Expansion of polyethylene pellets irradiated by a neodymium laser

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IPP 4/129 Januar 1975

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Abstract

The expansion of polyethylene pellets (200 μ diameter) after irradiation by a Nd laser pulse has been investigated by shadowgram diagnostics. Only a small part of the pellet is converted into hot plasma. For short pulses (5 nsec) the rest of the pellet explodes mainly into small pieces of solid matter. For long pulses (50 nsec) a part of the pellet becomes a dense gas or cold plasma. With increasing pulse energy the portion of solid pieces decreases and the portion of cold plasma increases. These results suggest a pre-pulse method for plasma production from pellets.

1. Introduction

The production of plasma for filling of magnetic confinement devices by laser should fulfill the following conditions: The plasma has to be produced from isolated pellets without contact to the wall of the vacuum chamber. The size of the pellets is determined by the desired plasma properties of the confinement device. The pellet should be ionized completely. Due to the difference between solid state density and cut-off density for a given laser frequency the production of hot fully ionized plasma needs laser pulses with extreme power and/or pulse duration. Using conventional lasers for plasma production and heating a pre-pulse concept can be applied. A first laser pulse with short wavelength will be used to vaporize and ionize the pellet at high density. After expansion of this cold partially ionized plasma to lower density, a second laser pulse of high energy and longer wavelength produces a fully ionized plasma by isotropic absorption in the pre-heated plasma cloud.

Medium sized stellarators like WIIb require pellet diameters of about 200 - 400 μ. To produce a hot 100 eV plasma,laser energies of 100 - 500 joules have to be absorbed from the second laser pulse. Optimization of absorption depends on the properties of the expanding pre-heated matter. The time varying density and temperature profiles of the expanding cold plasma cloud and its reproducible production from the pellet are the most interesting parameters for an efficient plasma heating.

Preliminary experiments for pre-pulse investigations have been done at the IPP neodymium laser system (5 nsec, up to 50 joules) using a picosecond shadowgram system (developed by one of the authors S.A.) with suspended polyethylene spheres.

2. Experiments

The experimental set up is shown in Figure 1. The polyethylene pellet (200 μ diameter) was adhered to a glass fiber of about 30 μ diameter (Fig. 2). The neodymium glass laser emitts a 5 nsec pulse with an energy of 1 to 22 joules. In a second series of shots the pulse duration of the neodymium laser was extended to about 50 nsec (Fig. 3a + b). The radiation was focused by an aspherical lens in a focal spot of about 30 - 50 μ diameter. In some experiments the pellet was not located in the focal plane but 500 μ outside along the optical axis of the system. There the laser radiation is concentrated within a circle of 300 μ diameter. At that position the full size of the pellet is irradiated.

For diagnostics the pellets are illuminated by a mode-locked dye laser. The selection of a single 5 picosecond pulse from the pulse train is synchronized with the neodymium laser. The diagnostic system itself is described elsewhere (1).

3. Results

In Figures 4 - 10 photographs of the expanding dense plasma are given. All photographs are taken from different shots. However, the reproducibility is good only for big spot size with full irradiation of the pellet, but it is poor for local irradiation of the pellet surface by the small spot in the focal plane. The poor reproducibility can be explained by variations of the localization of the focal spot on the pellet surface from shot to shot. The shadowgrams were taken with different time delays to the beginning of the laser pulse. In Figure 3 the dye laser pulse is indicated by a small positive signal at the oscillogram, as can be seen above the arrows. The exposure time is 5 psec. During this time very fast objects with speeds of 10^8 cm/s move only 5 μ.

In our experiments the velocities of the cold material are smaller at least by a factor of 10 than this velocity. Therefore, no motion effect of the expanding matter can be seen.

In the seven series of shots (Fig. 4 to 10) shadowgrams are taken with roughly same delays to the beginning of the Nd-laser pulse. Thus at the same interval to the beginning of the laser pulse the pellet expansion can be compared directly for different experimental conditions.

The magnification is the same for all figures except Figure 9. The pellet diameter for all experiments is 200 μ.

On the shadowgrams one can see the pellet and the supporting glass fiber. The fiber is outside the object plane and therefore not well focused on the pictures.The laser radiation is directed onto the pellet from the right hand side, as can be seen also in Figure 1.

In these experiments we are not investigating the early times of laser-pellet interaction. Nevertheless, it is interesting to observe that the first effect of the laser radiation appears at the rear of the pellet. An explanation for this phenomena can be given by the lensing effect of the sphere. Focusing of the radiation transmitting the pellet may increase power density and thus vaporization starts earlier at the rear than at the front of the pellet.

By the used diagnostic method only dense matter can be photographed. The hot thin plasma, which expands towards the laser, can not be seen by this method. The shadowgrams show solid matter, very high density plasma and dense gas flowing into the vacuum.

For small spot size (focal diameter < pellet diameter) and short laser pulse (Fig. 4) mainly two features should be discussed. The reproducibility is very poor especially up to 200 nsec. After 200 nsec it becomes better but it is still not good. The shape of the expanding cloud is a half sphere but the symmetry depends on the location of the focal spot on the pellet surface. Very surprising is the observation that the dense material is not only a gas cloud but it consists of many small pieces presumably of solid polyethylene.

For a better reproducibility, the pellet was shifted on the axis to a point where the spot size is about 300 μ (spot diameter $>$ pellet diameter). There the pellet is irradiated more homogeneous on its surface. The pulse duration was 5 nsec. Different energies were used for pellet vaporization in Figures 5 - 8. The shape of the expanding cloud seems to be characteristic for the energy of the laser radiation. The figure changes from conical for 1 joule into cylindrical for 6 joules and 12 joules and into near spherical for 20 joules. But never we met conditions for homogeneous expansion of the cloud. The effect of destroying the polyethylene pellet into many small particles is observed more or less for all shots. For high energy (20 J) a more efficient vaporization takes place.

Experiments were also done with long pulse duration. The pulse duration was 50 nsec but the pulse is not smooth and looks very fissured (Fig. 3b). In this "slow heating mode" with the long pulse the pellet tends to expand more spherical, however, the disrupture into many small particles can be observed also for energy of 1 joule (Fig. 9). Increasing the energy to 12 joules (Fig. 10), the expanding cloud becomes more spherical and the solid particles have disappeared partially. It can not be determined by the used diagnostic method whether the matter exists in a gaseous or in a solid state. Compared with the other series of photographs the conditions of Figure 10 (50 nsec, 12 J spot size $>$ pellet) promise mostly expanding gaseous matter. Due to the change in shape during expansion of the cloud only characteristic expansion velocities can be estimated. They increase slightly from $1 \cdot 10^5$ cm/s for small energies to $3 \cdot 10^5$ cm/s for the bigger energies of the Nd-laser pulse.

