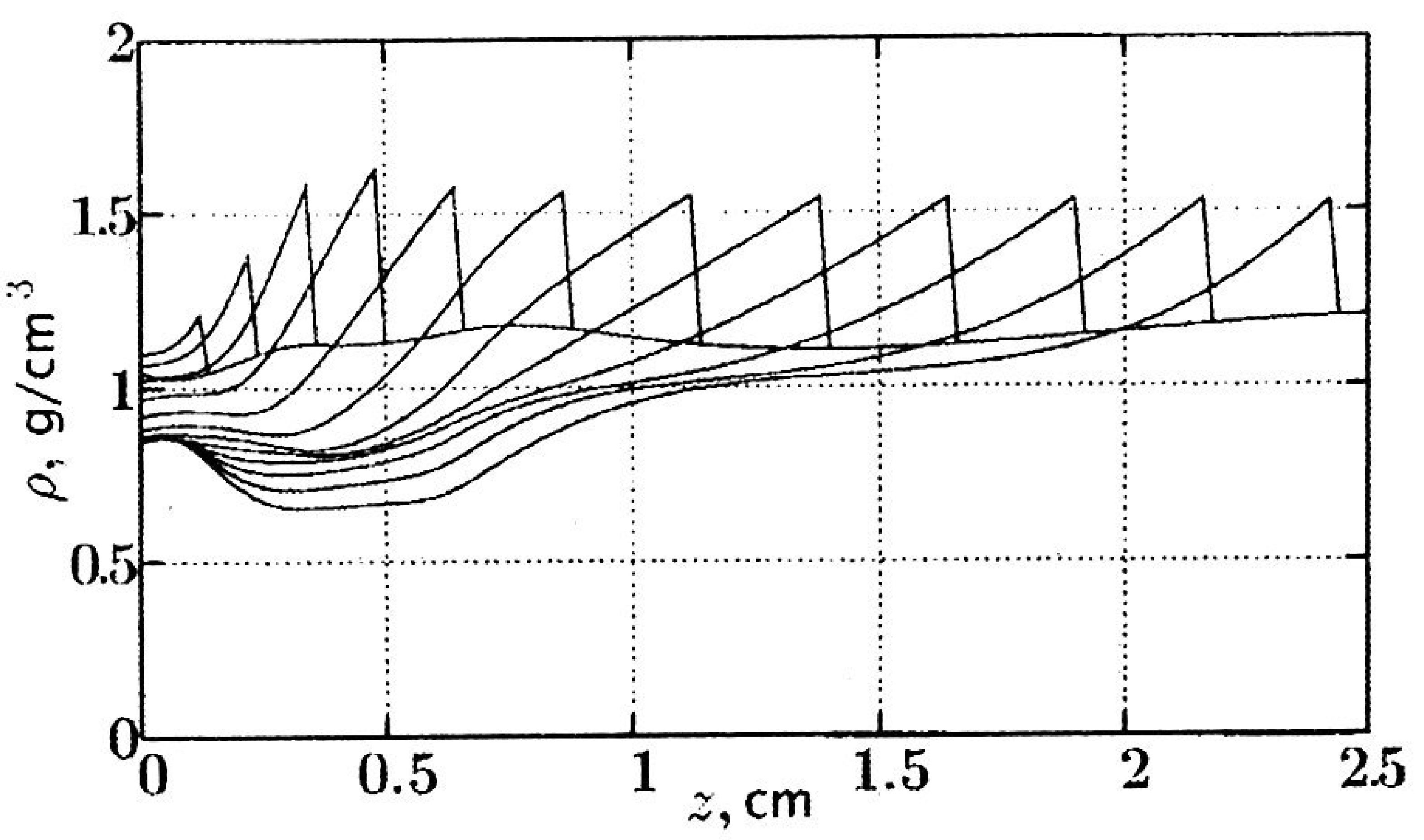

Figure 3. Density evolution on an axis of a charge.

