Review of cavitation X-ray emission experiments

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In numerous experimental LENR-related works were presented the results of investigation of soft X-Ray radiation (~1-3 keV) detected outside working chamber when palladium or nickel samples were exposed to deuterium and hydrogen.

Such effects were observed regularly during electrolysis, gas discharge, thermocycling etc. Intensity of this radiation was uncorrelated with heat generation and isotope changes into working chamber.

Moreover, this radiation was frequently registered in absolutely abnormal systems - e.g. behind the "black" screen (wall) which thickness much surpasses absorption mean free path of radiation.

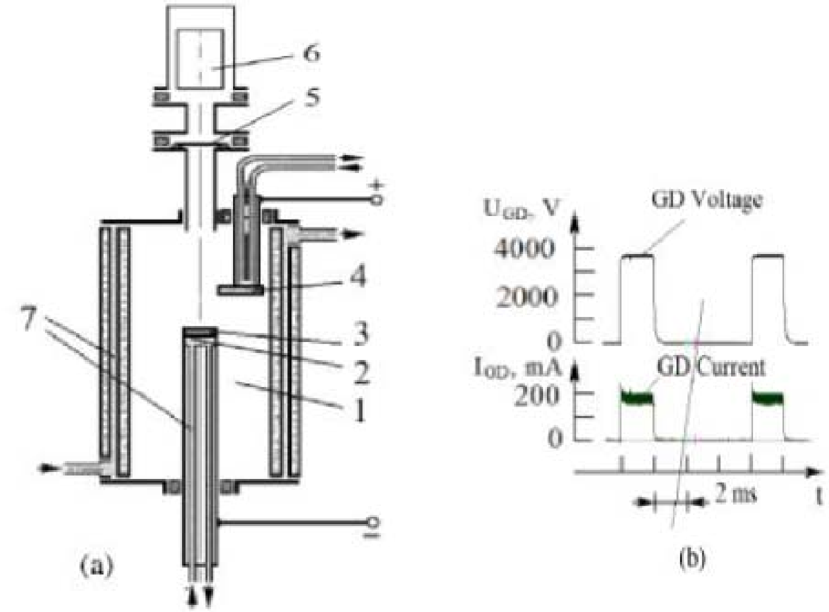


Figure 1. Schematic representation of the experiment. (a). Glow discharge device, 1 – discharge chamber, 2 – cathode holder, 3 – cathode sample, 4 – anode, 5 – Be foil screens, 6 – X-ray detectors different kind (pinhole, TLD detectors, scintillator- photomultiplier, spectrometer), objective, 7 –cooling water; (b) glow discharge voltage and current pulses.

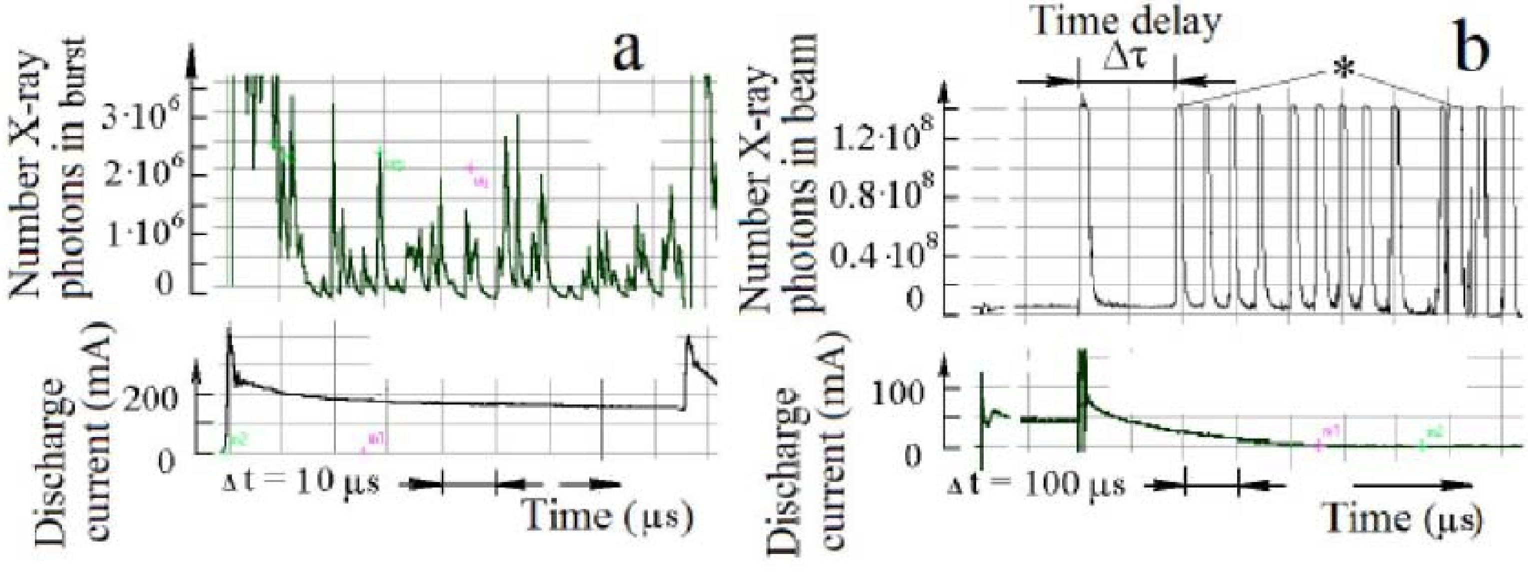


Figure 4. Typical oscillograms of the X-ray emission signal from the PMMA/PM scintillation detector. The cathode sample is Pd, run in a D_2

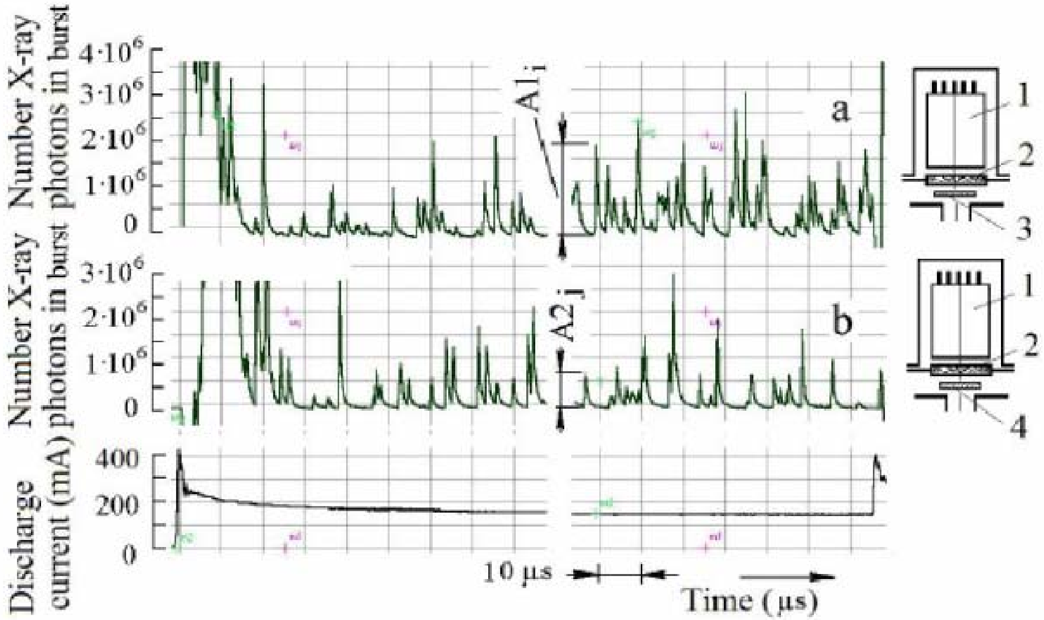
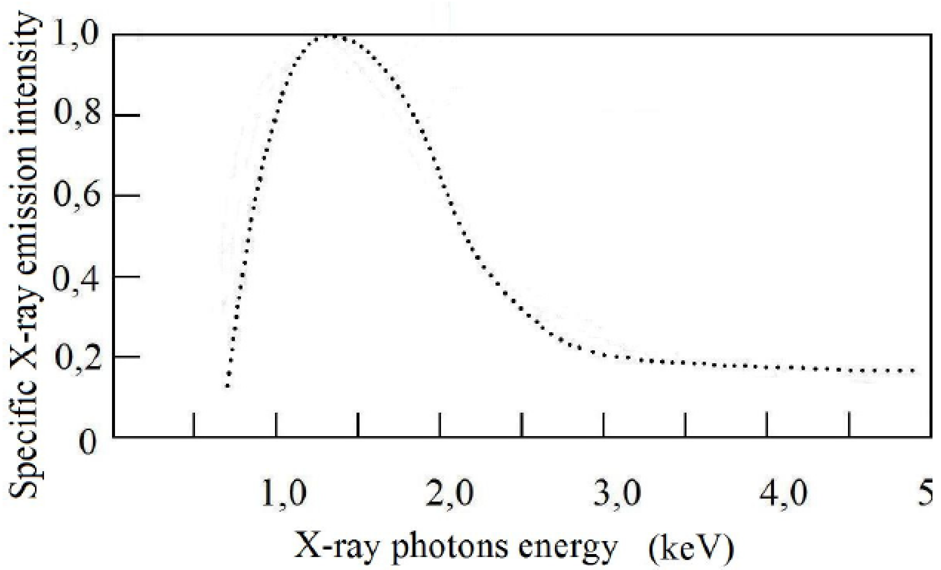


Figure 6. Typical oscillograms of X-ray emission from the PMMA/PM scintillator detector covered with Be foils with different thicknesses: (a) covered with a 15 μm Be foil; (b) covered with a 30 μm Be foil. In this case the cathode was Pd, the gas was D_2, and the discharge current was 150 mA.

Table 1. Average X-ray energy for different cathode materials.

Material of Cathode	Al	Sc	Ti	Ni	Mo	Pd	Ta	Re	Pt	Pb
Glow discharge voltage (V)	1650	1540	1730	1650	1420	1650	1600	1520	1650	1610
Glow discharge current (mA)	130	130	170	150	210	138	138	125	138	138
X-ray photons energy (keV)	1.54	1.26	1.45	1.91	1.48	1.98	1.62	1.36	1.47	1.36

Different cathodes (Al, Sc, Ti, Ni, Mo, Ta, Re, Pt, Pb) but the same X-Ray energy!!!



[A.V.Karabut, E.A.Karabut JCMNS, v.6 (2012) 199-216]

Continuum X-Ray emission measured with the curved mice crystal spectrometer from a glow discharge experiment with a Pd cathode

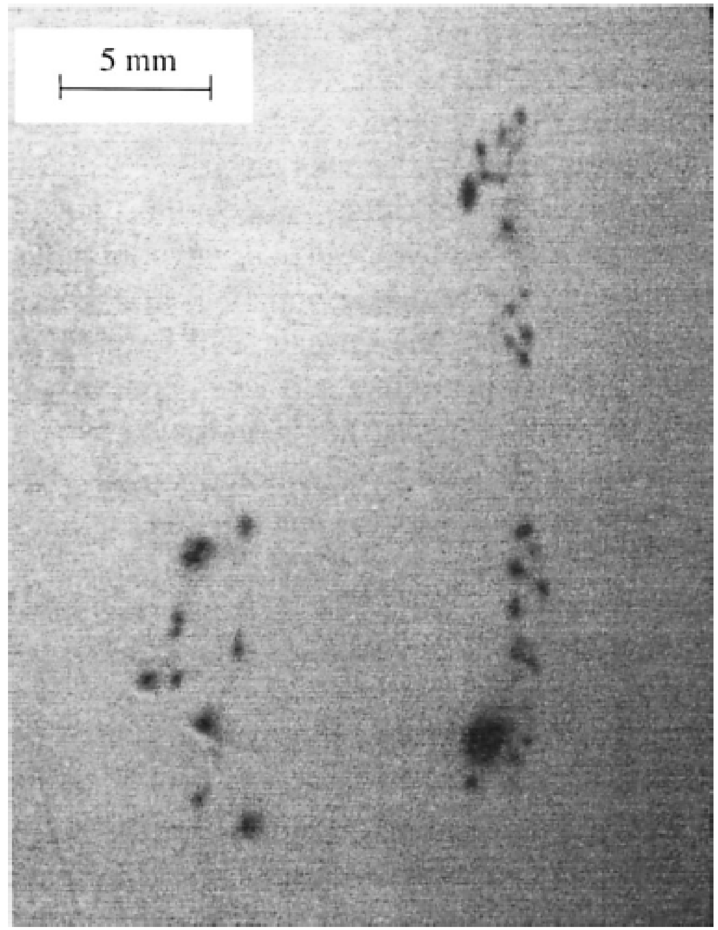


Fig. 13. X-ray film as obtained after an exposure of one week in front of cell #4.

These abnormal results on X-Ray registration in LENR-related experiments are similar to the results of our investigation of X-Ray radiation generated on outer surface of closed chamber (and registered behind this surface) at cavitation of liquid (see below):

A.A. Kornilova, V. I. Vysotskii, A. I., Koldamasov, Hyun Ik Yang, D. B. McConnell and A. V. Desyatov. Generation of Intense Directional Radiation during the Fast Motion of a Liquid Jet through a Narrow Dielectric Channel // *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques, 2007, Vol. 1, No. 2, 167–171*.

A.A. Kornilova, V. I. Vysotskii, N. N. Sysoev and A. V. Desyatov. Generation of X-Rays at Bubble Cavitation in a Fast Liquid Jet in Dielectric Channels // *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques, 2009, Vol. 3, No. 2, pp. 275–283*

A.A. Kornilova, V. I. Vysotskii, N. N. Sysoev, N. K. Litvin, V. I. Tomak, and A. A. Barzov. Generation of Intense X-Rays during Ejection of a Fast Water Jet from a Metal Channel to Atmosphere // *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques, 2010, Vol. 4, No. 6, pp. 1008–1017*

A. A. Kornilova, V. I. Vysotskii, N. N. Sysoev, A. V. Investigation of radiation effects at bubble cavitation in running liquid. *Proceedings of ICCF-14*, 2010, V.2, pp. 418-424,

In these works X-Ray processes have been associated with a liquid (machine oil or water) jet moving through the narrow channel.

