:0,
                                  10000 * Data1 [ab, i] :7:0,
                                  10000 * Data  [ab, i] :7:0, '   ');
         end;
         if Manual then writeln;
         if keypressed then begin
            z := readkey;
            Stop := z = 's';
            Break := z = 'x';
         end;
         if Break then exit;
      end;
      if k = Nmin - 1 then NewTime (Time [2]);
   end;
   End;

Procedure CalculateSpectrum;
   {Mobility : cm2/Vs,
    Spectrum : e/cm3 for fractions with relative width
                     1.25 (gate 5) or 2 (gates 4-6)}
   Var ab, i : integer;
           U : real;
           x : array [1..99] of real;
   Begin
   Celsius  := CelsiusS  / Nmin;
   Millibar := MillibarS / Nmin;
   Flowrate := FlowrateS / Nmin;
   for ab := 1 to 2 do begin
      for i := 1 to Nsec do begin
         U := 552 * exp (-2 * i / (10 + i / 250));
         Mobility [ab, i] := K0 [ab] * FlowRate / U;
         Spectrum [ab, i] := TransferCorrection * (Polarity - 3) *
                             (Spectrum [ab, i] / (Nmin - 1)) /
                             (GigaOhm [ab] * 1.602E-10 * Factor * FlowRate);
      end;
      Spectrum [ab, 0] := 2 * Spectrum [ab, 2] - Spectrum [ab, 4];
      Spectrum [ab, Nsec + 1] := 2 * Spectrum [ab, Nsec - 1] -
                                     Spectrum [ab, Nsec - 3];
      for i := 1 to Nsec do x [i] := Spectrum [ab, i] -
                                     Spectrum [ab, i - 1] / 2 -
                                     Spectrum [ab, i + 1] / 2;
      for i := 1 to Nsec do Spectrum [ab, i] := (2 * (i mod 2) - 1) * x [i];
   end;

   End;

Procedure CorrectAdsorption;
   Var i, ab : integer;
           c : real;
   Begin
   c := 12.6 / exp (0.615 * ln (FlowRate));
   for ab := 1 to 2 do for i := 1 to Nsec do
   Spectrum [ab, i] :=
   Spectrum [ab, i] / (1 - c * exp (0.69 * ln (Mobility [ab, i])));
   End;


Procedure MakeFractions;
   {given: Nsec, Gates, Mobility, Spectrum,
     make: Nfr, UpperMob, UpperDia, Fraction}
   Var minmob, maxmob, lomob, himob,
                r, fr, w, fb, fu : real;
                        ab, i, j : integer;
         weight : array [1..55] of real;
```

```
   Begin
      minmob := Mobility [2, 1]; maxmob := Mobility [1, Nsec];
      if Gates = 1 then
         begin r := exp (ln (10) / 10); himob := sqrt (10) end
      else begin r := 2; himob := 4 end;
      while himob > maxmob * sqrt (sqrt (r)) do himob := himob / r;
      lomob := himob; Nfr := -1;
      while lomob > minmob / sqrt (sqrt (r)) do begin
         lomob := lomob / r; Nfr:= Nfr + 1 end;
      UpperMob [0] := lomob * r;
      for i := 1 to Nfr do begin
         UpperMob [i] := Uppermob [i-1] * r;
         Fraction [i] := 0;
         weight [i] := 0;
      end;
      for ab := 1 to 2 do for i := 1 to Nsec do begin
         fr := ln (Mobility [ab, i] / UpperMob [0]) / ln (r);
         j := trunc (fr + 1); {calculated number of fraction}
         if (j > 0) and (j <= Nfr) then begin
            w := 1 - abs (fr + 0.5 - j); {internal weight}
            if ab = 1 then w := w * i else w := w * (Nsec + 1 - i);
            weight [j] := weight [j] + w;
            Fraction [j] := Fraction [j] + w * Spectrum [ab, i];
         end;
      end;
      for i := 1 to Nfr do begin
         Fraction [i] := Fraction [i] / weight [i];
         if Gates = 1 then Fraction [i] := 1.036 * Fraction [i];
      end;
      for i := 0 to Nfr do UpperDia [i] := Diameter (UpperMob [i]);
      for i := 1 to Nfr do begin
         fb := 0.0036 * exp (1.4 * ln (UpperDia [i] * sqrt (r)));
         fu := 3.4E-9 * exp (1.5 * ln (UpperDia [i] * sqrt (r)));
         if UpperDia [i] < DiaLimit then Total [i] := 0
            else Total [i] := (1.5 + 1 / (fb + fu * Nt)) * Fraction [i];
      end;
   End;