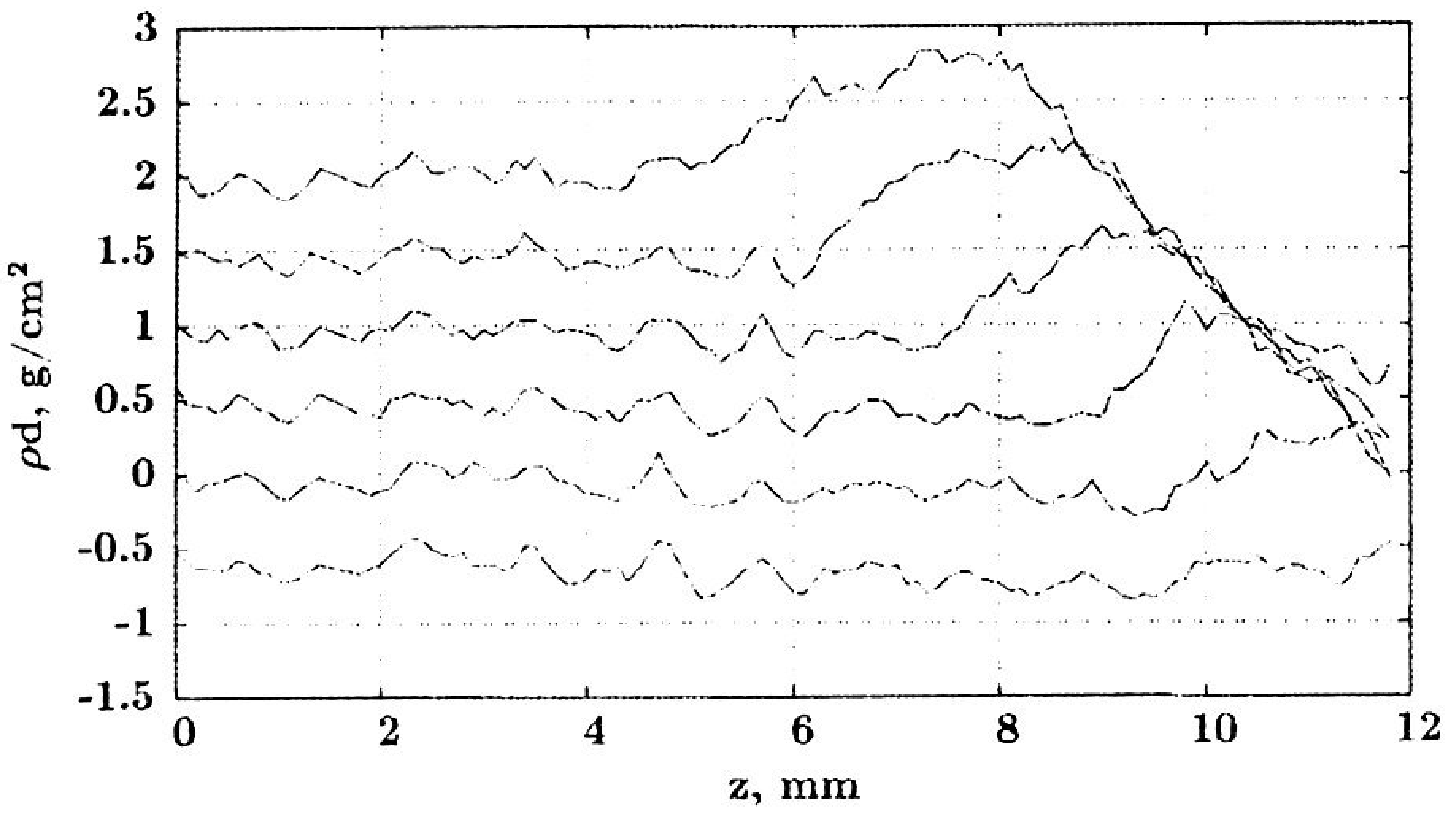

Figure 4. Integral density dymnamics in an inert powder.

to detonation. The measured rate of compression of substance in detonation front well agreed with model of an ideal detonation of Chapman-Jouget $\frac{\gamma+1}{\gamma}$ where γ for condensed HE is close to 3.

