Technical Papers

The Relative Biological Effectiveness of Radiation from a Nuclear Detonation on *Tradescantia* Chromosomes[1]

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The ionizing radiations emitted from a nuclear detonation are additional biological hazards that exist over and above the usual ones of blast effects from ordinary explosions. Although much was known about the biological effects of the various types of radiation when they are given singly in the laboratory, there was good reason to suspect that the biological effect might be greater when these radiations are emitted as a mixture of all types and energies and at extremely high intensity, as they are from a nuclear detonation. So, prior to the planned biological experiments at nuclear detonations, there was genuine cause for uncertainty about how much damage could be expected. quantitatively how much living material is affected unless, in the future, biological materials prove to be as easy to handle and as commonly available as are physical dosimeters. It is necessary to know the quantitative relation between dose and biological effect of the radiation, and also how this compares with the dose-effect relation of the same radiations, delivered by the usual laboratory sources. With this knowledge, the large background of laboratory radiation experience can be applied to the nuclear detonation results. This means that there must be dose measurements (i.e., by physical instruments) and biological measurements of effect for both laboratory and nuclear radiations, and that the usefulness of the biological data for conclusions about the biological damage of nuclear radiation will be dependent on the accuracy of measurement by these two, physical and biological, instruments. These remarks will explain the necessity for the marked preoccupation in this and the following "biological" papers on the relation of physical measurements to the biological effects observed.

The flowering plant *Tradescantia* was an obvious choice for experimentation of this sort, since a fundamental effect of radiation on all cells, chromosomal aberrations resulting from chromosome breaks, can be quantitatively measured in it, and its response under different radiative and environmental conditions was already well known. Lea (*1*) and Catcheside (*2*) give complete presentations of *Tradescantia* methods, experimental data, and theory.

TABLE 1. Irradiation conditions in three control experiments.

The control experiments are designed to simulate field conditions of: (1) gamma rays—flash exposures of different total doses; (2) fast neutrons—at high intensities; (3) airplane exposures—to mixed radiation in an atomic cloud at 0.4° C and 380 mm Hg pressure.

Experiment	Type of radiation	Intensity	Measured by (accuracy)	Conditions (temp., pressure)
(1) Gamma ray	Hard x-rays 250 kvp, 30 ma; ½ mm Cu, 3 mm Al filters	650 r/min and 504 r/min	Victoreen r-meter (±3%)	n.t.p 24° C
(2) Fast neutrons	Fast neutrons from uranium fission 4 Mev maximum, 1 Mev average	3.4 n units/min	Victoreen r-meter (±20%)	n.t.p 25° C
(3) Airplane	Gamma rays from Co^{60}	4.6 r/min	Gamma-ray thimble ionization chamber (±1%) (*4*)	+0.4° C, 380 mm Hg pressure for 10 min before, during, and 10 min after exposure

For the resolution of these problems, certain conditions must be met. In the first place, it is not enough merely to expose living material to nuclear radiation and then observe that it is affected—this tells nothing not already known. Neither is it enough to measure

At an early nuclear test operation it was proposed to expose *Tradescantia* to the nuclear radiation, but excluding blast and thermal effects, in three different situations, namely, (1) to the mixed radiation experienced inside an airplane flown through an atomic cloud (the "mushroom") at various altitudes, (2) to essentially pure gamma rays, inside thin protective

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[2] It is difficult to acknowledge all the individuals who have contributed in programs related to this one. Dorin S. Daniels and Lucile M. Fairchild did much of the *Tradescantia* work, the former at both Oak Ridge and the test site. Allyn W. Kimball and George Atta developed and applied the statistical analysis used throughout. Charles W. Sheppard advised and very generously helped from beginning to end. The author particularly wishes to acknowledge his indebtedness to Robert E. Carter whose efforts were responsible for many of the facilities and much of the information that was used in common by all the other biological investigators.

containers (gamma-ray stations), at increasing distances along the ground from the nuclear device, and (3) to mostly fast neutron radiation received inside special 7-in.-thick lead hemispheres (neutron stations), placed along the ground closer to the nuclear device than the gamma-ray containers. Physical instruments of various kinds were placed along with the *Tradescantia* and other living material in these three different situations.

