bran, wheat germ, rice bran, or rice polish were fed by incorporating them in the diet at the 10-percent level, uterine weight responses very similar to those obtained with the oils resulted (Table 3).

The findings recorded in this report may be related to observations of growth stimulation in chicks fed high levels of certain fats (*7*). This hypothesis is strengthened by the observations of Carew and Hill (*8*) that diethylstilbestrol stimulated chick growth when it was added to a high fat ration but did not when it was added to a low fat ration, it being assumed that the corn oil used did not supply enough estrogen for maximal response (*9*).

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16 February 1960

## Life Shortening and Tumor Production by Strontium-90

*Abstract.* A linear relationship between dose of internal radiation and two effects, which implies no threshold, is shown to be a possible interpretation of data given by Finkel in "Mice, men and fallout" (*1*). This interpretation is at variance with that offered by Finkel, which was that the dose-effect relationship is nonlinear and indicates a threshold.

In a recent article by Finkel (*1*) the result of a long-term experiment involving radiation to several groups of mice was presented. This was an excellent piece of work which gives us much more information than we have previously had regarding the relationships between radiation, life span, and tumors.

The data from this experiment were presented in such a way as to support the view that incidence of radiation-induced neoplasms does not bear a linear relationship to dose, but does indicate the existence of a threshold level. Doses below this threshold are thought not to produce neoplasms. This view was recently elaborated by Brues (*2*).

After presenting the data, Finkel, in commenting about the graph in which average survival time was plotted as a function of dose, stated that, although parts of the curve suggested a direct relationship between dose and response, it is not a linear one. In commenting on the production of tumors, Finkel stated, "There was a pronounced association between dose and both osteogenic sarcomas and hemangioendotheliomas of bone marrow," but when examining the five lowest dosage levels with regard to osteogenic sarcomas, she said, ". . . the data show no trend and no indication of any relationship between dose and response . . . Therefore, a threshold . . . might lie between . . ."

If Finkel had treated her data differently she might have reached quite different conclusions. In all her figures she plotted the effect against the injected dose in microcuries per kilogram. The amount of internal radiation delivered to an animal injected with a radionuclide is dependent upon several important factors other than the curies per gram injected. In most animal experiments these other factors are considered in calculating the radiation dose in terms of rads. If all of these other factors remain the same between experimental groups, then the results of the different groups may be compared on the basis of curies per gram, as well as on the basis of rads. In Finkel's experiment many of these factors were the same between the different groups, but they differed in one very important factor, that is, time. Some of the groups lived much longer than others, and were thus given radiation doses which were related to their lifetime as well as to the microcuries per kilogram administered.

It is to be hoped that Finkel will calculate an accurate dosage for the different groups in rads. Available information does not permit us to do so. However, we have arrived at a dosage unit which appears to permit comparison between the different groups. The total dosage from injected $Sr^{90}$ was divided into two components on the basis of estimated rapid excretion during the first several days and fairly constant retention thereafter. The first component covers the first 14 days after injection, during which $Sr^{90}$ is being excreted in an exponential manner. We have taken 33 percent (the geometric mean between 100 and 11 percent) of the administered amount as an approximation of the average amount in the body during this initial period. The second component covers the remainder of the average lifetime of each group, or life minus 14 days. We have used Finkel's figure of 11 percent retention as an approximation of the average amount in the body during this period. These approximations of average amounts may be a little low, but the error between groups is probably comparable.

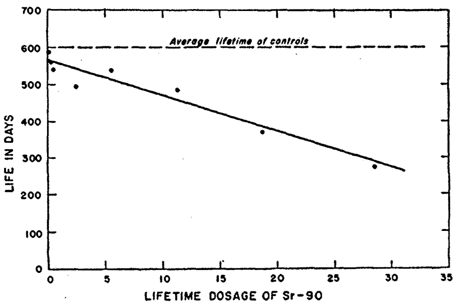


Fig. 1. Relationship between radiation from $Sr^{90}$-$Y^{90}$ and average lifetime of groups of animals. Dosage is in millicurie days per kilogram.

The average amount of $Sr^{90}$ in the body during each of the two component periods has been multiplied by the appropriate number of days, and the two products added to give a lifetime dose in millicurie days per kilogram.

In Fig. 1 the average lifetimes of the eight lowest dosage groups of Finkel's experiment are plotted on arithmetic paper against dosage in the above-described units. Although there is a moderate scatter of points, they suggest a direct linear relationship, which

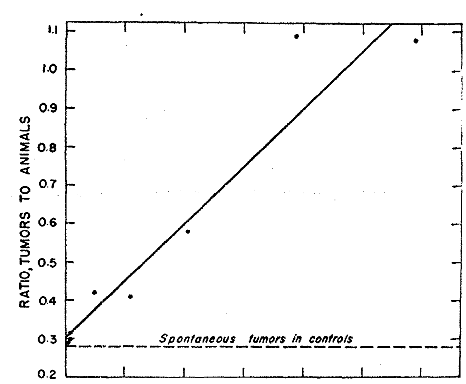


Fig. 2. Relationship between radiation from $Sr^{90}$-$Y^{90}$ and tumors in groups of animals. The dosage is in millicurie days per kilogram. The ratio of tumors to animals is the sum of animals bearing different types of tumors divided by the number of animals in each group.

apparently approaches zero dose and zero response.