Procedure PrintSpectrum; {to screen and file}
   Var k, i : integer;
         f : text;
     sf, st : real;
   Begin
   for k := 1 to 2 do begin
      if k = 1 then begin assigncrt (f); rewrite (f) end
      else begin assign (f, FileName); append (f) end;
      writeln (f);
      write (f, '   cm2/Vs        e/cm3   1/cm3       d:nm       ');
      write (f, FileName);
      for i := length (FileName) to 12 do write (f, ' ');
      writeln (f, TabNum:3);
      sf := 0; st := 0;
      writeln (f, '============================================    ', Date);
      for i := 1 to Nfr do begin
         write (f, UpperMob [i-1]:5:3, UpperMob [i]:7:3, Fraction [i]:10:0);
         if (UpperDia [i] < DiaLimit) or (Polarity = 2)
            then write (f, '      -')
            else write (f, Total [i]:8:0);
         write (f, UpperDia [i-1]:8:2, UpperDia [i]:6:2, '    ');
         if i = 1 then write (f, Time [1], '-', Time [2]);
         if i = 2 then begin
            write (f, 'Polarity ');
            if Polarity = 2 then write (f, '+') else write (f, '-');
         end;
         if i = 3 then begin
            write (f, 'Charging ');
            if Nt = 0 then write (f, 'natural')
                      else write (f, Nt/1E6:5:2, 'E6');
         end;
         if i = 4 then write (f, 'F =', FlowRate:5:0, ' cm3/s');
         if i = 5 then write (f, 'T =', Celsius:5:1, ' C');
         if i = 6 then write (f, 'p =', Millibar:5:0, ' mb');
         writeln (f);
         sf := sf + Fraction [i];
         st := st + Total [i];
      end;
      write (f, '==========================================    U =');
      writeln (f, PowerVolt:5:1, ' V');
      write (f, UpperMob [0]:5:3, UpperMob [Nfr]:7:3, sf:10:0);
      if Polarity = 2 then write (f, '      -') else write (f, st:8:0);
      write (f, UpperDia [0]:8:2, UpperDia [Nfr]:6:2);
      if k = 1 then write (f, '    BREAK = (x) !');
      writeln (f); writeln (f);
      close (f);
   end;
   TabNum := Tabnum + 1;
   End;

Procedure Measurement;
   Var hh, h, m, s, t : word;
   Begin
   gettime (hh, m, s, t);
   if Synchro * (m + 1.0833 * (Nmin + 1)) > 59 then
      repeat gettime (h, m, s, t) until h <> hh;
   MeasurePeriod;
   if Break then exit;
   CalculateSpectrum;
   CorrectAdsorption;
   Nt := kNt * NtF / FlowRate;
   MakeFractions;
```

```
   PrintSpectrum;
   End;

var c : char;
    k : integer;
    f : text;

BEGIN
textmode (259);
Gate := 0; Relay := 0; Bridge := 0; Control;
Polarity := 0; Break := false; TabNum := 1;
repeat
   write ('UT-9105             How many open gates (1 or 3) : ');
   readln (Gates);
until Gates in [1, 3];
repeat
   write ('                        Amplifier gain (1 or 10) : ');
   readln (Gain);
until (Gain = 1) or (Gain = 10);
repeat
   write (' Unipolar 100-200 cm3/s regime off (0) or on (1) : ');
   readln (kNt);
until kNt in [0, 1];
repeat
   write ('                           Directory for logfile : ');
   readln (Directory);
   {$I-} chdir (Directory); k := IOresult; {$I+}
   if k <> 0 then writeln ('Cannot find!');
until k = 0;
repeat
   write ('                                Name for logfile : ');
   readln (FileName);
   {$I-} assign (f, FileName); reset (f); k := IOresult; {$I+}
   if k <> 0 then begin assign (f, FileName); rewrite (f); end
   else repeat
         write ('It exists. Choose another name (0) or append (1) : ');
         readln (k);
   until k in [0, 1];
   close (f);
until k <> 0;
Initialize;
repeat
   writeln;
   Break := false; Stop := false;
   OldPolarity := Polarity;
   repeat
      write ('    Regime automatic (2), manual (1) or exit (0) : ');
      readln (k);
   until k in [0, 1, 2];
   if k > 0 then repeat
      write ('    Minutes per period  (3, 5, 7, 9, ..., 55, 57 : ');
      readln (Nmin);
   until (Nmin in [3..57]) and (Nmin mod 2 = 1);
   if k = 1 then begin
      Manual := true; Synchro := 0;
      write ('                             Polarity (+) or (-) : ');
      repeat c := readkey until c in ['+', '-'];
      writeln (c);
      if c = '+' then Plus else Minus;
      writeln; writeln ('REMEMBER: BREAK = (x) !'); writeln;
      Measurement;
   end;
   if k = 2 then begin
      Manual := false;
      write ('            Polarity (+), (-) or alternative (a) : ');
      repeat c := readkey until c in ['+', '-', 'a'];
      writeln (c);
      if c = '+' then Plus else Minus;
      repeat
         write ('        Hourly synchronization off (0) or on (1) : ');
         readln (Synchro);
      until Synchro in [0, 1];
      writeln; writeln ('REMEMBER: STOP = (s), BREAK = (x) !'); writeln;
      repeat
         if c = 'a' then Polarity := 6 - Polarity;
         Measurement;
         OldPolarity := Polarity;
         if Stop then begin
            writeln ('STOPPED, press Enter to continue!');
            Stop := false;
            readln;
         end;
      until Break;
   end;
until k = 0;
RestorePrinter;
END.
```

Appendix 2

SAMPLES OF MEASUREMENT RECORDS

The first sample is showing the structure of a record in an original logfile. A logfile can consist of many record that are separated from each other by two empty lines.

The measurement data in a record are written as a table. The content of columns is:
1) lower mobility limit of the fraction,
2) upper mobility limit of the fraction,
3) concentration of charge carried by particles of selected polarity,
4) number concentration of all particles of the fraction,
5) upper size limit of the fraction,
6) lower size limit of the fraction,
7) additional data.

Some cells of the fourth column can be empty in the original records. However, the empty cells can be easily filled using another data saved in the record. Such a calculations have been made when compiling the data table for Appendix 3.

The additional data are:
1) name of logfile and the number of the record in the logfile,
2) date,
3) time,
4) selected particle or ion polarity,
5) charging parameter $n_o t$,
6) flow rate in measuring condenser,
7) temperature in output of measuring condenser (a little warmer than in input),
8) air pressure,
9) voltage of power supply (should be 12..13 V).

