Table 2. Number of buds produced by irradiated hydras minus number of buds produced by controls ($\bar{x}$).

Group	Generation	$\bar{x}$	t	p
Parents	4	0.10	0.28	0.7
Parents	8	−0.24	.65	.5
Parents	12	.14	.47	.65
Buds	4	.50	1.37	.2
Buds	8	.20	0.79	.2
Buds	12	.06	.155	.9

resistance of hydras to adverse conditions (*4*) and that interstitial cells from a normal hydra can restore an irradiated one (*5*) support the notion of rejuvenescence.

However, several investigators have argued that aging does take place in *Hydra*. Hase and Grosz (*6*) found that the number of tentacles increases with age; Vishnevs'kii (*7*) found that the time required for successive buds to develop increases with age; and Hyman (*8*) noticed that both irregular budding and depression occur more readily in older individuals. Hase reported populations of *Hydra oligactis* and *H. vulgaris* that lived only 167 and 337 days, respectively. However, Pearl and Miner (*9*) examined Hase's data and found that the death rate was constant with increasing age. Therefore, death was probably due to environmental accidents.

It has not yet been adequately demonstrated by direct comparison between "old" and "young" hydras that there is no difference between them. In an attempt to throw light on this matter, the budding rates and tentacle numbers of parent hydras and of their youngest buds in a line of successive first buds were compared, both under normal conditions and under radiation stress.

Two groups of 20 *Hydra littoralis* lacking buds and gonads were selected at random from a large male clone and reared by Loomis's culture method (*10*) in individual 10-ml beakers each containing 5 ml of water. One group was irradiated with a dose of 2000 r of x-rays. Detached buds were isolated daily. A dose of 2000 r was chosen because this was the highest dose that did not decrease the budding rate.

The number of buds produced by each 4th-, 8th-, and 12th-generation offspring in each line of successive first buds was compared with the number of buds produced by the corresponding original parent over a 15-day period, and the mean differences were evaluated by Student's t test. Presumably fewer cell divisions occurred in the history of a bud produced by one of the parents than in that of one of the buds derived from a bud, several generations removed, of a parent. Thus, the performances of "old" (the original parents) and of "young" hydras were compared during the same period of time and under the same conditions. The results are summarized in Table 1.

As the original parents in the nonirradiated group became older, their budding rate became progressively slower compared with that of young hydras. At the 12th generation the difference was highly significant ($p < .005$). The irradiated hydras followed this same trend between the 4th and 8th generations ($p < .05$), but in these experiments the results are not conclusive at the 12th generation ($p = .07$). These results seem to support the hypothesis that older hydras bud more slowly than younger ones.

There was no significant difference between the budding rates of irradiated and nonirradiated hydras, compared group by group (Table 2), but there was some indication that doses of from 100 to 2000 r stimulate budding during the first week after irradiation.

The number of tentacles of each hydra in these experiments was recorded daily, and comparisons were made between the mean numbers of tentacles for the various groups. In contrast to the results of Hase and Grosz, no significant differences were found. Also, there was no increase with time in the mean number of tentacles of the original parents. We conclude that the number of tentacles does not increase with age in *Hydra littoralis*.

At the end of the first month of the experiments the hydras suffered from a depression possibly caused by traces of detergent left in the glassware when it was washed. Thirty-two percent of the original parents but only 8 percent of the youngest buds (in generations 2 through 6) became badly depressed. Six days later 7.5 percent of the original parents but only 2.5 percent of the youngest buds had died. This increased susceptibility of older hydras supports the hypothesis that aging takes place (*11*).

J. ROSS STEVENSON
Department of Biology, Kent State University, Kent, Ohio
RALPH BUCHSBAUM
Department of Biological Sciences, University of Pittsburgh, Pittsburgh, Pennsylvania

