comparisons are independent of the actual neutron dose.[3] Both these biological effects resulting from the test neutron radiation can be expressed (by using the laboratory-derived relation of effect to x-ray dose) as "dose (r) of x-rays to produce equal effect," which is compared for mice and *Tradescantia* in Fig. 3. The curves have been displaced upward to avoid confusion with the other curves. From the line fitted to the three points it can be seen that the effect of the test neutrons, relative to x-rays, is about two times as great on *Tradescantia* as it is on mice, at least over the range of doses experienced. This figure is in fairly good agreement with what is known about the RBE of the neutrons to x-rays for the two organisms. The following *Tradescantia* experiments by Kirby-Smith and Swanson (*6*) offer a solution to the problems left unsolved by these incomplete neutron experiments.

A final instrumental calibration of *Tradescantia* was made to be sure it had not altered its response because of different conditions or the time interval between the control calibrations at Oak Ridge and the test experiments at the test site. The specific control experiments at the test site used identical methods of handling and the same plants as were used at the nuclear tests, except that no dose, or a measured dose of hard x-rays was given. The results are summarized in Table 10.

The conditions and methods of handling have not caused any spontaneous aberrations. Also, a dose of radiation at test site produced the same amount of effect as an equal dose given in Oak Ridge. This can be seen from the data, for example, where 100 r delivered at test site produces an effect (chromosome deletions and exchanges) equal to what 99 r and 107 r, respectively, caused in Oak Ridge, on the basis of the Oak Ridge control data, Table 5. The stability of *Tradescantia* for the two situations seem well established. The result is what was expected, on the basis of previous experience.

[3] The author is indebted to Robert E. Carter for allowing him to use this small bit of his much more extensive experimental data (*5*).

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The Effects of Fast Neutrons from a Nuclear Detonation on Chromosome Breakage in *Tradescantia*[1]

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The work of Conger (*1*) on the effects of radiations from nuclear detonations on chromosome breakage in *Tradescantia* has shown the need for more quantitative data on the effects of fast neutrons on this material. The present investigation was thus undertaken to complement this earlier work. From these conditions, a reliable physical determination of the fast neutron dose delivered to the biological material in the field has been the major prerequisite for a successful experiment. This condition, although not complete, has been fulfilled sufficiently to justify publishing the present data. In addition to the field test results, the cyclotron calibration and control data for chromosome breakage by fast neutrons are of some interest in themselves.

Tradescantia paludosa inflorescences were exposed at the field tests in a number of the lead hemisphere neutron stations previously described in the paper by Conger (*1*). Material in seven stations received doses in the ranges suitable for studies of chromosomal breakage. Slides were prepared from the exposed anthers 24 hours and 4 days after exposure, allowing both chromatid and chromosome aberration frequencies to be determined at a number of dosage points.

These data are summarized in Tables 1 and 2. The neutron doses in rep given here are final values derived from the Sheppard-Darden ion-chamber readings (see Appendix). These figures have not been corrected for any contaminating gamma rays due to the uncertainty in this contribution. As will be seen later, this correction factor cannot be great. Rep values in parentheses have been determined from dosimeters placed in the front position in the hemispheres. Not enough physical data were obtained to derive a similar least squares fitted set of doses for the back positions. The most reliable dose-aberration frequency curves are thus obtained from measurements made at the front positions. In the hemispheres containing appreciable numbers of mice, the *Tradescantia* chromosome aberration data indicate an attenuation in neutron dose from front to back of approximately 25%. This can be clearly seen in the figures for stations 1, 2, 3, 4, and 5. In addition to the field test data, the tables contain the results of calibration studies made at Oak Ridge prior to the test. These measurements were made with a Victoreen chamber calibrated against Rossi-Failla tissue equivalent ion chambers as outlined by Sheppard and Darden (see Appendix). Plots of biological damage for chromosome and chromatid aberrations against physically determined dose for both the field test data and the cyclotron control data are shown in Figs. 1 and 2.

As has been pointed out, the major uncertainty in

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TABLE 1. *Tradescantia* chromosome aberrations.

Station	Dose (rep)	Cells scored	Aberrations per 100 cells	
			Deletions	Exchanges
	A. *Field Test*			
1 (Front)	107.7	150	217	166
(Back)		100	172	123
2 (Front)	74.3	200	140	130
(Back)		200	128	102
3 (Front)	48.6	400	94	86
(Back)		300	67	65
4 (Front)	23.2	200	33	37
(Back)		300	26	31
5 (Front)	16.4	600	22	21
(Back)	10.1	600	15	15
	B. *Oak Ridge Cyclotron*			
	67.5	300	122	91
	56	300	94	79.5
	45	300	72	67.5
	22.5	300	39	32.5

the physical dosage measurements is in the actual amount of contaminating gamma rays present in the lead hemispheres. Recent examination of the results of chemical dosimetry, as well as the U.S. National Bureau of Standards film pack data, indicates that, although gamma rays were undoubtedly present in the tests, the radiation did not result in a dominant contribution to the total dose. At the outer *Tradescantia* stations, we assume a 25% contribution due to gamma rays as an upper figure. Russell (*2*) has shown, for dominant lethals in mice, that if the ion-chamber measurements were correct, and if the biological efficiencies of detonation and cyclotron neutrons were the same, then the biological results observed by him would indicate a gamma contamination of 25%, with 95% confidence limits of 7.4 and 40%.

