

being measured directly, since only peripheral leukocyte counts were being considered.

The apparent "resistance" of leukocytes to higher radiation doses involves direct and indirect mechanisms. Among them one might consider "over kill" due to continued irradiation of cells already affected by the radiation; nonuniformity of the radiation flux within the marrow volume; the influence of the "reserve pool" of stem cells following marrow irradiation and its subsequent kinetics.⁽⁶⁾

The data presented were based on total leukocyte concentration in peripheral blood which represents a number of individual cell types. It is probable that each type of leukocyte, and possibly marrow precursor chain, has its own tolerance distribution. Some evidence for this has been found and will be presented in a later report.

Although the quantal model was illustrated here, another model, that of the quantitative response, could have been used and is currently under investigation. The latter does not demand an all or none response. It may be used if the relationship between dose and quantitative response is represented by a sigmoid curve. In the present case a plot of 18 month leukocyte counts against logarithm of radiation dose produced such a sigmoid curve and the variate was obviously quantitative.

Another use for the probit transformation lies in the field of biological assay, or the measurement of relative potencies. The radiobiologist may use probit methods to determine the relative biological effectiveness (R.B.E.) of different types of radiation, e.g., α , β , γ emitting radionuclides. FINNEY⁽²⁾ and GOULDEN⁽⁴⁾ may be consulted for appropriate methods.

These and other models are currently under investigation. It is hoped they will provide a better understanding of the relationship between bone-seeking radionuclide doses and the hematopoietic response.

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References

1. E. L. POWERS, *Phys. Med. Biol.* **7**, 3 (1962).
2. D. J. FINNEY, *Probit Analysis*. Second Edition. Cambridge University Press (1952).
3. W. D. BATEN and H. J. STAFSETH, *J. Bact.* **71**, 214 (1956).
4. C. H. GOULDEN, *Methods of Statistical Analysis*, p. 394. John Wiley, N.Y. (1952).
5. H. M. PATT and H. QUASTLER, *Physiol. Rev.* **43**, 357 (1963).
6. L. G. LAJTHA and R. OLIVER, *Br. J. Radiol.* **35**, 131 (1962).

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Ruby as a Thermoluminescent Radiation Dosimeter

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THE POTENTIAL of thermoluminescent radiation dosimetry has been recognized in recent years and several materials are now in use as thermoluminescent dosimeters. The thermoluminescent material which is most widely used at the present time is lithium fluoride.^(1,2) We have investigated some of the thermoluminescent properties of ruby ($\text{Al}_2\text{O}_3:\text{Cr}^{3+}$), (0.05%) sapphire (Al_2O_3) and lithium fluoride (TLD-100). Initial results indicate that ruby possesses several characteristics which compare very favorably with the thermoluminescent materials now available. Several authors^(3–7) have reported some studies on the thermoluminescence of ruby and sapphire in regard to color center phenomena.

The thermoluminescence of ruby samples (0.05% Cr_2O_3) and TLD (100) have been studied over a range of gamma exposures from 10^2 to 10^6 R, using the same apparatus. Ruby samples were prepared by powdering a crystal to pass through a number 200 mesh screen and the TLD-100 was used as received from the manufacturer. Samples weighing 10 ± 0.1 mg were placed on sample holders which were heated at a linear rate of about $0.4^\circ\text{C}/\text{sec}$. Also, single crystal discs 10 mm in diameter and 4 mm thick were studied. The thermoluminescence was measured using a 1P21 photomultiplier tube (S-4 spectral sensitivity) with maximum response at 4000 Å. The radiation sources used in the work were ^{60}Co (exposure rate of 1.8×10^5 R/hr) and ^{137}Cs (exposure rate of 5.7×10^3 R/hr).

The thermoluminescent glow curves of ruby and TLD-100 for two radiation exposures are presented in Fig. 1. The glow curve of ruby consists of one prominent peak at 350–400°C, which shifts slightly to lower temperatures with increasing radiation exposure. The TLD-100 glow curve is complicated and exhibits several peaks. The glow peak occurring at approximately 210°C in TLD-100 is the one customarily used in dosimetry. A relative comparison