Due to the inhomogeneous distribution of matter in the expanding clouds an estimation of a mean density is generally useless. Only in the case of a long laser pulse (Fig. 10) with high energy a mean density can be estimated and is shown vs time in Figure 11. From this expansion curve an optimized delay for the heating pulse can be determined. For heating by a neodymium laser the delay should be about 150 - 200 nsec, for a CO_2 laser about 800 - 1000 nsec. It can be seen that the plasma diameters are rather big, for the neodymium laser it is about 700 - 800 μ, for the CO_2 laser we estimate 3 - 4 mm.

4. Conclusions

The results of these preliminary experiments show that two different kinds of pre-pulses can be applied for plasma production. One way is to use short pre-pulses rending the pellet to pieces of 10 - 20 μ size. Such a cloud of solid particles can be the target for high energy laser radiation. Due to thin particles the time for vaporization and ionization is short and plasma will be produced in the same manner as known for plasma production from solid targets. The other way is to use long pre-pulses and to vaporize the pellet completely to a gas cloud. After expansion, this gaseous cloud will be fully ionized and heated by the high energy laser radiation. The plasma production in this case can be described by homogeneous absorption of radiation due to inverse bremsstrahlung.

It is not possible to decide between these two pre-pulse methods without additional experiments. It should be important to extend the experiments to hydrogen and deuterium pellets. Also experiments with shorter wavelengths (ruby laser for example) should be done, because theoretical calculations have shown better absorption of short wavelength radiation.

The authors thank Mr. Sachsenmeier and Mr. Wanka for their technical assistances.

(1) S. Ariga and R. Sigel: Investigations of Laser-Target Interactions with Picosecond Microphotography. IPP IV/81, March 1975

