Title

PRELIMINARY EXPERIMENTS WITH HELIUM ION RADIOGRAPHY AT THE 184-INCH CYCLOTRON

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Publication Date
1974-02-01

LBL-2654 c1

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February 1974

Prepared for the U.S. Atomic Energy Commission
under Contract W-7405-ENG-48

DISCLAIMER

PRELIMINARY EXPERIMENTS WITH HELIUM ION RADIOGRAPHY AT THE 184-INCH CYCLOTRON*

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SCOPE AND JUSTIFICATION

This report describes preliminary experiments with helium ion radiography of biological objects. Previous work using protons for imaging biological tissues has shown promising results (1-5). C. A. Tobias and coworkers (6, 7) have presented images with remarkably good contrast and mass thickness information using heavy ions such as oxygen and neon nuclei, and plastic detectors such as lexan and nitrocellulose.

The standard deviation of the longitudinal stopping point is inversely proportional to the square root of the atomic number. Thus heavy ions have a decided advantage over protons for accurate range or density measurements. The ratio of the standard deviations of the longitudinal stopping point distributions (straggling parameter) for protons and helium ions is 2. The projected rms scattering angle (radians) is

$$\theta = \frac{z\,15\,(\text{no. radiation lengths})^{1/2}}{p \cdot v},$$

where z is the charge, p is the momentum, and v is the velocity (8). Thus multiple scattering is proportional to charge/kinetic energy. The velocity of helium ions is the same as that for protons for a given range; thus, spatial resolution with helium ions should be improved over that from protons by a factor of 2. In going from helium ions to oxygen, one also has a similar incremental gain of 2 for range resolution and 2 for spatial resolution. It occurred to us that we should evaluate the resolution and range accuracy obtainable for both helium ions and protons in order to configure a particle detection system for proton or helium ion radiography. The goal is to develop a system for three-dimensional reconstruction of the distribution of density of tissues both for tumor detection (9) and early detection of heart disease (10).

METHODS

The beam was extracted at the 184-inch cyclotron and consisted of 840-MeV helium ions spread over a diameter of approximately 5 cm full width at half maximum with a flux of approximately 1.5×10^6 particles per square centimeter per second. Approximately $28/cm^2$ of polyethylene in plastic material was placed in the beamline, after which were inserted two types of targets:

1) A lucite block 1.3 cm thick consisting of holes of various widths and a range of depths was used to ascertain the spatial resolution and mass thickness detection sensitivity of helium ions.

2) A mouse was carefully extended in a formalin bath (35% formaldehyde in water) in a lucite tray 2 inches deep.

Stacks of 6 to 8 Polaroid type-57 high-speed film were used in packs with and without separators of 1.5-mm-thick lucite slabs. We also used stacks of x-ray film (du Pont Chronex 2D/C).

Scintillator paddles 3/64 inch thick were used to locate the Bragg peaks which had a width at one-third maximum of approximately 5 mm. In anticipation of clinical trials, health physics surveys using indium foils were done in the environs of the beamline.

RESULTS

It was possible to see holes in the plastic resolution phantom 1.7 mm in diameter and 0.25 mm deep (Fig. 1). This represents a range of detection of 0.09%. Using x-ray film it was possible to see 0.045% range, i.e., 0.13-mm thickness change over the total thickness of 28 cm simulated tissue.

The mouse images showed high contrast, as indicated in Figs. 2 and 3. Mouse bones, in particular the rib cage, cannot be detected because of small size (2-4 mm) and small contribution to the mass thickness.

The radiation field of concern in the vicinity of the beamline is mainly neutrons. For a helium ion flux of 2×10^8 per second in this experimental setup, the doses of neutrons in the region 20 cm from the stopping point were 100 to 200 mrem/hr.

DISCUSSION

The high sensitivity of mass thickness detection using helium ions is remarkable in view of the fact that the range straggling for helium ions of this energy is ~ 0.045 g/cm^2 or 0.16% (11). We used approximately 3×10^7 particles/cm^2, and the difference between our high sensitivity and that expected from the straggling parameter is due to these good statistics. However, the dose is 5 rads.

Multiple scattering limits the spatial resolution to about 2 mm when the phantom is placed at the end of the range. When the phantom is moved to mid-range, i. e., with approximately 14 cm of absorber in front of the target and 14 cm after the target, the film detection showed a degradiation in resolution greater than a factor of 2, but was not quantitated in this first series of experiments. The standard deviation of the lateral spread due to multiple scattering of a proton beam is: $\sigma = 0.0301\ R_H$ (cm), where R_H is the maximum range for a given energy proton. The multiple scattering is reduced by a factor of 2 for helium ions over protons for the same range or velocity; thus, $\sigma = 0.015\ R_{He}$. For a beam of helium ions which has an entrance diameter of 1 mm, we expect a standard deviation of the lateral spread to be 5 mm at the end of a nominal range of 30 cm. Once again our ability to realize a spatial resolution of 1-7 mm is due to good statistics we used.