```
   cm2/Vs        e/cm3   1/cm3       d:nm       field5        17
============================================    950511
0.004  0.008       799    1444   23.34 16.19    20:01-20:04
0.008  0.016      1268    2578   16.19 11.20    Polarity -
0.016  0.031      1207    2934   11.20  7.71    Charging  7.94E6
0.031  0.063       561    1764    7.71  5.26    F =  126 cm3/s
0.063  0.125       167     748    5.26  3.54    T = 20.9 C
0.125  0.250        69       -    3.54  2.36    p =  993 mb
0.250  0.500        15       -    2.36  1.62
============================================    U = 12.4 V
0.004  0.500      4086    9469   23.34  1.62
```

Following six records are showing the decay of the particle generation in the corona discharge reactor about 45 minutes after adding a fresh water to the humidifier. The same process is graphically depicted in Figure 6.

```
   cm2/Vs        e/cm3   1/cm3       d:nm       lab6          51
============================================    950518
0.004  0.008       277     484   23.58 16.36    17:36-17:39
0.008  0.016       151     292   16.36 11.33    Polarity -
0.016  0.031       145     327   11.33  7.80    Charging  9.81E6
0.031  0.063       310     879    7.80  5.33    F =  102 cm3/s
0.063  0.125       874    3414    5.33  3.59    T = 31.9 C
0.125  0.250      1265    7488    3.59  2.39    p =  990 mb
0.250  0.500       679    6289    2.39  1.63
============================================    U = 12.5 V
0.004  0.500      3702   19173   23.58  1.63
```

cm2/Vs		e/cm3	1/cm3	d:nm	
0.004	0.008	312	545	23.58	16.36
0.008	0.016	191	368	16.36	11.33
0.016	0.031	118	267	11.33	7.80
0.031	0.063	261	739	7.80	5.33
0.063	0.125	745	2904	5.33	3.59
0.125	0.250	1080	6383	3.59	2.39
0.250	0.500	731	6761	2.39	1.63
0.004	0.500	3437	17967	23.58	1.63

lab6 52
950518
17:42-17:45
Polarity -
Charging 9.83E6
F = 102 cm3/s
T = 31.9 C
p = 990 mb

U = 12.5 V

cm2/Vs		e/cm3	1/cm3	d:nm	
0.004	0.008	172	301	23.58	16.36
0.008	0.016	113	218	16.36	11.33
0.016	0.031	122	276	11.33	7.80
0.031	0.063	246	696	7.80	5.33
0.063	0.125	662	2583	5.33	3.59
0.125	0.250	947	5597	3.59	2.39
0.250	0.500	619	5732	2.39	1.63
0.004	0.500	2882	15403	23.58	1.63

lab6 53
950518
17:47-17:50
Polarity -
Charging 9.83E6
F = 102 cm3/s
T = 31.9 C
p = 990 mb

U = 12.5 V

cm2/Vs		e/cm3	1/cm3	d:nm	
0.004	0.008	300	525	23.57	16.36
0.008	0.016	162	313	16.36	11.32
0.016	0.031	152	342	11.32	7.80
0.031	0.063	223	630	7.80	5.33
0.063	0.125	570	2223	5.33	3.59
0.125	0.250	753	4445	3.59	2.38
0.250	0.500	576	5327	2.38	1.63
0.004	0.500	2736	13806	23.57	1.63

lab6 54
950518
17:53-17:56
Polarity -
Charging 9.84E6
F = 102 cm3/s
T = 31.8 C
p = 990 mb

U = 12.5 V

cm2/Vs		e/cm3	1/cm3	d:nm	
0.004	0.008	191	335	23.57	16.36
0.008	0.016	166	320	16.36	11.32
0.016	0.031	115	259	11.32	7.80
0.031	0.063	161	456	7.80	5.32
0.063	0.125	453	1765	5.32	3.59
0.125	0.250	693	4088	3.59	2.38
0.250	0.500	514	4743	2.38	1.63
0.004	0.500	2294	11967	23.57	1.63

lab6 55
950518
17:58-18:01
Polarity -
Charging 9.86E6
F = 101 cm3/s
T = 31.8 C
p = 990 mb

U = 12.5 V

cm2/Vs		e/cm3	1/cm3	d:nm	
0.004	0.008	41	71	23.57	16.36
0.008	0.016	81	157	16.36	11.32
0.016	0.031	39	87	11.32	7.80
0.031	0.063	133	376	7.80	5.32
0.063	0.125	448	1744	5.32	3.59
0.125	0.250	640	3777	3.59	2.38
0.250	0.500	375	3469	2.38	1.63
0.004	0.500	1756	9681	23.57	1.63

lab6 56
950518
18:03-18:06
Polarity -
Charging 9.85E6
F = 102 cm3/s
T = 31.8 C
p = 990 mb

U = 12.5 V

Next two records indicated the negative and positive small ion concentration under the HV line. The negative numbers in the data columns are a result of instrument noise. The artifical charging parameter in this measurement is zero that is note with words “Charging natural”.