TABLE 2. *Tradescantia* chromatid aberrations.

Station	Dose (rep)	Cells scored	Aberrations per 100 cells		
			Chromatids	Isochromatids	Exchanges
	A. *Field Test*				
4 (Front)	15	300	109.3	160.3	80.3
5 (Front)	9	450	51.5	82.7	37.1
6 (Front)	1.3	700	10.7	11.9	3.9
	B. *Oak Ridge Cyclotron*				
	10.8	450	72.3	95.8	46.0
	5.4	250	37.6	40.2	17.2
	2.7	300	17.5	25.0	7.9

Considering *Tradescantia* as a biological dosimeter, the close agreement in the biological effects of cyclotron neutrons measured in rep at Oak Ridge and those due to detonation neutrons measured by ionization dosimeters in the lead hemispheres indicate that the uncertainties in the physical measurement of neutron dose in the field are considerably less than the factor of 2 conservatively set by Sheppard and Darden (see Appendix). This conclusion is based on the assumption that there is either little difference between the neutron energy spectrum within the lead hemispheres and that in the lead exposure chambers used in the cyclotron studies, or that the dependence of chromosome breakage on neutron energy over these ranges is slight. Recent studies of our cyclotron facilities and information available to us on the neutron spec-

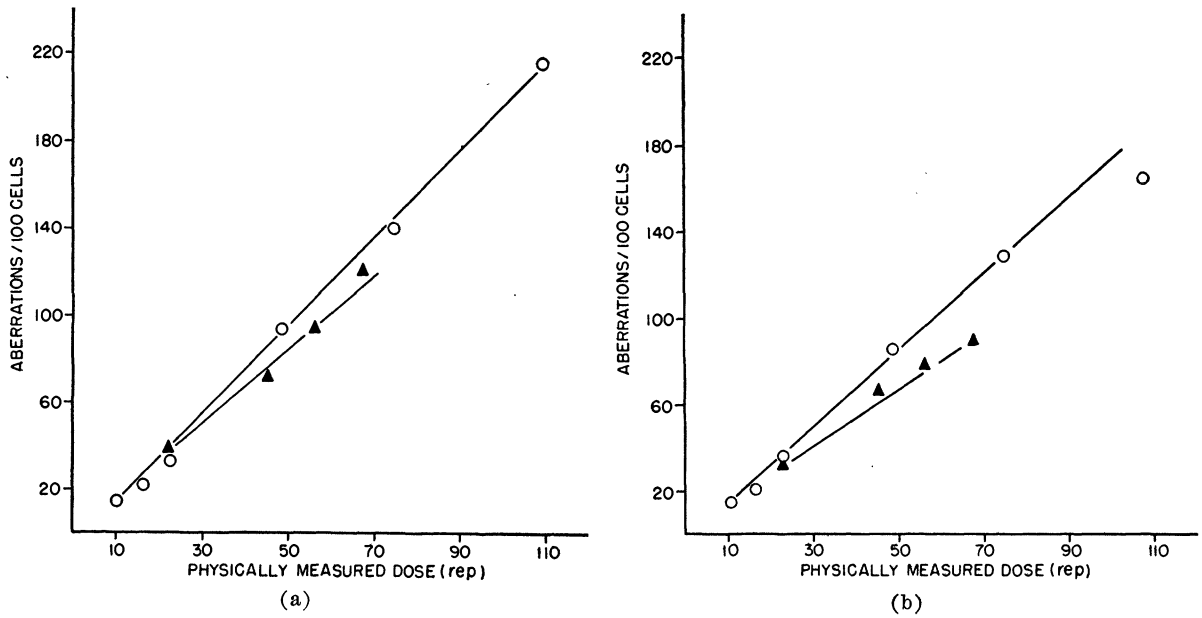

FIG. 1. (a) Chromosome deletions. ▲, Cyclotron control data. ○, Field test data. (b) Chromosome exchanges. ▲, Cyclotron control data. ○, Field test data.

trum in the lead hemispheres are in agreement with the first assumption. Although controlled laboratory experiments to determine the variation in chromosome aberration frequencies with incident neutron energy must be carried out before *Tradescantia* can function reliably as a neutron dosimeter, the present general agreement in dose determined in the field from biological and physical measurements is impressive. We can also assume that, in a general qualitative way for *Tradescantia,* there are no very great differences in the effects of laboratory-produced fast neutrons and those arising under the burst conditions of a nuclear detonation. Certainly, the relative biological efficiency (RBE) for detonation neutrons compared with fast neutrons from a cyclotron is $1 \pm 25\%$.

