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Dennis I. Maehara, M.D.
1010 S. King Street, Ste. #701
Honolulu, Hawaii 96814
29 August 1989

Mr. Robert J. Pate
District Director
Region V
U.S. Nuclear Regulatory Commission
1450 Maria Lane, Ste. 210
Walnut Creek, Calif. 94596

Dear Mr. Pate:

I am rushing this material to you since I have just completed a study of pertinent material in response to the enforcement conference of August 21st. Dr. Don Tolbert gave me the Sr-90 course curriculum and a copy is enclosed. His reading list materials were available at the Hawaii Medical Library and I have studied the following topics:

RADIATION PHYSICS - review of atomic and nuclear structure, generation of particles, ionization,detection, exposure units and dose equivalents, dosimetry of beta-ray applicator and limits, clinical applications.

RADIATION PROTECTION- units, regulation sources, background radiation in local areas, sublethal limits and safety criteria, biologic effects, dose related cataract studies, health risks vs exposure, radiation vs other health risks .

MATHEMATICS- decay, linear vs exponential equation, half-life.

RADIATION BIOLOGY- direct and indirect effects, beta tissue penetration, cell survival curves, the oxygen effect and enhancement curves , the oxygen effect in therapy, cell stages in radiosensitivity, linear energy transfer, relative biological effectiveness,mechanisms of radiation carcinogenesis.

BETA RAY APPLICATOR- Sr-90 source strength,decay particle pattern and half-life, dosimetry, design and radiation output patterns,shielding and housing, effective treatment area and dose rate as function of tissue depth, clinical applications, biologic calibration determinations.

The references:

"Medical Radiation Biology," by Pizzarello and Witcofski; Lea and Febiger, Philidelphia, 1982. 158pp.

"Radiobiology for the Radiologist," by Hall; Harper and Row, New York, Evanston, San Francisco, and London, 1978. 441pp.

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"Medical Radiation Biology," by Dalrymple-Gaulden-Kollmorgen-Vogel; W.B. Saunders Company, Philadelphia, London, Toronto, 1973. 329pp.

"An Evaluation of the Clinical Use of a Strontium-90 Beta Ray Applicator With a Review of the Under-lying Principles" by H.L. Friedell, C.I. Thomas, and J.S. Krohmer. Amer. J. Roentgen, 71(1954)25.

"Physical Study of Sr-90 Beta Ray Applicator" by S.J. Supe, and J.R. Cunningham. Amer. J. Roentgenal., 89(1963)570.

The material studied was more comprehensive than was discussed in Mr. G. Yuhas' letter of August 4th. I also hope that it meets approval of the gentlemen of the previous enforcement conference. I am requesting that you kindly allow me to proceed with using the beta applicator in my surgical practice, since I have completed all efforts to correct the deficiencies.

Thank you.

Sincerely,

Dennis I. Maehara, M.D.

Dennis I. Maehara, M.D.

TRAINING PROGRAM FOR PROSPECTIVE AUTHORIZED USERS OF Sr-90 OPHTHALMIC EYE APPLICATORS

A. Radiation Physics & Instrumentation (6 hours):

1. Review of atomic/nuclear structure.
2. Physics of ionization, excitation and energy deposition.
3. Detection of atomic/nuclear radiations.
4. Exposure and absorbed dose units.
5. Physical description and dosimetry of beta ray applicators.
6. Physics of clinical applications.

B. Radiation Protection (6 hours):

1. Units, nomenclature and their use in expression of protection formalism.
2. Criteria of radiation safety.
3. Data base for human biological effects from radiation exposure.
4. Recommendation/regulation sources and assumptions.
5. Summary of biological effects.
6. Risks from radiation exposure and its comparison with other environmental insults.

C. Mathematics Pertaining to the Use and Measurement of Radioactivity:

1. Review of basic algebra.
2. Review of the use of graphs.
3. Simple inverse and inverse square proportion.
4. Exponential decay, use of half-life, average life, etc.