For confirmation of the assumed mechanism of development of a detonation the experiments with an inert powder of close density have been made. On Fig. 3 dynamics $\rho d(z,t)$ is presented on an axis of a charge, curves are represented with displacement, true value ρd before arrival of a shock wave of 2 g/cm^2, an interval between curves 0.5 mks. At identical influence on an inert powder the compression rate more than in 2 time exceeding compression in HE, and low speed of a shock wave (about 2 km/s) is observed. It testifies about considerable influence of chemical reactions in explosive already in the first micro second of initiation.

Conclusion. Experiments for a tomography of a nonstationary, not one-dimensional flow of a porous explosive charge arising at initiation are made. The considerable curvature of front changing with development of a detonation in a charge is revealed. The estimation of rate of compression behind detonation front agreed with theoretical data. Density distribution $\rho(r,z,t)$ in all area of a flow from the moment of initiation before development of a stationary detonation is reconstructed. The method is applicable for specification of models of detonation and carrying out of researches of various structures HE with considerable curvature of front.

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HIGH EXPLOSIVES EXAMINATION BY HIGH-RESOLUTION X-RAY COMPUTED TOMOGRAPHY ON THE VEPP-3 SYNCHROTRON RADIATION

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Abstract. High-resolution X-ray computed tomography (HRXCT) is a technology ideally applicable to a wide range of materials investigations. It is an express non-destructive method to produce 3D images corresponding to series of slice projections through a sample.

In the present study, HRXCT was applied to high explosives samples with the use of synchrotron radiation from the VEPP-3 storage ring (Novosibirsk, Russia), at the station "X-ray microscopy and tomography". Comparative analysis of internal structure was carried out for different samples pure RDX, TNT and their alloys.

In order to efficiently increase the spatial resolution of the method, X-ray magnification system (Bragg magnifier) was used [1, 2]. The "Bragg magnifier" is based on the diffraction from an asymmetrically cut crystal. Bragg diffraction from an asymmetrically cut crystal produces one-dimensional magnification. Two asymmetrically cut crystals reflecting in mutually perpendicular directions gave a uniform two-dimension magnification. The using "Bragg magnifier" with magnification factor 20 allows achievement 4–5 microns spatial resolution in the registered images.

Introduction. HRXCT gives a detailed three-dimensional imagery of the interiors of high explosives samples, realized in a non-destructive manner. The essence of the method is scanning a sample with X-ray beams that are differently absorbed in its various areas. The attenuation of X-rays along the beam is an integrated characteristic of the density of the object to investigate. The degree of distinguishing different components of high explosives volume in HRXCT data depends on the difference in their linear attenuation coefficients.

The resulting data are reconstructed from a sequence of projections obtained during rotation of a sample as series 2D slices. Collecting a stack of contiguous slices allows reconstruction of a full 3D volume. Our applications include interior examination of textu-