References and Notes

1. P. Brien, *Biol. Revs. Cambridge Phil. Soc.* **28**, 308 (1953); —— and M. Reniers-Decoen, *Bull. biol. France et Belg.* **83**, 293 (1949).
2. Some of the hydras were observed for nearly 5 yr. Also, C. L. Turner [*Biol. Bull.* **99**, 285 (1950)] found no decrease in budding rate over 123 days.
3. A. L. Burnett, *J. Exptl. Zool.* **140**, 281 (1959); —— and M. Garofalo, *Science* **131**, 160 (1960).
4. W. Goetsch, *Biol. Zentr.* **41**, 374 (1921).
5. F. Stéphan-Dubois, *Année biol.* **27**, 733 (1951); V. F. Evlakhova, *Compt. rend. acad. sci. U.R.S.S.* **53**, 369 (1946).
6. A. Hase, *Arch. Rass. Ges. Biol.* **6**, 721 (1909); J. Grosz, *Biol. Zentr.* **45**, 321 (1925).
7. J. Vishnevs'kii, *Trudy Odessk. Derzh. Univ. Biol.* **2**, 57 (1937).
8. L. H. Hyman, *Biol. Bull.* **54**, 65 (1928).
9. R. Pearl and J. R. Miner, *Quart. Rev. Biol.* **10**, 60 (1935).
10. W. F. Loomis and H. M. Lenhoff, *J. Exptl. Zool.* **132**, 555 (1956).
11. This work was supported, in part, by the U.S. Atomic Energy Commission.

19 April 1961

Radiation Dosimeter Utilizing the Thermoluminescence of Lithium Fluoride

Abstract. A dosimeter, with little wavelength dependence and large useful energy range for electromagnetic radiation, which is simple to use and read, has been developed. It appears to have applications in personnel monitoring as well as radiation research.

A radiation dosimeter has been developed which utilizes the thermoluminescence properties of lithium fluoride crystals. The principles involved in such dosimetry have been previously described by Daniels *et al.* (*1–3*). A CaF_2 : Mn thermoluminescent dosimeter has recently been developed by Schulman *et al.* (*4*).

The phenomenon of thermoluminescence in crystals may be described as "frozen-in" or stored luminescence which is unavailable at normal temperatures but which may be recovered by heating. It is due to the trapping of electrons displaced by high-energy radiation. The amount of thermoluminescence stored in a given crystal is proportional to the amount of previous exposure to ionizing radiation. For dosimetry purposes the thermoluminescence must be stable in the temperature range of normal use, that is, it must have a high activation energy relative to room temperature. Several materials, including CaF_2, LiF, $CaCO_3$ (calcite), and SiO_2, have the capacity for such high-temperature thermoluminescence.

Lithium fluoride has a high-temperature thermoluminescence particularly suited for dosimetry purposes. As a

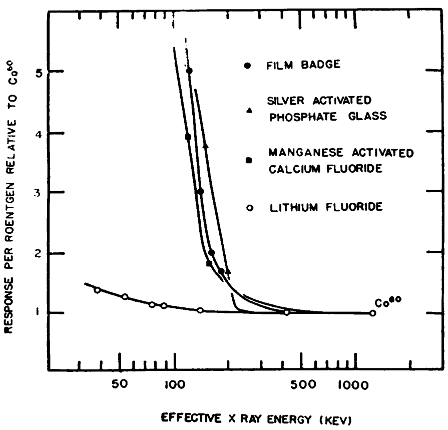

Fig. 1. Energy dependence of LiF compared with that of other dosimeters.

compound, LiF is inert, insoluble, and nontoxic. It has hard crystals which are stable in air and relatively free from mechanically induced luminescence. The thermoluminescence of LiF has an almost linear response to amount of radiation over a range of a few milliroentgens to many kiloroentgens. Because of the low atomic number of both lithium and fluorine, the energy dependence of LiF thermoluminescence is small compared with that of other common dosimeters (see Fig. 1). It is noted that over the range from 40-Kev effective x-rays to the 1.1- and 1.3-Mev gamma rays from cobalt-60, the thermoluminescence varies by only 40 percent. In addition, LiF luminescence systematically responds to alpha, beta, and neutron irradiation (*2*), thus making possible composite measurements of ionizing radiation. The LiF dosimeter shows less than measurable isothermal decay at 50°C for 1 day, and thereby assures a long-range retention of accumulated thermoluminescence.

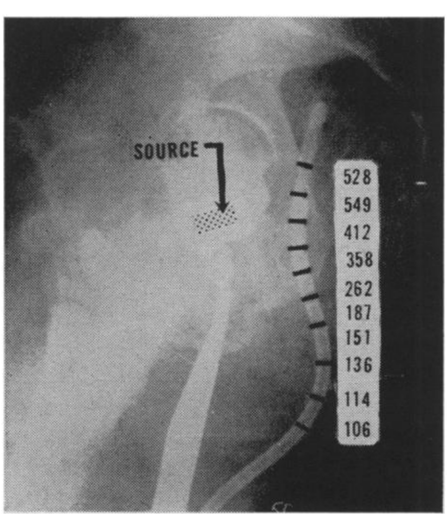

Fig. 2. Touched up x-ray, showing dosimeter tube in rectum near the radioactive source. Values are 24-hr dose in rads.