Comparing our cyclotron neutron data with the extensive x-ray control data obtained by Conger prior to the early tests, some fairly reliable determinations of the RBE of fast neutrons and x-rays can be made. In the case of predominantly one-hit chromatid aberrations, i.e., chromatid plus isochromatid breaks, an RBE for neutrons to 250 kvp x-rays of 13 was found. For chromatid/chromatid interchanges, as well as chromsome deletions and exchanges, in which a linear relation of aberrations with dose does not exist for x-rays, a definite exact RBE cannot be obtained. By assuming x-ray intensities sufficiently high to give maximum breakage rates and forcing the dose curves to a linear relation, an RBE of approximately 13 for chromatid/chromatid interchanges and 7 and 10 respectively for chromosome deletions and chromosome exchanges can be assigned.

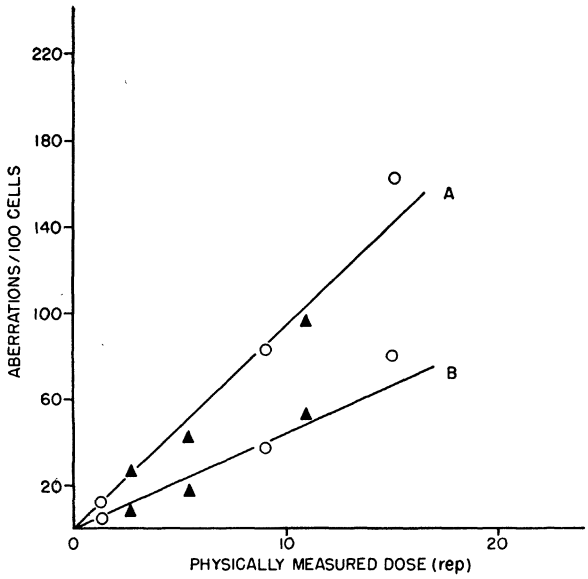

FIG. 2. Chromatid aberrations. Curve A, isochromatid breaks. Curve B, chromatid interchanges. ▲, Cyclotron control data. ○, Field test data.

APPENDIX

Physical Dose Estimates in the Detonation Experiments and Neutron Calibration in the Cyclotron

C. W. Sheppard and E. B. Darden, Jr.

The dose in the ORNL cyclotron was determined with a BF_3 proportional counter calibrated against two Victoreen condenser r-meters. The number of reps/n for the 100-r chamber with thimble of conducting lucite-graphite was 1.7. For the 25-r chamber, which was a conventional Bakelite thimble, the factor was 2.5. These figures were determined by comparing the readings with those of two Rossi-Failla tissue-equivalent ion chambers, one provided by Dr. Rossi and one constructed at ORNL. Comparisons were also made with the readings of an ethylene-filled polyethylene chamber whose walls were coated with a very thin layer of graphite (*3*). This "tissue equivalent chamber" and the Rossi-Failla chambers were themselves calibrated against x- and gamma-ray standards in the laboratory (*4*). Gamma-ray contamination was estimated with a condenser-type ion chamber made of bismuth whose design was similar to that of a beryllium chamber used by us for gamma-ray estimates in the presence of high fluxes of thermal neutrons (*5*). Slow neutrons were determined by gold activation. Approximately one gold neutron was found for every ten total neutrons. The neutrons were made by the Be^9 (p, n) reaction. The energy distribution was estimated by converting the spectrum for a thin target (*6*) to that for a thick one at our different angle of observation and different bombarding energy (22 Mev). Some approximate allowance was also made for the degradation of the neutrons in the 2-in. lead walls of the exposure facility. The result gave a broad distribution with maximum at about 1–2 Mev and tailing off at higher energies to less than 20% total neutrons above the S threshold. Because of the difficulties of physical measurements in the cyclotron, exact control of all variables was not possible and we therefore estimate the uncertainties as about $\pm 20\%$. Attempts to compare our dosimeter readings with those obtained under better physical conditions are now in progress.

In the detonation experiments, the methods of dosimetry were developed as a compromise when it was learned that a well-conceived program of tissue-equivalent chamber development could not be extended to cover our requirements. A total of 19 chambers were completed in time for the experiments. They were built according to the same design as that of the bismuth chambers, but had inner walls of polyethylene coated with thin aquadag.[3] Spacing between the concentric cylindrical electrodes was approximately 0.5 mm. Insulators were of fluorothene and mechanical rigidity was achieved by supporting the inner plastic electrode on a 2S aluminum cylinder and the outer electrode in an enclosing aluminum sleeve. The plastic was thick enough in all cases to stop the beta rays from the activation of aluminum. The chambers were

[3] We wish to acknowledge the assistance of R. K. Abele of the Oak Ridge National Laboratory, Instrumentation and Controls Division, in a portion of the design.