References and Notes

1. R. G. Canti, J. O. W. Bland, D. S. Russell, *Research Publs. Assoc. Research Nervous Mental Disease* **16**, 1 (1937).
2. C. E. Lumsden and C. M. Pomerat, *J. Exptl. Cell Research* **2**, 103 (1951).
3. C. M. Pomerat, *J. Nervous Mental Disease* **114**, 430 (1951).
4. ———, *J. Neuropathol. Exptl. Neurol.* **14**, 28 (1955).
5. ———, *Biology of Neuroglia* (Thomas, Springfield, Ill., 1958), p. 162.
6. G. G. Rose, C. M. Pomerat, T. O. Shindler, J. B. Trunnell, *J. Biophys. Biochem. Cytol.* **4**, 761 (1958).

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Age of Marginal Wisconsin Drift at Corry, Northwestern Pennsylvania

Abstract. Marl began to accumulate about 14,000 years ago, as determined by radiocarbon dating, in a pond in a kettle hole in Kent drift at Corry, Pa., 9 miles inside the Wisconsin drift margin. This radiocarbon age represents the minimum time since the disappearance of the ice from Corry and confirms an assignment of Cary age to the drift.

Samples of peat and marl from a bog in a kettle hole in the northwestern part of Corry, Pa., have been assayed for C^{14}. Corry, in southeastern Erie County, is 7 miles southeast of the southwestern corner of New York state.

The kettle hole is in a kame complex (*1*), the location of which is well shown on the *Glacial Map of the United States* (*2*), associated with the Kent till (*3*), which is the outermost Wisconsin till of the Grand River glacial lobe in northeastern Ohio and northwestern Pennsylvania. It has been earlier correlated as "early Cary" by White (*4*). The kettle hole is 9 miles northwest of the outer limit of Wisconsin (Kent) drift, which is marked by the prominent 4-mile-wide Kent moraine (*5*).

The kames at Corry are related to the disappearance of the marginal part of the ice sheet, but they may have been deposited at an ice edge which readvanced slightly to Corry after retreat from the Kent moraine. The age of the lowest part of the organic deposits establishes the minimum time since the kettle hole has been available for the accumulation of organic material.

The bog is being worked for peat for floriculture by Russell Graham and Earl Shade, who report that the peat in the center of the bog is as much as 30 ft thick and is everywhere underlain by marl. The section and samples for which data are given in Table 1 were secured in an auger boring; the dating of the samples was done in the radiocarbon laboratory of the U.S. Geological Survey. The apparent difference in age between the highest marl and the lowest peat may be real—that is, no material was deposited for almost 4000 years—or more probably it reflects contamination of the peat sample with peat from higher levels.

The age determination for the lowest marl is consistent with the interpretation of Cary age for the drift at Corry. This is the first determination of the age of drift of northwestern Pennsylvania to be made by means of radiocarbon analysis.

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References and Notes

1. The field study of the glacial deposits of this part of northwestern Pennsylvania was made by J. B. Droste as part of the investigation of till composition of the Allegheny Plateau supported by National Science Foundation grants to G. W. White. Publication of this report has been authorized by the director of the U.S. Geological Survey.
2. R. F. Flint, R. B. Colton, R. P. Goldthwait, H. B. Willman, *Glacial Map of the United States . . .* , (Geological Society of America, New York, 1959).
3. G. W. White, J. B. Droste, R. F. Sitler, V. C. Shepps, *Bull. Geol. Soc. Am.* **68**, 1902 (1957); V. C. Shepps, G. W. White, J. B. Droste, R. F. Sitler, *Penn. Geol. Survey Bull. G. No. 32* (1959).
4. G. W. White, *Ohio Div. Water, Bull.* **26**, 37 (1953).
5. ———, *Bull. Geol. Soc. Am.* **68**, 1902 (1957).

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Table 1. Description and radiocarbon dates of samples from an auger boring.

Sample	Ft	In.
Peat, brown to greenish brown, with leaves, grasses, seeds, and wood. Sample W-347 from lowest 8 in., age 9,430 ± 300 years	9	9
Marl, light to medium gray, rich in plant material, highly calcareous, very fossiliferous, contains pelecypods, gastropods, and ostracods. Sample W-346 from top 8 in., age 13,000 ± 300 years; sample W-365 from bottom 8 in., age 14,000 ± 350 years	3	0
Clay, blue gray, silty, laminated, highly calcareous	9	0
Sand and fine gravel, gray, calcareous	1	6
Bottom of auger hole		

Tolerance of Mouse-Brain Tissue to High-Energy Deuterons

Abstract. A striking relationship between the size of the impact area of a deuteron beam and the threshold dose for a radiogenic lesion has been noted. The dose required to produce a threshold lesion in mouse brain increases from 30,000 rad with a beam 1000 μ in diameter to 1.1×10^6 rad with a beam 25 μ in diameter.