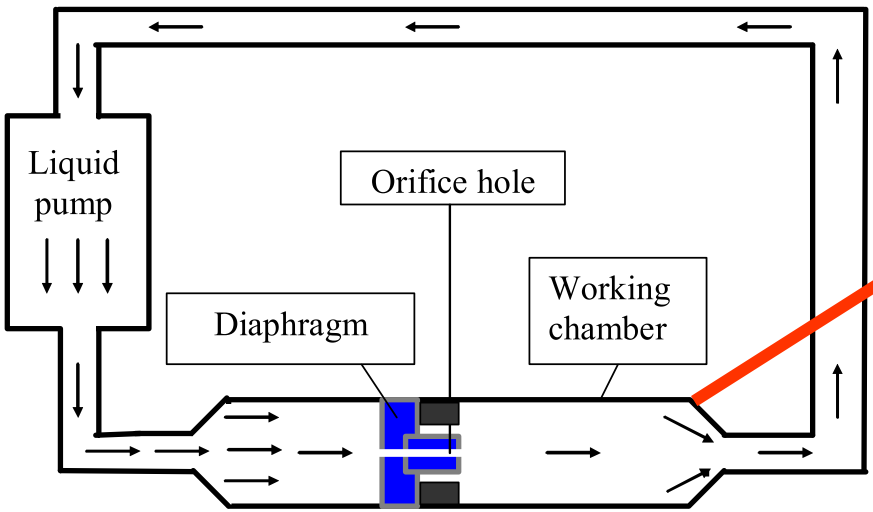
It has been found during detailed investigation that the outer surface of the working chamber are sources of intense X-radiation, generation of which is related to cavitation processes in the liquid jet bulk and subsequent excitation of internal shock waves. Interaction of these shock waves with external surface atoms of water jet, metal tube or thick screen leads to external X-Ray generation.

The frequency (energy) of X-radiation depends on the types of atoms on a radiating surface (for a jet, it is water; for a channel, the metal atoms on the surface (e.g. Fe, Cu, Pb, etc) and increases with the increase of atoms charge.

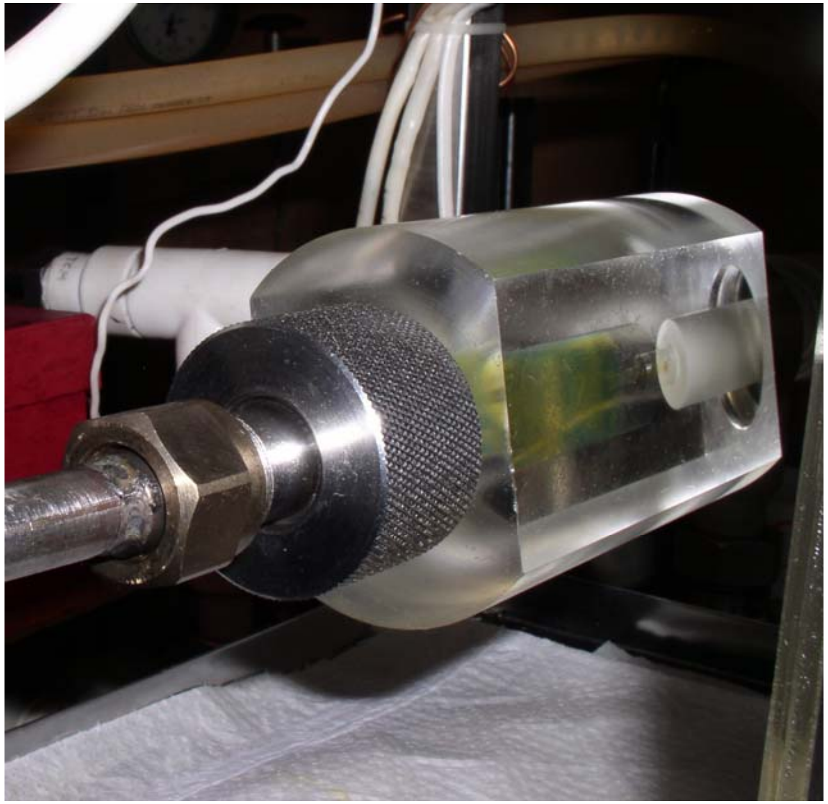
The total X-ray activity of working chamber reaches Q≈0.1 Ci.

X-RAY GENERATION AT BUBBLE CAVITATION.

1). cavitation of machine oil.



Scheme of the experimental setup for study of cavitation phenomena at intermediate pressure of spindel oil



In our earlier work [A. A. Kornilova, V. I. Vysotskii, A. I. Koldamasov, Hyun Ik Yang, Denis B. McConnell, A. V. Desyatov //Surface, №. 3 (2007) p. 55-60] the anomalous optical phenomena accompanying cavitational processes at directed motion of running liquids through thin dielectric channels to large-size working chamber were investigated.

The cylindrical working chamber (**cavitation chamber**) had a length of 15 cm, diameter of 8 cm and has been made of plexiglass. Inside the working chamber the special diaphragm (hermetic plastic wall) with orifice hole is situated. The diameter and the length of the orifice hole are 1 mm and 2 cm. For observation of the optical effects two opposite lateral faces of the cylinder have been vertically cut. Within these faces the thickness of the wall changed from 2 to 3 cm.

Regimes of activity of the cavitation system

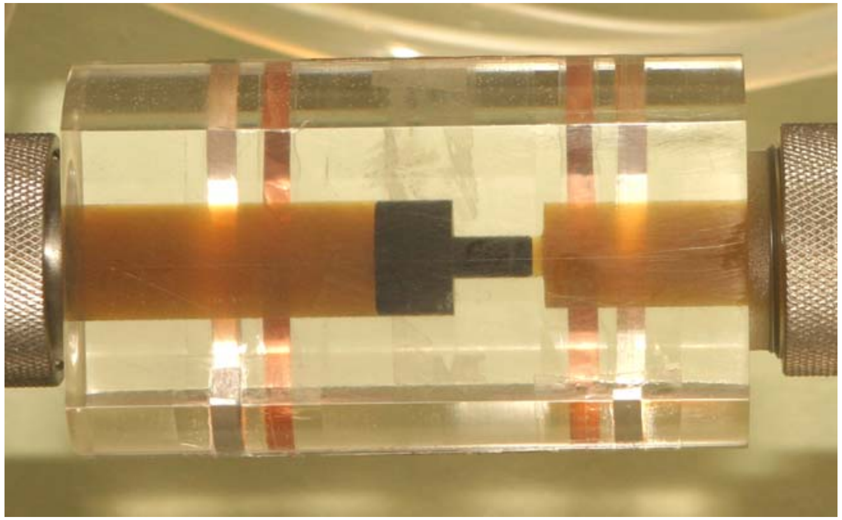


Fig.1. General view of the working chamber with low pressure moving oil

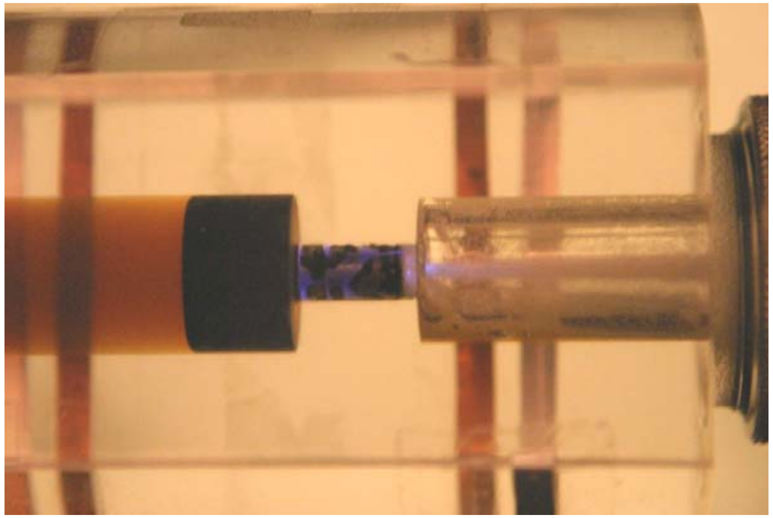


Fig. 3. Separation of the liquid stream from the chamber walls at the condition of intensive cavitation (P=60-70 atm)

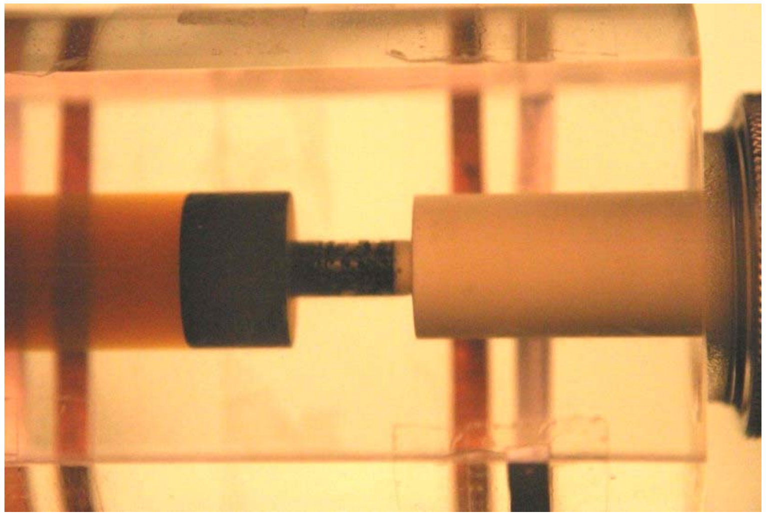


Fig. 2. Movement of a stream of liquid oil at cavitation condition (P=30-40 atm)

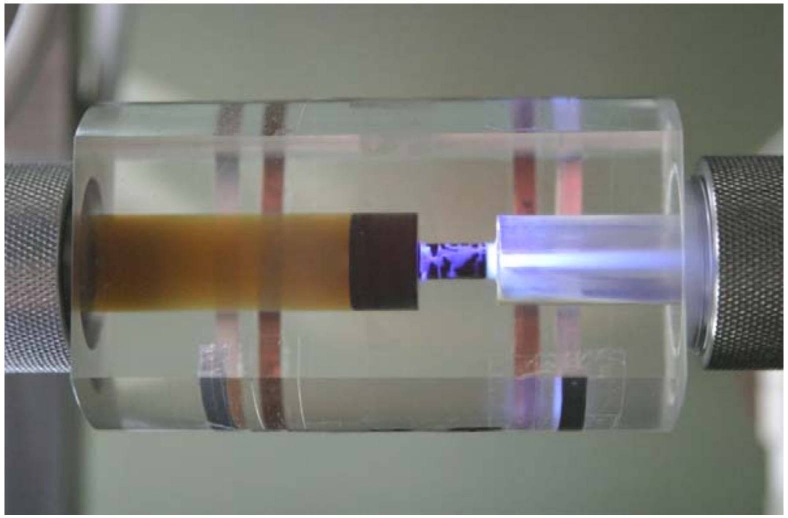


Fig.4 Bright luminescence of the directed stream with cavitation bubbles (P≥90 atm)

The important question - what is the nature and origin of the directed luminous beam?

It was not a directed light beam from the internal part of the orifice hole because the initial diameter of the directed beam is 4 times greater than the diameter of the output aperture of the insert (orifice hole).

It also was **not equilibrium thermal radiation** (**sonoluminescence**) from the region of cavitation. Several arguments support these conclusions:

Argument 1. The length (about 5-10 cm) and very narrow cylindrical form of the beam are sharply different from the dimensions and shape of the usual cavitation region (jet-like cone, sphere or short cylinder with size 1-3 mm).

Argument 2**.** The rather bright observed luminescence and rather high derived temperature (about 10^5 K) are comparable only to the intensity and temperature spectrum from sonoluminescence of single bubbles, and are the direct result of the spherical symmetry of the bubble at collapse. In the case of multibubble cavitation, the sonoluminescence spectrum indicates that the temperature inside a bubble at collapse is relatively low (2000-5000 K), and the intensity of the sonoluminescence is also low ("cold sonoluminescence").

Argument 3**.** The intensity of sonoluminescence decreases strongly with increasing temperature of the cavitating liquid (e.g., at increasing temperature from 10 C up to 400 C the intensity decreases by 100 times). But in our system the intensity of radiation does not depend on the temperature in the explored interval 20…60 C.

So, the observed phenomenon is not the usual kind of sonoluminescence.

Using three different methods, we have studied the mechanism whereby Cherenkov radiation might be emitted by fast electrons when accelerated along the axis of the chamber to velocities $v > c/n(\omega)$ in the field of **large separated charges.**

We used a ground connection to neutralize the separated volume charges in the chamber. This did not influence the directed properties or intensity of the laser-like beam.

We measured the angular distribution of the directed beam and found that it is isotropic and differed from the distribution typical of Cherenkov radiation:

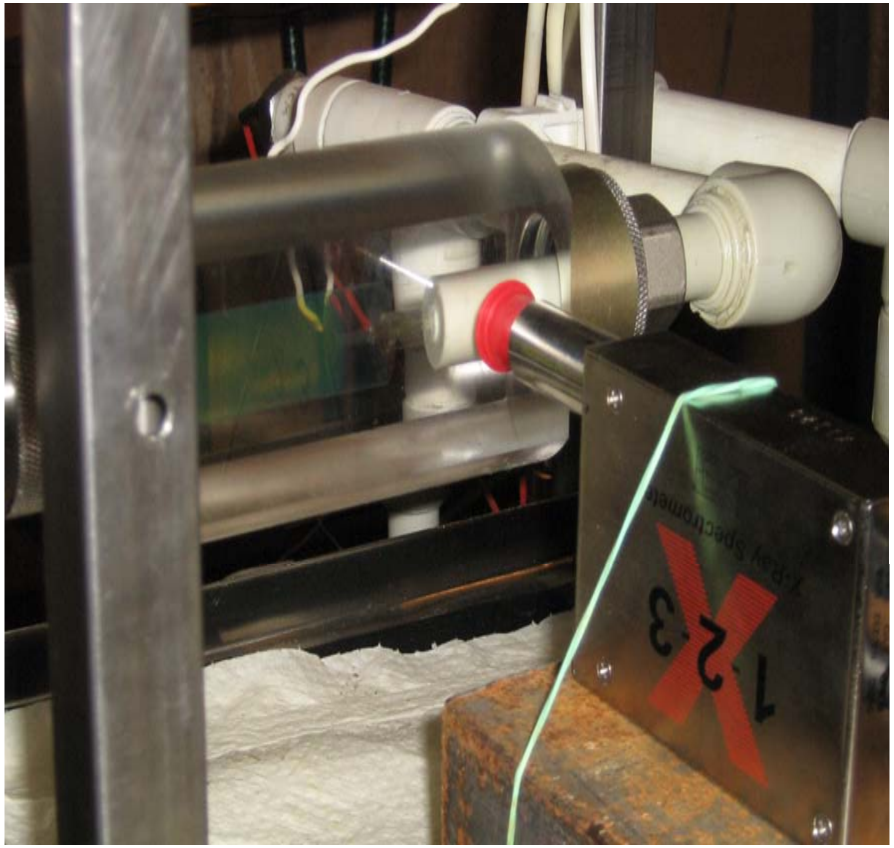
$\sin\theta = c/n(\omega)v$.

We investigated the action of an external transverse magnetic field on the direction and angular properties of the directed beam. The result was negative – a transverse magnetic field with magnitude of 300 to 500 Oersted did not significantly influence the direction of the beam.

In view of these results, the directed beam is not believed to be connected with Cherenkov radiation.

Investigation of characteristic X-ray radiation generation at the cavitation phenomena

From detailed research of cavitation phenomena we have observed that at certain critical regimes of cavitation outside of the thick-walled dielectric chamber intensive characteristic X-ray radiation is registered.