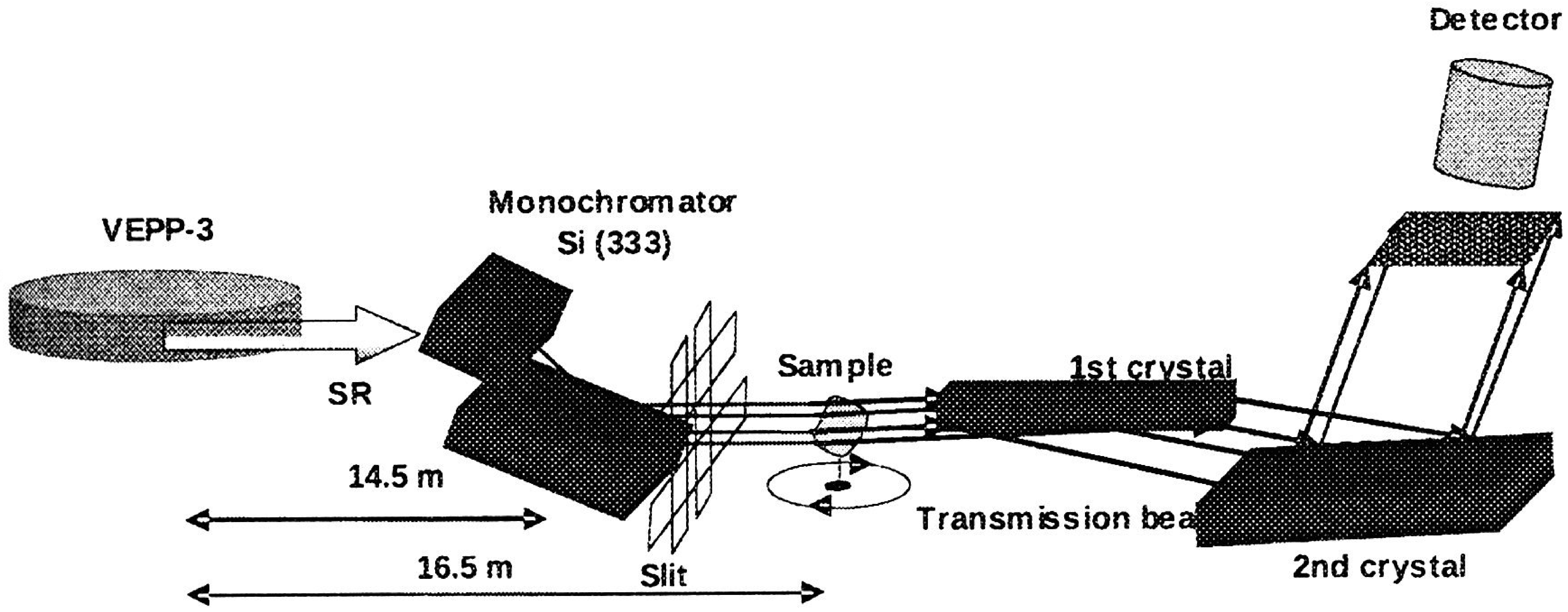

Figure 1. Scheme of the experiment, illustrating HRXCT image obtaining.

ral analysis of igneous and other tasks demanding 3D data that previously required serial sectioning. These data revealed general relationships among high explosives components in the 3D space.

Experiment and Setup. The HRXCT method was realized in SR beamline station "Microscopy and tomography" of the VEPP-3 synchrotron source. The experimental setup is shown schematically in Fig. 1. The X-rays working wavelength were selected by double crystal Si (111) monochromator used in parallel Bragg-geometry and installed at the distance 14.5 m from the SR emission point. HRXCT used to visualize inhomogeneities in the high explosives samples on micrometric scale such as, pores, inclusions, etc.

For excluding influence high energy harmonic in registered images the monochromator was tuned on (333) reflection. The wave length of photons of X-ray monochromatic beams, used in the experiments, was 0.89 A. The slits installed before the sample formed collimated X-ray beam with the geometric sizes 2x2 mm^2. The sample was placed at the distance 16.5 m from the source. The investigated high explosive was prealigned in translated axis with accuracy 1 m and in rotation axis with accuracy 0.01°.

In order to efficiently surpass the spatial resolution of the detector, a magnification system is being used. Using two asymmetrical cut crystals reflecting in mutually perpendicular direction produces uniform two-dimensional magnification with factor 20 in registered images. The approach for achieving enhancement spatial resolution is to magnify the image with asymmetrically cut crystals and to detect it with a low-resolution but high-efficiency detector.

Fig. 2 depicts the Bragg magnifier installed at SR beamline station "Microscopy and tomography" of the VEPP-3 synchrotron source.