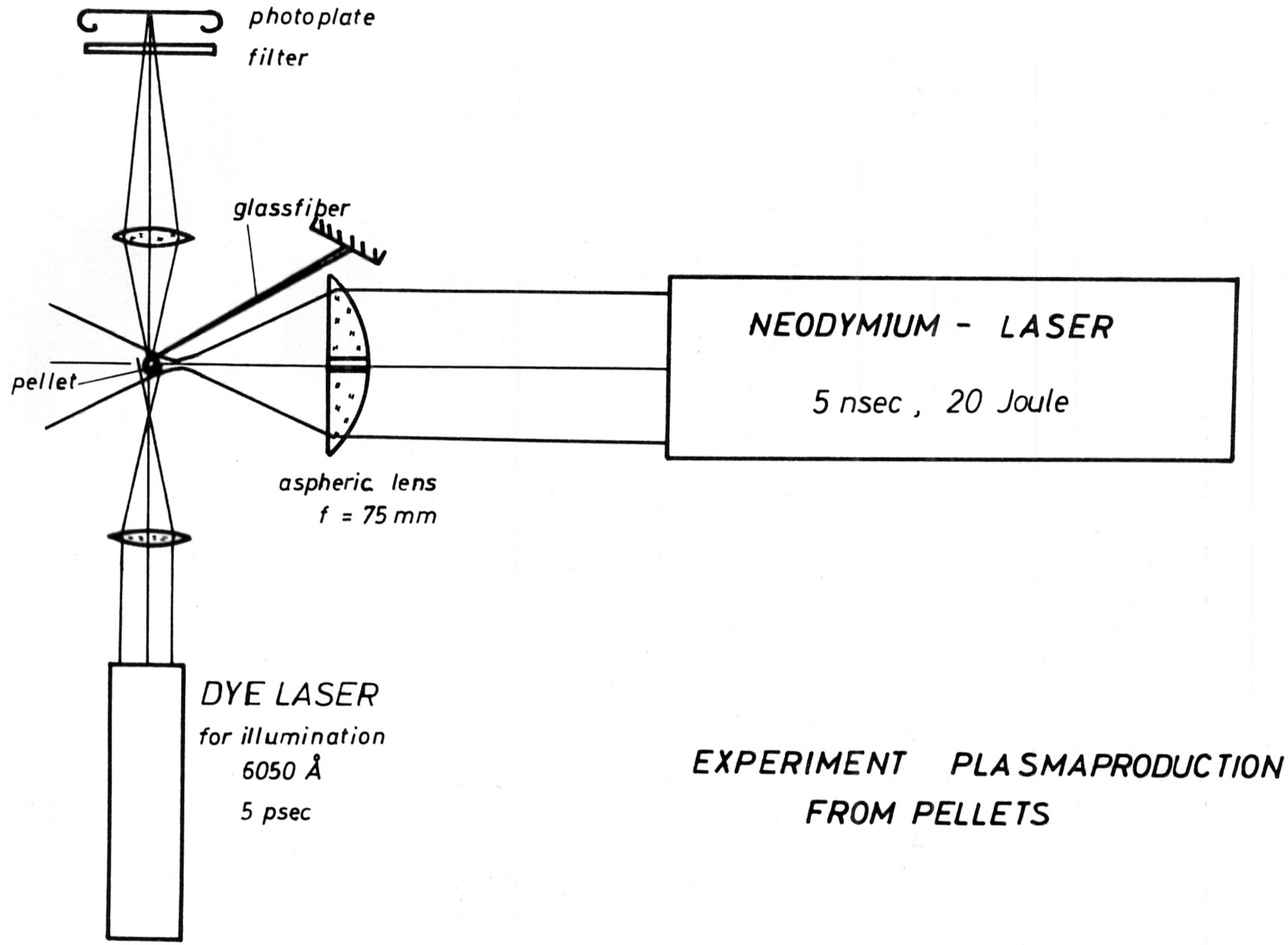


Figure 1: Experimental set up

Figure 2: Suspended polyethylene pellet

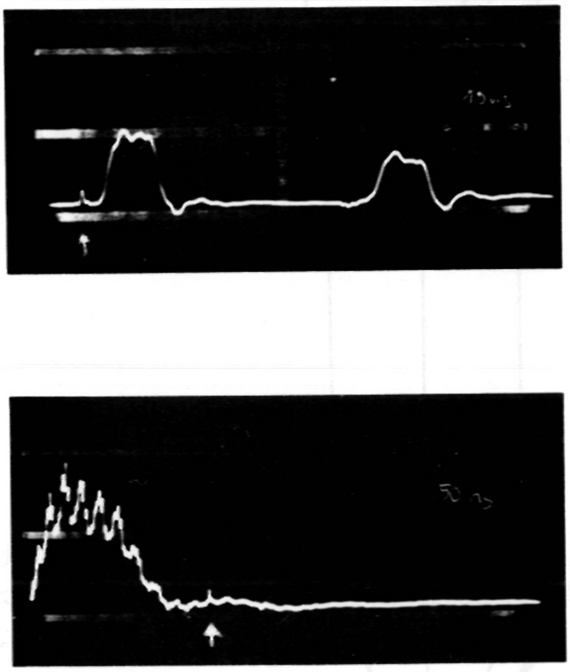
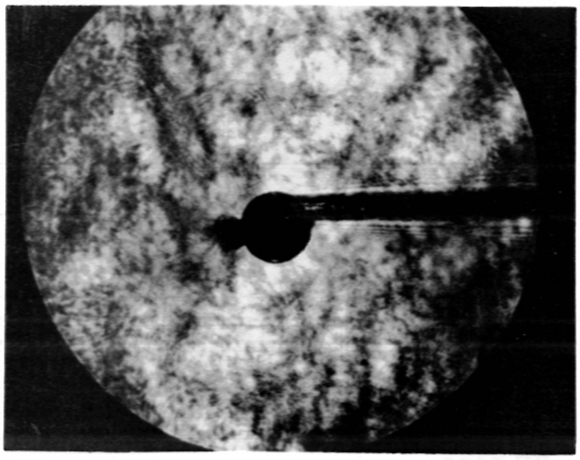


Figure 3: Nd-laser pulse a) 10 nsec/cm, second pulse due cable reflection b) 50 nsec/cm. The arrow indicates the dye laser pulse. The Nd-laser signal is delayed by cable for 5 nsec to the dye laser signal.