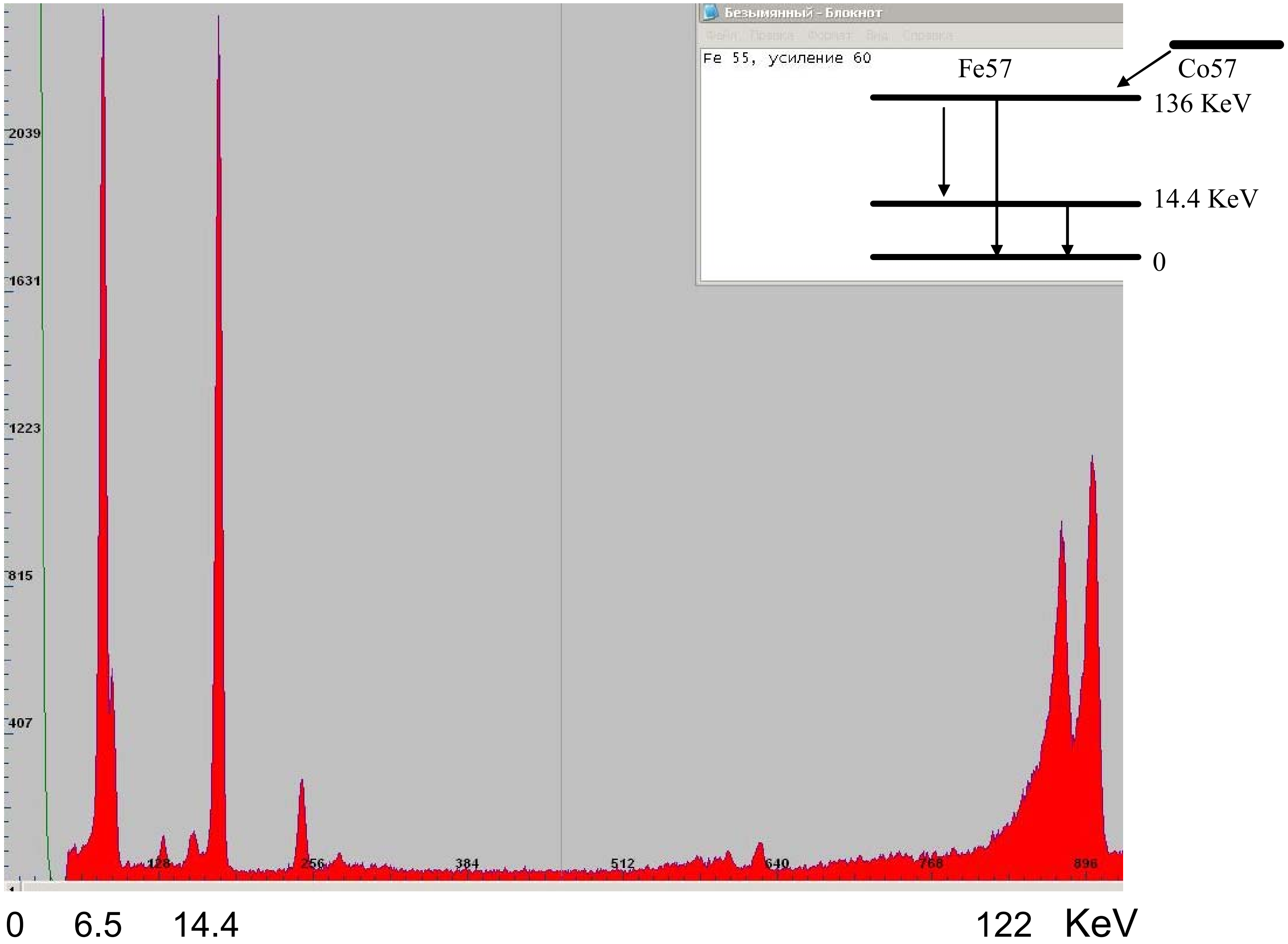


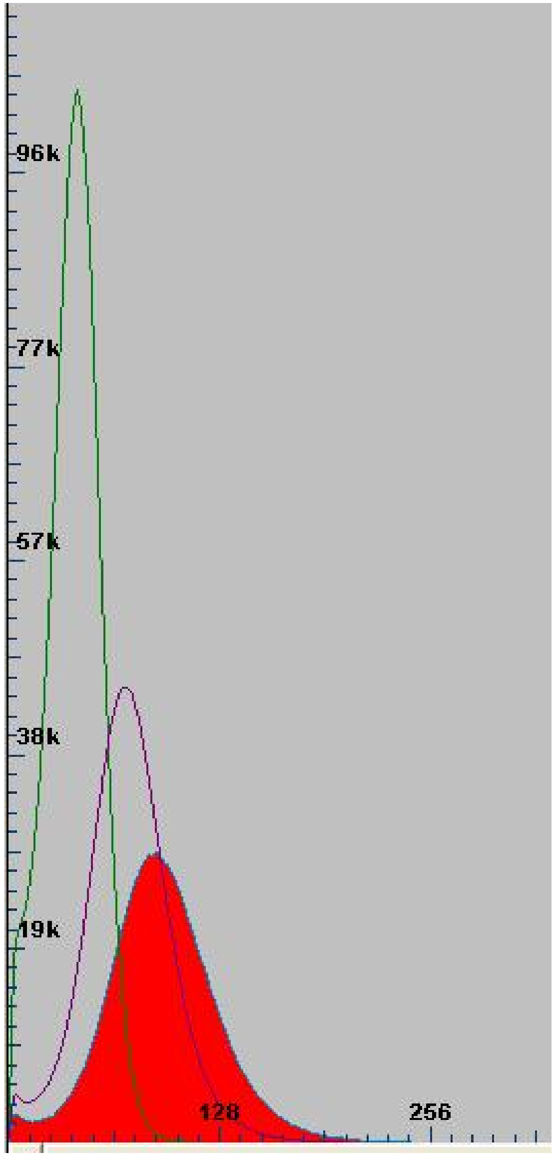
X-Ray detector during radiation measurement in the cavitation regime

For registration of the radiation X-Ray and gamma-detector (X-Ray detector) AMPTEK X-123 been used.

Cylindrical collimator of the detector had a length (L) of about 6 cm and an internal cross-section (S_0) of 0.5 cm^2. The solid angle of detection (Ω) was 0.02 steradian. The entrance cross-section of the collimator was closed by very thin Be foil.

Calibration of X-Ray detector and control investigation of the Mossbauer Fe-57 isotope





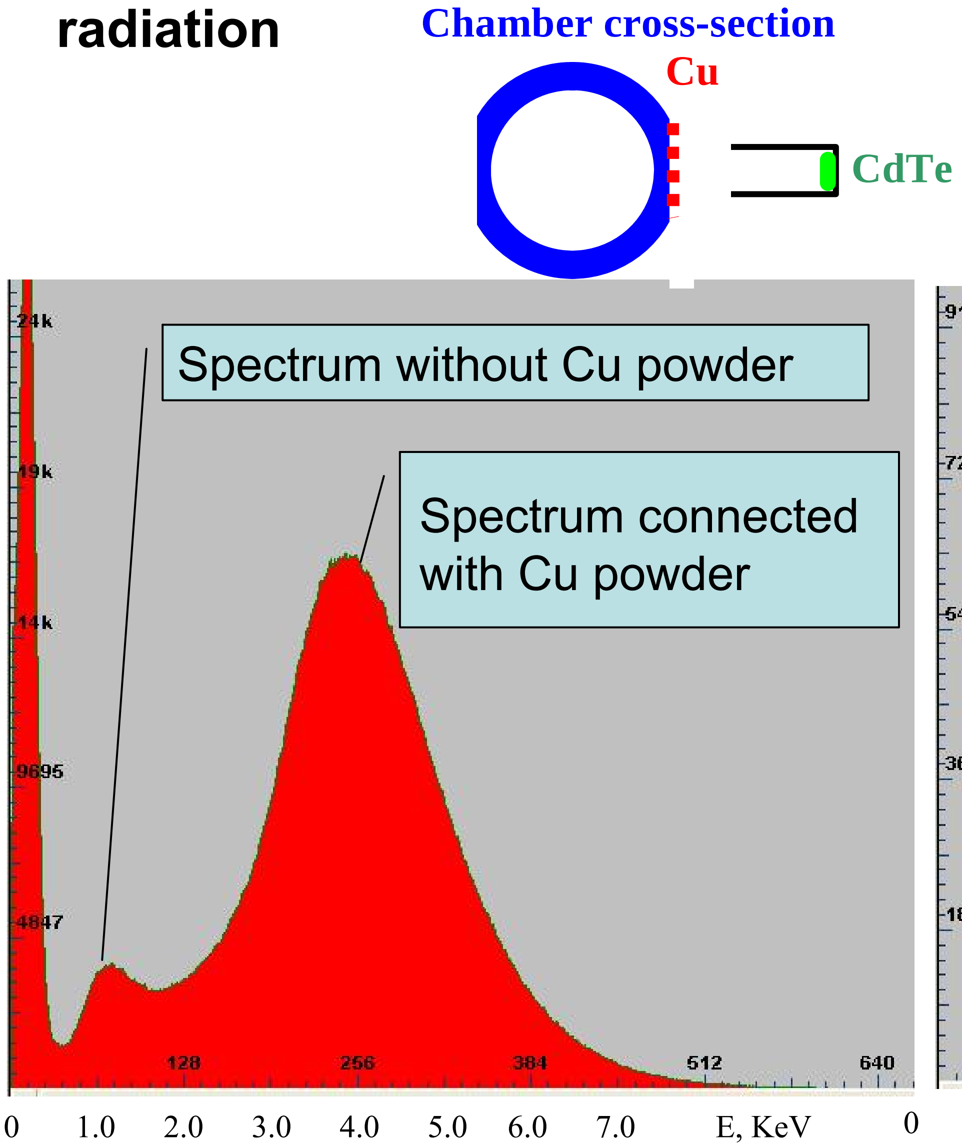
The change (shift) of spectra of X-Ray radiation generated by the surface of cavitation chamber at stage-by-stage increases in oil pressure (left to right - 20, 40 and 65 atm).

Registration of such **soft X-ray radiation with energy about 1-2 keV (which is connected with the cavitation phenomena inside the chamber) outside of the thick-walled (thickness is about 2-3 cm) cavitation chamber** is, at first sight, **very strange** because of the very low absorption mean free path (less than 10-20 microns) in the oil and plexiglas.

The same paradox takes place in LENR experiments!

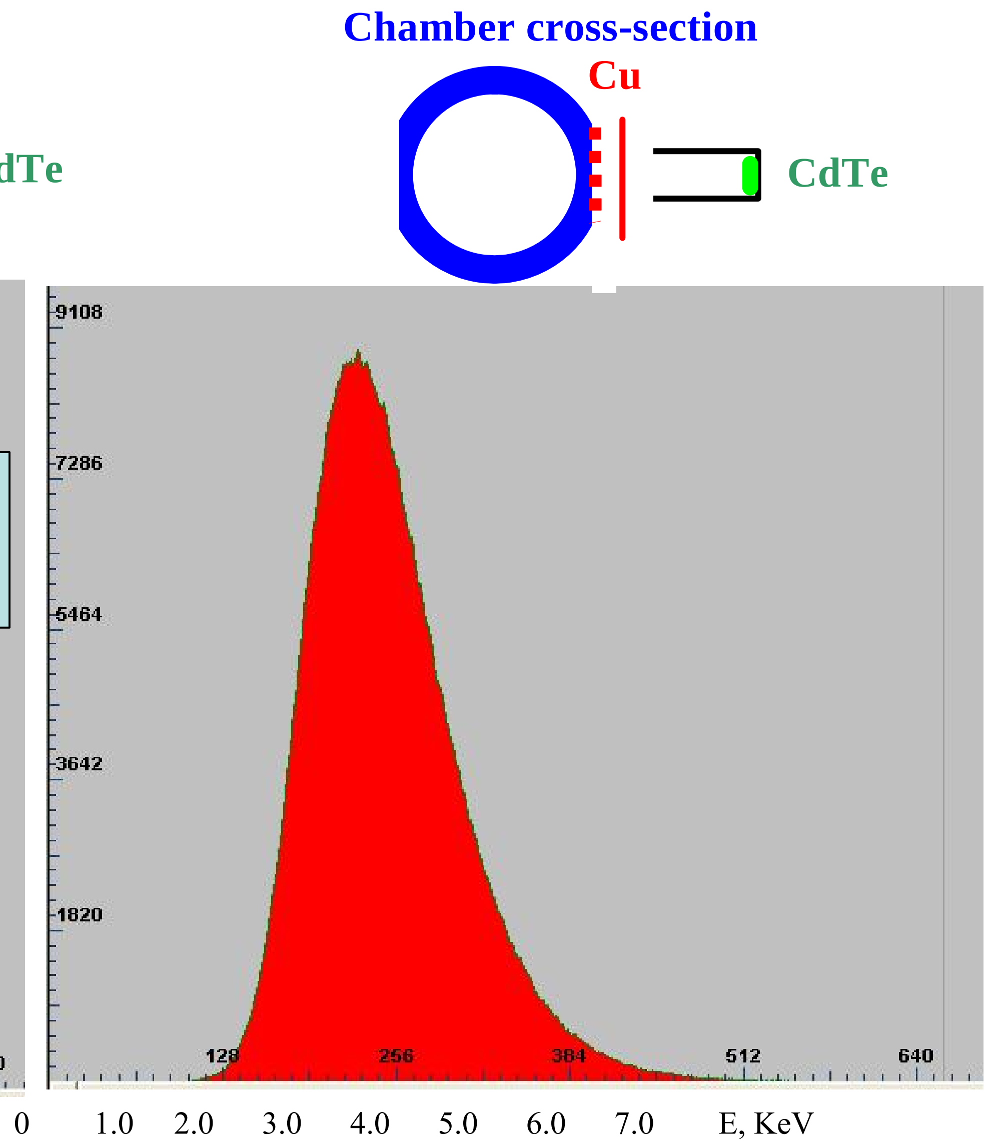
We have studied this paradox using different methods

1. Stimulation of generation of additional radiation



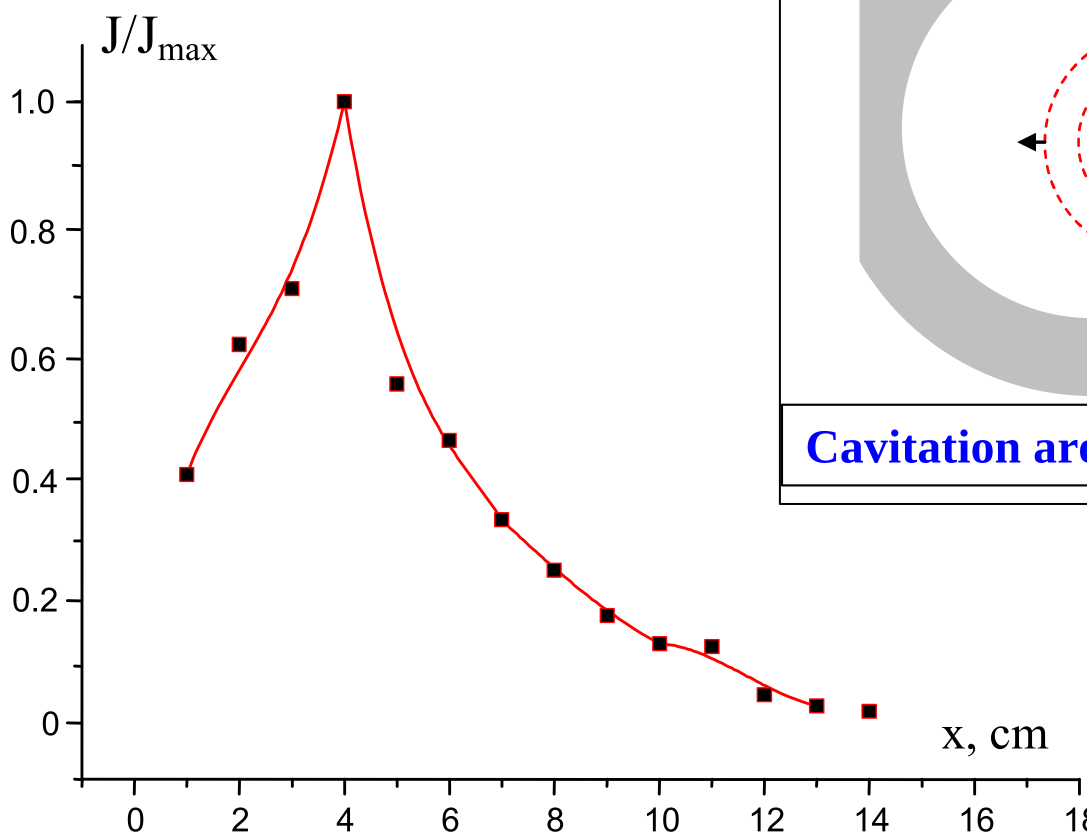
Spectrum of X-Ray radiation outside of the chamber in the presence of copper powder, mechanically and acoustically connected with its external surface.