```
   cm2/Vs         e/cm3   1/cm3       d:nm       field3         2
============================================    950511
0.031  0.063         -4     -75    7.71  5.26    15:14-15:19
0.063  0.125         -3     -96    5.26  3.54    Polarity -
0.125  0.250          4       -    3.54  2.36    Charging natural
0.250  0.500          5       -    2.36  1.62    F = 1017 cm3/s
0.500  1.000         14       -    1.62  1.08    T = 22.8 C
1.000  2.000         32       -    1.08  0.59    p =  995 mb
2.000  4.000         14       -    0.59  0.30
============================================    U = 12.4 V
0.031  4.000         61    -171    7.71  0.30
```

```
   cm2/Vs         e/cm3   1/cm3       d:nm       field3         3
============================================    950511
0.031  0.063         16       -    7.71  5.26    15:23-15:28
0.063  0.125          6       -    5.26  3.54    Polarity +
0.125  0.250         -8       -    3.54  2.36    Charging natural
0.250  0.500         -2       -    2.36  1.62    F = 1017 cm3/s
0.500  1.000         11       -    1.62  1.08    T = 22.3 C
1.000  2.000         26       -    1.08  0.59    p =  995 mb
2.000  4.000          1       -    0.59  0.30
============================================    U = 12.5 V
0.031  4.000         51       -    7.71  0.30
```

Last two records are the output of a data processing program that is reading the original logfiles and calculating the averages over selected periods. The results are presented nearly in the same form as in original output files. Note the time period that is about one hour in the examples below.

```
   cm2/Vs         e/cm3   1/cm3       d:nm       week1         16
============================================    950511
0.004  0.008        708    1280   23.35 16.19    19:01-19:58
0.008  0.016        985    2003   16.19 11.20    Polarity -
0.016  0.031        898    2182   11.20  7.71
0.031  0.063        471    1483    7.71  5.26
0.063  0.125        167     747    5.26  3.54
0.125  0.250         61       -    3.54  2.36    p =  993 mb
0.250  0.500         44       -    2.36  1.62
============================================
0.004  0.500       3334    7694   23.35  1.62
```

