Plasma formation under the foam layer irradiation by soft x-ray radiation.

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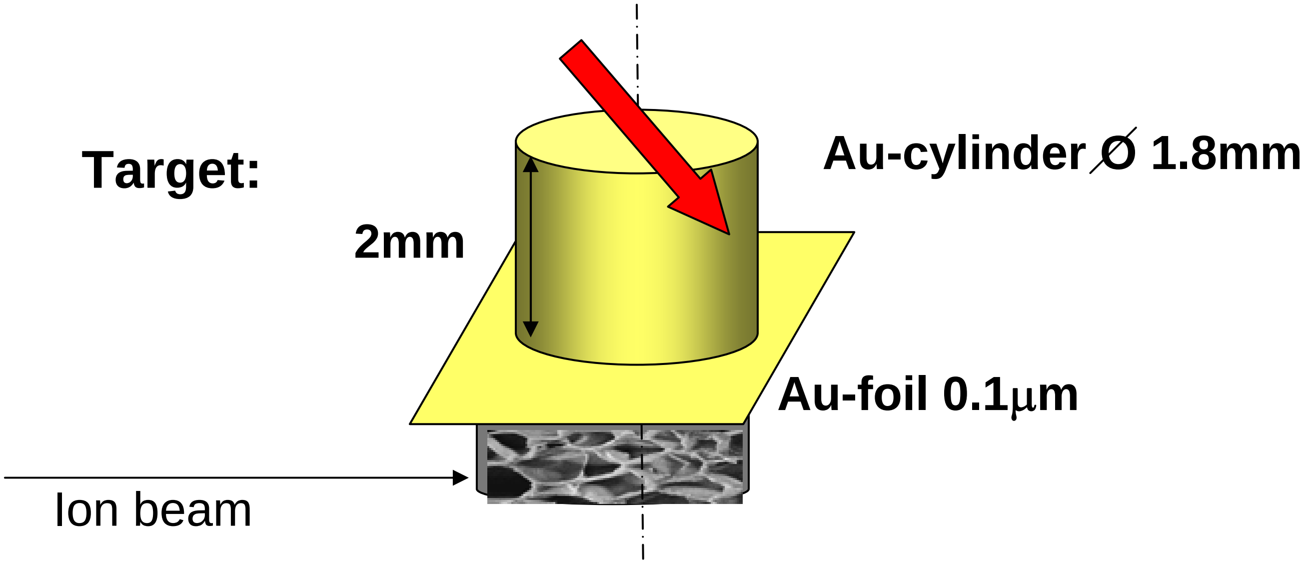
PHELIX Laser: **1ω, 1ns, 250J, Ø~400µm, 10^{14} W/cm^2**

Target:



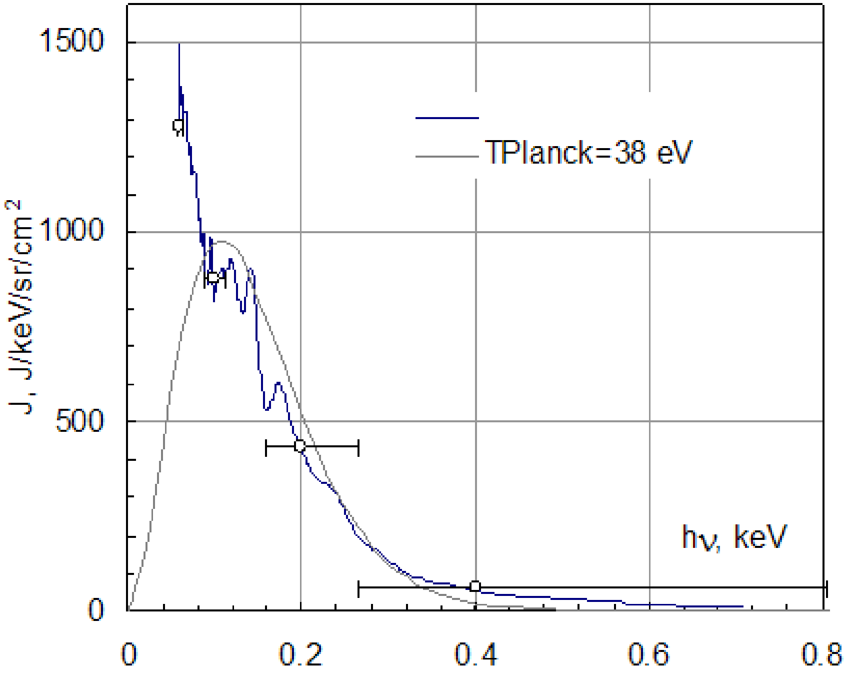
CH-foam 10 mg/cm^3 (1/100 of solid)

Areal density ρx=50-500 µg/cm^2

The experimental data are the following:

X-ray spectrum on the plastic foam layer was measured:

- T_{rad}=30-40 eV
- Transmitted energy makes 10-25% of the irradiation energy
- The incident radiation flux on the plasma flow (experimental data) is presented at the right
- The purpose is simulation of plasma parameters for ion beam deceleration .