2. Screening

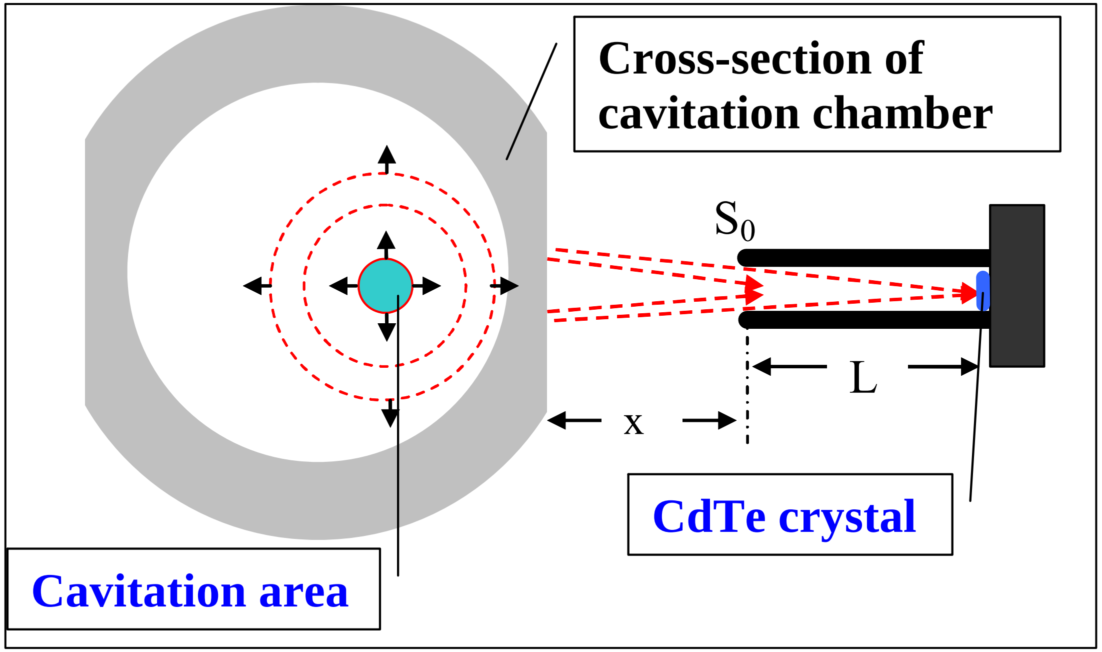


Spectrum of X-radiation in the presence of copper powder and **additional thin copper foil X-ray absorber which has not been mechanically connected with the cavitation chamber**

3. Investigation of space distribution of X-Ray sources



The dependence of the X-ray registration intensity on the distance between the detector and the surface of cavitation chamber.



$$J(x) = J(0)\left\{1 + \frac{x}{L}\right\}^2 e^{-x/\bar{l}}$$

$$x_{opt} = 2\bar{l} - L$$

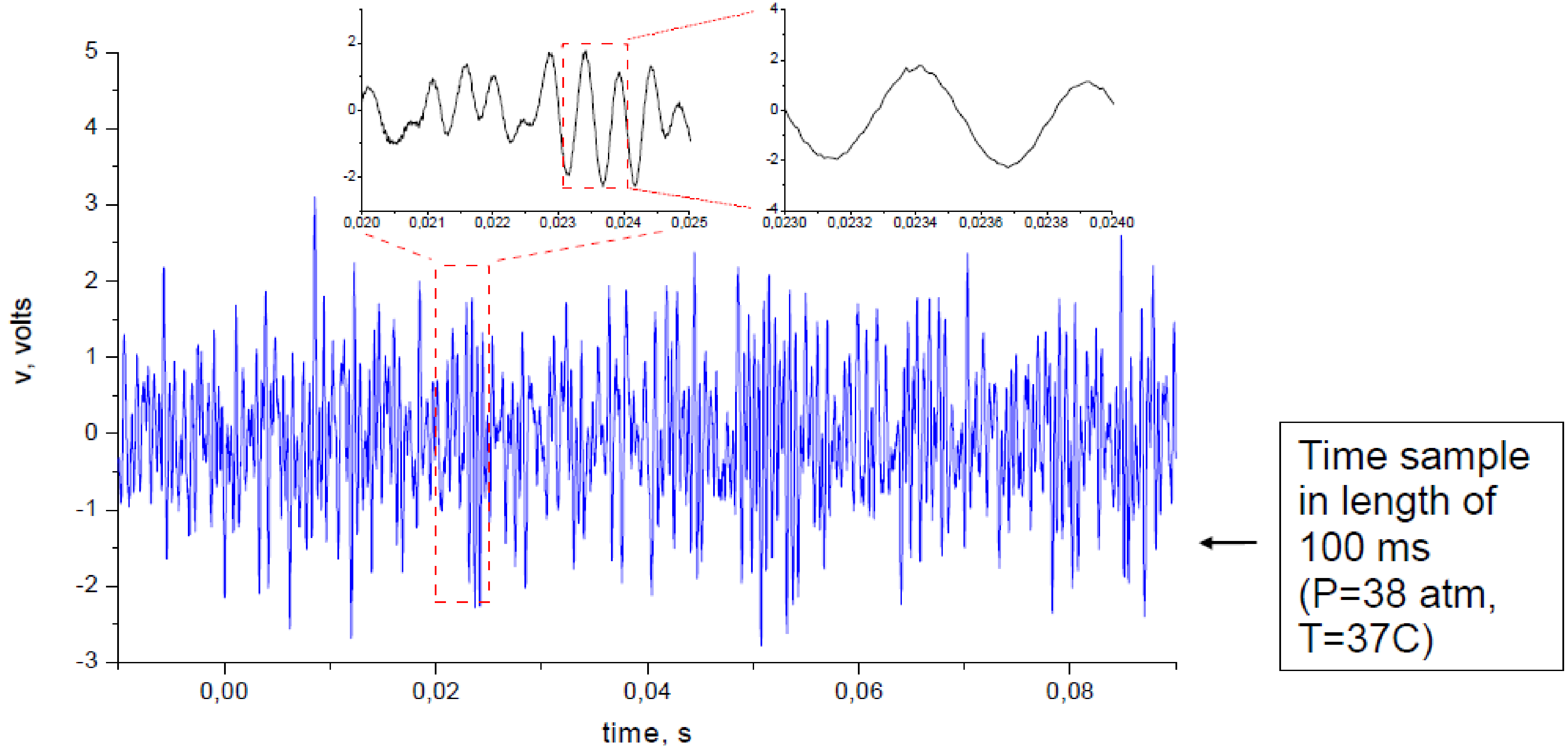
$\bar{l} \approx 4\,cm$ – absorption path,

$E_X \approx 3 - 3.5\,KeV$

So, the sources of X-Ray radiation are situated on the surface of the cavitation chamber!

Investigation of acoustic impulses generated by cavitation bubbles in the liquid

For measurement of the acoustic impulses of pressure a piezoelectric converter with a diameter of 20 mm and an oscilloscope (Tektronix 3032 B) have been used



The cavitation & shock wave mechanism of the generation of characteristic X-ray radiation outside of the cavitation area

Formation of shock waves during bubble cavitation is described by the system of Navier-Stokes equations and the equations for shock waves.

$$\rho\left(\frac{\partial\vec{u}}{\partial t}+\vec{u}\nabla\vec{u}\right)=-\nabla p+\eta\Delta\vec{u},$$

$$M=\frac{v_{shok.wave}}{v_1}$$ - Mach number

$$\frac{\partial\rho}{\partial t}+\nabla(\rho\vec{u})=0,$$

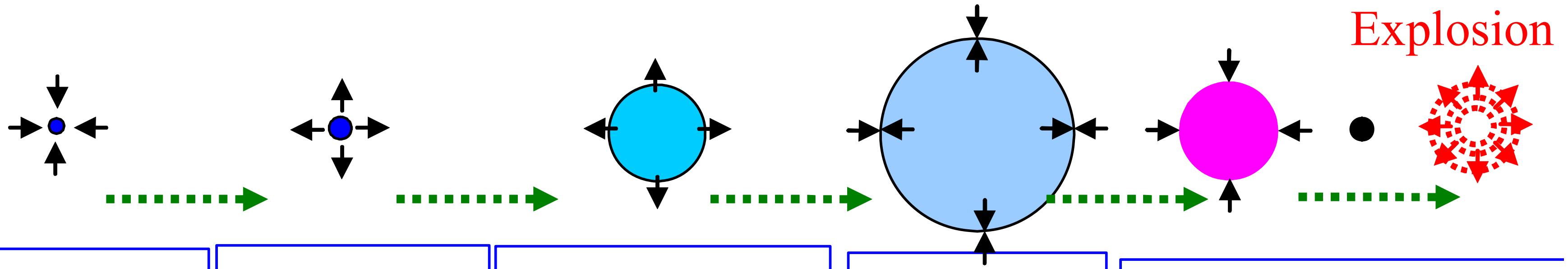
$$P_2/P_1=\frac{(\gamma+1)V_1-(\gamma-1)V_2}{(\gamma+1)V_2-(\gamma-1)V_1},$$

$$T_2/T_1=\frac{[2\gamma M^2-(\gamma-1)][(\gamma-1)M^2+2]}{(\gamma+1)^2M^2},$$

$$\rho_2/\rho_1=\frac{(\gamma+1)M^2}{(\gamma-1)M^2+2},$$

$$P_2/P_1=\frac{2\gamma M^2}{\gamma+1}-\frac{\gamma-1}{\gamma+1}$$

The typical evolution of the bubble cavitation process



Micro-nucleus of a gas bubble in the compressed liquid

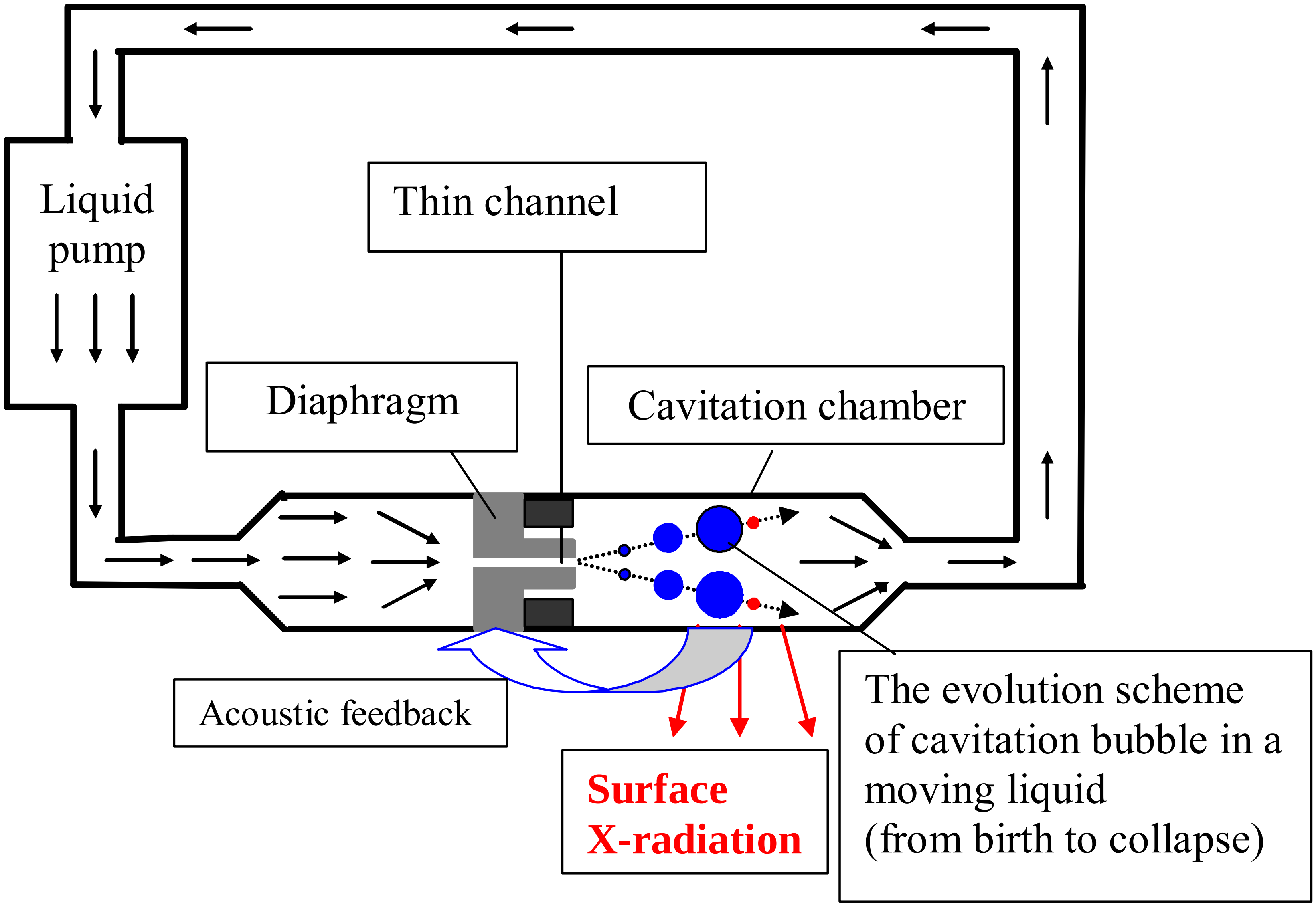
The beginning of growth of a gas bubble in the tensioned liquid

Growth phase of a gas bubble. Growth speed of the bubble is less than the speed of sound.