Asymmetrical cut crystals have been prepared in collaboration with the Institute of Semiconductor Physics, Novosibirsk, Russia. The silicon crystals have been cut with an asymmetry angle of 9.15° respect to the (111) planes with an angular accuracy of about one minute of arc. The working surface of crystals has roughness of better than 1 micron. After a high quality polishing of their back-side, the crystals have been fixed on a high precision metal support. In this way, no mechanical deformation of the crystals themselves can occur. For each crystal unit the mechanical mounting allows an adjustment around each rotation axis. The movement that corresponds to the Bragg angle can be performed in steps of 0.1 arcsec. In addition, the second crystal can be positioned by means of a XZ-table.

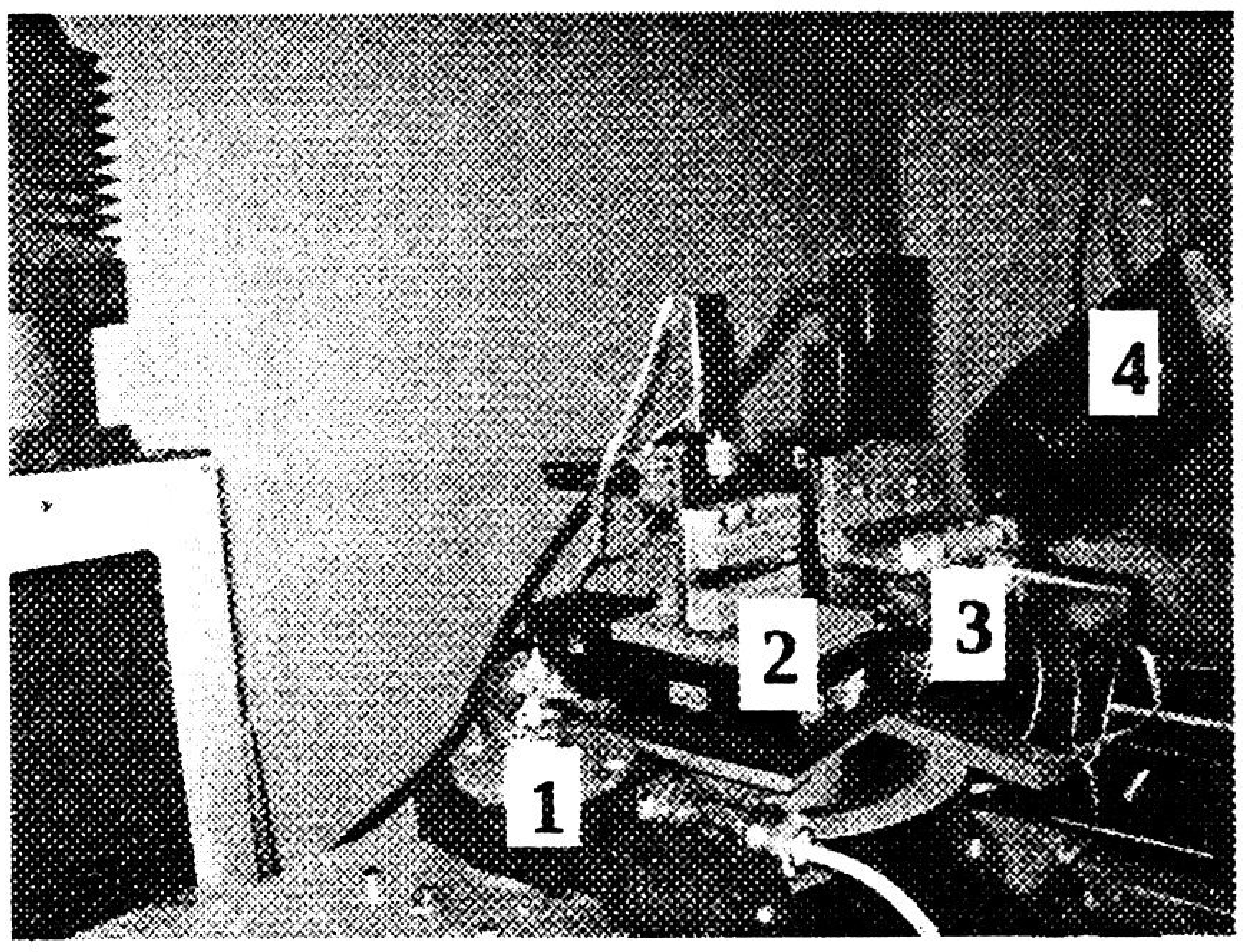

Figure 2. Setup of the "Microscopy and tomography" beamline station. 1—the sample, 2—the first asymmetrically cut crystal, 3—the second asymmetrically cut crystal, 4—the detector.

The magnified x-ray image, with size 30x30 mm^2, was imaged with a high-efficiency 16-bit CCD camera (Photonic Science). The CCD has 4008x2760 pixels, each 15x15 microns.

The effects caused by heterogeneities in the incident X-ray beams and non-uniformity in the response of the detectors were corrected using an appropriate calibration.

Some similar technique was developed in [3].

Results and discussion. The 3D visualization technique consists of volume rendering, in which each grayscale value in the data set is assigned a color and an opacity value. This allows some materials components to be rendered transparent and others partially or entirely opaque, providing unique opportunities for high explosives analysis in three dimensions.