Code RADIAN: two-temperature hydrodynamics plus radiative transfer equation

$$\frac{\partial r}{\partial t} = u(m,t), \qquad dm = \rho r^n dr\,, \qquad \frac{\partial u}{\partial t} = -r^n \frac{\partial p}{\partial m} \quad , \quad 0 \le m \le M \quad , \quad q \le t \le \infty \quad ,$$

$$\text{a}\,\frac{\partial}{\partial t}\left(\frac{1}{\rho}\right) + \frac{\partial}{\partial m}\left(r^n u\right) = 0$$

$$p = p_e + p_i\,,$$

$\varepsilon_e = \varepsilon_e(T_e)\,, \quad p_e = p_e(T_e)$, n=0 – plane, n=2 – spherical geometry

$$\frac{\partial \varepsilon_e}{\partial t} = -p_e \frac{\partial r^n u}{\partial r} + \frac{\partial}{\partial m} r^{2n} \lambda \frac{\partial T_e}{\partial m} - K - \frac{\partial}{\partial m} r^n W\,,$$

$$\rho \frac{\partial \varepsilon_i}{\partial t} = -p_i \frac{\partial r^n u}{\partial m} + K$$

$$\mu \frac{\partial I_\nu}{\partial r} + \delta_{2n} \frac{1-\mu^2}{r} \frac{\partial I_\nu}{\partial \mu} + \chi_\nu I_\nu = 2\pi \chi_\nu I_{\nu p}$$

$$W = \int_0^\infty d\nu \int_{-1}^{1} \mu I_\nu d\mu\,, \qquad \chi_\nu = \chi_\nu(\nu, \rho, \mathrm{T}_e), \qquad I_{\nu p} = \frac{4\pi h^2}{c^2} \frac{\nu^2}{e^{h\nu/kT_e} - 1},$$

bound condition $I_\nu(r=0,\mu) = 0\,;\ \ I_0(r=R, \mu \le 0) = I_0\,.$

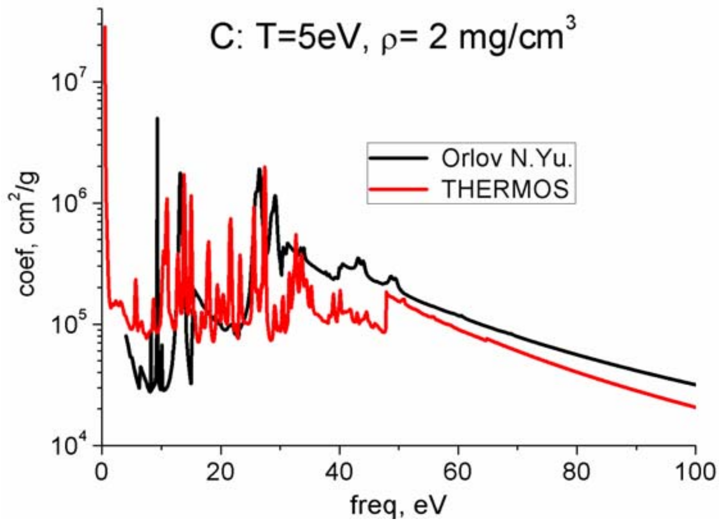
u is the matter velocity; r, space coordinate; p$_e$ and I_0 the electron and ion pressure; ρ, density; ε$_e$ and ε$_i$, the electron and ion internal energy; W$_e$ and W$_i$, the electron and ion heat flows; K, the rate of energy exchange between the electrons and ions; T$_e$ and T$_i$, the electron and ion temperature; G$_e$ and G$_i$, the mass density of the electron and ion sources (thermonuclear energy yield, the laser light absorption, etc); W, the radiation energy flow of the matter; v, the radiation frequency; μ, the cosine of the direction of the photon flight and the radius to the given point.

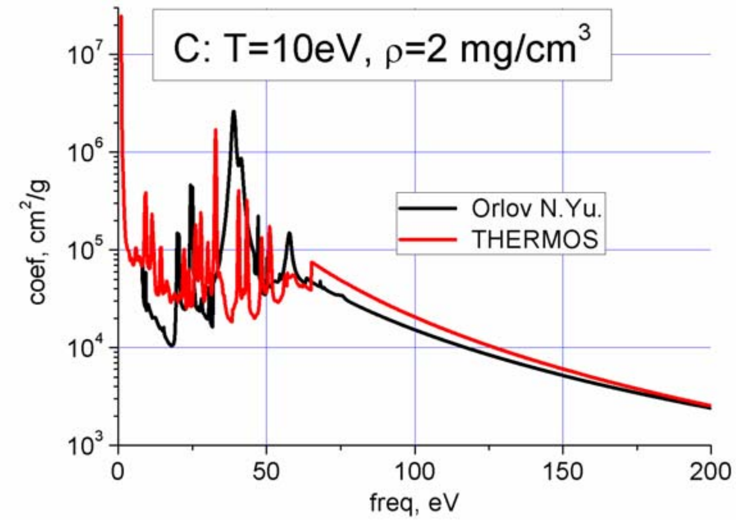
We use optical constants from code THERMOS (Inst. Of Appl.Math.) and DESNA (Lebedev Phys.Inst.) for CH_2. These constants we indicate below as “real”. We compare the absorption coefficient for C with the coefficients simulated by Prof. Orlov N.Yu. (T=5 and 10 eV). They prove to be similar.

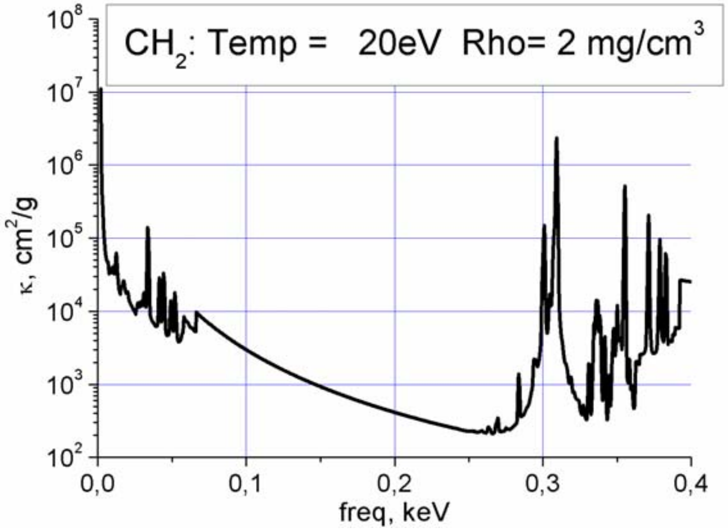
It is seen that the absorption coefficient drops with the temperature increase. To determine the influence of the constants on the simulation results we use also