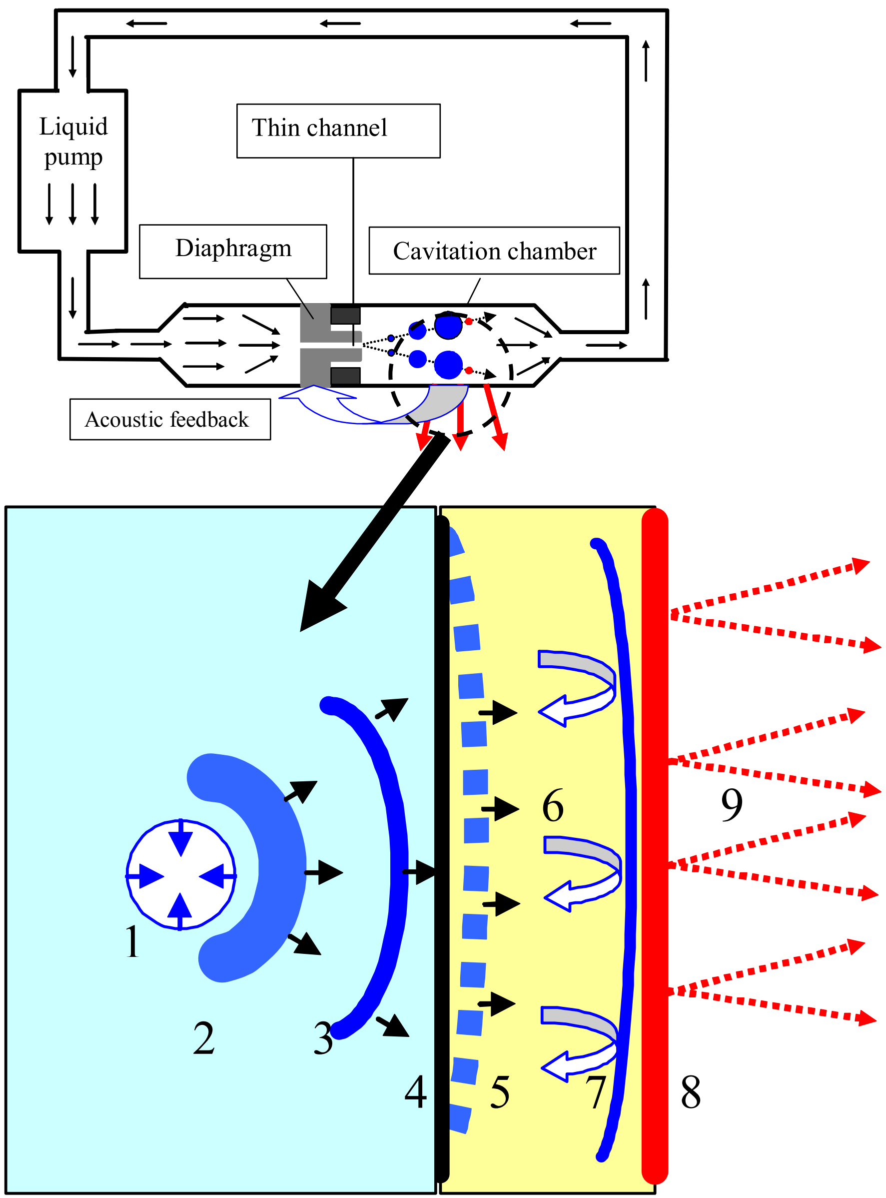
The phase of unstable balance at the maximum size of the bubble.

The phase of bubble collapsing. The speed of squeezing is more than the speed of sound. The collapse ends with an explosion and the formation of a divergent shock wave with supersonic speed.

The same process takes place in the liquid stream moving through thin channel



The scheme of transformation of the the energy of bubble cavitation collapse to the outside X-ray radiation



Cavitation collapse (1) in liquid;

Acoustic impulse (2);

Shock wave in liquid (3);

Formation of elastic wave (5) on the surface (4) of a thick wall (6) of the cavitation chamber;

Shock wave (7) in the wall of the cavitation chamber;

Excitation of surface atoms (8) of the wall (6) of cavitation chamber during reflection of shock wave from external surface of the wall;

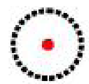
X-Ray generation (9)outside of chamber

The mechanism of atom excitation by action of shock wave

Excitation of atom (e.g. transition $1s_0 \rightarrow 2p_0$) takes place at **its sudden acceleration** during reflexion of shock wave front from the border between chamber wall and air. The width of front of shocking wave in dense medium is tens of angstroms.

Wave function of the atom on the surface of the chamber in it's initial state is

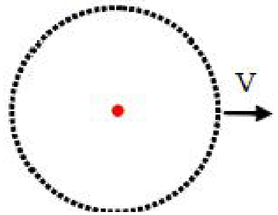
$$\Psi_{100}(\vec{r},t) = \sqrt{\frac{Z^3}{4\pi a^3}} e^{-Zr/a} \exp(-iE_1 t/\hbar)$$



The wave function of the same (now moving) atom after action of chock wave is

$$\Psi_{210}(\vec{r}',t) = r' \sqrt{\frac{Z^5}{32\pi a^5}} i \cos\theta e^{-Zr'/2a} e^{i m_e v z'/\hbar} \exp\{-i[E_2 + m_e v^2/2] t/\hbar\},$$

$$\vec{r}' = \vec{r} + i\vec{e}_z v t$$



Probability of excitation of atom transition $1s_0 \to 2p_0$ is the following

$$W_{100,210} = \left| \int_V \Psi^*_{100}(\vec{r},0)\Psi_{210}(\vec{r},0)e^{imvz/h}dV \right|^2 =$$

$$\left| \frac{iZ^4}{4\pi a^4\sqrt{2}} \int_0^\infty \int_0^\pi e^{-3Zr/2a} e^{im_e vr\cos\theta/\hbar} r^3 \cos\theta \sin\theta d\theta dr \right|^2 = \frac{9}{32} \frac{\left(v/v_{100}\right)^2}{\left\{\frac{9}{4} + \left(v/v_{100}\right)^2\right\}^6};$$

$v_{100} = Ze^2/\hbar \approx 2.3*10^8 Z \quad cm/s$ - orbital velocity of atom electron

$$W_{100,210} \approx 2.2*10^{-3}\left(v_{Shock\ wave}/v_{100}\right)^2$$

- probability of excitation

At $v_{Shoking\,wave} \approx 4.10^{6}\ cm/s$ we have $W_{100,210} \approx 4.10^{-12}/Z^{2}$

At $n_{atom} \approx 10^{17}\,cm^{-2}, Z = 29\ \ and\ \ \frac{dN_{SW}}{dt} \approx 10^{4}\,s^{-1}$ we have

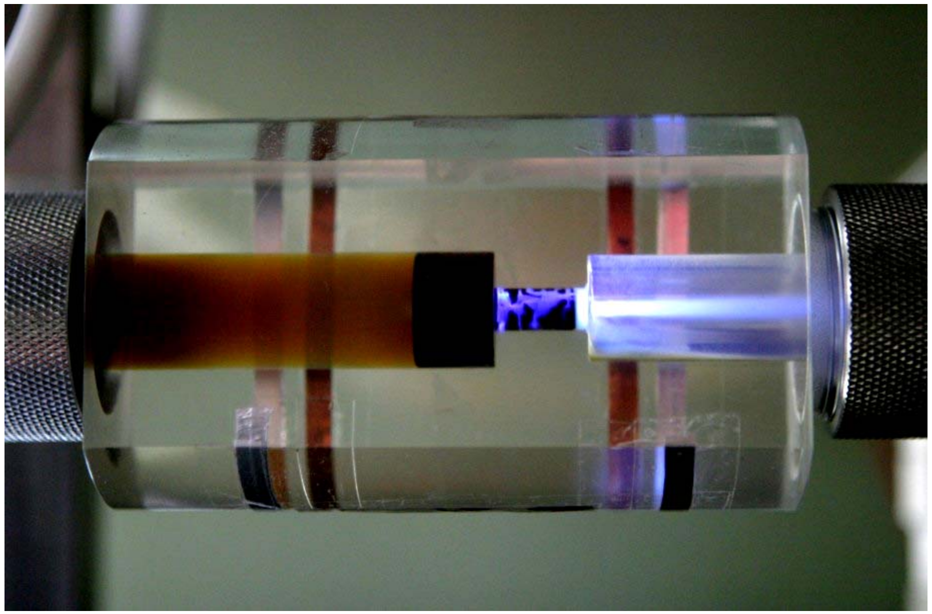
$$\frac{dn^{*}}{dt} = W_{100,210}\, n_{atom} \frac{dN_{SW}}{dt} \approx 10^{6}\ excited\ atoms/s\ cm^{2}$$

The same mechanism of surface atom excitation takes place for another atom transitions

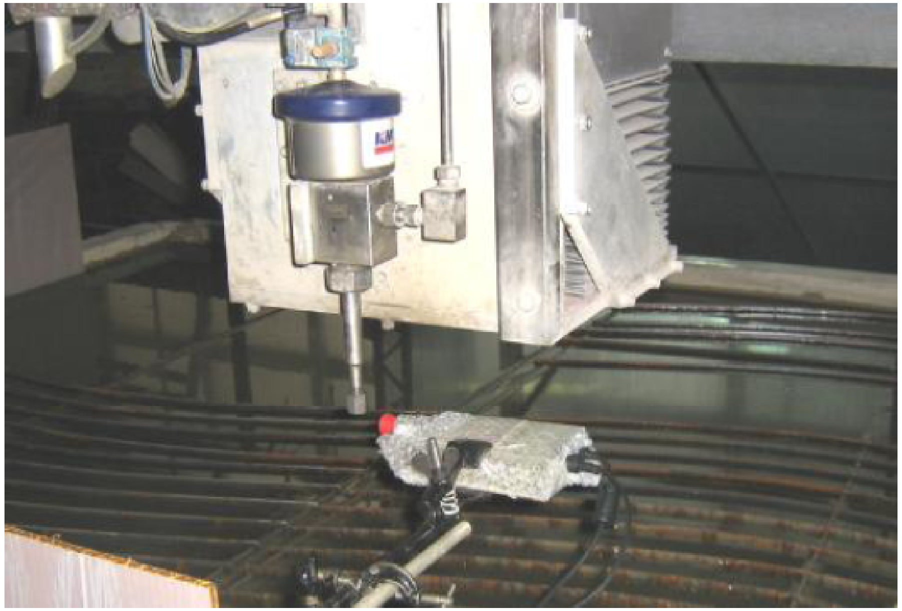
Intermediate Conclusion

The generation of X-Ray radiation outside of the cavitation chamber is the result of the transformation of the cavitation shock wave in liquid to a shock wave in the cavitation chamber wall and further excitation of atoms on the external surface of the chamber during reflection of its shock wave from the wall-air border.

At high liquid pressure the liquid jet does not touch the internal surface of chamber wall and the cavitational shock waves lead (through reflection from the jet-vacuum border) to the excitation of jet surface atoms and to the subsequent generation of optical and X-ray radiation in the jet.
This generation was observed in experiments.



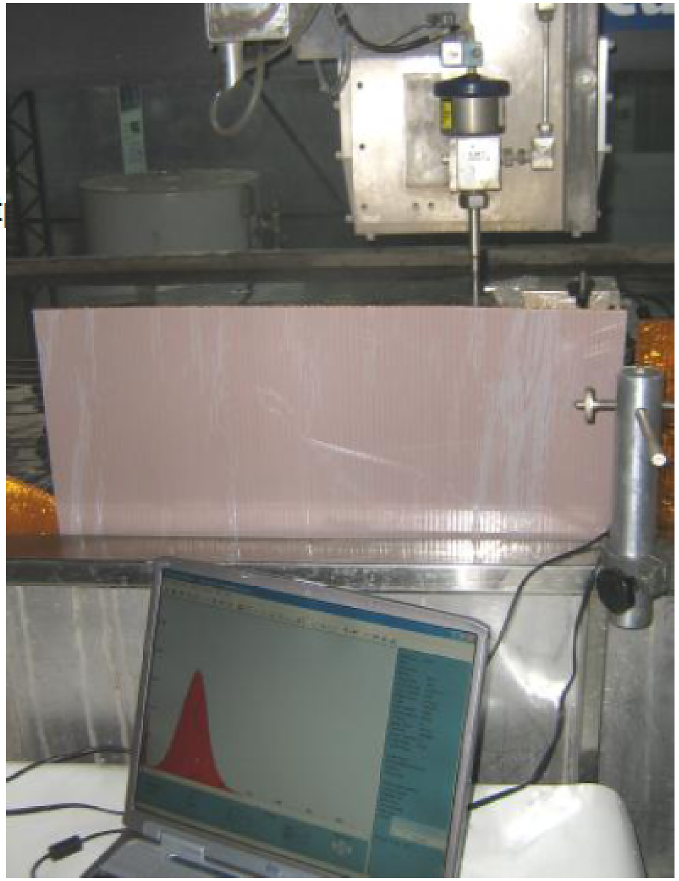
2. Generation of intensive x-ray radiation at free exit of the fast water jet from metal channel



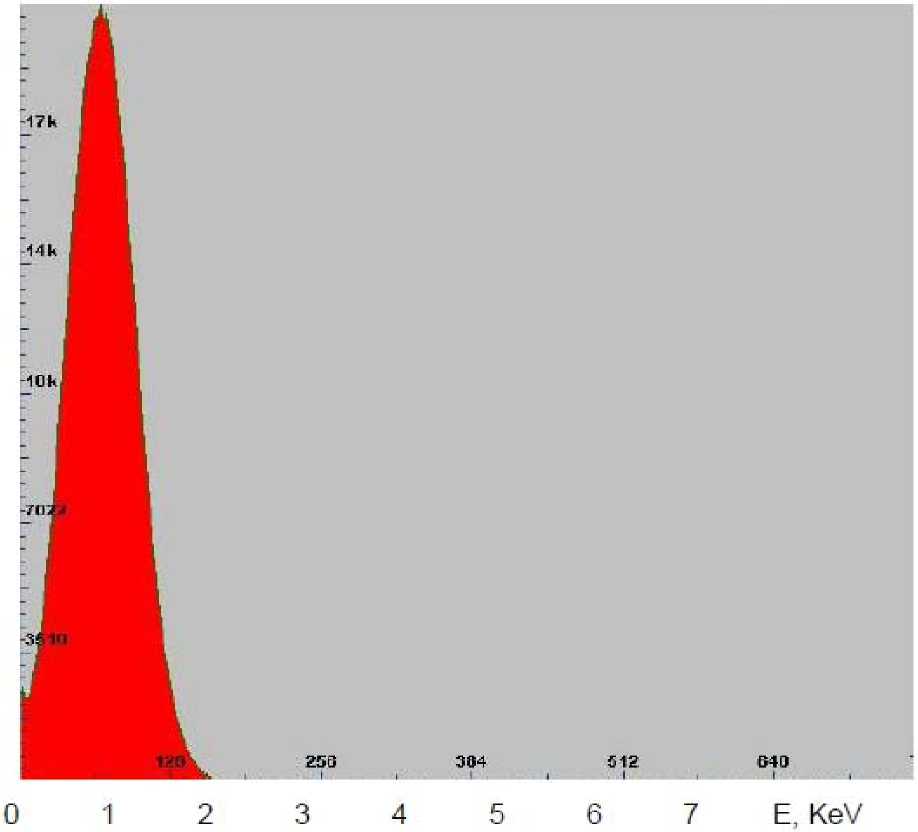
The KMT industrial equipment for cutting and drilling of thick (up to 2-3 cm) metal and ceramic plates by water jet at ultrahigh pressure (P=250-2000 atm) was used for study of X-Radiation at water cavitation