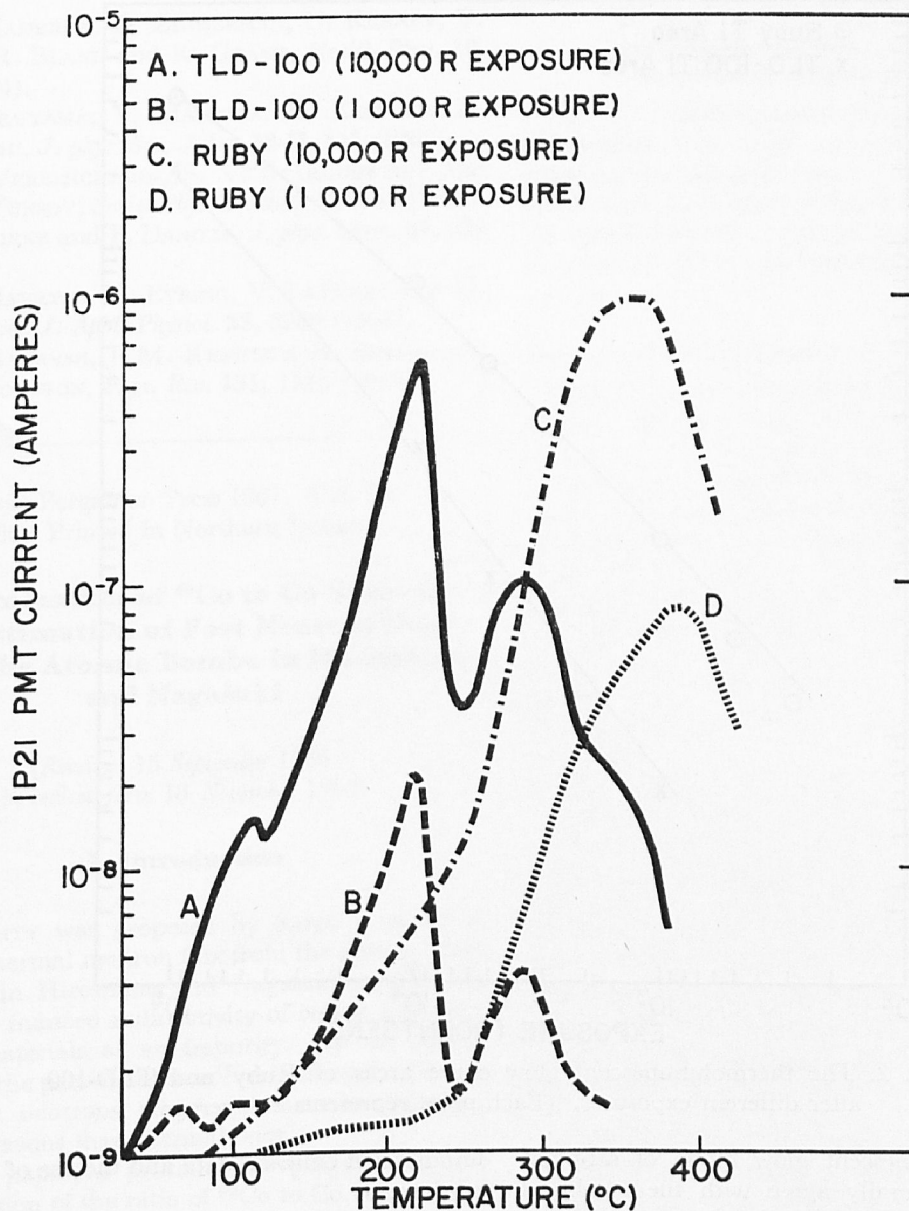


FIG. 1. Thermoluminescent glow curves of Ruby and TLD-100.

of the areas under the glow curves for ruby and TLD-100 is shown in Fig. 2. Essentially the same results were obtained in each of several experiments with different exposure rates and radiation energies.

The main advantage that ruby has over the TLD-100 is the larger thermoluminescent yield and its greater thermal stability. The light emitted by TLD-100 occurs in a broad band around 4100 Å which is the region of maximum response of the IP21 photomultiplier. On the other hand, the emission of ruby occurs in a broad band around 7000 Å with strong emission corresponding to the chromium R-lines. The IP21 photomultiplier is at least two

orders of magnitude more sensitive to the TLD-100 emission than it is to the ruby emission. Hence, a more appropriate choice of photospectral response would utilize the larger light yield of ruby and would result in better thermoluminescent dosimeter measurements. Light bleaching effects were not detected for the ruby samples in normal room light.

The solid ruby samples have several advantages including reproducibility and ease of handling. This avoids the difficulties of obtaining reproducible aliquots and distribution of powdered specimens. The solid samples permit optical absorption measurements to be made.