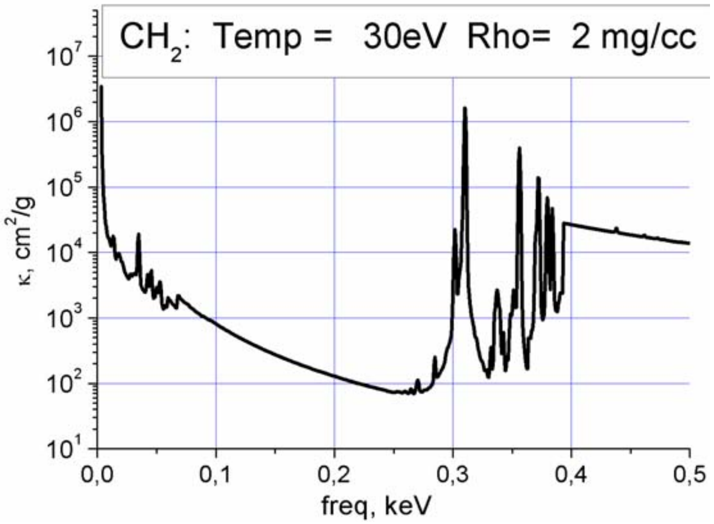
1) the spectral bremsstrahlung coefficient, and

2) the model coefficient obtained from the “real” coefficients by multiplication on number 1/5-2





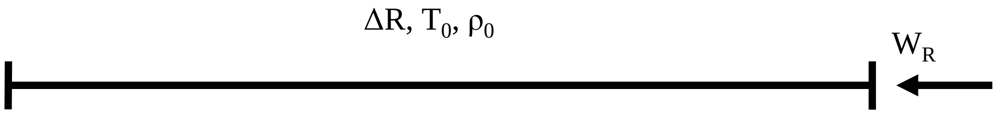




We can predict before demonstration the following numerical results:

- 1) An increasing radiation temperature T_{rad} of the incident flux leads to a higher plasma heating. As the temperature rises the absorption coefficient drops, so the transmitted radiation energy increases.
- 2) The results will depend on the absorption coefficients. If the coefficients are greater the transmitted energy is smaller.
- There are two possibilities to control the plasma parameters:
- 1) The lower the external temperature T_{rad} and the more optically transparent the coefficients.
- 2) The higher the external temperature T_{rad} and the more optically opaque the coefficients.

Geometry of simulation



- On the plane layer (thickness 800 μm, density 2 mg/cc) of the polysterene foam was irradiated by X-ray sources (Planckian) T_{rad}, W_{rad} ,t_{rad}.
- The depth of the external source radiation depends on the incident radiation frequency. Low frequencies are absorbed more effectively than the harder ones.

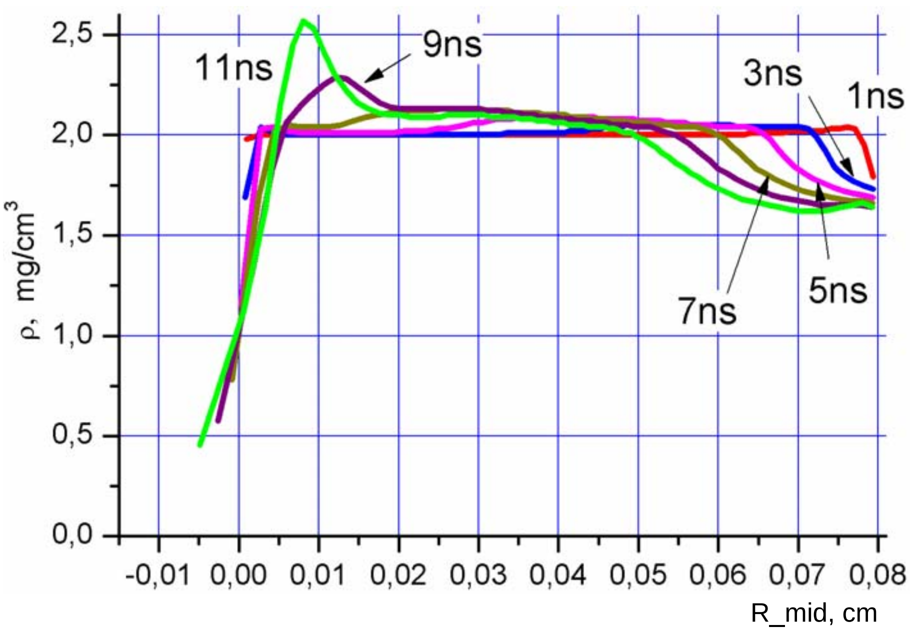
The table of simulation examples

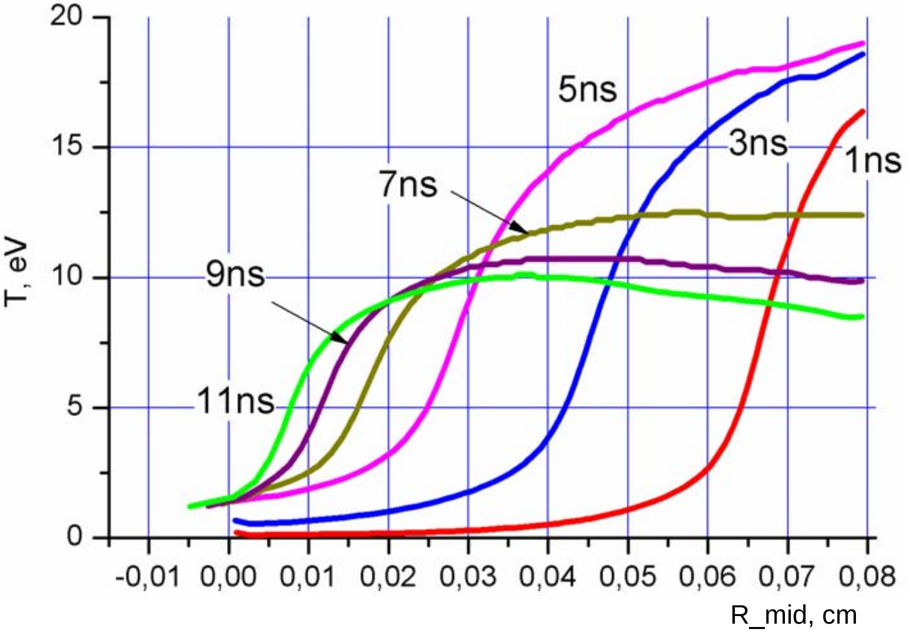
N	T_{rad}, eV	τ_{rad}, ns	W_{rad}, 10^{11} W/cm^2	coef	E_{out} /E_{rad}
169	20	5	0,17	“real”	0.04
172	20	5	0,17	Bremss.	0.95
175	20	5	0,17	1/5* “real”	0.15
176	25	5	0.39	“real”	0.15
171	30	5	0.83	“real”	0.20
174	30	5	0.83	2* “real”	0.10
170	40	5	2.6	“real”	0.64