1. Investigation of spectrum of X-Ray radiation generated by free water jet

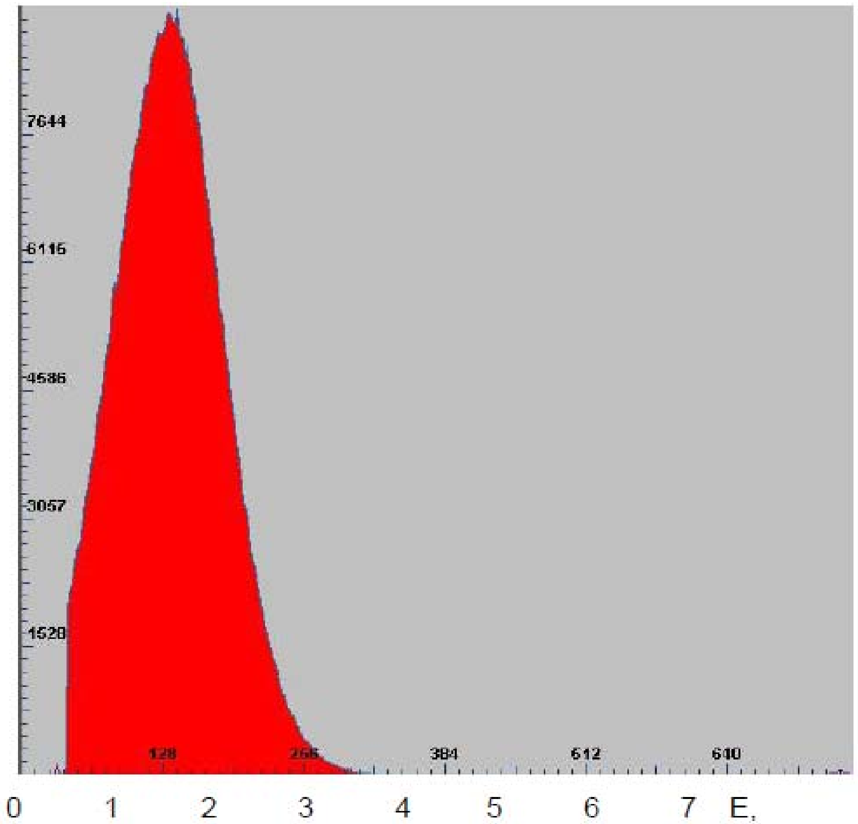
out



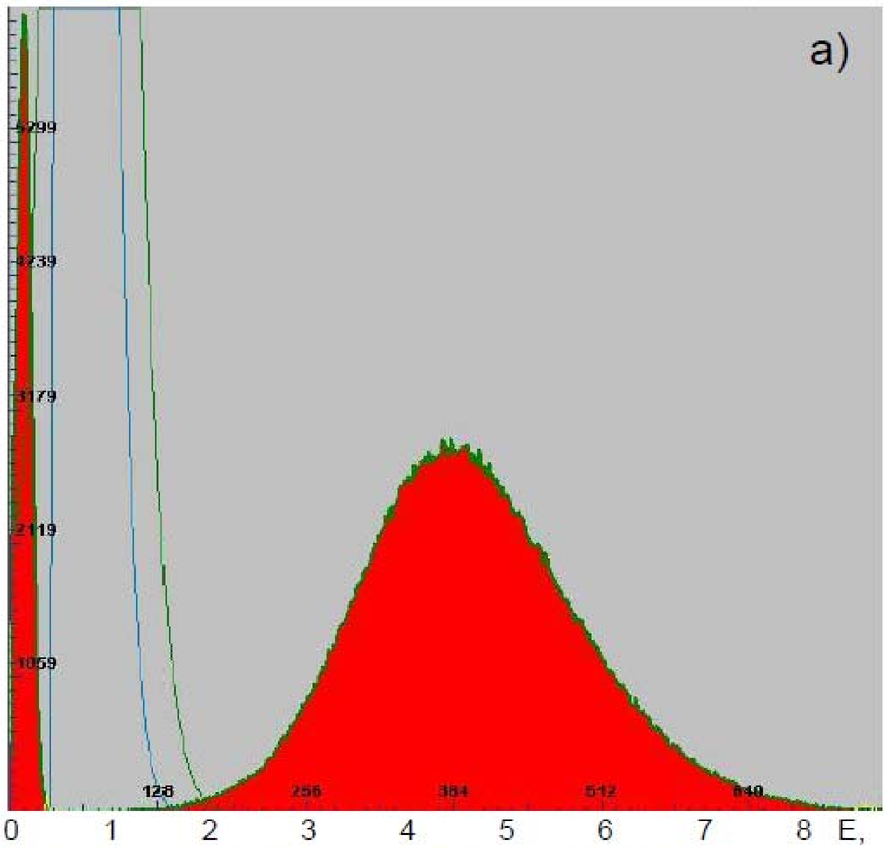
Measurement of X-ray radiation spectrum of fast caviting water jet



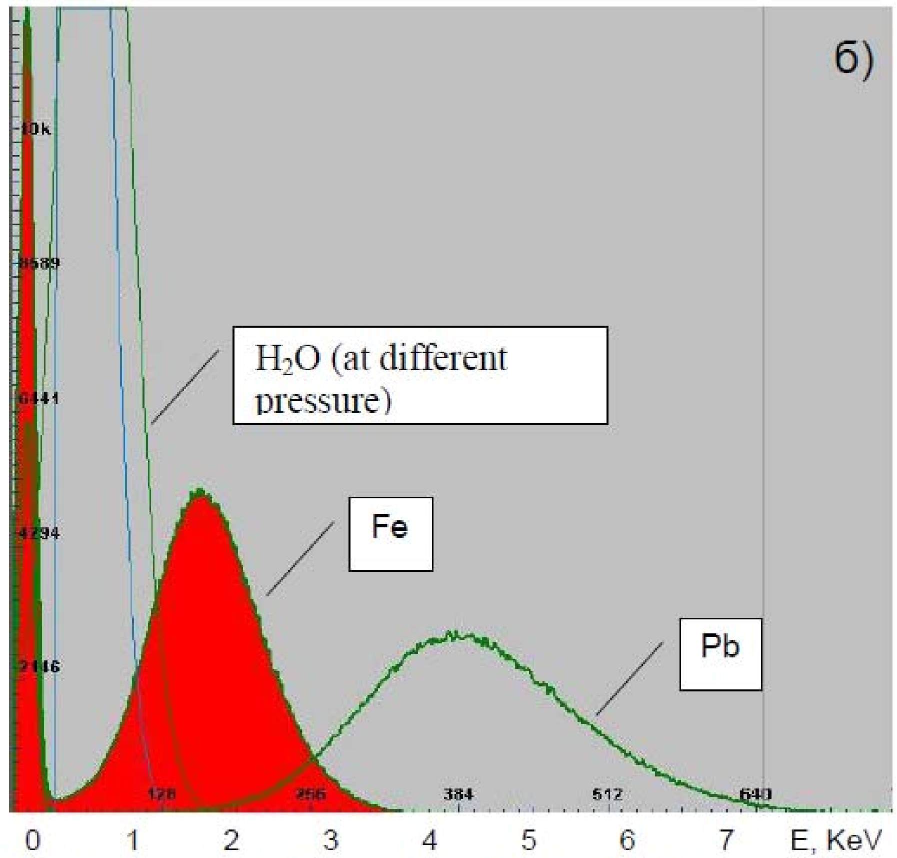
Spectrum of X-ray radiation generated by a free fast caviting water jet (pressure 600 atm). X-ray free path is <L>≈6 mm.



Spectrum of X-ray radiation of steel surface of the rod. The channel with caviting water at pressure of 600 atm is situated inside the steel rod (<L>≈ 2.5 cm)



Spectrum of X-ray radiation of steel surface of the rod. The surface was covered by fine-dispersed Pb powder

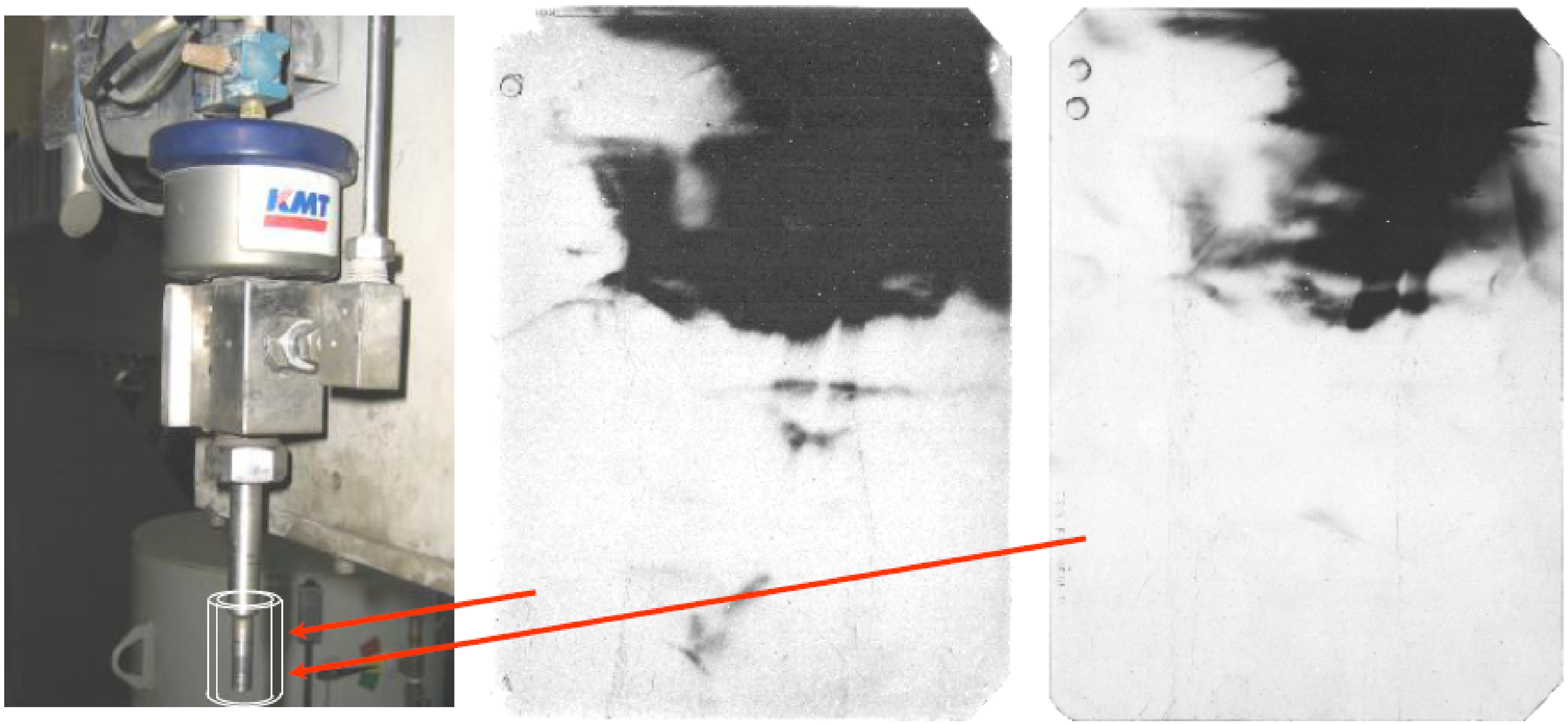


Comparison of spectra of X-radiation from different surfaces at cavitation of water jet

Investigation of features of X-ray radiation of fast water jet by the method of X-ray films photoregistration

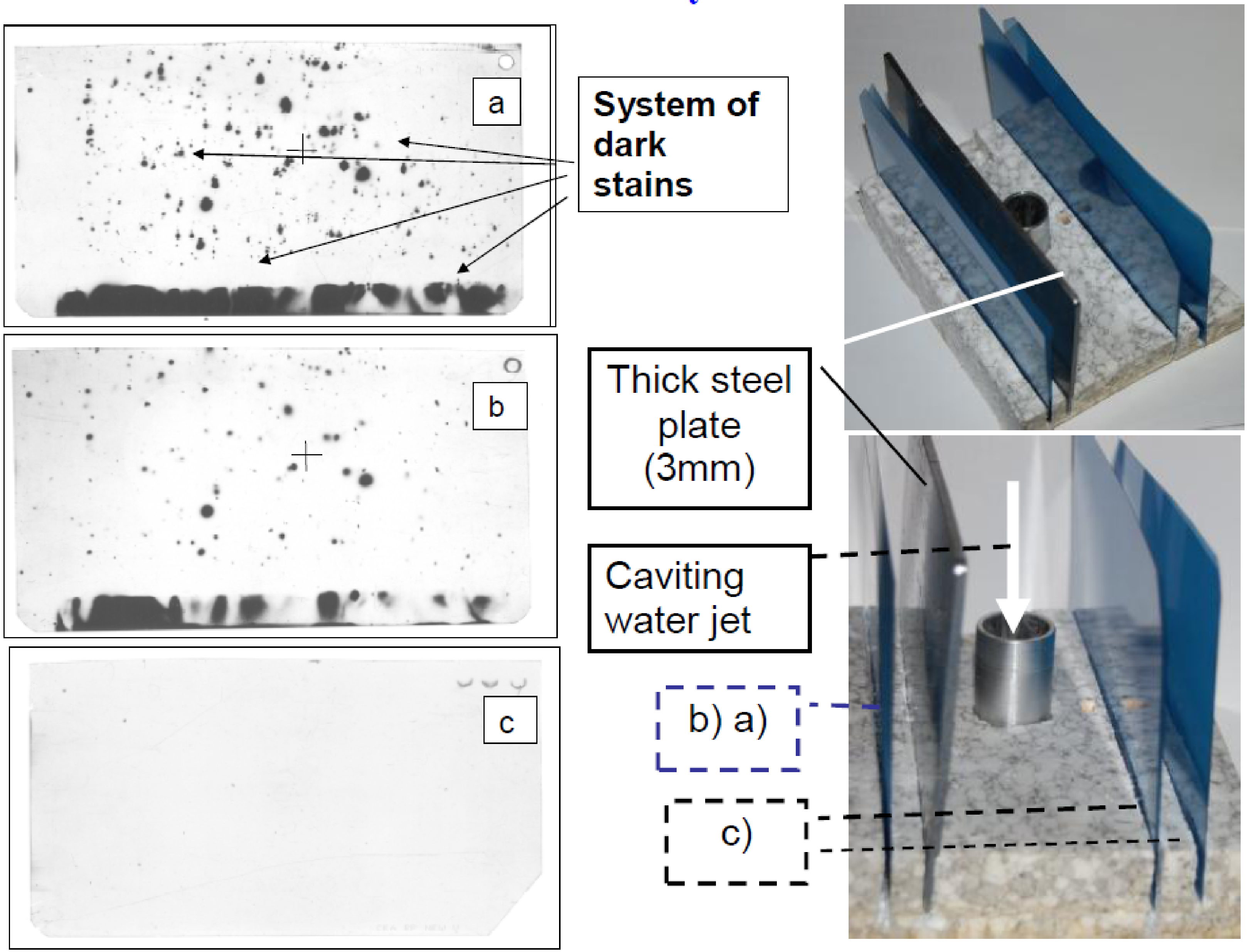
(**Medical X-Ray screen CEA A3SE-645-41 (Sweden), Kodak)**