```
   cm2/Vs         e/cm3   1/cm3       d:nm       week1         27
============================================    950511
0.004  0.008        898    1614   23.28 16.15    20:01-20:58
0.008  0.016       1260    2541   16.15 11.17    Polarity -
0.016  0.031       1056    2538   11.17  7.69
0.031  0.063        510    1581    7.69  5.24
0.063  0.125        172     754    5.24  3.53
0.125  0.250         64       -    3.53  2.35
0.250  0.500         43       -    2.35  1.62
============================================
0.004  0.500       4004    9029   23.28  1.62
```

Appendix 3

PARTICLE FRACTION CONCENTRATIONS
(Full data table)

Structure of the table:

First column: Date/Time (DD/HHMM)
Year (1995) and month (May) are not indicated.

Following seven columns: Number concentrations of particles in seven size fractions. The measurement unit is 10 particles per ccm. The fractions are limited by eight particle efficient diameters 1.6, 2.4, 3.5, 5, 7.5, 11, 16 and 23 nm.

Some measurements are made in the inverted charging regime to check the instrument zero level and noise. In this occasion, the recorded values should be near zero (a very low negative value due to the particle diffusion is possible) and the results in the table are characterizing the instrumental noise or random measurement error. *Such a zero records are marked in the table with italic* and the symbol **Z** in the remark column.

Some obviously failed data are replaced by the sign “**?**” .

11-15 May 1995 : field measurements under and near HV line

Dt/Time ==== Number concentration : 10 cm^{-3} ====

Dt/Time	Dia:1.6	2.4	3.5	5	7.5	11	16 23 nm	Remark
11/1704	59	44	83	125	163	152	92	The instrument is located
11/1710	62	58	82	155	210	191	119	straight under the HV line.
11/1715	3	15	45	104	113	97	82	The air input is about 33 cm
11/1720	62	23	59	124	156	108	73	over the ground or 10-15 cm
11/1726	*31*	*14*	*1*	*5*	*2*	*11*	*-12*	**Z**
11/1731	97	37	54	113	186	166	121	over the grass. The same
11/1737	7	77	101	180	206	186	134	location is used in most of
11/1742	47	49	74	157	232	207	121	measurements and indicated
11/1747	66	38	58	85	117	105	75	below as “standard location”.
11/1753	42	45	68	110	145	136	61	
11/1758	41	29	67	95	131	138	110	
11/1804	*-72*	*12*	*-51*	*-5*	*-4*	*-6*	*-13*	**Z**
11/1809	*-26*	*-107*	*-34*	*-3*	*-4*	*-9*	*-14*	**Z**
11/1815	*-1*	*22*	*5*	*12*	*-9*	*-5*	*-4*	**Z**
								The instrument is carried away
								and located in the distance of
								60 m from the HV line.
11/1834	*48*	*23*	*-2*	*4*	*3*	*-3*	*7*	**Z**
11/1840	*-33*	*1*	*9*	*10*	*13*	*-3*	*-5*	**Z**
11/1845	31	35	66	98	130	111	86	Measurements 60 m away from
11/1850	53	31	60	104	144	139	95	the HV line.
11/1856	120	26	81	111	150	156	90	
11/1901	43	55	84	150	208	168	103	
11/1907	9	58	73	142	191	154	89	
11/1912	34	24	81	117	146	146	98	
11/1917	142	45	65	143	208	167	125	
11/1923	104	25	87	183	238	190	115	
11/1928	59	61	97	207	295	268	176	
11/1934	44	56	86	152	242	223	122	
11/1939	44	48	42	108	171	167	124	
11/1945	42	18	64	127	191	204	144	
11/1950	9	53	63	135	237	247	150	
11/1955	3	24	79	168	273	269	160	
11/2001	17	48	75	177	293	258	144	

Dt/Time ==== Number concentration : 10 cm^{-3} ====
Dia:1.6 2.4 3.5 5 7.5 11 16 23 nm Remark

11/2006	9	28	79	165	232	249	136	
11/2012	66	87	58	156	266	273	164	
11/2017	86	45	66	146	235	258	172	
11/2022	3	20	79	146	214	200	133	
11/2028	76	18	74	166	249	252	147	
11/2033	98	49	76	137	218	216	161	
11/2039	96	46	75	148	236	250	153	
11/2044	-6	43	83	160	268	265	185	
11/2050	57	37	74	164	281	271	199	