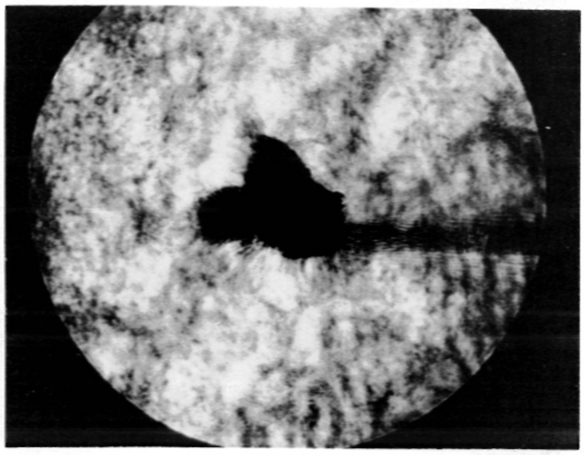
Nd-Laser : 5 nsec, 6 J

Fokus : 50 µ ø

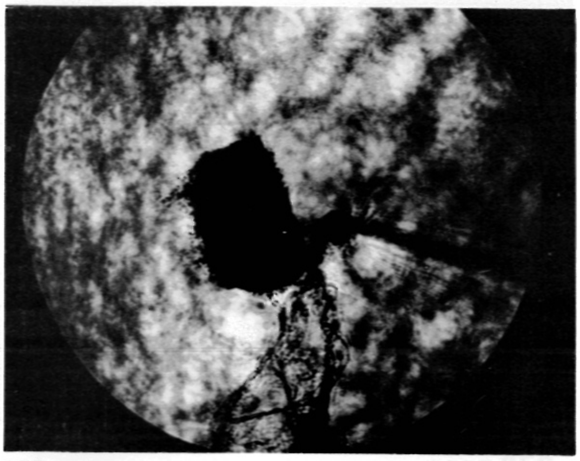
Pellet : 200 µ ø $(CH_2)n$



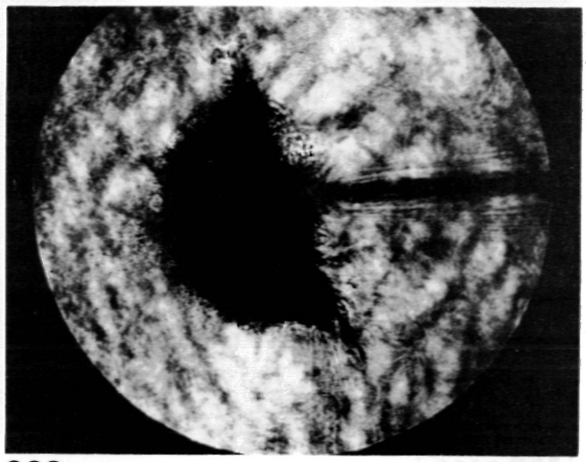
0 nsec



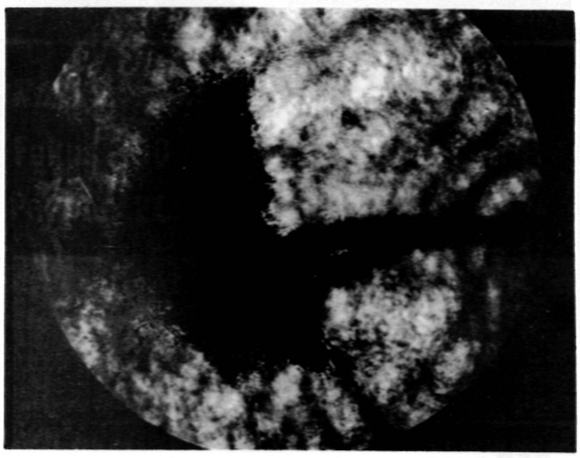
30 nsec



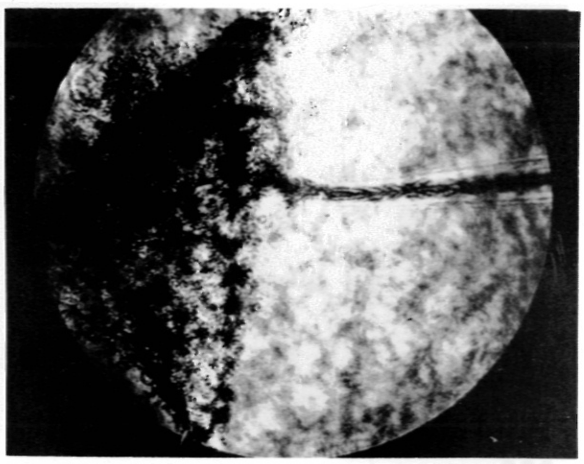
170 nsec



200 nsec



280 nsec



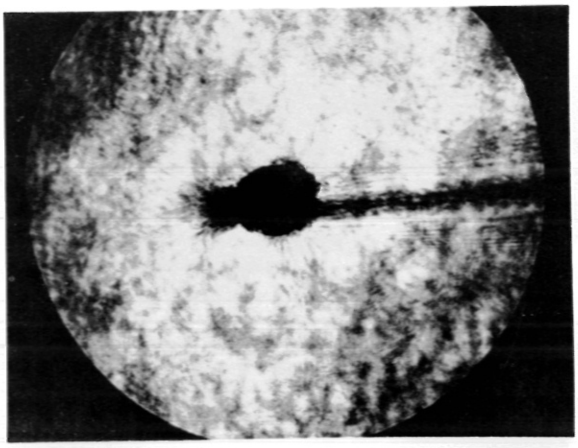
400 nsec

Figure 4: Shadowgrams of irradiated pellet