Prior to the tests, *Tradescantia* was irradiated at Oak Ridge in a series of control experiments designed to simulate as closely as possible the conditions anticipated in the three different nuclear test irradiation situations just mentioned. The irradiation conditions for these control experiments are given in Table 1 and the biological results in the succeeding Tables 2, 3, and 4. It is important to mention that the usefulness of the control data is dependent on how closely the (pertinent) control conditions actually simulated the test conditions. Proper simulation was achieved in all cases but one, but fortunately there were data which were independent of the particular variable which differed between test and control.

TABLE 2. Gamma-ray control experiment.
X-rays, 250 kvp, 30 ma, ½ mm Cu + 3 mm Al
Irradiated in resting stage; chromosome aberrations observed 4 days later

Dose (r)	No. of buds	No. of cells	Fraction normal cells	Aberrations per cell	
				Exchanges	Deletions
Intensity, 605 r/min					
27	7	1301	0.96	0.014	0.028
54	6	868	0.93	0.024	0.053
108	8	650	0.78	0.11	0.13
217	7	650	0.50	0.24	0.39
433	7	317	0.08	0.90	1.44
Intensity, 504 r/min					
50	9	850	0.90	0.032	0.074
101	6	592	0.79	0.12	0.14
151	4	317	0.68	0.17	0.23
202	8	549	0.53	0.28	0.34
403	5	250	0.08	0.89	1.12
605	8	400	0.005	1.50	2.25

TABLE 3. Fast neutron control experiment.
Fast neutrons from uranium fission, 4 Mev maximum, average 1 Mev 3.1 n units/min
Irradiated in resting stage; chromosome aberrations observed 4 days later

Dose (n units)	No. of buds	No. of cells	Fraction normal cells	Aberrations per cell	
				Exchanges	Deletions
4	6	650	0.67	0.16	0.25
8.1	1	100	0.47	0.32	0.49
16.2	4	150	0.21	0.66	0.80
24.2	5	249	0.11	0.85	1.31
32.4	3	150	0.05	1.18	1.65

TABLE 4. Airplane control experiment.
Co^{60} gamma rays at 0.4° C, pressure of 380 mm Hg, 4.6 r/min
Irradiated in prophase; chromatid aberrations observed 21–24 hours later

Dose (r)	No. of buds	No. of cells	Fraction normal cells	Aberrations			
				One-hit types			Cd./Cd. interchanges per cell
				Chromatid no.	Isochromatid no.	Cd. + Isocd. per cell	
25	4	187	0.82	19	9	0.15	0.032
50	10	853	0.69	127	118	0.29	0.057
100	6	429	0.42	146	142	0.67	0.10
200	6	275	0.13	190	156	1.26	0.42

For these tests, two things are observed, biological effect and physical dose from both the test radiation, and, since we desire also to know how the nuclear detonation compares with laboratory experience, from laboratory radiation. From the test exposures, it is desired to estimate biologically the unknown radiation dose x' received at a station from the observed aberration frequency y' caused by it. This estimate is made by using the data from the appropriate control experiment in which the aberration frequency y caused by a known dose x of the same radiation has been measured. Aberration frequency is related to ionization dose as $y = a + bx$ for the "one-hit" aberrations, and $y = d + ex + fx^2$ for the "two-hit" or exchange aberrations, which for more accurate statistical treatment is expressed as $\sqrt{y} = a' + b'x$.

The solutions of these equations, by least-squares fits to the data from control experiments in Tables 2, 3, and 4, is given in Table 5. It can be seen that changes in the type of radiation and in the environmental conditions during irradiation have a pronounced effect on the yield of aberrations from a given dose.

The point estimate of nuclear radiation dose x' received at any one station is

$$x' = \frac{y' - a}{b} \quad \text{(for linear cases)}$$

and

$$x' = \frac{\sqrt{y'} - a'}{b'} \quad \text{(for quadratic cases).}$$

The confidence intervals for the dose estimates may be obtained with a straightforward application of a method described by Mood (*3*).

Airplanes. The biological results and dose estimates from the airplane exposures are given in Table 6. It will be noticed that the dose estimates from the essentially "one-hit" (chromatid plus isochromatid deletions) and the "two hit" or interchange aberrations, both of which are from the same population of cells, differ from each other. This is because the radiation intensity differed among the various airplanes, and also from the control experiment. In this case, it is

TABLE 5. Regression equations to the control data from least-squares fits.