11/2055	8	54	91	174	300	304	182	
11/2100	*53*	*1*	*-20*	*-1*	*1*	*-1*	*-3*	**Z**
11/2106	*17*	*-16*	*8*	*-9*	*10*	*7*	*6*	**Z**
12/1416	*2*	*-12*	*5*	*2*	*-10*	*-0*	*-4*	**Z**
12/1422	*-81*	*-10*	*-25*	*-1*	*-5*	*-1*	*3*	**Z**
12/1427	88	42	25	102	143	196	189	The instrumentation is again
12/1432	192	58	56	99	177	193	171	in the standard location
12/1438	4	51	91	147	219	249	188	
12/1443	93	15	41	91	137	172	159	
12/1449	111	61	71	85	146	186	187	
12/1454	111	20	45	112	181	224	210	
12/1500	?	61	85	100	160	203	198	
12/1505	?	86	49	171	224	301	249	
12/1510	91	66	51	91	159	216	203	A light rain is beginning
12/1516	12	11	41	100	159	182	179	
12/1521	13	33	45	92	158	196	183	
12/1527	96	40	70	146	242	302	247	
12/1532	64	72	33	80	131	201	172	
12/1537	21	44	49	97	163	228	192	
12/1543	1	19	67	126	219	293	273	
(sheating)........	......	......	......	......	......	......	266	Instrument is sheated by a box,
12/1554	71	52	50	131	200	277	266	it can be expected, that only
12/1559	74	39	57	89	166	225	219	one record was disturbed and
12/1605	83	66	61	100	186	254	235	the particle concentration is
12/1610	9	39	47	103	182	244	245	not considerably biased by
12/1615	106	49	66	99	152	210	239	the box.
12/1621	-3	42	65	116	224	283	302	
....	......	......	......	......	......	......	......	Instrument is carried into
....	......	......	......	......	......	......	......	the tent that is located about
12/1710	*-13*	*85*	*5*	*-8*	*-11*	*-3*	*-3*	**Z** 10 m downwind of the HV line.
12/1715	*-115*	*5*	*-0*	*-1*	*-10*	*-1*	*-14*	**Z**
12/1720	-8	33	54	145	265	342	343	Instrument is in the tent in
12/1726	22	74	75	165	266	408	432	distance of 50 cm from the open
12/1731	138	87	91	157	277	390	410	door. The wind is ventilating
12/1737	131	79	30	157	277	365	354	the tent and the particle
12/1742	46	76	63	139	239	340	364	concentration is expected
12/1748	19	36	61	122	231	307	353	nearly the same as outside.
12/1753	71	-8	50	112	223	273	321	
12/1758	92	-1	64	136	250	363	368	
12/1804	48	51	79	161	259	373	419	
12/1809	26	43	34	85	192	312	412	
12/1815	-23	-18	44	116	212	346	426	
12/1820	-3	46	48	139	233	346	438	
12/1825	90	35	79	140	215	318	385	
12/1831	34	68	84	140	241	380	433	
12/1836	18	90	74	156	271	385	414	
12/1842	153	62	83	145	274	458	507	
12/1847	93	55	82	121	239	366	399	
12/1853	10	10	90	143	289	380	387	
12/1858	114	60	80	177	298	410	442	
12/1903	42	61	54	100	185	300	390	
12/1909	108	69	64	109	201	316	434	
12/1914	*50*	*6*	*-14*	*-10*	*-18*	*-17*	*-17*	**Z**
Dt/Time	==== Number concentration : 10 cm^{-3} ====							
Dia:1.6	2.4	3.5	5	7.5	11	16	23 nm	Remark

15/1342	*-26*	*15*	*-22*	*0*	*-22*	*12*	*5*	**Z**
15/1351	*23*	*18*	*2*	*8*	*-6*	*-9*	*11*	**Z**
15/1418	-65	107	49	49	81	127	249	Measurements in standard
15/1423	492	144	41	73	127	170	263	location.
15/1429	14	39	43	122	206	273	343	
15/1434	-240	-109	26	110	184	306	378	NB! The instrument noise
15/1439	8	121	56	94	123	136	138	in the two finest fractions
15/1445	-106	44	50	68	104	125	94	is enhanced in measurements
15/1450	40	22	47	80	82	109	99	of 15 May and the results
15/1456	-113	2	14	64	90	133	155	for particles below 3.5 nm
15/1501	-59	24	20	88	144	190	248	should be ignored!
15/1506	-39	64	-5	90	93	116	166	
15/1512	-178	35	63	65	85	124	93	
15/1517	71	-39	41	82	111	118	84	
15/1523	-156	48	42	64	97	130	138	
15/1528	-104	-20	11	46	98	140	122	
15/1534	171	87	8	74	123	124	117	
15/1539	229	71	72	61	69	68	79	
15/1544	97	-23	53	69	131	121	92	
15/1550	-85	83	50	73	114	113	65	Until these measurements the
15/1555	29	-14	33	82	148	149	143	standard (low) location.