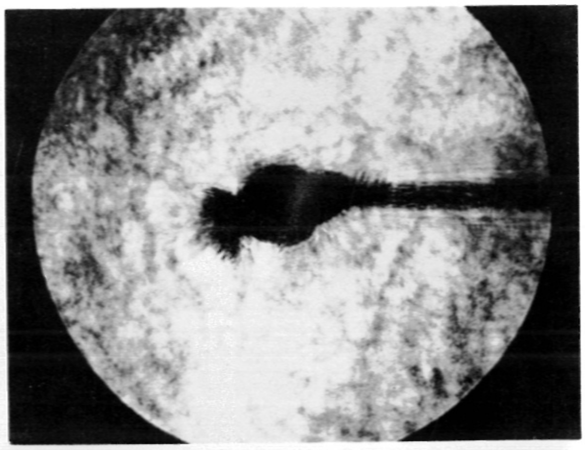
Nd-Laser: 5 nsec, 1J

Fokus: 300 μ ø

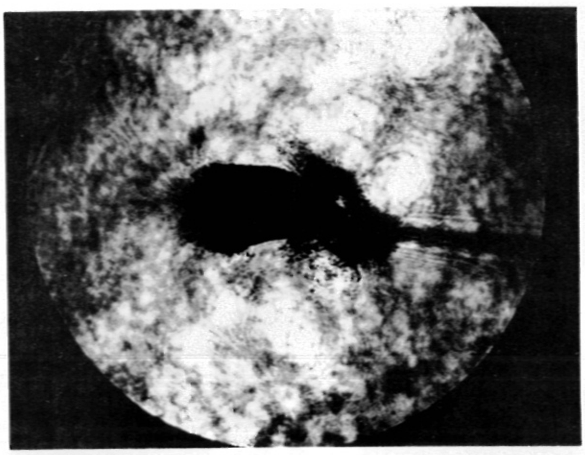
Pellet: 200 μ ø $(CH_2)_n$



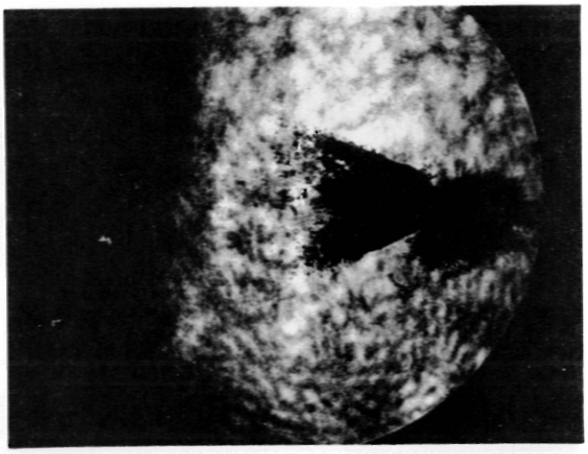
0 nsec



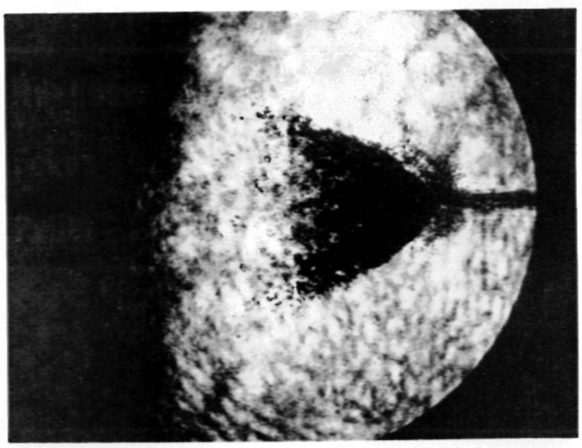
30 nsec



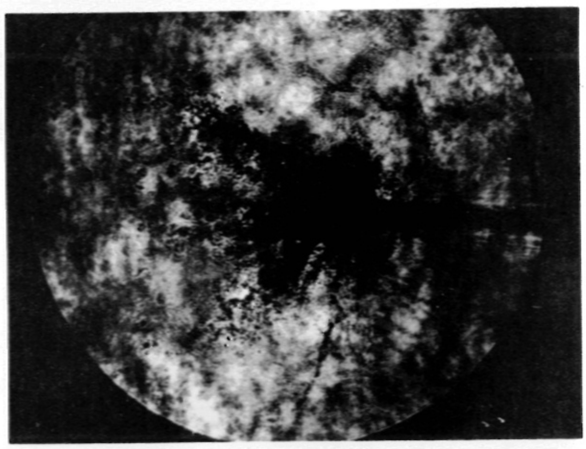
140 nsec



270 nsec



330 nsec



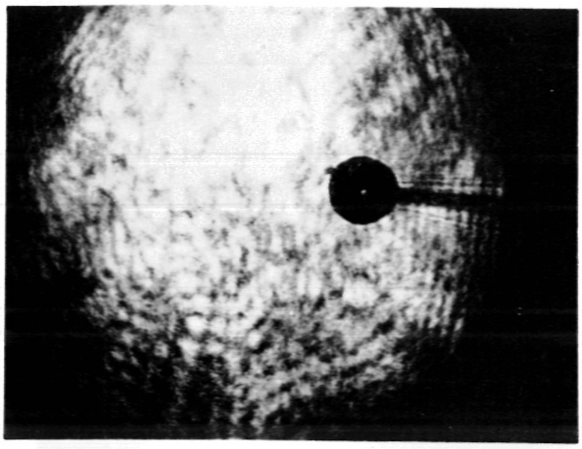
350 nsec

Figure 5: Shadowgrams of irradiated pellet