Type of radiation, for comparison	Control experiment table	Chromatid or chromosome observations	Type of aberration	$y = a + bx$ or $\sqrt{y} = a' + b'x$		
				y	a	b
X-rays at high intensity; for gamma-ray station	2	Chromosome	Exchanges	$\sqrt{y}$	0.101	0.00194
	2	Chromosome	Deletions	$\sqrt{y}$	0.122	0.00234
Fast neutrons; for neutron hemispheres (n units)	3	Chromosome	Exchanges	y	0.0373	0.0351
	3	Chromosome	Deletions	y	0.0577	0.0496
Gamma rays at 0.4° C and 380 mm Hg pressure; for airplanes (r)	4	Chromatid	One hit	y	−0.00783	0.00640
	4	Chromatid	Interchanges	$\sqrt{y}$	0.0947	0.00268

TABLE 6. Biological observations and dose estimates in airplanes. Chromatid aberrations observed 21–24 hr after irradiation.

Airplane	Biological observations					Dose estimates (r) and 90% confidence intervals			
	No. of buds	No. of cells	Fraction normal cells	Cd. + Isocd. per cell	Cd./Cd. interchanges per cell	From Cd. + Isocd.		From interchanges	
						Dose est.	90% conf.	Dose est.	90% conf.
a	6	303	0.34	0.74	0.17	117	101–133	120	74–171
b	9	332	0.48	0.45	0.17	71	54–87	118	75–167
c	2	106	0.49	0.49	0.23	78	61–93	142	97–195
d	12	475	0.78	0.21	0.02	34	16–51	19	0–66
e	13	371	0.57	0.46	0.07	73	56–89	66	14–112
f	5	205	0.18	1.13	0.30	178	160–196	170	124–232
g	8	236	0.94	0.05	0.004	8	0–26	—	—
h	14	317	0.92	0.07	0.003	12	0–30	—	—
i	11	238	0.91	0.09	0	16	0–33	—	—

justified to ignore the results from the intensity-dependent interchange aberrations and to utilize only the intensity-independent "one-hit" aberrations, thus eliminating the one variable, intensity, known to differ in the control and the test exposures. In this way the results given in Table 7 are obtained. In this table

TABLE 7. Dose measurements in airplanes by *Tradescantia* and NBS film packs (roentgens).

Airplane	*Tradescantia*	Film
a	117	112 and 104
b	71	66 and 62
c	78	80 and 84.5
d	34	35.5
e	73	54
f	178	135
g	8	4.5
h	12	11
i	16	18

are compared the dose estimates from *Tradescantia*, by one-hit (chromatid-plus-isochromatid) aberrations, and the dose measurements by National Bureau of Standards film packs which were exposed with the *Tradescantia*. It can be seen the agreement between measurements of dose by the film packs and by *Tradescantia* is quite good.

The yield of chromatid-plus-isochromatid (one-hit) aberrations from the airplanes is plotted against dose measurements by the NBS film packs in Fig. 1. The plotted line is the yield of these same aberrations against dose from the control experiment (Table 5, the least-squares fit). It will be seen that the dose esti-

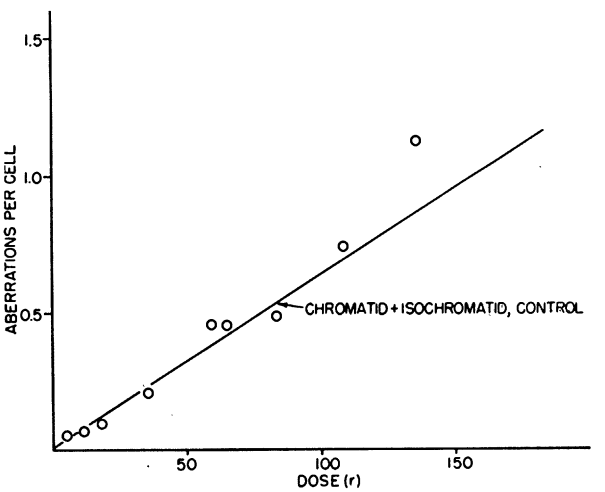

FIG. 1. Production of chromosomal aberrations inside airplanes flown through an atomic cloud, and by control radiation in the laboratory. ○, chromatid plus isochromatid aberrations vs. dose (r) measured by NBS film packs in airplanes. ———, same aberrations vs. dose (r) of Co^{60} gamma rays from laboratory control experiment.