Run # 169: T_{rad}=20eV, W_{rad}=1.7·10^{10} W/cm^2, t=5ns.

The picture illustrates the results of modeling. It is seen that during 5 ns the plasma is heated by the external source flow. About 500 μm of the foam is heated. After the end of the external source action the heat transfer is realized by the electron heat conductivity flow. The plasma temperature drops from 17 to 10 eV. In this case the thermal wave heats up the matter for ~250 μm during 5 ns.

1ns < time < 11ns





Run # 169: T_{rad}=20eV, $W_{rad}=1.7\cdot10^{10}$ W/cm^2, t=5ns.

In the Fig.1 is presented the radiation spectra at the right side (here falls the external flux) and the left side (back side) of the plasma are given for 1 ns and 4 ns moments of time. The radiation propagating into the target is shown by black line; the green line shows the irradiation coming from the plasma at the left. The heated plasma presents itself a source of thermal radiation. The spectra of plasma thermal radiation are also shown: the red line - from the right boundary toward the incident flux; the blue line – from the left boundary of the incident flow. The thermal radiation is generated at more low spectral frequencies as compared to the spectrum of the incident flow. This is connected with the fact that the plasma temperature is lower than the external source temperature.

Fig. 2 shows the spectral energy generated up to 1,4, 5 ns. After 5 ns the plasma losses for the radiation decrease.There takes place the energy re-distribution over the space coordinate. In this calculation the radiation transmitted energy is 4% of the incident energy.