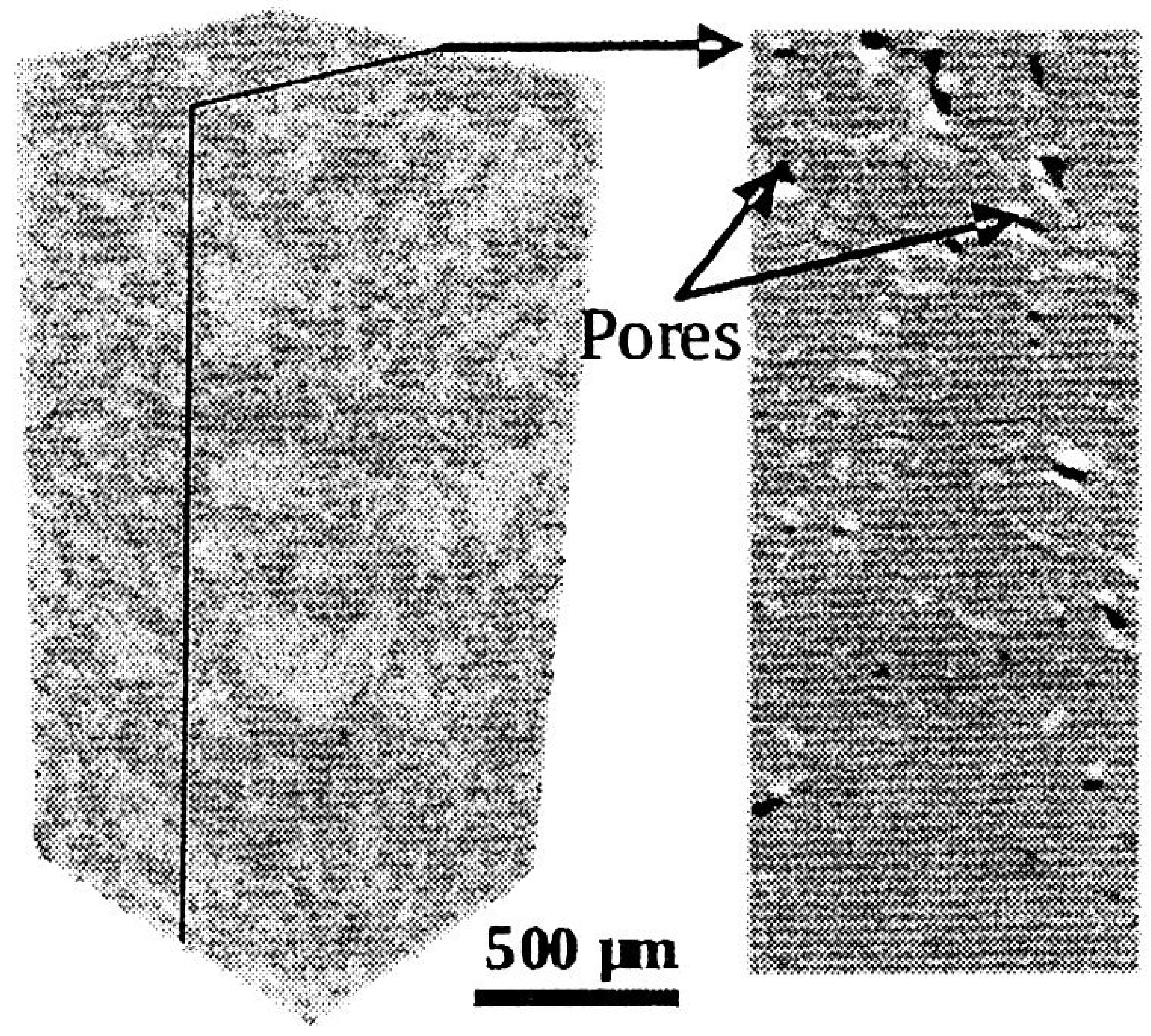

Figure 3. 3D image and one slice of high explosive sample (RDX/TNT alloy).

The simplest segmentation method for data is to define a grayscale threshold or range that is unique to the component of interest. However, this approach is complicated by the finite resolution of the imagery. Because each data voxel (volume elements) can encompasses a range of material, that if more than one material is present in that voxel, the resulting grayscale will be some average of the phases present; this is known as the partial volume effect. Furthermore, some blurring is inevitable, causing the grayscale value within a voxel to be influenced by surrounding material. Thus, the material boundaries often extend across 2 voxel featuring a gradual grayscale transition between the corresponding values characterizing each phase. The threshold level for proper location of a boundary between two different materials is the mean of their exact values. For our samples scan data, the threshold value for high explosives was 130 and pores had a value of 110, its appropriate threshold value is 120. In this manner, it is easy to distinguish pores distribution in the investigation samples Fig. 3.

Several such 2D images (slices) are stacked together using volume-visualization software to produce a 3D model of the high explosives. This essentially represents a density map of the sample, from which one can extract the sizes, shapes, textures, and locations of individual pores that have dimensions exceeding the spatial resolution of the scans. The spatial resolution of this technique is close to 4–5 microns, which is essentially helpful in visualization of pores with size 10 microns and bigger.

Fig. 4 demonstrates pores size distribution obtained for alloys RDX/TNT alloy which generally was used in investigated wave detonation process in beamline station "Extreme Conditions of matter" the VEPP-3 synchrotron source [4].

Structure of high explosive media such as density heterogeneity and porous distribution is an important characteristic. Heterogeneity of high explosives influences to stability of detonation process and is very important characterization for explosion applications. Density heterogeneities of size smaller than 100 microns, especially cavity, can form sources of "hot spots" that determine sensitivity of explosives and averaged chemical velocity of explosive decomposition.