The experiments reported here are part of a program designed to investigate the biological effect of heavy cosmic ray primaries upon brain tissue by a simulated technique. This technique is based on the expectation that most of the biological effect of a cosmic ray primary would result from the dense cluster of secondary protons surrounding the path of the primary. It is estimated that such a cluster would create a core of ionization about 25 μ in diameter (*6*). Thus, a beam of protons or deuterons of a certain dose and about 25 μ in diameter should simulate to a certain extent the spatial pattern of ionization energy of the thindown of a heavy cosmic primary. On the other hand, by this technique one is unable to approximate the dose rate of a cosmic primary, which transfers its energy within a billionth of a second. However, preliminary studies indicate that, with a 25-μ beam, an increase in the dose rate from 15,000 to 400,000 rad/sec decreases the threshold dose for a radiogenic lesion only by approximately 10 to 20 percent. This suggests that the differences in dose rates between cosmic primaries and the simulating techniques may be of minor biological significance.

The phase of the study reported here is concerned only with the independent variable of beam size.

The irradiations were performed with a 22.5 Mev deuteron beam from the 60-in. cyclotron at the Brookhaven National Laboratory. After passing through a helium ionization chamber and 2 in. of air, the beam had a depth range in tissue of approximately 2.5 mm. Dosimetry was based on continuous recording of the current in the ionization chamber. The mean dose rate varied from 15,000 to 60,000 rad/sec. Density measurements on phantoms consisting of laminated photographic films distal to the apertures were used to calculate dose distributions. The dose in rad was calculated from the total number of deuterons absorbed per unit volume of tissue, and this calculation was confirmed, to a first approximation, by depth dose measurements with films. The ionization in tissue is quite uniform to a depth of 1.5 mm, and this was the only region considered, since beyond this depth the ionization density in-

creases markedly (Bragg effect) and makes dosage calculation very difficult.

Round apertures with a diameter of 1, 0.075, and 0.025 mm, respectively, in 0.4-mm platinum foil were placed directly in front of the target area to achieve the desired beam profile. After passing the aperture the beam was relatively well collimated to a depth of 1.5 mm, but beyond this scattering broadens the beam considerably for the smaller beam diameters.

One hundred Carworth CF_1 female mice 6 to 7 weeks old and weighing 25 to 32 gm were used. The beam was directed to the exposed skull at a point 1.5 mm to the right of the longitudinal suture and 1.5 mm anterior to the lambda suture. The head was kept in a fixed position by placing the upper front teeth over a bar and inserting two metal pins into the outer auditory meatus on each side. The animals were kept under light Nembutal anesthesia. None of the animals exhibited any abnormal reactions after irradiation.

After 3, 6, 12, 24, and 48 days, respectively, the mice were anesthetized with Nembutal and perfused with Susa fixative. The brains were embedded in paraffin and cut in serial sections at 8μ. The following staining methods were used: gallocyanin, hematoxylin-van Gieson, and PAS-gallocyanin.

With a 1-mm beam, a single exposure with 30,000 rad produced within 12 days a cavitation—that is, complete destruction of all tissue components in the center of the beam. After 24 days the lesion had grown somewhat larger and comprised almost the entire beam path (Fig. 1, *A*). A dose of 60,000 rad produced a larger and more uniformly shaped cavity within 24 days (Fig. 1, *B*). No lesion was observed at 15,000 rad. This means that the threshold for a destructive lesion along the first half of the beam path is between 15,000 and 30,000 rad for a 24-day latency.

With a 0.075-mm beam, a dose of 150,000 rad resulted in complete loss of ganglion cells along the beam path within 6 days. Mice that had survived for 24 days after exposure to the same dose exhibited a similar lesion. With a dose four times higher, the histologic character of the lesions did not change. The tract, however, became somewhat broader, reaching a diameter of 100 μ as compared to one of 70-μ diameter produced by 150,000 rad. With 75,000 rad no lesions developed until the 24th day. It may therefore be concluded that the threshold dose for producing a lesion within 24 days is about 75,000 rad.

To produce a histologic lesion with a beam of 0.025 mm, a dose of 1.1×10^6 rad was required (Fig. 1, *C* and *D*). A dose of 550,000 rad did not result in any histopathologic changes. A dose of 2.2×10^6 rad did not alter the histologic appearance of the lesion, although it widened the tract from 25 to 40 μ. Cavitation have never been observed, even at very high dosages, and this constitutes a striking qualitative difference between these findings and those with the 1-mm beam.