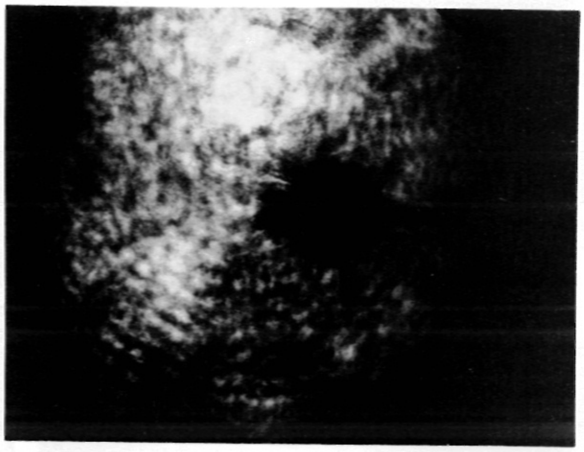
Nd-Laser : 5 nsec , 6J

Fokus : 300 µ Ø

Pellet : 200 µ Ø $(CH_2)_n$

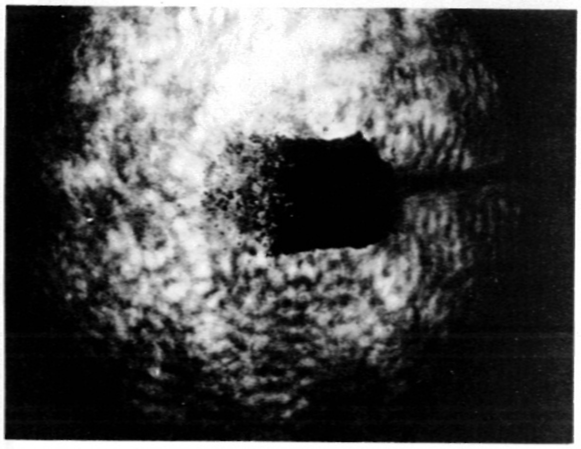


– 10 nsec

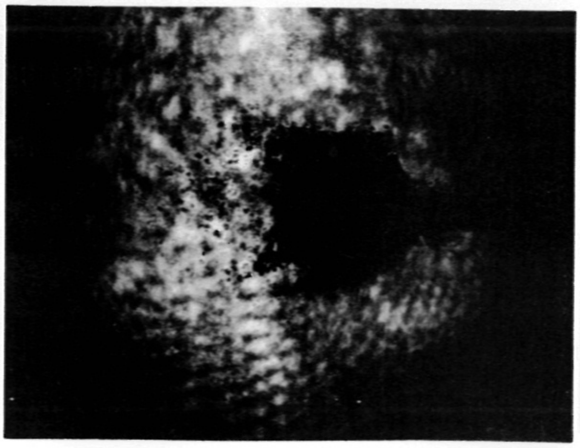


30 nsec

150 nsec



240 nsec



330 nsec

Figure 6: Shadowgrams of irradiated pellet

Nd-Laser: 5 nsec, 12 J

Fokus: 300 µ ø

Pellet: 200 µ ø $(CH_2)_n$

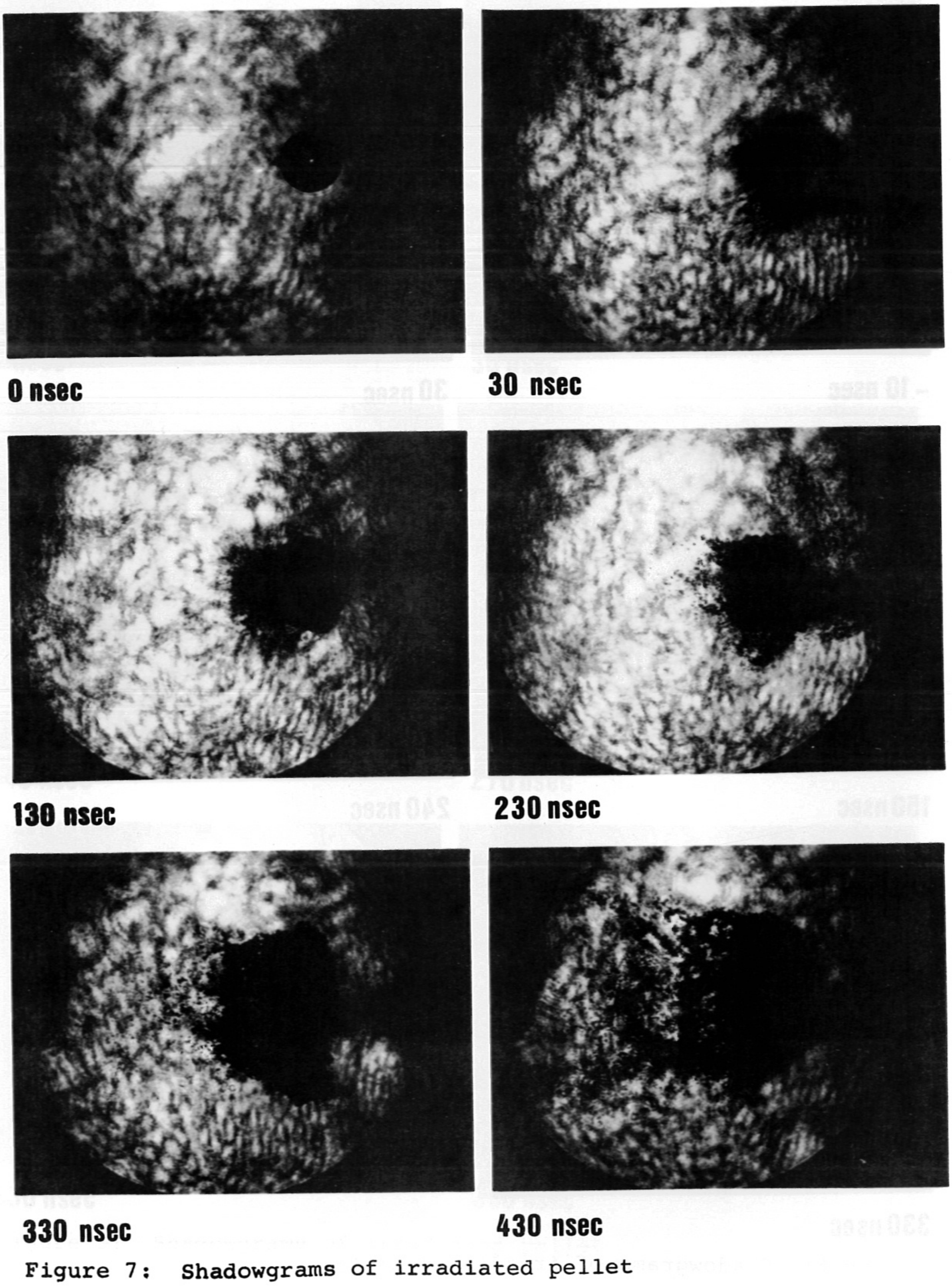
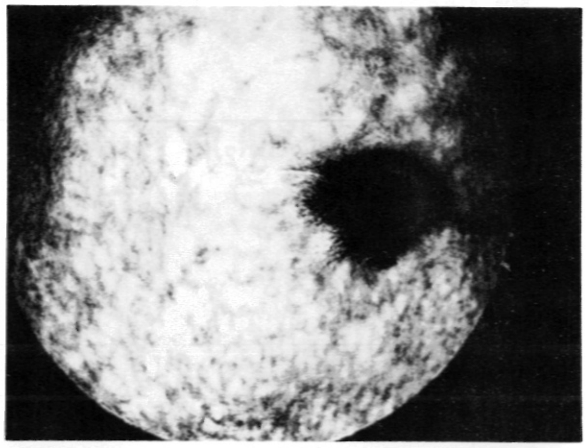


