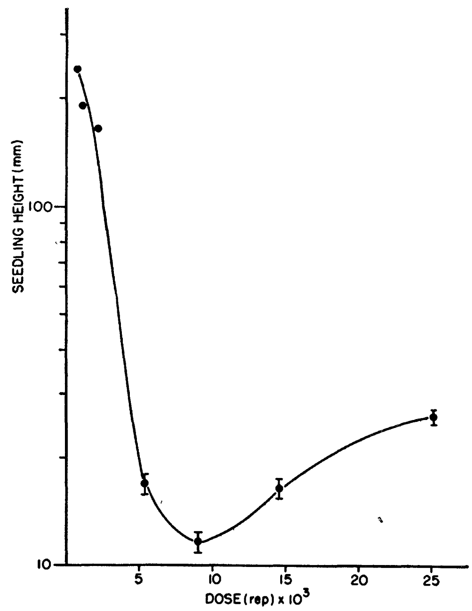

FIG. 1. Relation between seedling height and neutron dose (rep) from nuclear device test. Confidence limits are 95%.

from these data. The first is that there is a direct correlation between seedling height and neutron dose, signifying a very large error in the physical dose estimates. This would indeed be a surprising result since it would mean that the material exposed in hemispheres close to the detonation received a lower dose of radiation than did the material in the more distant hemispheres. The dosage was estimated by an extrapolation of the rep at the low dose ranges as measured by the polyethylene thimble chambers of C. W. Sheppard. The extrapolation was made to follow the slope of the sulfur neutron flux. The second possibility is that the admittedly rough physical dose estimates were not very seriously in error, thus pointing to a failure of correlation between seedling height and dose.

To distinguish between these two alternatives, similar experiments were conducted using gamma radiation from a Co^{60} source where the dose can be measured more accurately. Seeds were exposed to doses of radiation ranging from 75,000 to 500,000 r. The same phenomenon was observed in these experiments (Fig. 2). There is an increase in seedling height with increased doses above 125,000 r with the effect leveling off at 400,000 r.

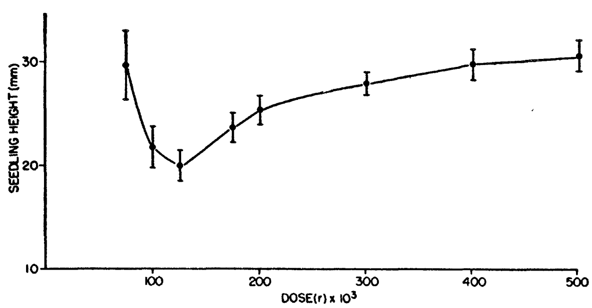

FIG. 2. Relation between seedling height and γ dose from Co^{60} source. Confidence limits are 95%.

Do these data point to a stimulatory effect of radiation on plant growth? The answer is definitely, no! Cytological examination of the root tips from plants which received high doses of radiation revealed a complete absence of cell division. In other words, the "growth" was due entirely to cell elongation in these seedlings. This was borne out by the observation that seedlings which received more than 9000 rep at the test and 125,000 r of gamma radiation from the cobalt source reached their maximum height at about 5 days after planting. No further elongation was observed for the next 5 days. The seedlings irradiated at the higher dose levels were not only taller but also much healthier in appearance than those at the lower levels. In fact, those seedlings could not be differentiated from normal unirradiated young seedlings except that there was a cessation of further growth after approximately 5 days.

The conclusion drawn from these data is that at high radiation levels the seeds are killed in the sense that no further cell divisions occur. To explain the increased "growth" made by the seedlings which received the higher doses it is postulated that the effect was due to an inactivation by high doses of radiation of those processes in the cell which are responsible for the breakdown of the plant tissue, probably the enzyme systems. Thus in the neighborhood of 125,000 r cell division is completely knocked out and the plant tissue degenerates. At higher doses both cell division and enzymatic activity are affected so that the seedling grows to its maximum height through cell elongation and for a period remains at a status quo, neither degenerating nor making more growth.

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The Production of Dominant Lethals in *Drosophila* by Fast Neutrons from Cyclotron Irradiation and Nuclear Detonations[1]

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A considerable area of disagreement exists between the relative biological effectiveness (RBE) of x-rays and fast neutrons in producing chromosome aberrations in plants and in *Drosophila*. For example, Thoday (*1*) reports that in *Tradescantia* fast neutrons are 5–10 times as effective per unit dose in producing interchanges and 3.6 and 2.4 times as effective in in-

[1] Work performed under Contract No. W7405-Eng-26 for the Atomic Energy Commission.

[2] The authors would like to acknowledge the unselfish cooperation, during the detonation experiments, of Harold H. Plough, at that time Assistant Chief, Biology Branch, Division of Biology and Medicine of the U.S. Atomic Energy Commission.