15/1601	....							Lifting of the instrument.
15/1606	-235	-58	-29	65	125	131	121	The instrument is in the same
15/1611	28	69	41	72	132	158	153	place under the HV line but
15/1617	4	45	55	67	101	179	227	90 cm higher (about 1 m over
15/1622	83	99	81	95	144	238	278	the grass)
15/1628	169	50	62	111	127	166	119	
15/1633	35	1	-8	68	135	130	158	
15/1639	153	131	67	87	132	210	300	
15/1644	55	80	71	121	181	269	272	
15/1649	101	-6	47	79	99	187	250	
15/1655	220	80	36	96	129	265	283	
15/1700	-60	-25	41	70	139	232	268	Until these measurements the
15/1706	-214	-23	53	89	124	155	91	high locatiom
15/1711	....							Sinking of the instrument.
15/1716	34	-76	67	98	82	106	98	Now again the standard (low)
15/1722	-30	92	40	45	55	70	61	location
15/1727	168	93	82	111	125	117	98	
15/1733	-7	15	87	120	157	133	138	
15/1738	-47	-20	-32	37	72	111	119	
15/1744	-50	132	59	160	259	236	204	
15/1749	-118	16	44	94	133	152	147	
15/1754	124	55	44	28	25	41	50	
15/1800	72	16	67	67	113	175	169	
15/1805	-59	23	96	97	156	301	260	
15/1811	-50	140	76	131	224	407	422	
15/1816	79	64	139	224	386	563	544	
15/1821	-78	115	107	148	195	269	236	
15/1827	90	15	93	180	216	288	202	
15/1838	*41*	*-46*	*-19*	*13*	*4*	*3*	*1*	**Z**

16-18 May 1995 : measurements in the laboratory

The air is flowing into the nanometer particle spectrometer from the corona unit through a short teflon tube. The air flow through the corona unit was 7.33 l/min in all measurements.

A number with sign % in the remark column is indicating the relative humidity as measured in the output of the spectrometer. A number with sign + or - or ± (that means alternative) and unit µA is indicating the corona current.

The records during the adjustment of instrumentation are omitted in the table without special comments.

Dt/Time ==== Number concentration : 10 cm^{-3} ====

Dt/Time	Dia:1.6	2.4	3.5	5	7.5	11	16	23 nm	Remark	
16/1106	97	69	99	29	3	28	13		0 µA	0%
16/1111	-31	42	0	-15	4	5	-2		+100 µA	0%
16/1122	43	13	20	-9	5	-4	-3		±x µA	0%
16/1149	480	400	319	121	44	117	269		-180 µA	78%
16/1154	625	845	433	114	79	131	293		-180 µA	78%
16/1200	1167	1450	790	184	74	130	242		-180 µA	78%
16/1205	1399	1755	1025	231	74	95	149		-180 µA	78%
16/1211	79	70	69	33	22	22	24		0 µA	78%
16/1216	43	20	17	4	2	11	6		0 µA	78%
16/1545	28	42	44	9	3	-1	-10		0 µA	78%
16/1551	842	1021	612	165	19	2	2		-180 µA	78%
16/1556	626	804	391	87	18	6	8		-180 µA	78%
16/1602	454	538	225	51	24	5	-10		-180 µA	78%
16/1607	325	377	167	30	17	0	5		-180 µA	78%
16/1612	224	248	111	14	11	13	30		-180 µA	78%
16/1618	156	224	88	16	-6	7	2		-180 µA	78%
16/1623	79	142	-207	28	-222	-71	-11		-180 µA	0%
16/1629	63	27	41	16	9	10	11		-180 µA	0%
16/1634	129	77	25	19	8	4	15		-180 µA	0%
16/1640	-25	7	13	5	-1	-2	10		-180 µA	0%
16/1645	27	23	0	-9	2	9	-5		-180 µA	0%

Dt/Time ==== Number concentration : 10 cm^{-3} ====

Dt/Time	Dia:1.6	2.4	3.5	5	7.5	11	16	23 nm			Remark
17/1113	407	878	209	90	10	-4	22	-180	µA	81%	
17/1119	317	459	238	59	-4	-11	-5	-180	µA	73%	
17/1124	303	247	118	39	317	-46	2	-180	µA	70%	
17/1130	46	157	76	18	8	8	7	-180	µA	67%	heating on
17/1135	78	94	46	9	4	15	9	-180	µA	66..80%	
17/1140	325	185	101	58	-2	23	-65	-180	µA	86%	
17/1146	743	407	156	120	30	32	40	-180	µA	89%	
17/1151	474	554	363	151	100	59	36	-180	µA	90%	
17/1157	1105	1340	960	365	20	32	-62	-180	µA	91%	fog on the walls
17/1202	160	92	32	24	-18	3	2	-180	µA	89%	
17/1207	92	41	0	3	-13	-0	5	-180	µA	88%	
17/1213	143	48	27	1	5	2	2	-180	µA	85%	
17/1218	100	20	6	13	23	-124	-48	-180	µA	83%	
17/1224	29	37	7	13	16	-0	0	-180	µA	80%	
17/1229	35	51	29	11	6	22	3	-180	µA	79%	