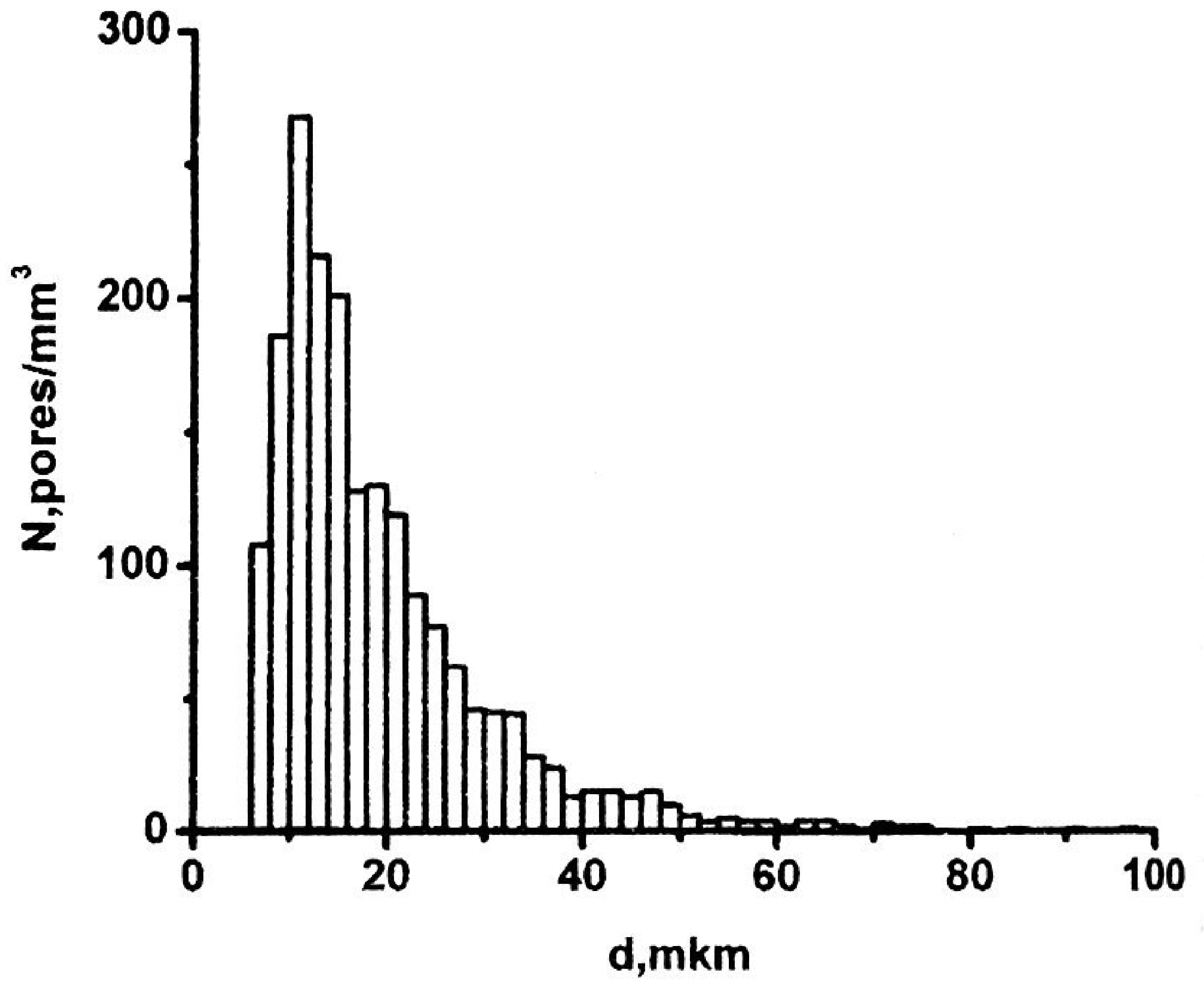

Figure 4. Pores size distribution in high explosive sample (RDX/TNT alloy).

Conclusion. 3D models of the samples reveal clearly the spatial relationships between different components high explosive and their surroundings. This gives clues to the control production high explosive processes. This study confirms the high efficiency of HRXCT method to recover the information on internal structure of the high explosives samples.

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ACTION OF THE WATER CONTENT ON THE SCATTERING DYNAMICS OF DETONATION PRODUCTS OF WATER-CONTAINING EXPLOSIVES

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The explosive switches. This work is caused by the analysis of an opportunity of explosive switch application for 50 Hz alternating current circuits. Explosive switches have found application in circuits of

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