life of 27.7 years gives ample time for solvation and precipitation processes to act selectively on Ac^{227} and effect a separation of it from its parent Pa^{231}, I thought that a direct determination of Pa^{231} in ocean water was necessary.

The procedure, a modification of one developed by Potratz and Bonner (*2*), was as follows. A known activity of Pa^{233} (a beta emitter which results from the decay of Th^{233} produced by the thermal neutron irradiation of Th^{232}), Fe^{3+} solution, and acid were added to portions of ocean water filtered through Whatman 41H paper. Naturally occurring Pa^{231} and the added Pa^{233} were concentrated by co-precipitation with $Fe(OH)_3$ upon the addition of NH_4OH and then separated from the iron by two co-precipitations on $ZrO(IO_3)_2$ from 4*M* HNO_3 solutions. Further purification of the protactinium isotopes was obtained by their extraction from a 6*M* HCl solution into diisobutylcarbinol. After washing the organic phase with several portions of 6*M* HCl, protactinium was back-extracted into a dilute HF solution which was washed with several portions of fresh diisobutylcarbinol and evaporated to dryness on a platinum plate. After these operations, the yield of protactinium was determined by comparing the Pa^{233} beta activity with that of an aliquot of the original tracer solution mounted and counted in the same manner. Counts of the total alpha activity gave a measure of Pa^{231}, since this is the only naturally occurring alpha-emitting isotope of protactinium.

For sediments, 2-g samples were digested with H_2SO_4 and addition of HF was repeated until no silica remained. After the last traces of HF had been removed by fuming with H_2SO_4, the solution was cooled and diluted, and the procedure described above was followed, starting with the precipitation of $Fe(OH)_3$.

In order to test the validity of the foregoing methods, several Pa^{231} determinations were made on material which had a known amount of uranium and the equilibrium quantity of daughter elements. The results are listed in Table 1. There is rather good agreement between experimental and theoretical values, and the experimental alpha activity did not change with time—a finding which indicated the absence of short-lived radioactive species or long-lived species with short-lived daughter elements.

On the assumption that the foregoing procedures are valid, determinations were made on two 76-lit. samples of Pacific Ocean water collected from the end of the pier of the Scripps Institution of Oceanography at La Jolla, Calif., and the results in Table 2 were obtained.

It appears that one may safely state that the Pa^{231} alpha activity in 76 lit. of ocean water is less than 0.2 disintegration/min, which is less than 3 percent of the amount which could be in equilibrium with a uranium content of 3 μg/lit. (*3*).

The deficiency of Pa^{231} in ocean water indicates that Pa^{231} is removed as it is formed from the radioactive decay of U^{235} in a time much shorter than its half-life; this behavior is similar to that of ionium (Th^{230}). Therefore, as in the case of ionium, one may expect to find quantities of unsupported protactinium in ocean sediments. This was experimentally verified for the six samples listed in Table 3.

The data indicate that there is unsupported Pa^{231} in the top layers of equatorial Pacific deep-sea sediments and that there is also the expected decrease with depth. Apparent protactinium-ionium ages for the two sections for which ionium values were obtained agree with estimates based on productivity studies and extrapolated C^{14} ages (*4*). Protactinium-ionium dating promises to be a valuable tool in the geochronological study of deep-sea sediments (*6*).

Table 1. Protactinium-231 content of New Brunswick Laboratories AEC counter calibration sample, which contained 0.5 percent of uranium.

Sample size (g)	Yield (%)	Pa^{231} (disintegration/min)	
		Experimental	Theoretical
0.200	96 ± 4	31.6 ± 1.3	33.8
0.200	75 ± 3	28.3 ± 1.1	33.8
0.400	66 ± 2	65.0 ± 2.0	67.6
0.400	80 ± 2	64.5 ± 2.0	67.6

Table 2. Protactinium-231 content of ocean water.

Sample	Tracer yield	Total alpha activity corrected for yield and geometry (disintegration/min)
Reagent blank	72 ± 3	0.22 ± 0.06
No. 1, 76 lit.	57 ± 2	0.22 ± 0.08
No. 2, 76 lit.	36 ± 1	0.24 ± 0.10

Table 3. Protactinium content of deep-sea sediments. Ppm, parts per million; *A*, activity.