In Fig. 2 the ratio of tumors to animals in each of the eight lowest dosage groups is plotted against dosage in the above-described units. The tumors represented in this graph are the sum of the malignant bone tumors and the reticular tissue tumors reported in *Argonne Natl. Lab. Rept. No. 5597* and the sum of the sarcomas, giant cell tumors, and epidermoid cancers reported in *Argonne Natl. Lab. Rept. No. 5841* by Finkel *et al.* (*3*). Since some animals had more than one type of tumor, the resultant ratio in two of the groups was greater than 1.0. The points on this graph also appear to represent a direct linear relationship between dosage and response which approaches zero dose and zero response.

When presented in this way, the results of Finkel's work can thus be used not only as an argument against the stand taken by Brues (*2*) but can be used to support the views of the United Nations Scientific Committee on the Effects of Atomic Radiation (*4*) and of Lewis (*5*), which are that there may be no threshold for radiation injury, and that the dose-response curve may be straight, extending to zero dose and zero response.

As noted above, in Figs. 1 and 2 only the eight groups of animals having the lowest doses have been used. The four high dosage groups, which were not used, do not continue on the straight line exhibited by the eight lower dosage groups. This alteration of the curve at high radiation levels may be attributed to the fact that at high levels there is considerable "wastage" of radiation. That is, much of the radiation energy is absorbed by dead or dying tissue. Energy which is absorbed by dead or dying tissue is not likely to produce tumors or to shorten life.

In all experience with radiation-induced neoplasms, a latent period between irradiation and resultant neoplasms has been observed. This latent period has been thought to be shortened by larger radiation doses. In Finkel's experiment (*1*) there was an initial whole body radiation dose followed by chronic radiation, primarily to bone. Under these conditions, the longer-lived (low-dose) groups might be expected to exhibit proportionately more neoplasms by virtue of having lived farther past an average latent period. However, this effect might be counteracted by a shortened latent period in the high-dose (shorter-lived) groups.

Without the knowledge to assess the importance of these three factors—initial radiation dose, chronic radiation dose, and possibly variable latent period—one must consider that the linear response suggested in Fig. 2 may be merely fortuitous. However, it gives no comfort to those who would interpret this data as demonstrating a threshold for radiation-induced neoplasia.

In both Fig. 1 and Fig. 2, uncertainties in the values for the points near zero dose as well as uncertainties in the average lifetime of the controls and per cent of tumors in controls are sufficiently great that little reliance can be placed on the exact position or shape of the curves as they approach zero dose.

There are, no doubt, other informative methods of presenting the data from this excellent experiment. In a more recent publication Finkel has presented the data somewhat differently (*6*). This presentation indicates, among other things, an apparent independence of $Sr^{90}$ dose and latent period of resultant tumors.

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11 March 1960

## Weber Ratio for Visual Discrimination of Velocity

*Abstract.* As an approximation based on various experiments reported in the literature, the least detectable difference in speed ($\Delta\omega$) varies in direct proportion to the speed ($\omega$) over a range from 0.1 to 20 degrees of visual angle per second. The constancy of the Weber ratio ($\Delta\omega/\omega$) aids in understanding how men react to velocity in various situations.

Need for information on the Weber ratio has recently been stressed in research on traffic dynamics. Chandler, Herman, and Montroll (*1*) have reported that drivers react mainly to relative velocity rather than to relative distance. This finding provides an experimental basis for models of vehicular interaction which may be applied to multiple collisions on modern superhighways and to other traffic problems.

Fortunately, a rather extensive literature has accumulated on visual discriminations of velocity. Plotting of data from the literature yields a useful generalization. The inference may be applied not only to the dynamics of moving vehicles, but also to other interactions of men with machines.

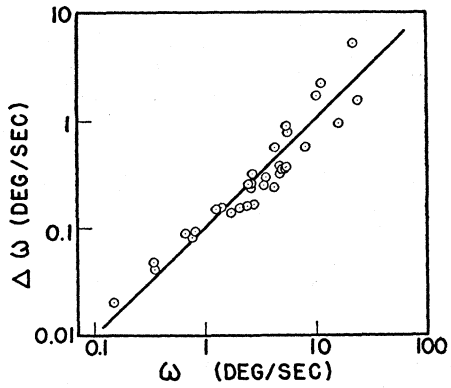


Fig. 1. The differential threshold ($\Delta\omega$) as a function of angular speed ($\omega$). Experimental points are the thresholds as measured in eight experiments (*5*). A least squares solution for the intercept constant yielded the straight line with unit slope; $\log_{10}\Delta\omega = -1.00 + \log_{10}\omega$.

Graham (*2*) has emphasized the importance of expressing extent in terms of the visual angle subtended at the eye. Similarly, it is advantageous to use angular units for velocity. Expression of speed in units of visual angle per second makes it easy to compare measurements which experimenters have made from different distances of observation. In addition, angular speed has advantages for experimental design since its use facilitates the recognition and control of major variables. These and other methodological considerations have been reviewed recently (*3, 4*).

Visual sensitivity to velocity is indicated by the differential threshold, which may be defined as

$$\Delta\omega = \omega_2 - \omega_1 \qquad (1)$$

where $\omega_2$ is a uniform angular speed an observer discriminates, according to a specified criterion, from the constant rate of motion $\omega_1$. The differential threshold has been of continuing interest since the turn of the century; in eight papers (*5*), scientists have reported measurements over a wide range of speeds.

The difference thresholds are plotted against the angular speed in Fig. 1. The straight line of unit slope represents a constant Weber ratio $\Delta\omega/\omega$. Solution for the intercept constant by least squares yields the plotted equation

$$\Delta\omega = (0.10)\,\omega \qquad (2)$$

As a very rough approximation, Fig. 1 shows that the differential threshold in-