Figure 7: Shadowgrams of irradiated pellet

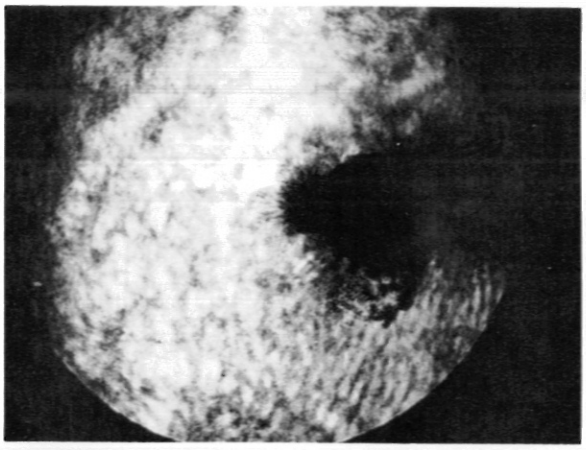
Nd-Laser: 5 nsec, 20 J

Fokus: 300 µ ø

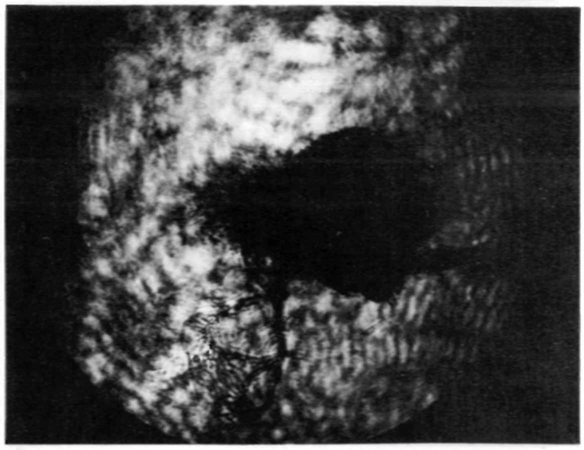
Pellet: 200 µ ø $(CH_2)_n$



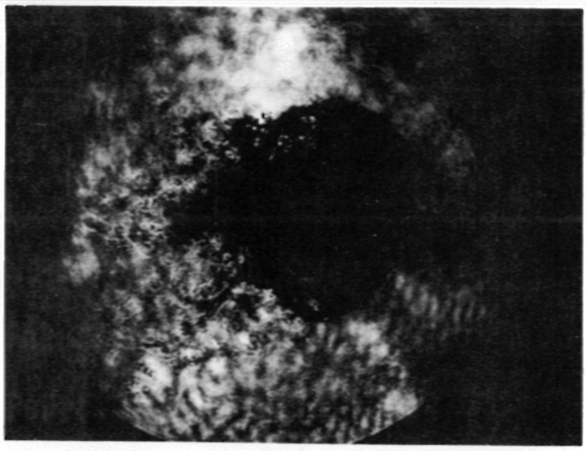
30 nsec



125 nsec



220 nsec



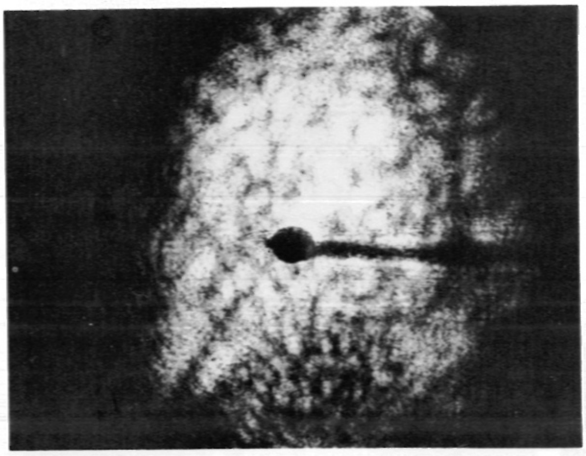
320 nsec

Figure 8: Shadowgrams of irradiated pellet

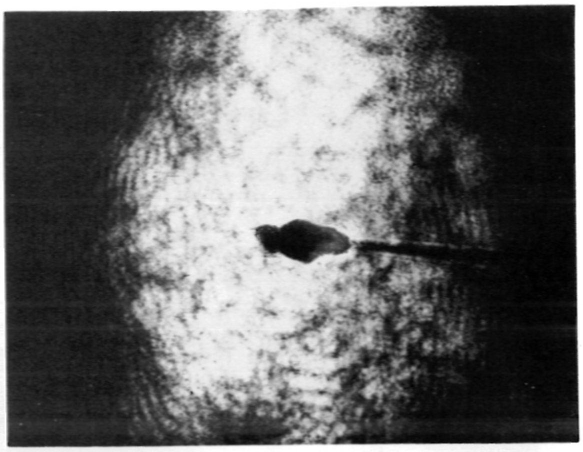
Nd-Laser : 50 nsec, 1J

Fokus: 300 μ ø

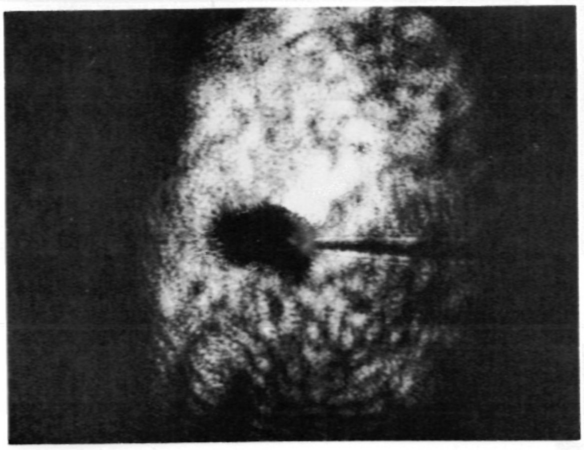
Pellet : 200μ ø $(CH_2)_n$