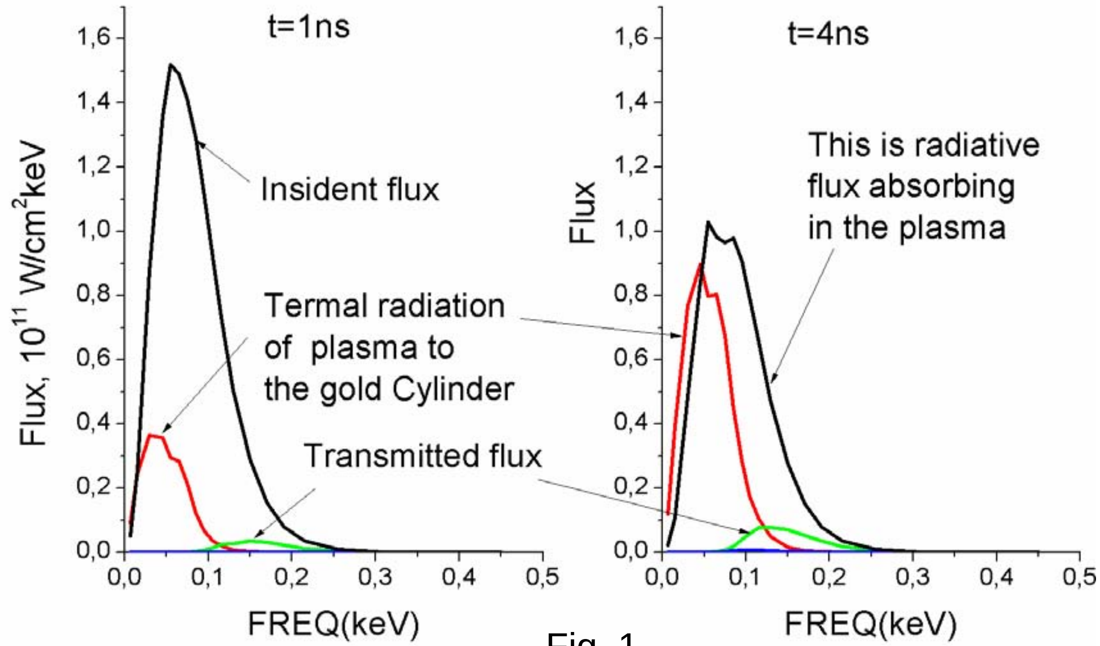


Fig. 1

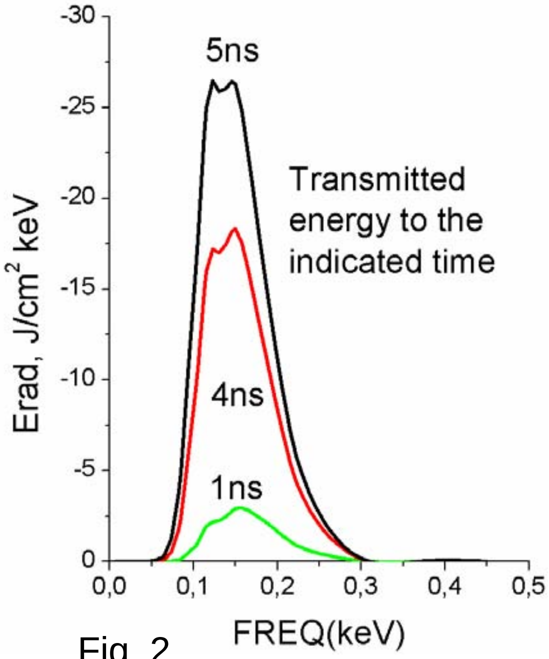
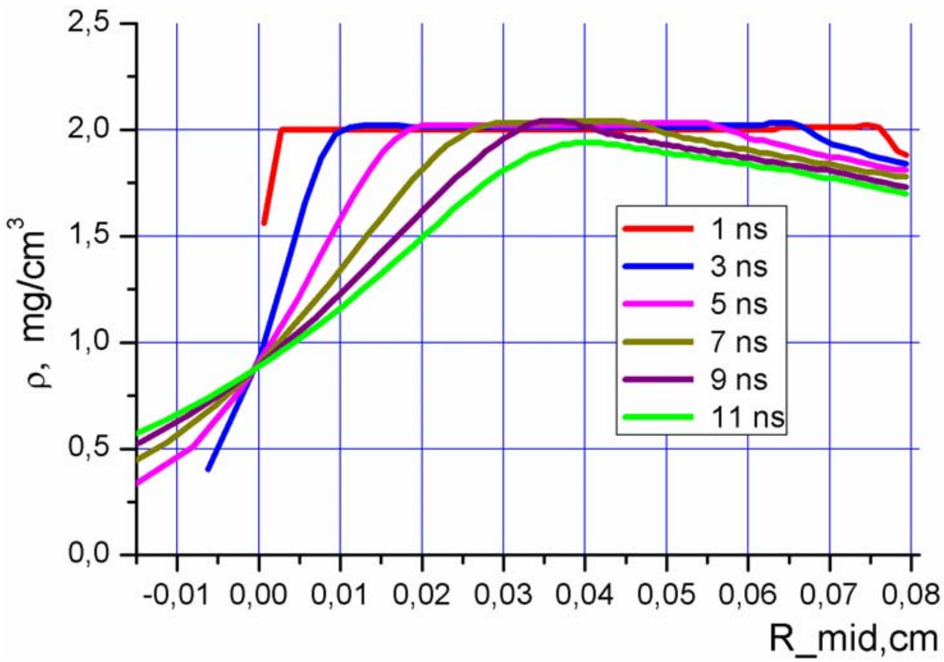
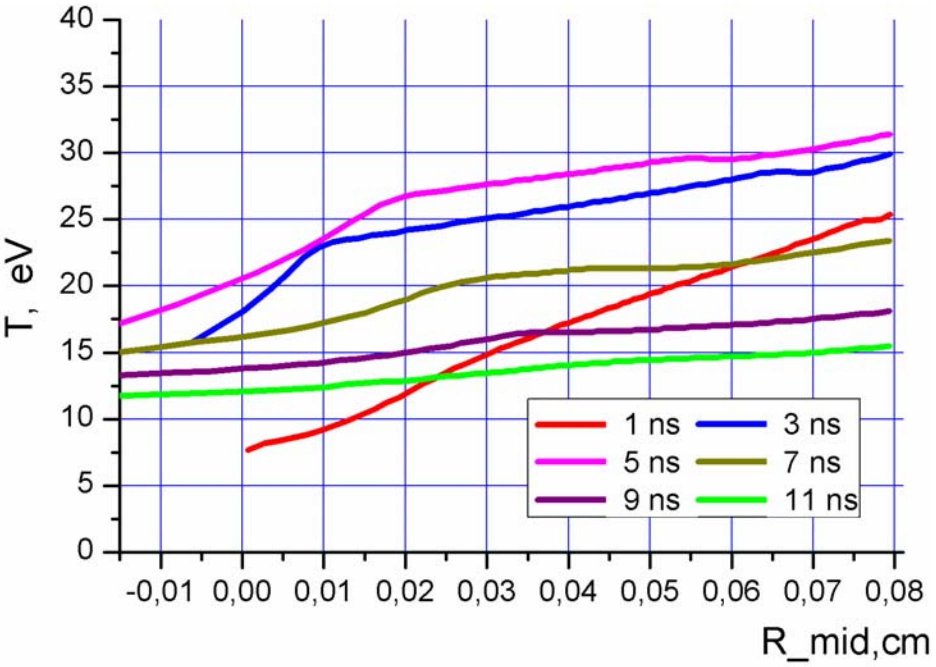