TABLE 1. The induction of dominant lethals by fast neutrons.

Cyclotron			Nuclear device A			Nuclear device B		
Dose (rep)	Eggs counted	Hatch freq.*	Dose (rep)	Eggs counted	Hatch freq.*	Dose (rep)	Eggs counted	Hatch freq.*
None	3889	0.968	None	1807	0.978	None	2584	0.946
250	2867	0.673	129	3428	0.853	32	2318	0.978
500	1754	0.469	340	3325	0.670	65	2333	0.941
700	3494	0.324	1250	2660	0.225	140	1982	0.756
1000	2193	0.275	2400	4687	0.0406	400	2663	0.574
1650	3524	0.0721	3300	1806	0.0204	740	2438	0.344
2700	3140	0.0125	5300	1859	0.00110	2050	2575	0.0632
3500	1007	0.00205						

* In the irradiated series, the actual hatch frequency has been divided by the control frequency. Thus the former frequency is related to a control value of 1.0.

ducing isochromatid and chromatid breaks, respectively. On the other hand, Demerec *et al.* (*2*), studying cytologically recoverable rearrangements in *Drosophila melanogaster* salivary glands, Eberhardt (*3*), working with induced position effect at the *ci* locus, and Catsch *et al.* (*4*), determining the frequency of translocations between chromosomes 2 and 3, find that fast neutrons are no more effective than x-rays. The published results on dominant lethals in *Drosophila* (most of which are undoubtedly caused by lethal chromosomal aberrations) confuse the picture even more. In this case, fast neutrons are shown to be more effective, but the RBE's are only as great as 1.5 (*5*) or 2.0 (*6*).

The question posed by these conflicting results is whether the reported difference in the comparative behavior of *Tradescantia* and *Drosophila* chromosomes to neutron and x-irradiations is real, or whether the discrepancy is an artifact caused by either inaccurate neutron dosimetry or use of neutron sources contaminated with unknown amounts of gamma radiation, or both. It is a well-known fact that even at the present time the dosage (rep) of fast neutrons cannot be measured with the desired precision (i.e., ±5% or better), especially when there is gamma-ray or slow neutron contamination, as is almost always the case. However, the dosimetry problem is much nearer solution at the present time than it was when the above-mentioned *Drosophila* work was performed. Therefore, we feel that our finding—that the RBE for dominant lethals in *Drosophila melanogaster* is in the same range as that for chromosome rearrangements in *Tradescantia*—is the result of the improvements which have been made in neutron irradiation methods and dosimetry within the past few years.[3]

The Oak Ridge 86-in. cyclotron was used as the source of neutrons in the laboratory experiments (*7*). A description of the lead-lined facility in which the flies were exposed and the method of neutron dosimetry used are given in (*8*). It should be noted, however, that several calibration runs were made with the 100-r-7 thimble chamber just prior to exposure of the flies. Oregon-R males of from two to four days of age were placed in lusteroid tubes which were inserted into the facility at the spot where dosimetry measurements had been made. After exposure, the males were mated to Oregon-R females and the exact procedure given by Baker and Von Halle (*9*) was used in collecting the eggs and determining their survival frequency.

The results of the cyclotron treatment are presented in Table 1. Contrary to the finding in x-ray-induced dominant lethals (*9*), there is no difference in the hatch frequency among eggs fertilized by the first and second batches of sperm. Consequently, the data from the two sperm batches are combined in this table.

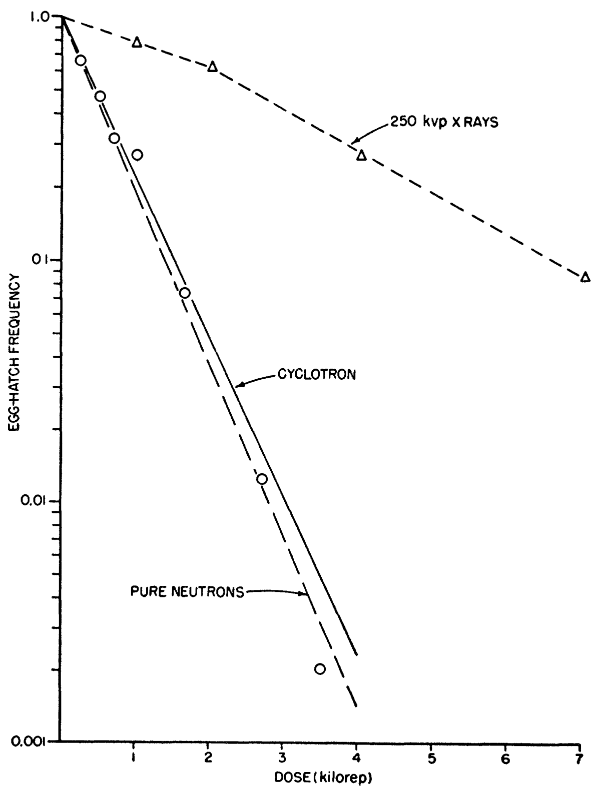

FIG. 1. The relation between dose of fast neutrons from the cyclotron and the frequency of dominant lethals induced.