The dosimeter now in use by this laboratory consists of powdered LiF crystals (*5*). No attempt has been made so far to control the concentration of luminescence activators. However, the efficiency of the dosimeter for low-level radiation will perhaps improve with the use of optimum-activated crystals. The present dosimeter is prepared by grinding and mixing pure, fused LiF in order to average out chemical and physical inhomogeneities. The washed and screened powder (100–200 Tyler) is then annealed to eliminate the undesirable low-temperature thermoluminescence previously described (*3*). Consequently, annealed LiF powder is used in the present dosimeter, either free or in containers. Tubes and capsules of gelatin, vinyl, and polyethylene have been used to date; no special shielding is necessary to improve the energy dependence.

To measure the thermoluminescence quantitatively after irradiation, a measured volume of powder is placed under a photomultiplier tube and heated to a temperature of about 250°C in a period of less than 1 min. The thermoluminescence intensity is integrated by collecting the photomultiplier current on a Mylar capacitor and then measuring the voltage of this capacitor with an electrometer voltmeter. By the use of this technique the thermoluminescence of a given sample may be reproduced with a standard deviation of 2 percent.

An example of this dosimeter in medical use is illustrated in Fig. 2. The catheter containing a long plastic tube of powdered LiF is placed in the rectum of a patient who is receiving internal radiation treatment. Figure 2 shows a touched up x-ray of a radioactive applicator in place, with the values of the radiation dose in rads after 24 hr listed adjacent to the dosimeter tube. Dose measurements in vivo during such treatment are useful to prevent excessive radiation to the rectum and to determine the length of the treatment. Figure 3 shows a similar laboratory test under controlled conditions with a radium standard used as a source of radiation. The solid line represents the calculated theoretical dose and the dots represent the measured values.

With a sensitized LiF dosimeter it might be possible to have any member of the population carry a dosimeter attached to his person. Accurate meas-

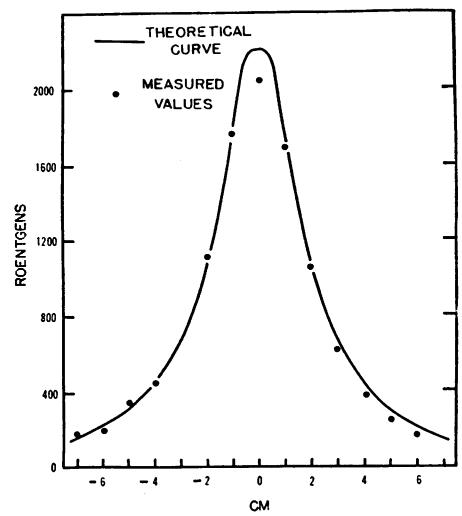

Fig. 3. Comparison of theoretical and measured values obtained by using the dosimeter tube near a radium source.

urements of radiation doses to members of the general population would then be available in case of an atomic attack. Dosimetry information would also be of interest in measuring average radiation to the general population under peacetime conditions. The LiF dosimeter would also be useful to persons who have some contact with radiation in their daily work but not sufficient exposure to warrant the usual monitoring methods now available. The accumulated dose on these monitors could then be read yearly or whenever a person changes employment.

Such a dosimeter could also play an important role in research. The cost of the dosimeter is small enough to warrant the monitoring of individual animals undergoing radiation experiments (*6*).

J. R. CAMERON, F. DANIELS, NOYE JOHNSON, G. KENNEY

Departments of Radiology and *Chemistry*, *University of Wisconsin, Madison*

References and Notes

1. F. Daniels, C. A. Boyd, D. F. Saunders, *Science* **117**, 343 (1953).
2. F. T. Morehead and F. Daniels, *J. Chem. Phys.* **27**, 1318 (1957); W. P. Rieman and F. Daniels, in preparation.
3. F. Daniels and W. P. Rieman, *Chemical Procurement Agency, Wash. D.C., Final Rept. Project No. 4-12-80-001* (1954).
4. J. H. Schulman, F. H. Attix, E. J. West, R. J. Ginther, *Rev. Sci. Instr.* **31**, 1263 (1960).
5. Harshaw Chemical Co., Cleveland, Ohio. The material being used was purchased before 1954. Their present LiF does not contain the activating impurity. Work is continuing to determine the activator.

6. We are pleased to acknowledge support for part of the work by the U.S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation. The earlier work was supported by the Army Chemical Corps.

27 March 1961