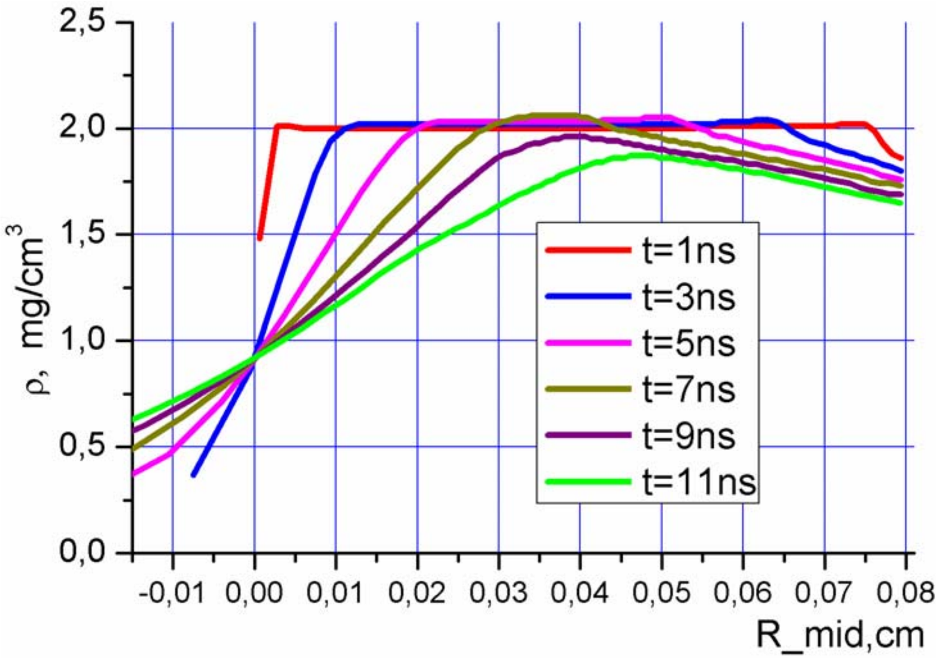
Fig. 2

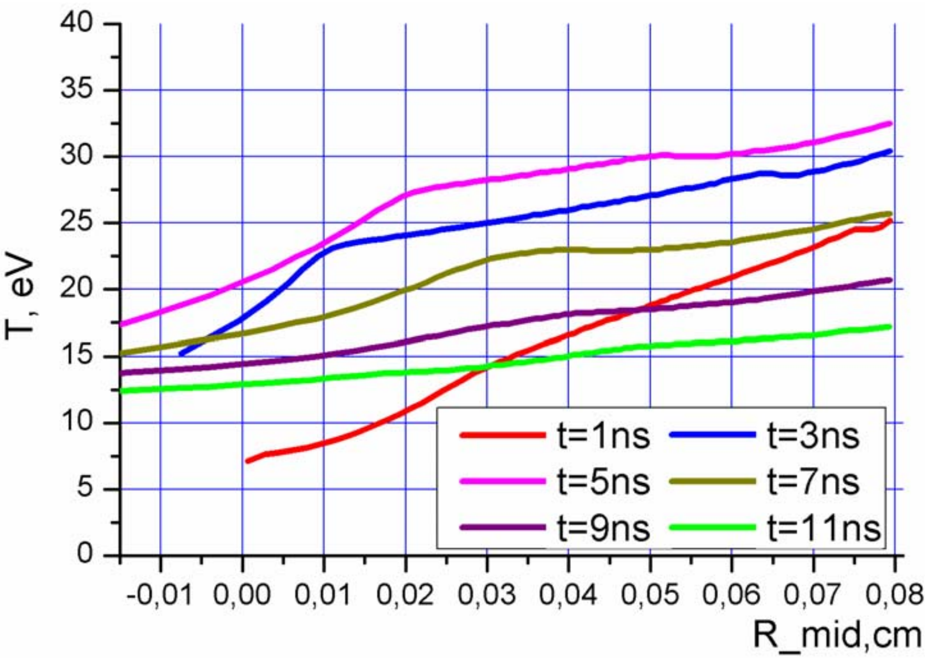
Run # 171: T_{rad}=30eV, $W_{rad}=0.83\cdot10^{11}$ W/cm^2, t=5ns.