17/1235	17	-6	0	15	-3	-11	-3	-180	µA	78%	
17/1240	44	-7	-14	23	34	32	19	0	µA	75%	
17/1245	-8	31	10	22	19	32	27	0	µA	70%	
17/1251	712	33	13	43	129	28	23	0	µA	63%	
17/1256	31	26	26	21	-10	1	5	-180	µA	56%	
17/1302	69	17	34	1	0	14	-8	-180	µA	52%	
17/1307	162	19	23	9	11	8	1	-180	µA	50%	
17/1351	86	22	-8	5	-4	-3	1	+180	µA	60%	
17/1357	-12	11	-5	7	-3	5	-3	+180	µA	63%	
17/1402	184	127	43	-15	40	69	-8	+180	µA	70%	
17/1408	50	16	28	15	4	8	11	+180	µA	75%	
17/1413	158	12	12	28	13	14	-48	+180	µA	77%	
17/1418	37	27	8	8	10	15	-18	+180	µA	79%	fog on the walls
17/1424	136	57	24	44	15	13	14	+180	µA	80%	
17/1429	88	-18	29	13	6	9	-8	+180	µA	82%	
17/1435	56	18	3	6	13	11	21	+180	µA	85%	
17/1440	?	?	?	?	?	?	?	+180	µA	87%	
17/1445	159	131	63	33	10	15	19	+180	µA	88%	
17/1451	27	43	40	11	15	-20	-1	+180	µA	89%	
17/1456	-3	42	0	33	23	-16	9	+180	µA	90%	
17/1502	14	23	25	26	18	25	11	+180	µA	91%	
17/1507	70	28	92	21	2	2	-2	+180	µA	92%	

Experiments with polypropylen film on the plain electrode and 50 Hz alternative corona.
Thickness of the film is 15 µm.

Dt/Time ==== Number concentration : 10 cm^{-3} ====
Dia:1.6 2.4 3.5 5 7.5 11 16 23 nm Remark

18/1328	412	450	254	86	37	40	61	±200 µA	64%	
18/1333	802	740	376	118	50	47	80	±200 µA	61%	
18/1338	844	887	388	107	30	45	101	±200 µA	57%	
18/1344	757	766	323	94	43	35	85	±200 µA	55%	
18/1349	787	787	331	97	34	49	89	±200 µA	53%	
18/1355	721	621	265	56	35	54	70	±200 µA	52%	
18/1400	28	3	27	12	18	6	7	0 µA	50%	
18/1405	25	26	20	11	11	13	-18	0 µA	49%	
18/1411	571	538	292	101	6	31	53	±200 µA	48%	
18/1416	549	483	189	60	26	38	36	±200 µA	48%	
18/1422	345	276	361	113	14	6	23	±200 µA	48%	
18/1427	349	252	107	28	16	25	47	±200 µA	48%	
18/1432	....							installing of new polymer film		
18/1438	265	247	146	48	6	-1	-24	±200 µA	52%	
18/1443	260	197	86	25	16	15	19	±200 µA	52%	
18/1449	134	154	95	24	22	6	-5	±200 µA	51%	heating turned on
18/1454	13	49	37	9	14	18	17	±200 µA	51..68%	
18/1500	53	27	32	27	7	28	6	±200 µA	72%	
18/1505	121	30	-9	5	-5	3	5	±200 µA	78%	fog on the walls
18/1510	95	59	26	13	18	17	9	±200 µA	80%	
18/1516	123	30	24	6	4	1	-11	±200 µA	80%	
18/1521	13	19	25	23	18	4	-6	±200 µA	80%	
18/1527	....							installing of new polymer film		
18/1532	....									
18/1537	16	68	27	15	15	-7	-3	±200 µA	76%	
18/1543	108	24	7	-13	-10	-3	19	±200 µA	70%	
18/1548	133	18	7	1	5	2	7	±200 µA	65%	
18/1554	126	57	24	8	7	-30	-23	±200 µA	60%	humidifier off
18/1559	63	6	-120	-42	0	-2	-3	±200 µA	55..10%	
18/1604	82	3	-9	-8	1	5	-23	±200 µA	9%	
....	....							replacement of wire and film		
18/1632	75	28	-15	0	2	-2	13	±170 µA	0%	
18/1637	62	20	26	9	-8	10	5	±170 µA	0%	
18/1642	97	66	5	8	4	-1	-5	±170 µA	0%	
18/1648	-138	23	20	14	6	13	-22	±170 µA	x%	**adding some water**
18/1653	58	4	12	11	3	-6	-5	±170 µA	62%	
18/1659	607	607	299	89	47	58	31	±170 µA	60%	
18/1704	919	1011	521	134	67	69	105	±170 µA	53%	
18/1709	946	1181	531	163	66	71	113	±170 µA	51%	
18/1715	815	805	410	124	77	60	57	±170 µA	50%	
18/1720	642	711	331	90	46	53	43	±170 µA	49%	
18/1726	....							removal of the polymer film		
18/1731	630	843	384	107	49	30	50	±160 µA	48%	without film
18/1736	631	747	341	88	33	29	48	±160 µA	48%	without film
18/1742	678	637	290	74	27	37	55	±160 µA	48%	without film
18/1747	574	558	258	70	27	22	30	±160 µA	48%	without film
18/1753	534	446	222	63	34	31	52	±160 µA	48%	without film
18/1758	476	410	176	46	26	32	33	±160 µA	48%	without film
18/1803	347	379	174	38	9	16	7	±160 µA	48%	without film
18/1809	269	288	131	36	14	22	69	±160 µA	48%	without film
18/1814	269	250	112	33	24	12	23	±160 µA	48%	without film