CONCLUSIONS

In these preliminary experiments with 840-MeV helium ions and x-ray film as a detector, we have been able to assess the range sensitivity and spatial resolution for eventual patient studies wherein the range is ~ 30 g/cm^2. These experiments show spatial resolution of < 2 mm is obtainable, and a sensitivity in range or mass thickness of 0.045% can be achieved with a total flux of 3×10^7 ions/cm^2 through a range of 28 g/cm^2. Future experiments will include use of wire chambers and single-particle trajectory detection for a comparison of the advantages of helium ions over protons for radiography of human tissues.

ACKNOWLEDGMENTS

This work was supported by the U. S. A. E. C. Technical assistance was generously provided by J. A. Bistirlich, J. L. Cahoon, V. P. Elischer, B. R. Moyer, L. D. Stephens, and the entire cyclotron crew. We benefited from conversations with Drs. Cornelius Tobias, Luis Alvarez, Owen Chamberlain, Arthur Rosenfeld, Aloke Chatterjee, Walter Schimmerling, Henry Aceto, and Ron Martin.

FOOTNOTE AND REFERENCES

*Work done under the auspices of the U. S. Atomic Energy Commission.

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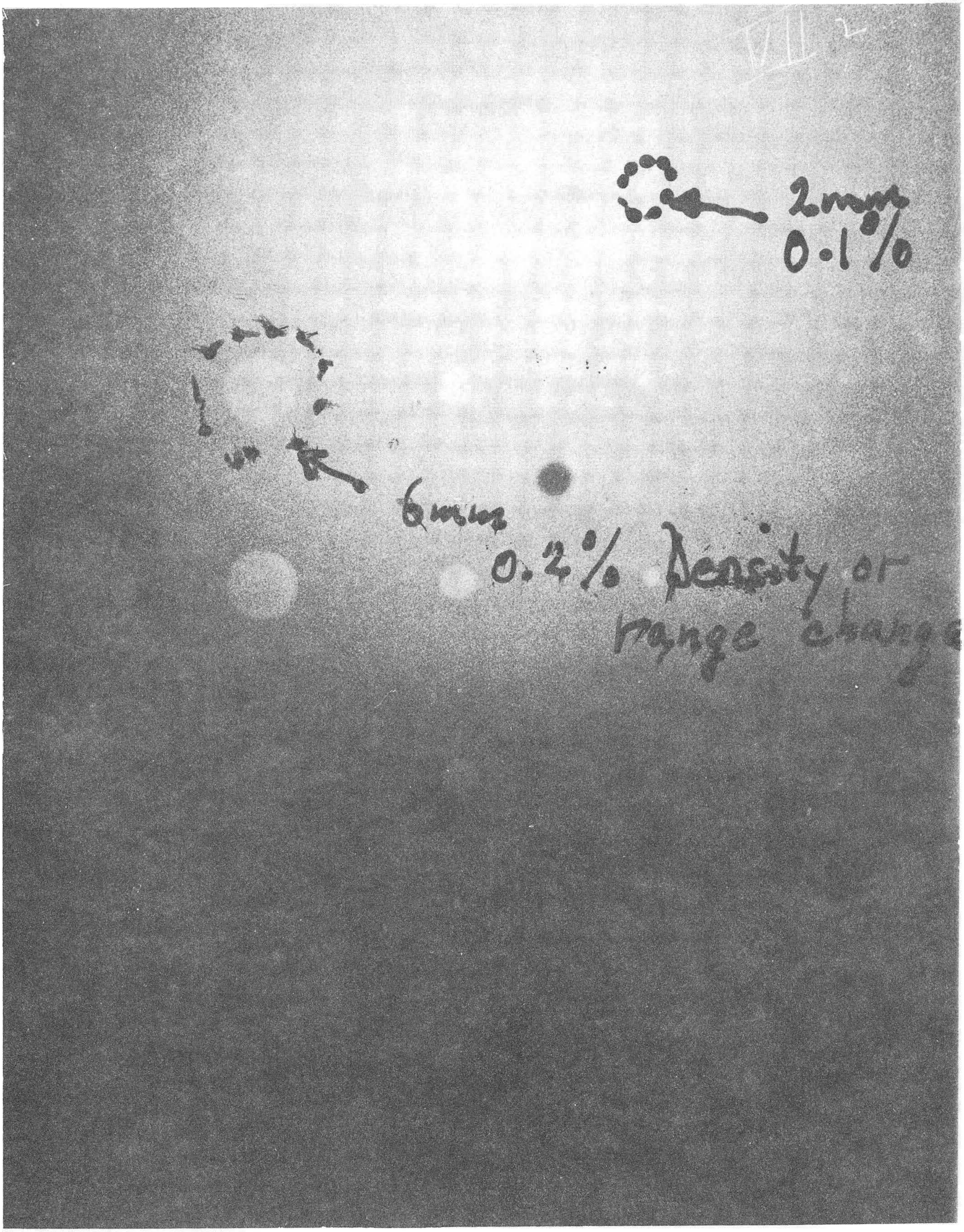
FIGURE CAPTIONS