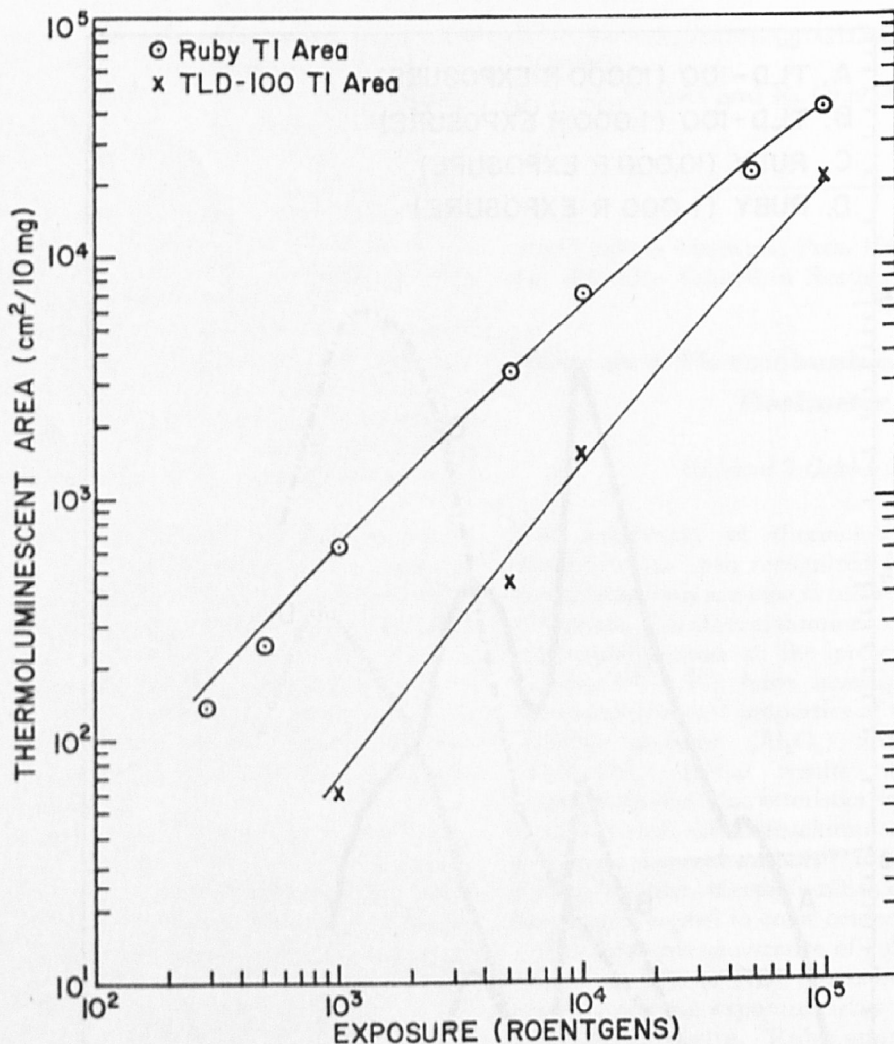


FIG. 2. The thermoluminescent glow curve areas of Ruby and TLD-100 after different exposures. (Each point represents an average.)

The thermoluminescent glow curve of sapphire was found to generally agree with the results of GABRYSH *et al.*⁽⁷⁾ The thermoluminescent emission spectrum of sapphire occurs in a broad band centered around 2900 Å. Also, emission was observed in the 7000 Å region, which indicated that chromium was an impurity in the nominally pure sapphire.

It should be noted that the thermoluminescent emission in ruby is directly associated with the chromium ion. The strong component of line emission from ruby is basically different from broad band emission seen from LiF and sapphire specimens.

Based on these initial experiments, ruby is a worthy candidate as a thermoluminescent dosimeter.

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References

1. J. R. CAMERON, F. DANIELS, N. JOHNSON and G. KENNEY, *Science* **134**, 333 (1961).

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2. J. R. CAMERON, D. ZIMMERMAN, G. KENNEY, R. BUCH, R. BLAND and R. GRANT, *Health Phys.* **10**, 25 (1964).
3. T. MARUYAMA, Y. MATSUDA, H. KON and H. YOEMITSU, *J. phys. Soc. Japan* **18-II**, 315 (1963).
4. L. F. VERESHCHAGIN, S. V. STARODUBTSEV and M. S. YUNSOV, *Soviet Phys. Doklady* **9**, 983 (1965).
5. J. K. RIEKE and F. DANIELS, *J. phys. Chem.* **61**, 629 (1957).
6. A. F. GABRYSH, H. EYRING, V. LEFEBRE and M. D. EVANS, *J. Appl. Physiol.* **33**, 3389 (1962).
7. A. F. GABRYSH, J. M. KENNEDY, H. EYRING and V. R. JOHNSON, *Phys. Rev.* **131**, 1543 (1963).