X-Ray radiation from rod with caviting water jet



The image on two X-ray films situated without clearance in coaxial geometry around cylindrical rod with caviting water jet on distance of 7 mm. The left film was situated more close to a rod, and right - closely behind it

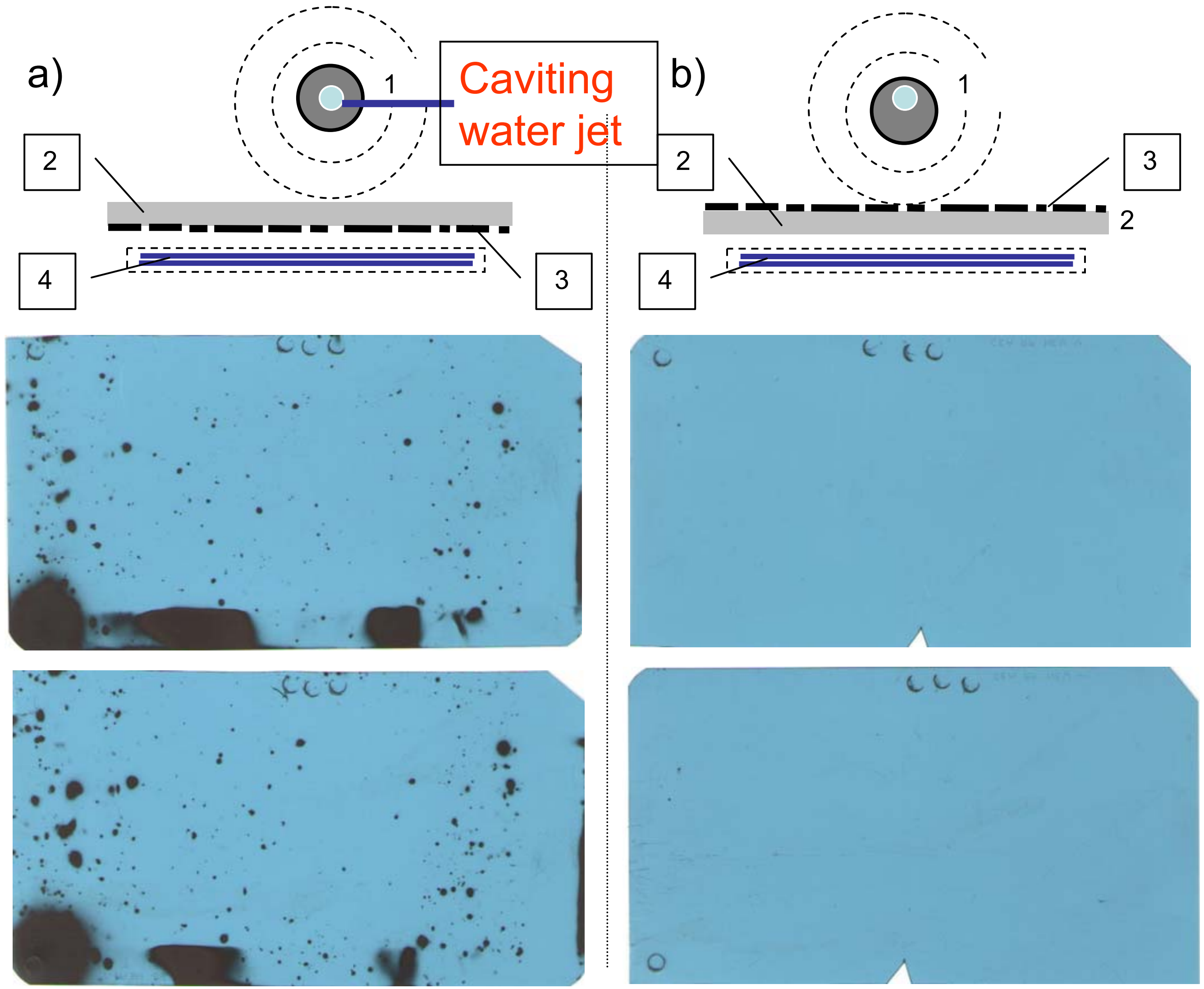
Abnormal X-Ray transparency of "black" screens (registration of X-ray radiation and discrete stains on the X-ray films behind thick metal screen)



It was found for the first time that the impact of shock acoustic waves 2 (see below), which are formed in the air as a result of cavitation in water jets 1, on distant thick screen 3 (made of stainless still with stickiness 3 mm) leads to the generation of a quasi-coherent directional X-ray emission from the back side of screen 3, that was registered by two films 4a,4b stacked to each other! The spatial parameters of this radiation depend on the shape and size of the screen and characteristics of shock wave.

There is a high probability that X-Ray phenomena observed at explosion of cavitation bubbles and connected with the interaction of cavitation induced shock waves with outer surface of working chamber or screen are similar to X-Ray phenomena, which take place during generation of similar shock waves at fast formation of numerous micro-cracks at loading and interaction of hydrogen or deuterium with metals matrix during electrolysis, gas discharge or thermocycling.

Abnormal X-ray radiation registration behind thick metal screen with one-side defects at frontal and reversed orientation



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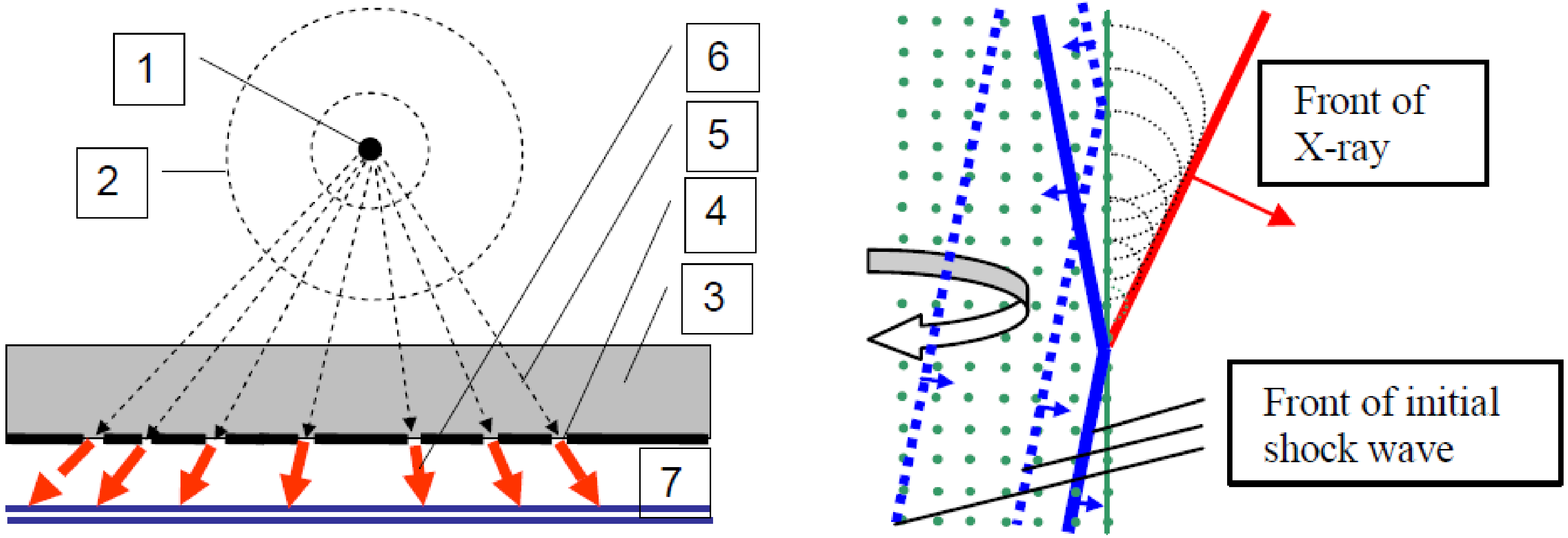
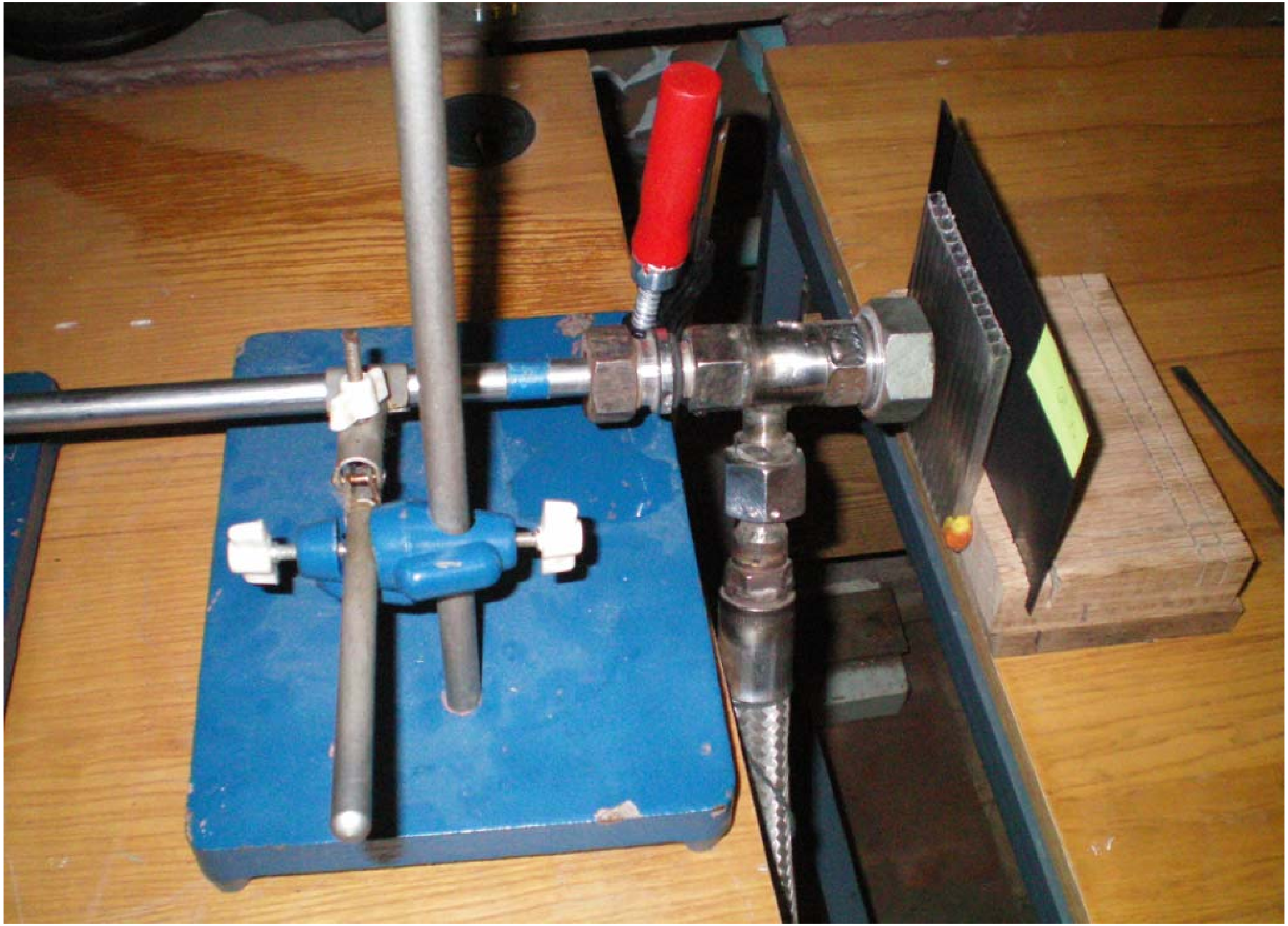
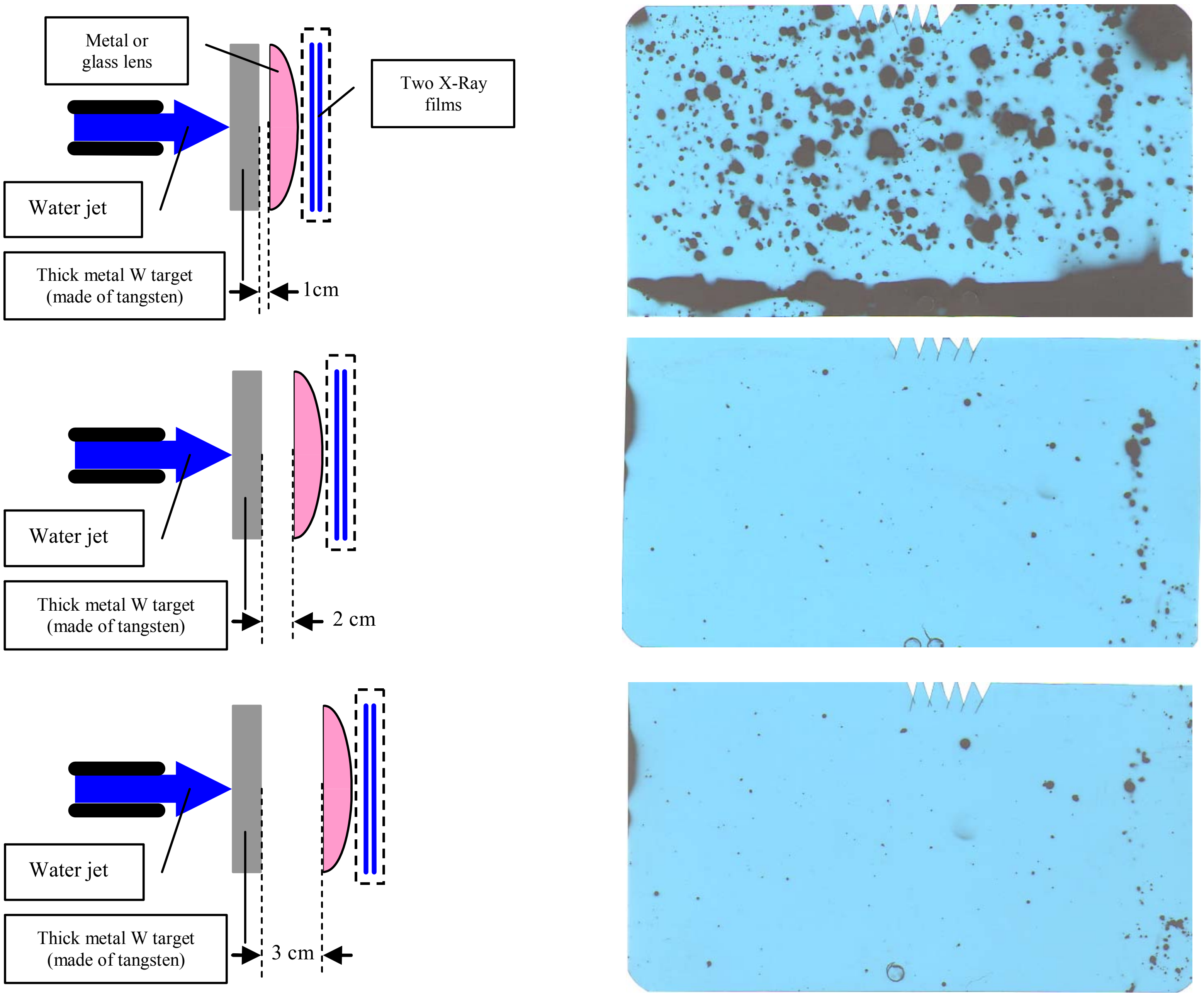
The possible mechanism of formation of discrete stains on X-ray films