[3] The authors are indebted to C. W. Sheppard and E. B. Darden for calibration of the neutron facility in the cyclotron and for dosage measurements at the field tests. Without these measurements our results would be meaningless.

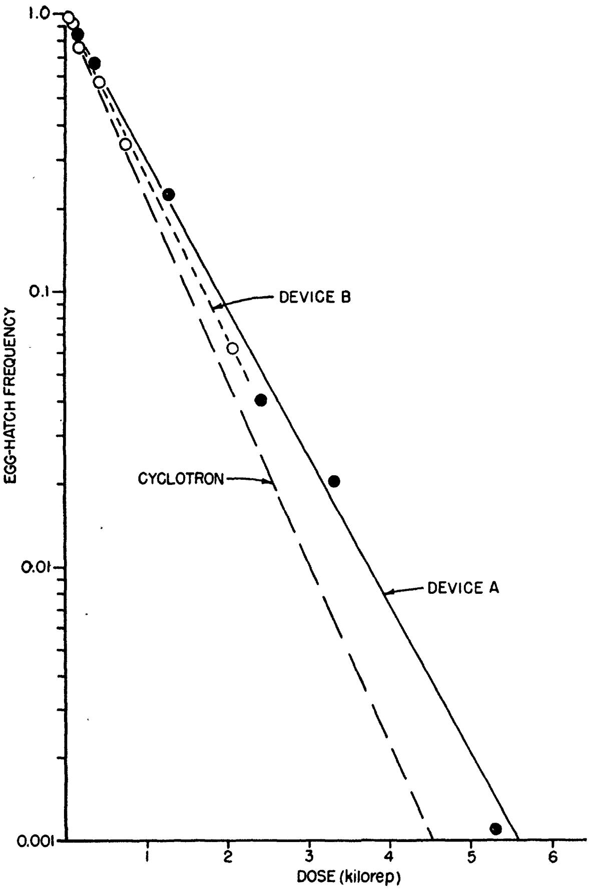

FIG. 2. The relation between estimated dose of fast neutrons from nuclear detonations and the frequency of dominant lethals induced.

These data are plotted on a semilogarithmic scale in Fig. 1. The weighted (np/q) exponential regression line which, by the method of least squares, best fits the data has the equation $\hat{Y} = e^{1.52D}$, where ^{D} is the dose in kilorep. It is known that there is approximately 10% gamma-ray contamination in the cyclotron facility used. The long-dashed line in this figure indicates the expected relation between hatch frequency and dosage if there had been no gamma-ray contamination $\hat{Y} = e^{-1.66D}$). Also in Fig. 1 are plotted the results of the 250-kvp x-ray study of Baker and Von Halle (*9*). This figure presents two facts which are worthy of note. In the first place, it is evident that the neutron data follow a "one-hit" curve whereas the x-ray data follow a "multi-hit" relation. This is to be expected since lethal chromosomal aberrations caused by more than one break could be produced by a single recoil proton track. Secondly, it can be seen that, in the low dosage range, neutrons are about 7.3 times as effective as 250-kvp x-rays. At higher dose levels, the RBE falls to about 4.8 because of the change in slope of the x-ray curve.

Since the cyclotron results appeared to rest on as good physical measurements as are presently available, it was felt that determination of the dominant lethal frequency induced by neutrons from nuclear detonations might be of some theoretical and practical interest. Of primary theoretical interest is the fact that neutrons from nuclear detonations are all delivered within a matter of microseconds, while cyclotron neutrons were given in a matter of minutes. Naturally, the feasibility of such an intensity study would depend on whether an accurate measurement could be made of total dosage of a magnitude that would be useful in *Drosophila* experiments. Unfortunately, no physical dosimeters which could measure dosage in the 500-rep region and above were available in the field-test experiments to be described. Therefore, one is left with the alternative of considering the dominant lethal frequency as a biological dosimeter in this dosage range. The usefulness of this alternative rests on several unproven assumptions, among which are the assumptions that the great intensity difference and any dissimilarity in the energy spectrum of neutrons from the detonations and cyclotron are without influence on the dominant lethal frequency.