mates from the aberration frequency points can be obtained visually by striking off their intersects with the control curve, and reading the dose off the abscissa. The fit of the *Tradescantia* aberration yields from the airplanes to the control curve against dose is dependent on: (1) the accuracy of the dose measurements in the control experiments, (2) the accuracy of the dose measurements by the NBS film packs exposed in the airplanes with the *Tradescantia,* and finally, (3) the equality or nonequality of *Tradescantia* response to control and nuclear radiation. Dose measurements in the control experiment are accurate to ±1%, or ±5% at the very worst. The film packs are probably accurate in most cases to *ca.* ±10%, since the radiation received inside the airplanes was mostly gamma rays plus a small amount of hard beta rays. This amounted to good conditions for these instruments. With the dosimetry thus properly resolved it can now be determined if *Tradescantia* responds equally to control and nuclear test radiation. It is obvious from the graph that it does, for at most doses the aberration yield falls on or almost on the control line curve. If the airplane radiation were, for example, more effective than the control, the points should all fall uniformly above the control line. The worst case, at the highest dose is only 24% off the line, and in this airplane other biological measurements also departed from the films in the same direction, suggesting that this particular measurement may have been in error. The others deviate by only 10% or less.

Taking all the data, it can be said that the radiation received inside an airplane from an atomic cloud has a relative biological efficiency (RBE) to Co^{60} gamma rays of about 1, and this is accurate to about 20%, perhaps less. Mice which were exposed with *Tradescantia* gave about the same result. The physical instruments are therefore reliable indicators of the amount of biological damage that will be caused, and physical measurements plus laboratory experience will predict the radiobiological effect caused in airplanes flown through atomic clouds.

Gamma Rays. The second situation investigated was the effect of gamma rays at increasing distances along the ground from the nuclear device. *Tradescantia* and mice were exposed at a number of gamma-ray stations, along with ionization chambers and film packs both inside and outside the exposure containers. The results are given in Table 8. It is seen that for most stations the dose estimates from "deletions" (chromosome terminal deletions plus minutes) are lower than the estimates from "exchanges" (chromosome dicentrics plus rings). It is common experience that when slide preparations are poor (as were those from the test exposures) fewer deletions are observed than when slides are good. This is understandable, for most of these deletions are small dot fragments which can escape microscopic observation in poor preparations. The slides from the nuclear tests were much poorer than those obtained from the control experiments, which probably accounts for the low dose estimates from deletions. Fortunately, exchanges are large aberrations which are seen equally well in poor or good slide preparations and are therefore the suitable ones for the control-test comparisons.

TABLE 8. Biological observations and dose estimates in gamma-ray stations. Chromosome aberrations observed 4 days after irradiation.

Station	Biological observations					Dose estimates (r) and 90% confidence intervals				Physical dose (r) from least-squares curves	
						From deletions		From exchanges			
	No. of buds	No. of cells	Fraction normal cells	Deletions per cell	Exchanges per cell	Dose est.	90% conf.	Dose est.	90% conf.	NBS film packs, outside	Ionization chambers, inside
a	3	44	0.52	0.34	0.27	197	158–237	217	174–260	210	175
b	10	202	0.41	0.42	0.44	224	184–263	290	248–334	315	270
c	4	191	0.12	0.83	1.03	337	298–377	462	417–509	470	415
d	6	97	0.03	1.20	1.38	416	376–455	554	507–604	615	550
e	1	34	0	3.18	1.97	710	670–751	672	621–727	750	680

To avoid the difficulty of dealing with a curvilinear relation, since the exchange aberrations being considered increase quadratically with dose of x or gamma rays, we have plotted in Fig. 2 the linear relation, square root of exchange aberration yield against dose, measured by ionization chambers and films in the gamma-ray stations. The solid line is square root of exchange aberration yield against dose from the least-squares fit to the control data, Table 5. The experimental points are from the test measurements, Table 8.

In these gamma-ray stations, unlike the airplanes, there is a definite relation between the doses at the different stations, which were at increasing and known distances away from the nuclear device. So, for both the aberration yield and dose data we have not only the experimental measurements at each station, but the curves of least-squares fits to the measurements over the whole range of doses experienced. Comparison of these curves gives much more reliable information than the individual points, and is indicated by the two lines "exchanges vs. film dose" and "exchanges vs. ionization chamber dose."