Core No.	$CaCO_3$* (%)	Total uranium (ppm)	Pa^{231} uranium equivalents† (ppm)	Th^{230} uranium equivalents (ppm)	$A_{Th^{230}}/A_{Pa^{231}}$	Apparent age (yr)
Scripps						
Capricorn 33HG 1 cm	86		342 ± 17			
Capricorn 42HG 0 cm	85		447 ± 33			
Capricorn 50HG 0 cm	76		123 ± 9			
Swedish deep-sea expedition						
Core 61, surface	65	1.5	216 ± 11	86 ± 9	9 ± 1	(0 ± 10) × 1000
Core 61, 161 cm	87		133 ± 30			
Core 61, 232–240 cm	67	1.0	86 ± 9	111 ± 11	28 ± 4	(95 ± 13) × 1000

* Cores with a high calcium carbonate content and thus with a comparatively high rate of deposition were selected for analysis in order to minimize the effect of mixing by organisms at the sediment surface on the resolution of time (*4*, *5*). Protactinium and ionium values are listed on a carbonate-free basis. † Uranium equivalents are defined as that concentration of uranium which is necessary to support the protactinium or ionium activity found, or both.

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References and Notes

1. F. F. Koczy, E. Picciotto, G. Poulaert, S. Wilgain, *Geochim. et Cosmochim. Acta* **11**, 103 (1957); W. M. Sackett, H. A. Potratz, E. D. Goldberg, *Science* **128**, 204 (1958).
2. H. A. Potratz and N. A. Bonner, *U.S. Atomic Energy Comm. Rept. No. La-1721* (1958).
3. M. Nakaneshi, *Bull. Chem. Soc. Japan* **24**, 36 (1951).
4. G. Arrhenius, *Report of the Swedish Deep-Sea Expedition* (Royal Society of Arts and Sciences, Göteborg, 1952), vol. 5.
5. ———, *Researches in Geochemistry*, P. H. Abelson, Ed. (Wiley, New York, 1959), p. 22.

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Some Effects of Ionizing Radiation on Translocation in Plants

Abstract. Petioles and apical regions of *Phaseolus vulgaris* var. Black Valentine were subjected to ionizing radiation to study the effect on the translocation process. Petiole irradiation produced no discernible effect. Inhibition of translocation to the irradiated meristems was reversed by application of the auxin naphthaleneacetic acid.

The tissue generally accepted as the locus of translocation of organic material and minerals from leaves is the phloem. More specifically, the cytological evidence would implicate the sieve

tube elements in the major role of connector between regions of supply and those of utilization ("sinks"). Tissue autoradiography showing a concentration of activity in companion cells (*1*) has cast some doubt on the validity of this conclusion. Mechanical and thermal damage to the vascular system results in reduced phloem-limited translocation; application of metabolic inhibitors indicates the process to be metabolically dependent in the phloem itself. These methods, however, do not differentiate between enucleated sieve tube elements and the nucleated cells of the phloem.

In view of the report (*2*) that nucleoplasm is more radiosensitive than cytoplasm, we felt that application of x- or β-radiation (*3*) to the phloem tissue might differentially affect the enucleated sieve tube elements and the nucleated cells of the phloem. For this study, bean plants, *Phaseolus vulgaris* var. Black Valentine, were cultivated hydroponically in a controlled-environment room. Translocation was estimated by direct counting of dried stem sections with a Geiger-Müller tube and conventional scaler after application of phosphorus-32 or of a dried ethanol extract after application of carbon-14.

Phosphorus-32 was applied as phosphate HCl (about *p*H 3) as a drop to the upper side of the leaf; C^{14} was supplied as CO_2 to the under side of the leaf by a leaf cup (*4*). The supply leaf petioles of five groups of two bean plants each were x-irradiated in doses of from 1000 to 50,000 r. Four days after irradiation, 3 μc of P^{32} were applied to the treated leaf, and after a 6.5-hour migration period, the amount and distribution of the P^{32} was determined. All differences between these plants and two control plants could be accounted for by random variation, indicating that treatment at these dosages had no effect. One bean petiole was subjected to irradiation of 683,000 reb (roentgen-equivalent-beta) over a 5.75-hour period with no apparent reduction in translocation of P^{32}. Estimates indicated that phloem tissue absorbs approximately 2 percent of the x-ray energy and 5 percent of the β-ray energy.

The radioresistance of the translocatory pathway seems to be further circumstantial evidence pointing to the enucleate sieve tube as this pathway.