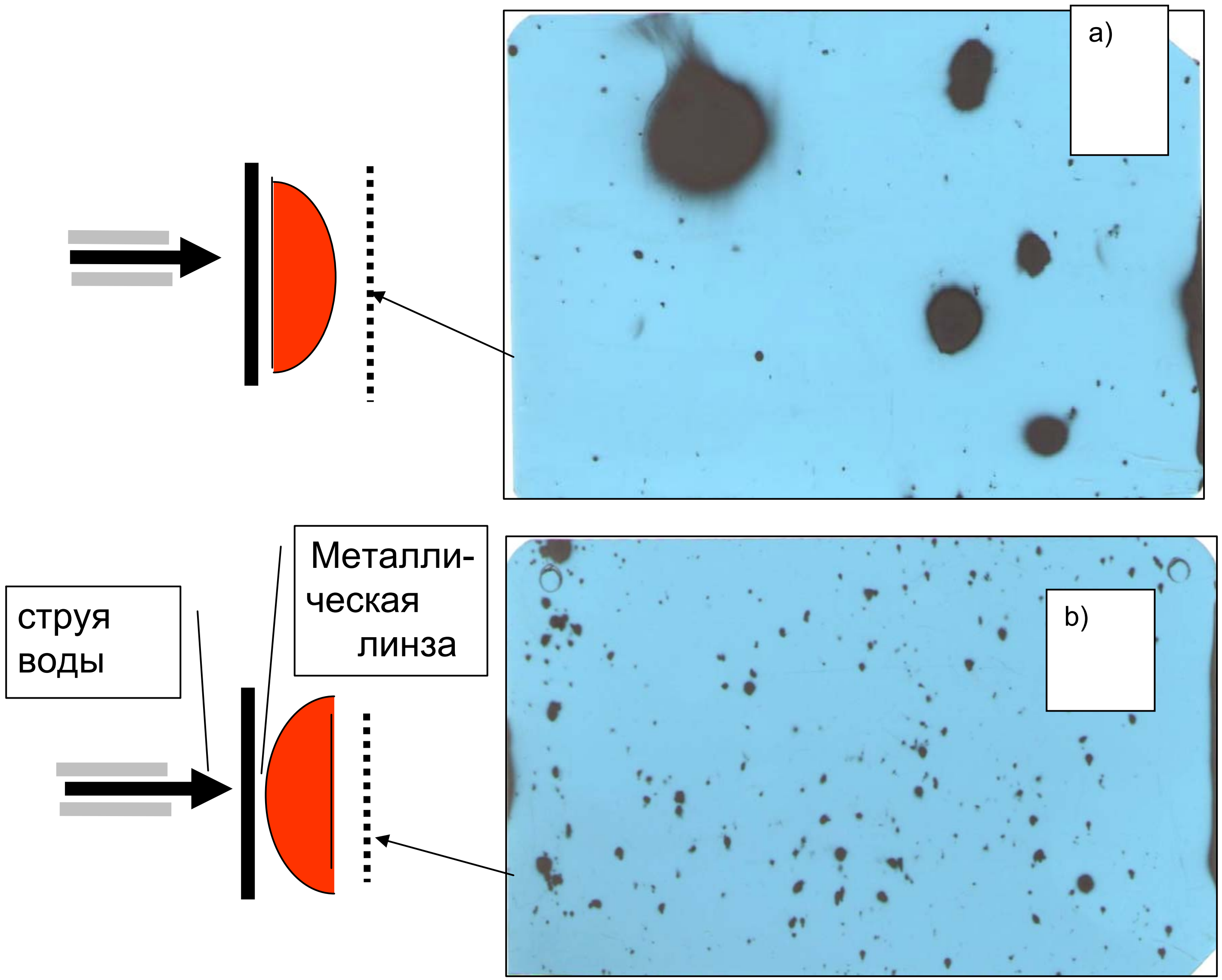
The schema of possible formation of discrete stains on the X-ray films situated behind a thick screen: 1 – a local source of a spherical acoustic shock wave, 2 – fronts of X-Ray and shock waves front in air, 3 - the thick metal screen, 4 - local defect paint on a screen backside, 5 - direction of movement of a spherical shock wave in screen volume, 6 - generated secondary X-ray wave, 7 - X-ray films.



“Closed” cavitation chamber for X-Ray generation



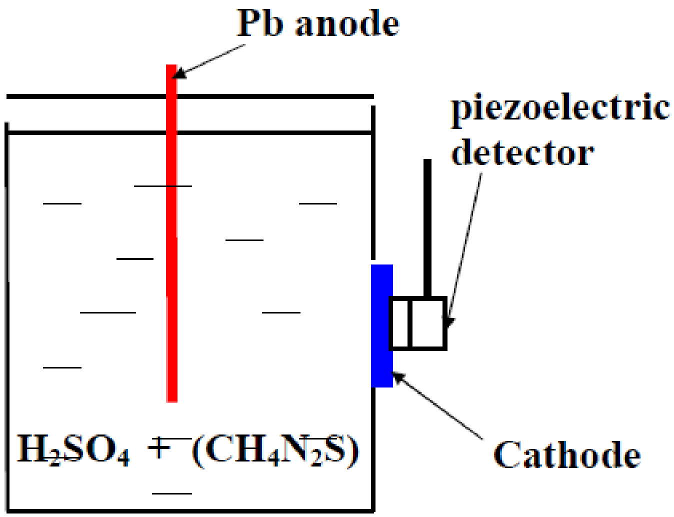
Metal or glass lens
Two X-Ray films
Water jet
Thick metal W target (made of tangsten)
1cm
Water jet
Thick metal W target (made of tangsten)
2 cm
Water jet
Thick metal W target (made of tangsten)
3 cm

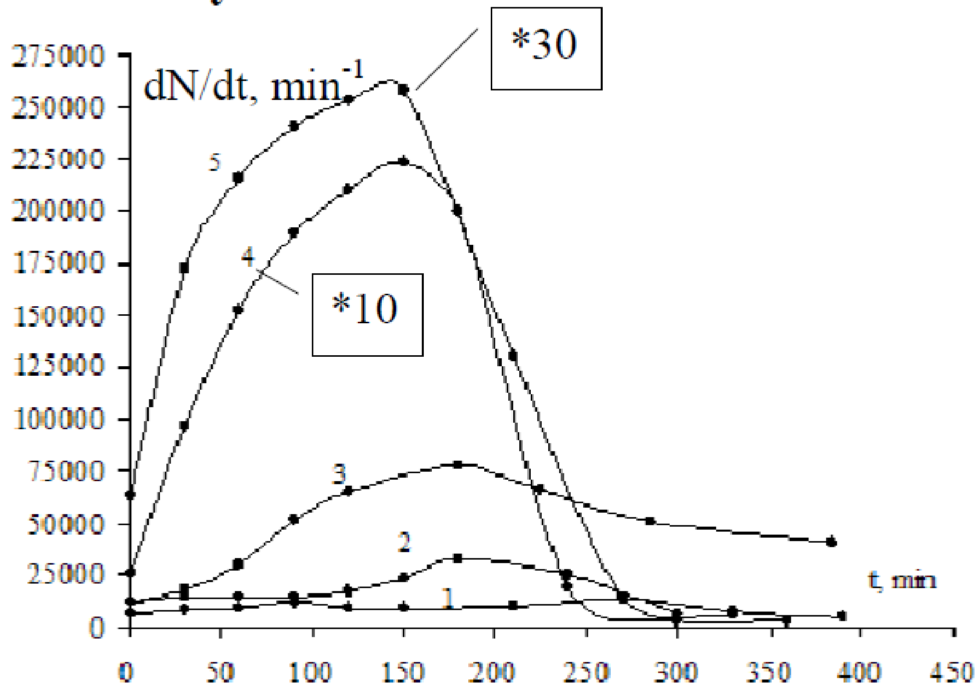


Focusing (a) and defocusing (b) action of metal lenses on combinational "акусто" - a "x-ray" field

These results are similar to the results of investigation of external X-Ray radiation generated on outer surface of closed chamber at glow discharge or electrolysis in LENR experiments (see above)

Generation of acoustic impulses at electrolysis

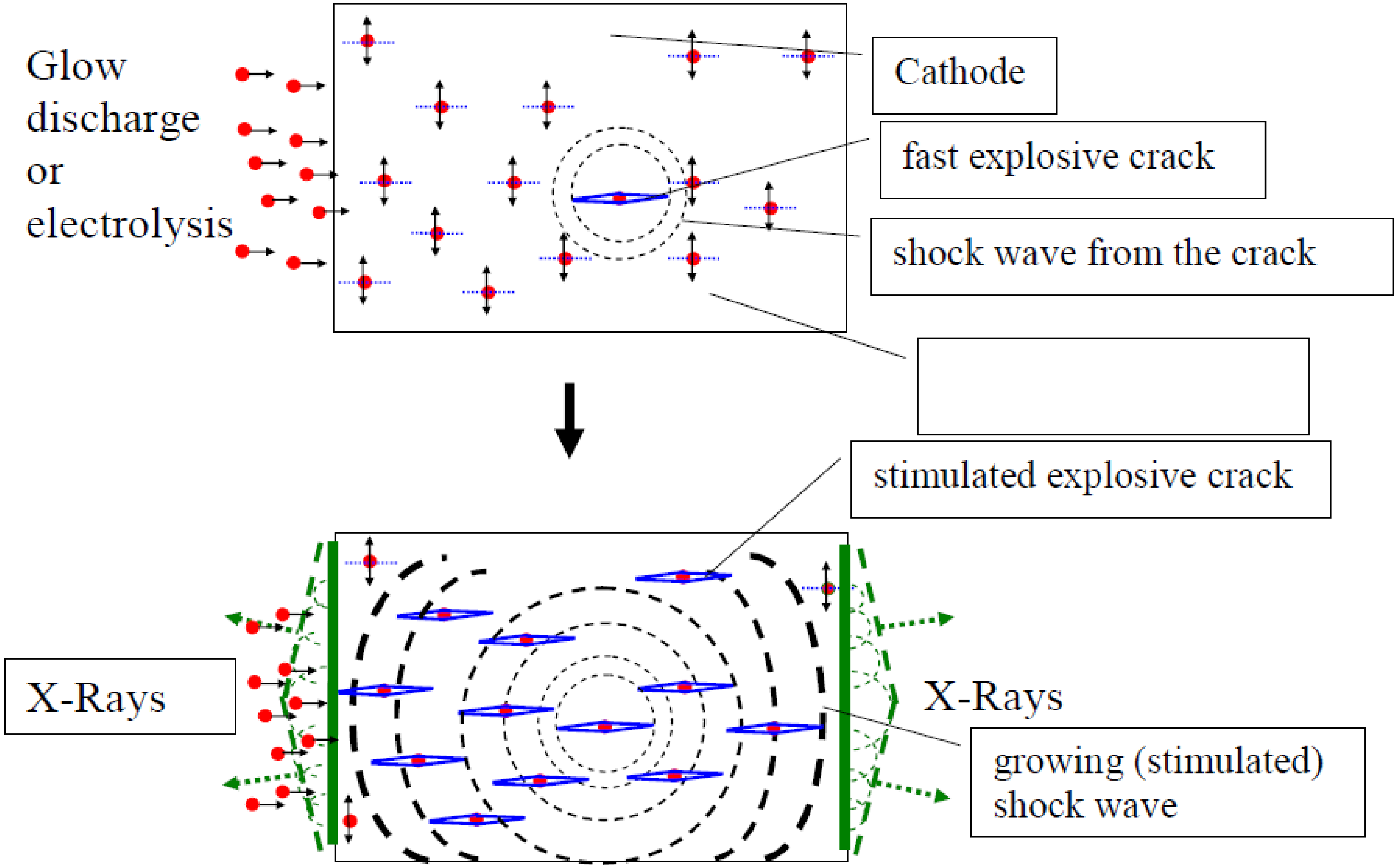




Generation of acoustic impulses vs time of electrolysis on cathode (steel surface) at current density 1 - $j = 1 mA/cm^2$; 2 - $j = 5 mA/cm^2$; 3 - $j = 10\ mA/cm^2$; 4 - $j = 50\ mA/cm^2$ (count rate is reduced by 10 times); 5 - $j = 100\ mA/cm^2$ (count rate is reduced by 30 times).

In Pd and Ni: dN/dt≈10^4-10^5 sec^{-1} at $j \geq 100\ mA/cm^2$

The possible method of generation of shock waves and X-Ray at fast formation of numerous micro-cracks at loading and interaction of hydrogen or deuterium with metals matrix during electrolysis, gas discharge or thermocycling



Conclusions

The generation of X-Ray radiation outside of the cavitation chamber is the result of the transformation of the cavitation shock waves in liquid to a shock waves in the cavitation chamber wall and further excitation of atoms on the external surface of the chamber during reflection of its shock wave from the wall-air border.

Results of experiments show that the intensive acoustic shock waves connected with the cavitation processes are a source of intensive X-ray radiation. Frequency of radiation depends on substance in which shock waves extends and is transformed.

Relatively soft radiation with energy about 1 keV is generated by a surface of fast water jet in the area of cavitation. The more high energy (up to 2 keV) is generated by a surface of a cylindrical steel rod with caviting water jet. At the presence of heavy atoms on the rod surface this energy increase up to 5 keV.

Total intensity of X-Radiation at cavitation is about 0.1 Ci.

There is a **very high probability** that X-Ray phenomena observed at explosion of cavitation bubbles and connected with the interaction of cavitation induced shock waves with outer surface of working chamber or screen are similar to X-Ray phenomena, which take place during generation of similar shock waves at fast formation of numerous micro-cracks at loading and interaction of hydrogen or deuterium during metal matrix during electrolysis, glow discharge or thermocycling.

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