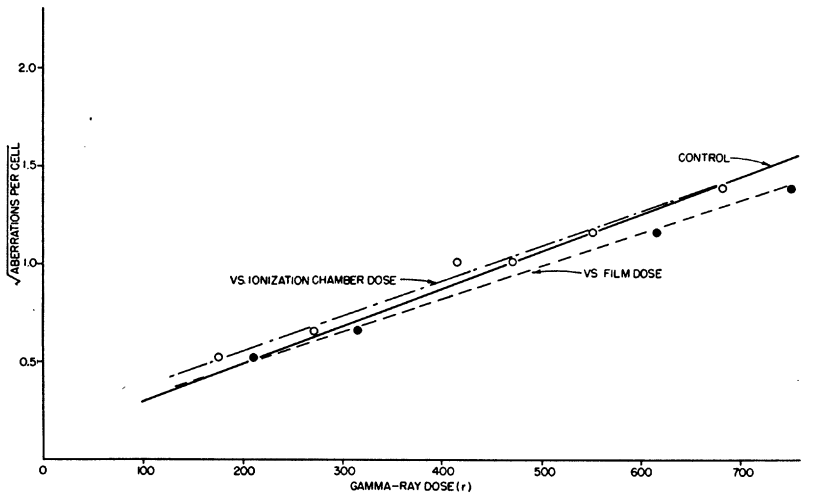

FIG. 2. Production of chromosome aberrations by nuclear gamma rays, and by control radiation in the laboratory. — — —, ● $\sqrt{\text{aberrations per cell}}$ vs. nuclear gamma ray dose (r) measured by NBS film packs. — · — · —, ○ same, measured by ionization. Chamber dose. ——— same, vs. dose (r) of hard x-rays from laboratory control experiment.

Inspection of the graph shows that the nuclear gamma rays are just about as effective as the control radiation (hard x-rays) in causing *Tradescantia* chromosomal aberrations, whether the test dose is measured by ionization chambers or by films. Actually, taking the very worst cases at the two extremes of greatest divergence, the films would indicate that nuclear gamma rays are 10% less effective than the control radiation (at the highest dose), the ionization chambers would show them to be 18% more effective than control radiation (at the lowest dose). From the careful work of Kirby-Smith and Daniels (*4*) on the RBE of x-rays to Co^{60} gamma rays in causing *Tradescantia* aberrations, this would indicate that the quality of these test gamma rays was about that of the hard x-rays used for the control experiments. This is approximately true; the long traverse through air and the ground scattering had degraded the gamma-ray energy considerably, practically down to the range of x-ray energy. But over the whole range of doses measured, these curves differ from one another by only about 10%. It can thus be stated that nuclear gamma rays and the control radiation, hard x-rays, produce equal biological effects, i.e., the RBE of nuclear gamma rays to hard x-rays is $1 \pm 20\%$.

Fast Neutron Stations. Tradescantia and mice were exposed to fast neutrons inside special lead containers placed at closer distances to the nuclear device than the gamma-ray containers. The above-ground part of a neutron container was a lead hemisphere with 7-in.-thick lead walls, and a central cavity 14 in. in diameter containing the specimens. The intent was that the 7 in. of lead should be opaque to the external gamma rays but transparent to neutrons.

The *Tradescantia* results from the fast neutron lead hemisphere stations are given in Table 9. It is apparent that the dose estimates from deletions are variable, as was true for the gamma-ray stations and probably for the reasons already given, so only the more reliable data from chromosome exchanges will be considered.

Unfortunately, the only physical measurements made at these stations which are pertinent to our purpose will show only the relative doses received at the different stations. What was measured was the number

TABLE 9. Biological observations and dose estimates in neutron hemisphere stations. Chromosome aberrations observed 4 days after irradiation.

Test Station		Biological observations					Dose estimates (n units) and 90% confidence intervals			
							From deletions		From exchanges	
		No. of buds	No. of cells	Fraction normal cell	Deletions per cell	Exchanges per cell	Dose est.	90% Conf.	Dose est.	90% conf.
A	a	4	97	0.54	0.35	0.25	5.9	2.9– 8.7	6.0	2.7– 9.0
	b	2	116	0.24	0.64	0.63	11.7	9.0–14.4	16.8	13.9–19.7
	c	5	176	0.03	2.00	1.15	39.2	35.8–43.0	31.6	28.5–35.2
B	d	9	253	0.50	0.29	0.39	4.7	1.7– 7.5	10.0	6.8–12.8
	e	13	550	0.08	1.08	1.00	20.7	18.1–23.4	27.5	24.5–30.8
	f	7	210	0.005	2.62	1.72	51.8	47.6–56.5	47.9	44.0–52.6
	g	2	64	0	3.62	2.20	71.8	66.1–78.7	61.6	56.2–68.0