Skok (*5*) has suggested that translocation of carbohydrates into "sink" regions such as meristems is directly dependent upon the cellular activity of the region. Thus a metabolically active site would reduce the substrate concentration, establish a concentration gradient, and promote translocation into the region. Support was given to this suggestion when excision of the terminal buds of sunflower resulted in an approximate 50-percent reduction in upward translocation of C^{14} from the supply leaf without significantly affecting the amount moving downward. Subsequently, Crafts and Yamaguchi (*6*) reported that phloem translocation of herbicides was correlated with both sink activity (root growth) and source activity (amount of green in variegated leaves). If we suppose Skok's hypothesis to be valid, factors directly affecting the metabolism of the meristem would indirectly control translocation into the region.

Table 1. Effect of naphthaleneacetic acid (NAA) on translocation of C^{14} to apical regions. The results are averages for three plants.

Treatment	Count/min mg (dry weight)	
	Small leaf	Meristem
Control	350.1	272.6
9900 reb	62.0	72.7
9900 reb with NAA added to meristem	91.6	212.6

Exposure of meristems to relatively small doses of ionizing radiation results in temporary reduction in growth, presumably through a reduction in auxin and deoxyribonucleic acid concentrations (*7*). To determine whether the reported growth reduction was accompanied by concomitant reduction in translocation, the apical regions of eight bean plants were irradiated with a strontium-90 source at surface incident doses (two plants at each dose) of 0.1, 1, 10, and 100 kr, respectively. Phosphorus-32 was applied 48 hours after irradiation. After a 7-hour translocation period, the amount of activity in the terminal region of the plants treated with 10 and 100 kr was less than that in the control plants by 97 and 98 percent, respectively. Findings for the other treatment groups, were not significantly different from those for the control group, indicating a threshold within the 1- to 10-kr range.

Topical application of auxin can maintain normal growth after irradiation. No natural recovery has been reported after x-ray doses above about 2 kr (*7*). If the translocation to the apical meristem region is a function of growth, topical application of auxin to the irradiated bud should also maintain translocation.

Table 1 shows the results of an experiment on three groups of three plants each. The apical region for the two irradiated groups consisted of the meristem and a small trifoliate leaf. Immediately after irradiation and again 19 hours later, one of these groups received 10 μl of a 5-parts-per-million naphthaleneacetic acid solution applied to the meristem only. Carbon-14 dioxide was released to a fully expanded primary leaf approximately 21 hours after irradiation, and the experiment was terminated 3 hours later. Irradiation at this level significantly reduced carbon translocation to the irradiated portions; however, application of auxin did result in the translocation of significantly more activity to the meristem than to the irradiated leaf.

While there is no real way of differentiating causes and effects in this case, the known relationship between auxin and growth and the correlation between auxin and translocation demonstrated in this study clearly support the hypothesis that translocation is correlated with and probably dependent upon cellular or metabolic activity at the site of utilization (*8*).

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References and Notes

1. R. S. Gage and S. Aronoff, *Plant Physiol.* **35**, 65 (1960).
2. O. A. Schjeide, J. F. Mead, L. S. Myers, Jr., *Science* **123**, 1020 (1956).
3. The x-ray machine employed was a Norelco contact-cavity therapy unit, operated at 2 ma, delivery 45 kv (peak) x-rays, surface incident dose rate about 7500 r/min, over a 20-mm field. Beta-radiation was supplied by a Tracerlab Sr^{90} medical applicator, model RA-1. The calculated surface incident dose rate was 33.0 reb per second.
4. S. Aronoff, *Plant Physiol.* **30**, 184 (1955).
5. J. Skok, *ibid.* **32**, 648 (1957).
6. A. S. Crafts and S. Yamaguchi, *Hilgardia* **27**, 421 (1958).
7. S. Gordon, *Quart. Rev. Biol.* **32**, 3 (1957).
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Transplantation and Malignancy in a Companion-Host System on the Chorioallantoic Membrane

Abstract. Pairs of tissue fragments in contact with one another were transplanted onto the chorioallantois. Ten days after transplantation, embryonic lung and liver were found to be accepted, without obvious infiltration of one another. When Walker tumor was substituted for either of the normal tissues, the pair of transplants was also accepted by the chorioallantois, and in addition there was extensive invasive replacement of the normal tissue by the cancer transplant.

In the search for the essence of cancer in a microsystem, reference is often made to bioassay methods for evidence that the elemental factor under study is related to some quality of