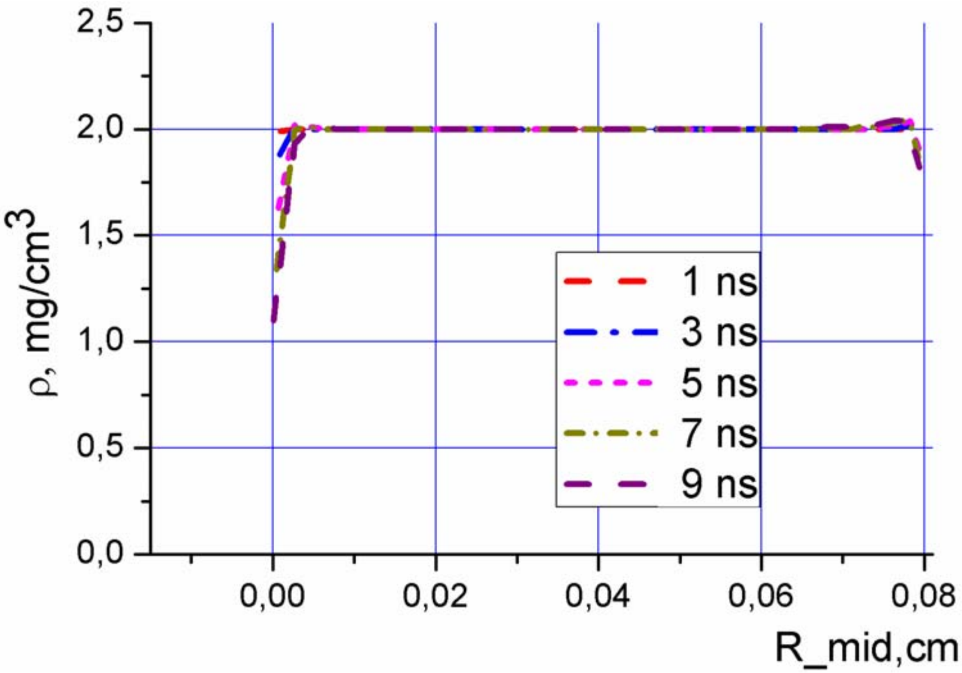


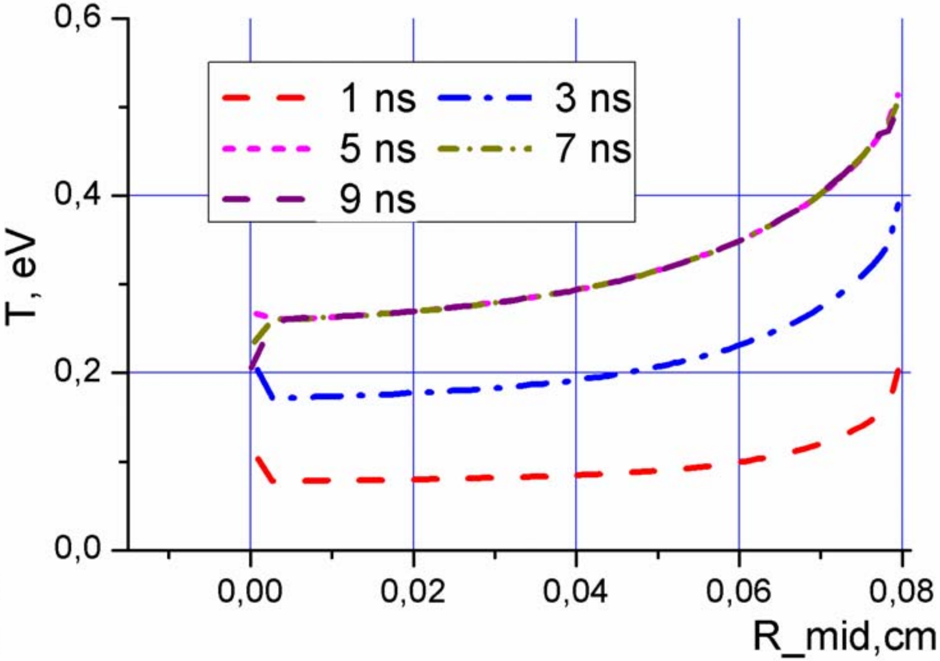
Run # 170: T_{rad}=40eV, $W_{rad}=2.6\cdot10^{11}$ W/cm^2, t=5ns.





Run # 172 bremsstr: T_{rad}=20eV, $W_{rad}=1.7\cdot10^{10}$ W/cm^2, t=5ns.



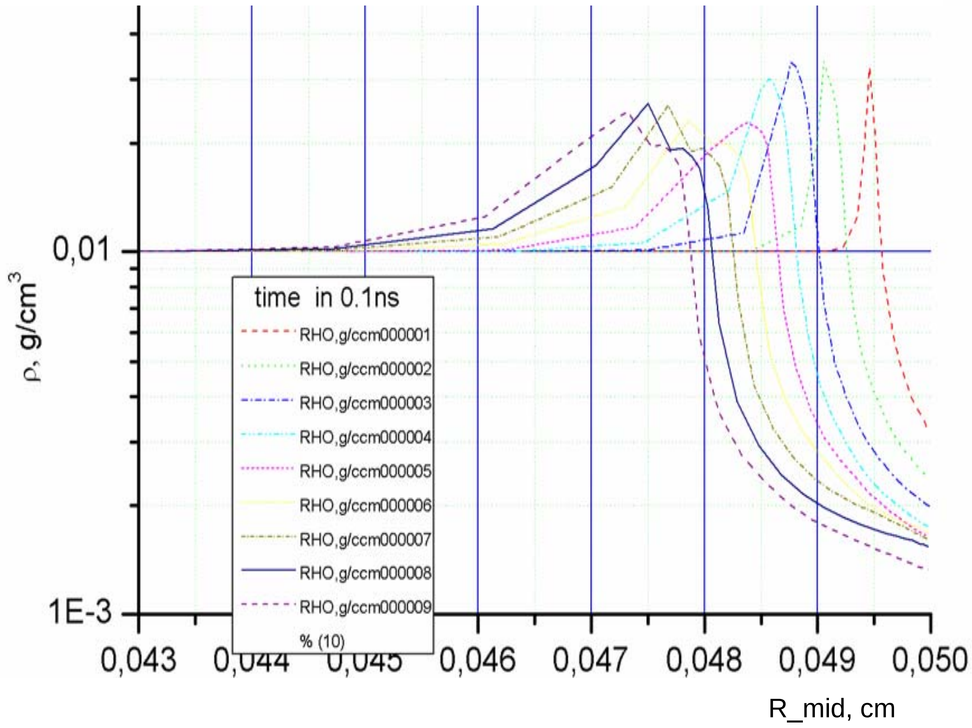


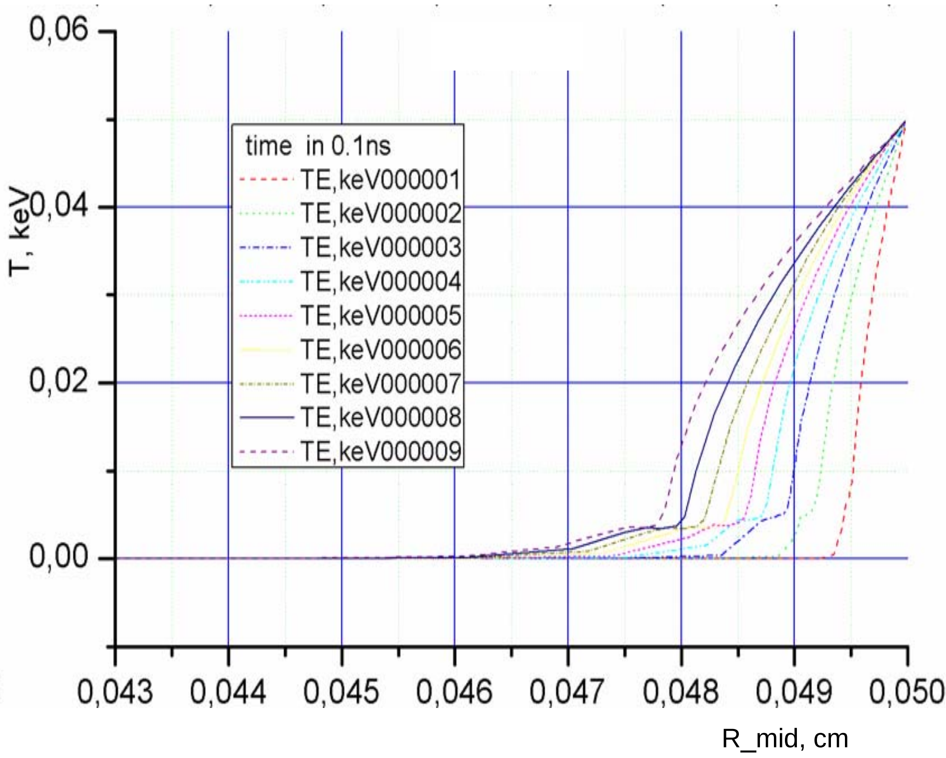
If an external radiation source is not a “black body”, and if it radiates in a more narrow spectral range, then an absorption of external energy occurs in a more narrow region of the plasma corresponding to those quanta. In our calculations we simulate this case as a single spectral group radiation. The energy is absorbed in a relatively narrow spatial region. In the plasma, a shock wave is formed, which very quickly passes ahead of a thermal wave making the matter heated and compressed. As a result, an essentially non-homogeneous plasma is produced.