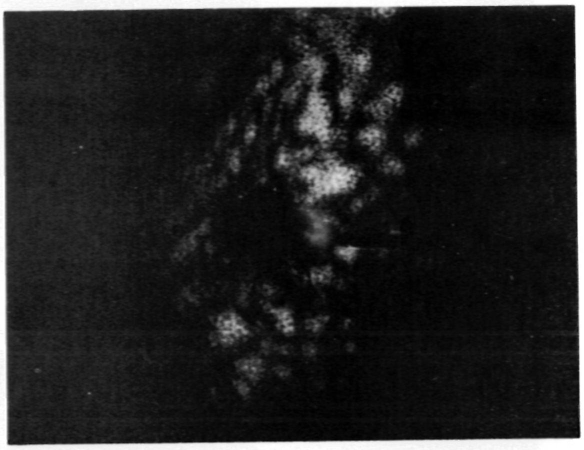
0 nsec



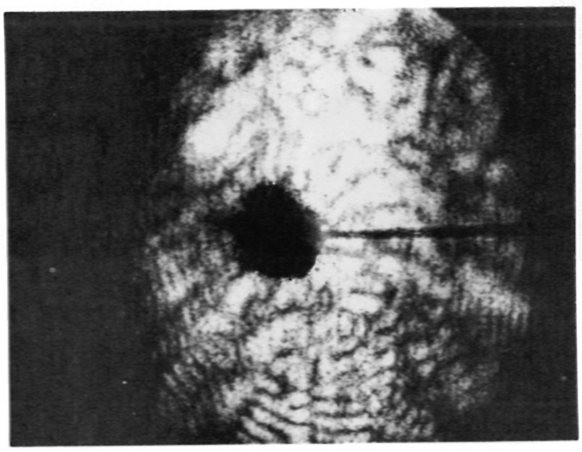
30 nsec



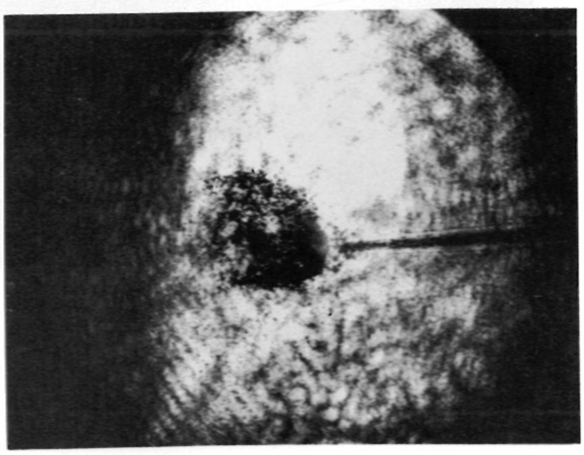
105 nsec



210 nsec



315 nsec



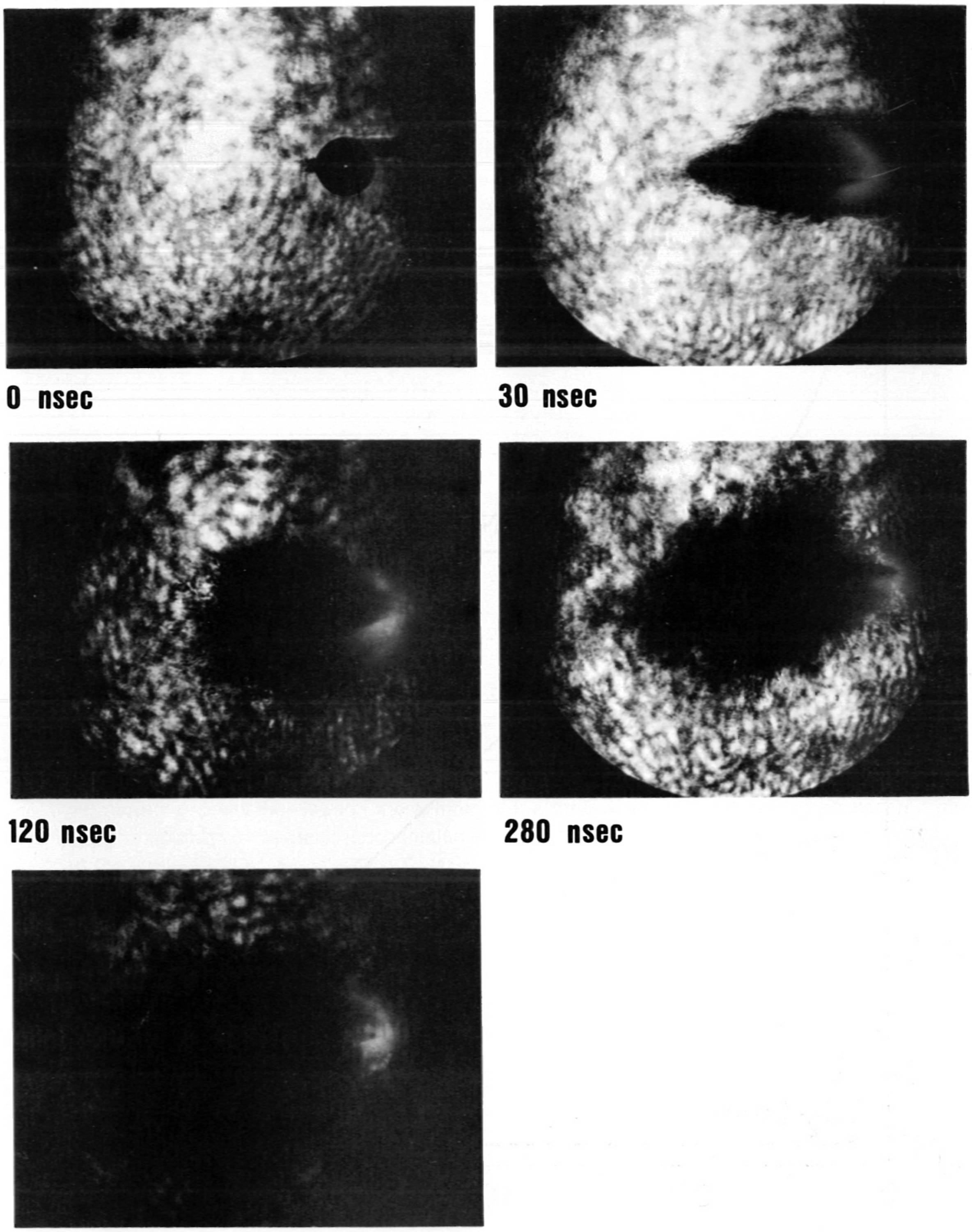
415 nsec

Figure 9: Shadowgrams of irradiated pellet

Nd-Laser : 50 nsec, 12 J

Fokus : 300 μ ø

Pellet : 200 μ ø $(CH_2)_n$



0 nsec **30 nsec**

120 nsec **280 nsec**

350 nsec

Figure 10: Shadowgrams of irradiated pellet

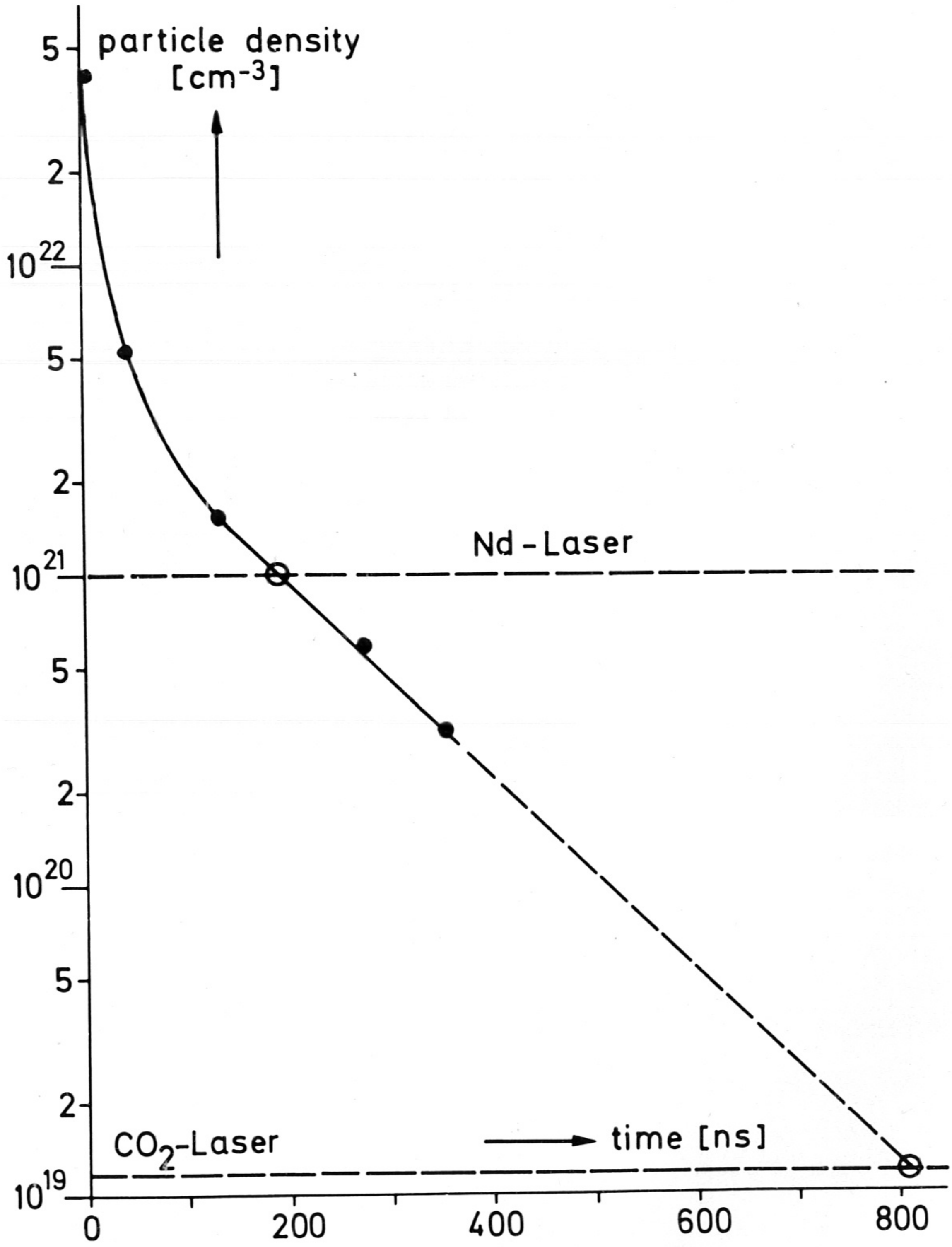


Fig.11 Expansion of Gas Cloud