With these thoughts in mind, flies were exposed to neutrons from nuclear detonations by placing them within the lead hemispheres described by Conger (*10*). Hemispheres were located at various distances from ground zero in order that exposure to different dosages could be made.[4] As previously noted, there were no physical dosimeters in the range where most of the *Drosophila* were placed although the flux of sulfur neutrons (3 Mev and above) were available. Nevertheless, polyethylene thimble chambers of C. W. Sheppard (*8*) were in hemispheres at lower dosage levels. The rep measurements of these thimble chambers did parallel quite closely the sulfur neutron flux in this region. In order to obtain an estimate of the dosage in the hemispheres where *Drosophila* were placed, the thimble chamber readings were extrapolated into this region by having them continue to parallel the sulfur neutron flux. The dosages given in Table 1 and Fig. 2 were determined in this manner.

Only slight differences existed between the experimental techniques of the field-test experiments and the cyclotron and x-ray studies. The males were not mated until approximately 4 hours after the detonation. Also, the first 24-hour mating period of the males was done under field, rather than laboratory, conditions.

The data obtained from two nuclear detonations are shown in Table 1 and Fig. 2. In spite of the rather crude method of estimating dosage, it is comforting to note that in both tests the points fall quite close to a straight line passing through at 1.0 at zero dosage. The weighted regression lines for device A and B respectively are $\hat{Y}_A = e^{-1.24D}$ and $\hat{Y}_B = e^{-1.36D}$. In a comparison of results from field tests and the cyclotron irradiations it appears that more eggs hatch per unit dose in the former experiments. The question arises as to whether this discrepancy is due to the lower effectiveness of neutrons from nuclear detonations than those

[4] The invaluable advice and assistance given by Robert E. Carter during the field tests are deeply appreciated.

produced by the cyclotron, or to overestimation of the neutron dose in the field experiments. A satisfactory answer to this question cannot be given on the basis of these experiments. It is known that gamma-ray contamination existed within the hemispheres and that the amount of contamination varied with the hemispheres. It does not seem likely that this can explain the difference since experiments conducted in the same hemispheres with another genetic effect (sex-linked recessive lethals) having a low RBE, and thus more sensitive to gamma-ray contamination, gave no evidence of any larger contamination than in the cyclotron (*11*). The final answer to this question will have to await the development of reliable neutron dosimeters of sufficient capacity.

Until adequate dosimeters are available, the frequency of dominant lethals may be useful in nuclear detonations as a rather rapid, but crude, biological measurement of fast neutron dosage at high levels. For example, it may be determined from Table 1 that with device A the biological dose was within about 23%, and with device B within approximately 12%, of the dose extrapolated from physical instruments.

In summary, the main conclusion to be drawn from the data presented is that the relative biological effectiveness, in producing chromosome aberrations, of fast neutrons (as compared with x-rays) is about as great in *Drosophila* as in *Tradescantia.*

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The three papers by J. S. Kirby-Smith and C. P. Swanson, Drew Schwartz, and W. K. Baker and E. Von Halle were part of a larger test program on the genetical effects of radiation from nuclear detonations conducted under AEC direction. Additional papers will appear in the literature.

Comments and Communications

Nomenclature of Cyclohexane Bonds

IT was shown originally by x-ray and electron diffraction, and has been confirmed by other physical and by chemical means, that the most stable and permanent form of the cyclohexane ring is that particular strainless form which is sometimes likened to a chair or a staircase. Geometrically, its chief feature is a six-fold alternating axis of symmetry. Its 12 extracyclic bonds fall into two classes (*1*): 6 lie parallel to the axis, while 6 extend radially outward at angles of $\pm 109.5°$ to the axis. The stereochemical properties of substituents bound by these two classes of bond are so different that a need has been felt for verbal and symbolic means of distinguishing the classes.

The first suggestion (*2*) to this end designated the six parallel bonds as 'ε' and the others as 'κ'. However, although these symbols have been considerably used, their origins in the Greek language, and particularly their allocation between two classes of bond, have been found difficult to remember. A more obvious description was given (*3*) when the six parallel bonds were called "polar" and the others "equatorial" in analogy to the geographical terms. This nomenclature has had a wide use, but is unsatisfactory in that it employs the word "polar" for a stereochemical concept, thereby tending to confuse discussions which have to take account of the electropolar nature, side by side with the stereochemical character of cyclohexane substituents.

The purpose of this note is to suggest a simple change which avoids these difficulties. It is that the six bonds parallel to the main cyclohexane axis should be called "axial"[1] (and symbolized '*a*'), while the other six retain the name "equatorial" (and become symbolized '*e*'). The private discussions we have had with friends and colleagues lead us to hope that this suggestion may find favor.

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[1] The term "axial" was suggested to us by Professor C. K. Ingold, London.

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