The same situation occurs if the energy transfer by an electron heat conductivity wave is dominating.

Heating of matter due to a heat transfer from a hot wall (run #117). The temperature is sustained at 50 eV during one nanosecond at the right-hand boundary of a plane polyethylene layer of 500 μm thickness and 10 mg/cm^3 density.

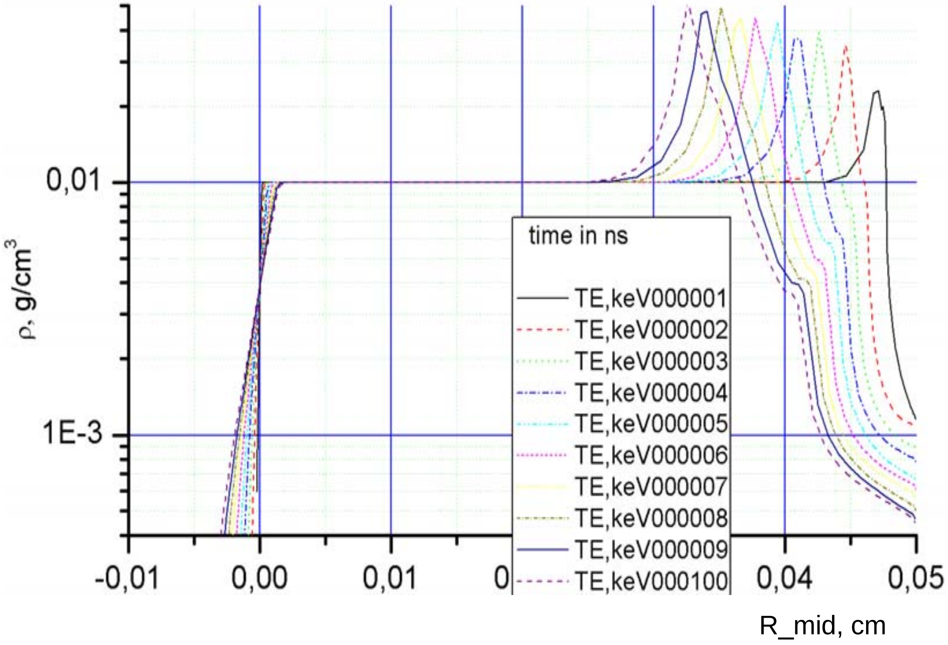
Time is up to 0.9 ns

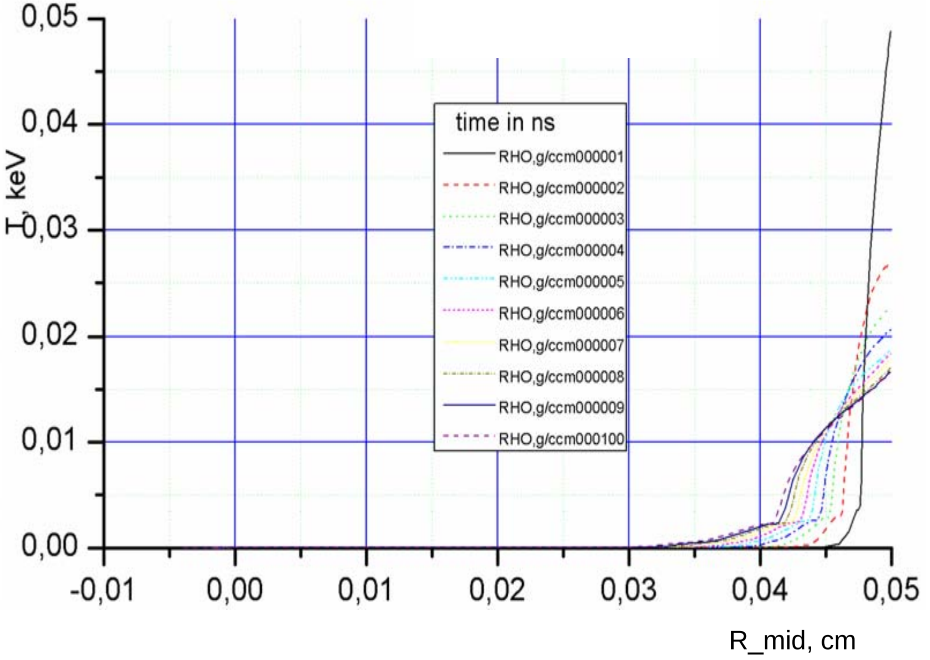




Heating of matter due to a heat transfer from a hot wall (run #117, continue). The temperature is sustained at 50 eV during one nanosecond at the right-hand boundary of a plane polyethylene layer of 500 μm thickness and 10 mg/cm^3 density.

Time is 1-10 ns





Conclusions

- Our analysis and simulation demonstrate the possibility to realize the plasma layer parameters (temperature, density and its distributions) which will be needed for future experiments on deceleration of the ions in the plasma: density 2 mg/cm^3 and temperature T=15-25eV,
- But the results demonstrate the sensitivity to the optical constants of the plasma. So it will be useful to arrange the preliminary experiments for the determination of optical characteristics of plasma.