Fig. 1. Reproduction of a Polaroid film image of a lucite phantom with holes drilled to various depths and diameters to give a measure of the sensitivity of density detection over a range of 28 cm with 840-MeV helium ions.

Fig. 2. Left, x-ray image of a mouse suspended in liquid, using 68 kV p at 100 mA for 0.7 sec. Beam spot is 2 mm and 1.75 mm. Al filtration used. Right, helium ion radiograph using 3×10^{7} He ions and a 28-cm polyethylene path. Image collected on x-ray film.

Fig. 3. Sequence of images recorded by a stack of four Polaroid packs positioned near the end of the range for 840-MeV helium ions.



XBB 742-1256

Fig. 1

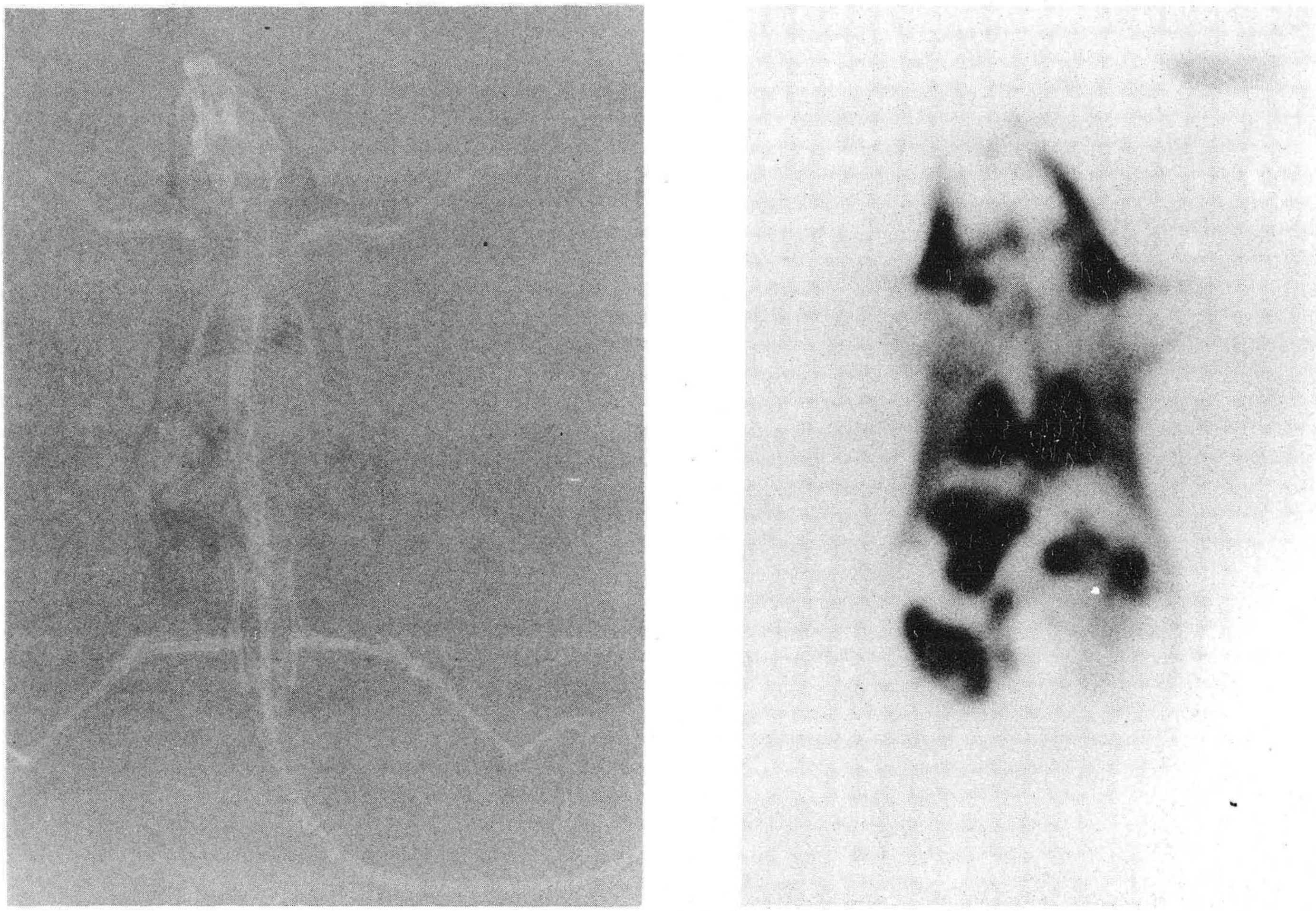


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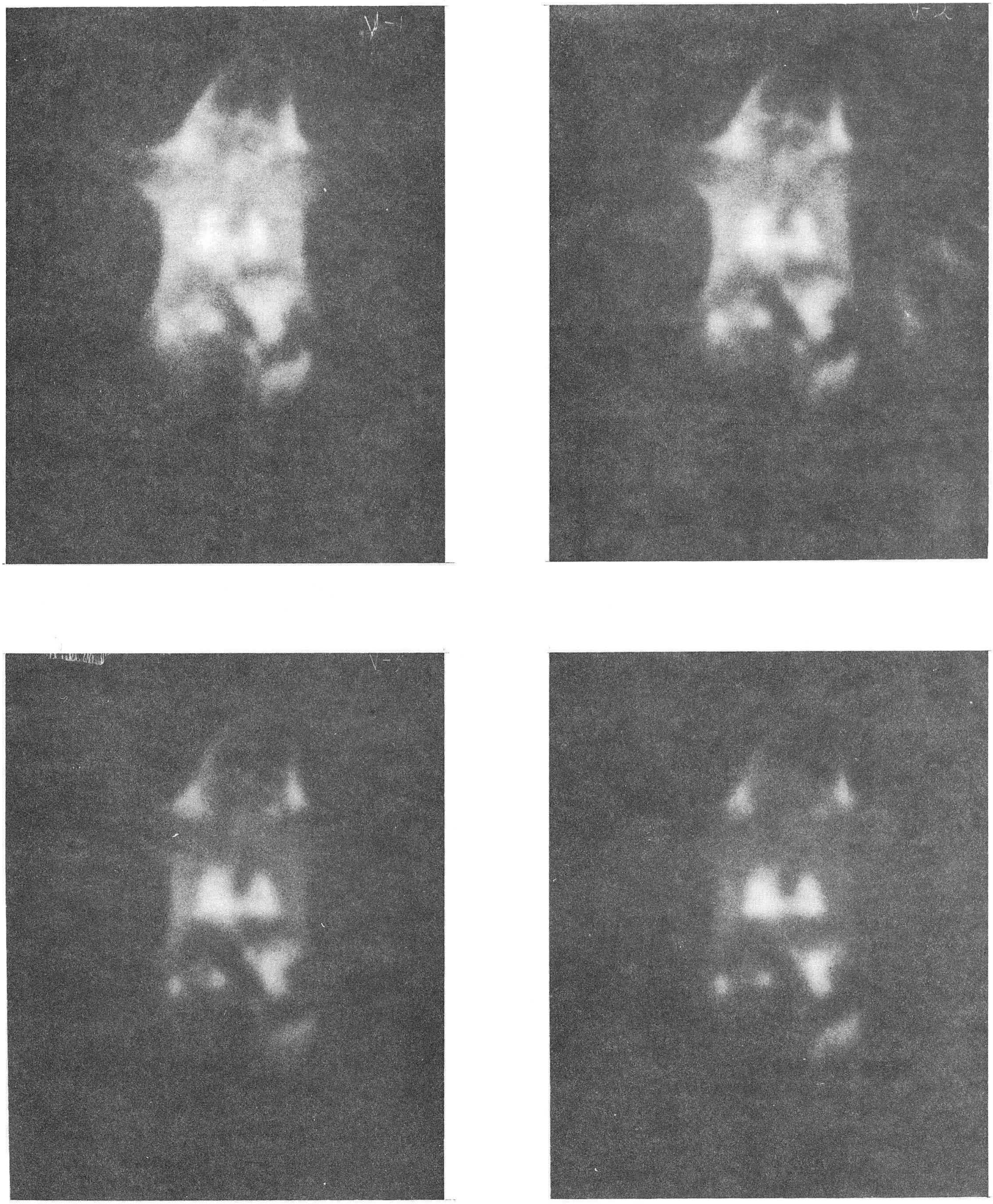
Fig. 2



XBB 744-2170

Fig. 3

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