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Determination of ^{60}Co to Co Ratio for the Estimation of Fast Neutron Dose from the Atomic Bombs in Hiroshima and Nagasaki

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I. Introduction

A POSSIBILITY was proposed by SAITO *et al.*^(1,2) to estimate thermal neutron flux from the atomic bomb explosion in Hiroshima and Nagasaki in 1945, by measuring induced radioactivity of cobalt contained in iron materials as an impurity. By the similar principle, the present authors⁽³⁾ estimated the air dose due to fast neutrons, which are more hazardous to exposed persons than thermal ones.

In this paper, a procedure is proposed for the determination of the ratio of ^{60}Co to Co. Calculated from the cross section of the reaction $^{59}\text{Co}(n, \gamma)^{60}\text{Co}$, the available data on neutron fluxes at the time of bombardment, and from the elapsed time after the explosions, it was estimated that the specific activity of cobalt would be of the order of $\mu\mu\text{Ci/mg}$. Since cobalt is contained in iron materials only as an impurity (of the order of a few mg per 100 g of iron), it would be necessary to use as large amount of sample as possible in order to obtain reasonably accurate results. Actually, it was decided to use about 50 g of iron material as the starting material, considering the difficulty of handling a good many samples. As only the ratio of ^{60}Co to Co is required, emphasis was placed in purifying cobalt both chemically and radiochemically rather than in extracting cobalt quantitatively.

II. An examination of optimum conditions for determining ^{60}Co to Co ratio in iron materials

For the establishment of optimum conditions for determining ^{60}Co to Co ratio in iron materials, the following three processes were examined; (1) removal of iron and purification of cobalt by anion exchanger, (2) absorptiometric determination of cobalt, (3) preparation of the sample and determination of ^{60}Co activity.

Removal of iron and purification of cobalt by anion exchanger

One of the best methods for the removal of a large amount of iron from aqueous solutions is the extraction with di-isopropyl ether from 8 N hydrochloric acid solution.^(4,5) The effect of the concentration of ferric ion on the extractability was checked. As shown in Fig. 1, the extractability was slightly less than 100 per cent for tracer concentration, but increased with increasing the concentration of ferric ion, and remained constant (100 per cent) over the concentration range from 0.1 to 1 M, which is consistent with the results obtained by DEAN and HERRINGSHAW.⁽⁸⁾ Above 1 M, the extractability decreased.

The volume of 1 M ferric ion solution containing 50 g of iron will be 1.1 l. As it is not only dangerous to use such a large volume of concentrated hydrochloric acid and organic solvent for extraction, but also difficult to handle, the actual extraction was divided into three steps and the first step was conducted with an iron concentration of 3 M. Extraction with methylisobutyl ketone-isoamyl acetate (2:1)^(7,8) is known to be effective for other elements than those extracted with di-isopropyl ether. As methylisobutyl ketone gives off an offensive odor, it was used only

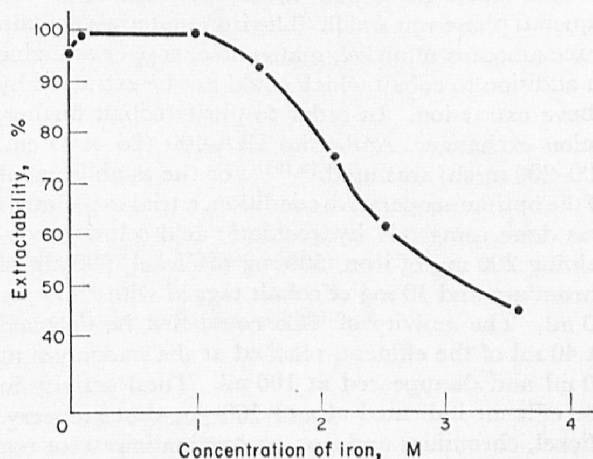


FIG. 1. Variation of extractability of iron from 8 N hydrochloric acid by di-isopropyl ether system.