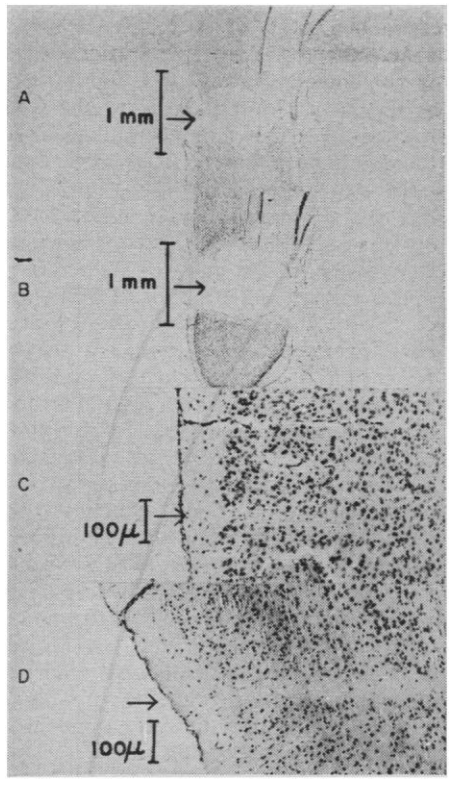

Fig. 1. Frontal sections of visual cortex of mice irradiated with deuteron beams. The arrows indicate the direction of the beam. (A) 1-mm beam, 30,000 rad, 24-day survival; (B) 1-mm beam, 60,000 rad, 24-day survival; (C) 0.025-mm beam, 1.1×10^6 rad, 6-day survival; (D) 0.025-mm beam, 1.1×10^6 rad, 48-day survival.

For production of a histologic lesion 24 days after exposure to deuteron beams of 1.0, 0.075, and 0.025 mm, radiation doses of approximately 25,000, 75,000, and 10^6 rad, respectively, are necessary. These results indicate that there is an inverse relationship for small volumes between radiosensitivity and tissue volume exposed, and that if the beam size were further decreased the sensitivity might be very low indeed.

The decease in sensitivity found for small exposure volumes is quite consistent with the finding of Kereiakes *et al.* (*1*)—that grids with small holes afford more x-ray protection for rats than grids of the same exposure area with large holes. These findings also correlate well with results of Devik (*2*), who used very small wires to shield skin areas, and of Chase (*3*), who exposed skin to small proton and x-ray beams. The basis of this increased tolerance is not well understood; it has been surmised that it results from a protection of the irradiated tissue by its unirradiated surroundings. Another explanation, more appropriate to the experiments described here, would be that the microbeams cause a predominantly direct radiation injury, whereas the large beams produce additional indirect effects. Indeed, the studies of Larsson, Leksell, Rexed, and Sourander (*4*) suggest that in large radiation areas vascular disturbances in the form of plasma exudation, hemorrhages, and edema play an important role in the pathological development of radiogenic lesions of the nervous system. Such factors hardly apply to the lesions produced by microbeams, because vessels are only occasionally located within the beam path, as seen in serial sections. If a length of 1400 mm of capillaries per 1 mm^3 of brain tissue is assumed (*5*), the capillaries would be spaced about 78 μ apart, from outside wall to outside wall. This would theoretically permit even a 75-μ beam to pass through the tissue without hitting a significant number of vessels. Further support for a direct action by the microbeams is derived from the observation that the lesions are sharply delimited and do not follow any vascular distribution pattern.

It would appear from these results that the biological effects of primary cosmic rays may not be as damaging as has been supposed (*6*). These data also have very important implications for basic radiobiology (*7*).

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References and Notes

1. J. G. Kereiakes, W. H. Parr, J. R. Storer, A. T. Krebs, *Proc. Soc. Exptl. Biol. Med.* **86**, 153 (1954).
2. F. Devik, *Advances in Radiobiology* (Oliver and Boyd, Edinburgh, 1957), p. 226.
3. H. B. Chase, *J. Aviation Med.* **25**, 388 (1954).
4. B. Larsson, L. Leksell, B. Rexed, P. Sourander, *Acta Radiol.* **51**, 52 (1959).
5. H. S. Dunning and H. G. Wolf, *J. Comp. Neurol.* **67**, 433 (1937).
6. H. J. Schaefer, *J. Aviation Med.* **25**, 388 (1954).
7. This work was carried out partly under the auspices of the U.S. Atomic Energy Commission and partly with funds from USAF project 7851, Aero Medical Field Laboratory, Holoman Air Force Base, N.M. We wish to thank C. P. Baker for invaluable assistance.

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