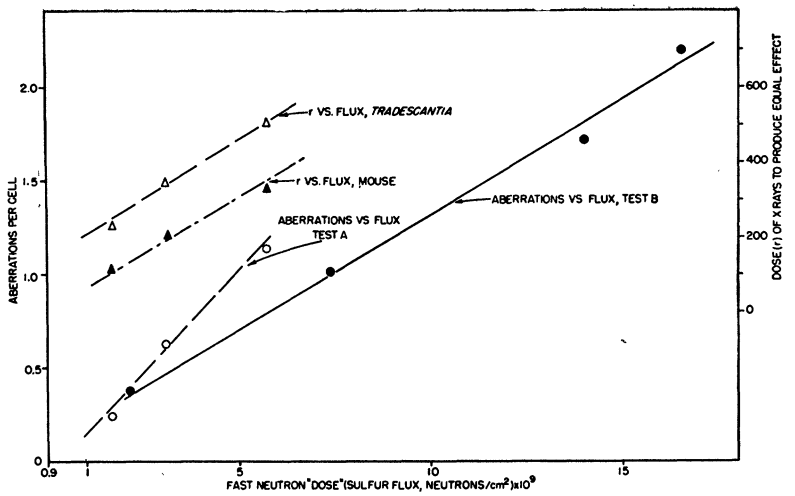

FIG. 3. Effect of nuclear fast neutron radiation on *Tradescantia* and on mice. ○, ● aberrations per cell vs. neutron "dose" (sulfur flux) on tests A and B. Read from left ordinate scale. — — —, △ Dose (r) of laboratory hard x-rays which would cause an equal number of aberrations as was found on test A. Read from right ordinate scale. — · — · —, ▲ Dose (r) of laboratory hard x-rays which would cause an equal effect on mice as was found on test A.

of neutrons (of energy greater than 3 Mev) per square centimeter received at positions outside the hemispheres, the so-called sulfur flux. Although this sulfur flux is proportional to the dose received by the material inside the hemispheres, any conversion of it to inner biological dose is subject to prohibitive errors and assumptions; it is, however, useful for prediction of biological effect as a function of distance and of other variables. The complication that may be caused by any (unknown) dependence of effect on neutron energy spectrum is believed to be minimized by emperical simulation of test conditions in the control experiments which were made with uranium fission neutrons transmitted through 4 in. of lead. The increase of chromosome exchanges with relative neutron "dose" is shown for two different tests in Fig. 3. Since dose is in relative units, the only conclusion that can be made is that biological effect increases linearly with dose, which is as it should be if the radiation were neutrons, or mostly neutrons. Had the radiation been gamma rays, the effect would have increased quadratically with dose. No comparisons with the control data, such as were made for the airplanes and gamma-ray stations, are possible.

To derive other information, it is necessary that dosimeters be measured in the same units. Fortunately, this is possible for two of the dosimeters exposed together in the hemispheres. The dosimeters were biological, mice and *Tradescantia,* and the readings were in terms of biological effect, thymus weight loss for the mice and chromosome aberrations for *Tradescantia.* Since the two were exposed together,

TABLE 10. Specific control experiments at test site.

Treatment (radiation)	Biological observations					Dose estimates (r) and 90% confidence intervals			
	No. of buds	No. of cells	Fraction normal cells	Chromosome deletions per cell	Chromosome exchanges per cell	From deletions		From exchanges	
						Dose est.	90% conf.	Dose est.	90% conf.
None*	7	483	0.993	0.008	0	—		—	
Specific control† (in neutron stations)	2	313	1.00	0	0	—		—	
Specific control† (gamma-ray stations)	2	183	1.00	0	0	—		—	
Sum and av. of above (no radiation)	11	979	0.997	0.003	0	—		—	
Specific control‡ 100 r of x-rays	2	200	0.78	0.14	0.085	107	68–147	99	55–141
Specific control‡ 135 r of x-rays	7	246	0.72	0.175	0.175	127	87–165	163	120–206

* None: from the plants used at the tests.
† Specific control: from plants treated exactly as for a test, but not irradiated.
‡ Specific control: from plants treated exactly as for a test, but irradiated with 100 r and 135 r of x-rays.

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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