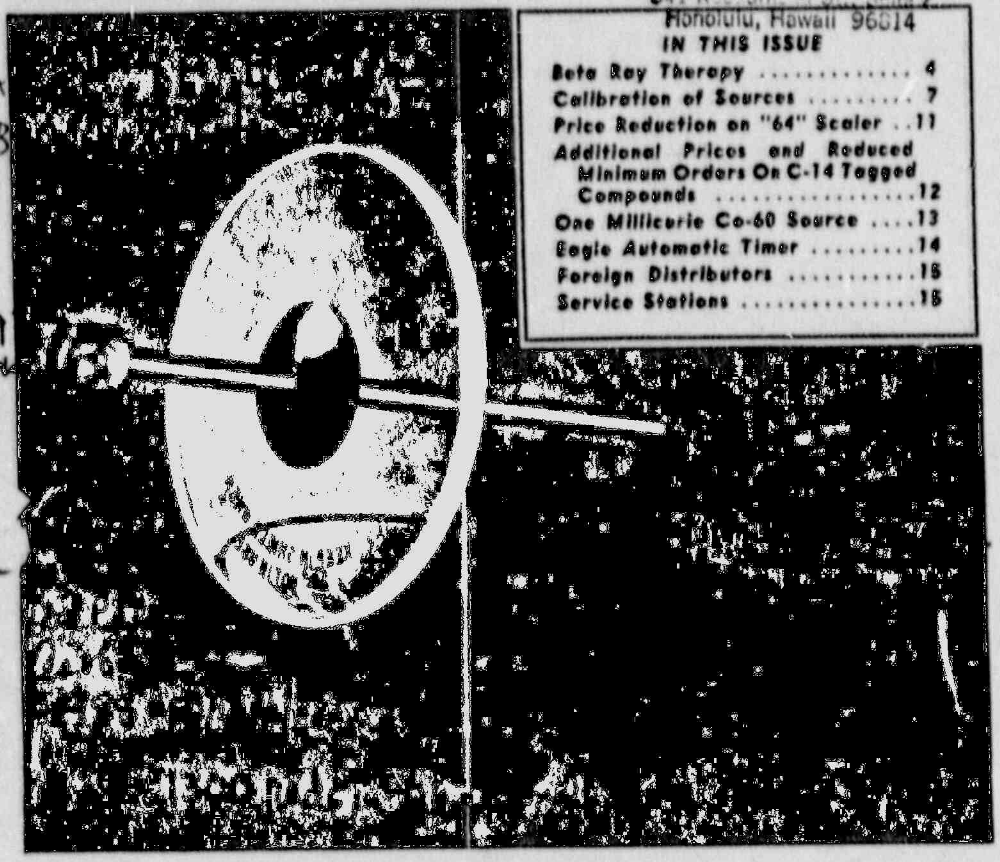
D. Radiation Biology:

1. Biological interaction of radiation with tissue.
2. Cell survival curves.
3. Oxygen effect.
4. Radiosensitivity, cell age in mitotic cycle.
5. Dose fractionation and repair.
6. LET and RBE
7. Tumor/normal tissue response to radiation and complications.

tracerlog

NO. 28 TRACERLAB, INC. JULY, 1950

CALVIN M. MIURA, M.D., INC.
641 [illegible] St., Suite 7
Honolulu, Hawaii 96814



IN THIS ISSUE

STRONTIUM MEDICAL APPLICATOR

Tracerlab has received numerous requests from the medical profession for a suitable applicator containing a radioactive isotope for use in the treatment of certain surface conditions, particularly in reference to the eye. The Tracerlab RA-1 Strontium Medical Applicator has been made available for use by qualified physicians.

The activity of the applicator consists of a source of about 25 millicuries of Strontium-90 which has a half life of thirty years. This results in a dosage rate of approximately 20 roentgens-beta equivalent at the aluminum surface of the applicator. The exact surface dosage is stamped on each instrument. The radiation emitted by the source consists of 0.65 Mev beta rays through which Strontium-90 decays to Yttrium-90, and 2.16 Mev beta rays through which Yttrium-90 decays to stable Zirconium. Thus, essentially only beta radiation is given off by this source.

The source has an active diameter of 7.8 mm. and an outside diameter of 12.7 mm., and is protected by a double hermetic seal so that under normal usage no leakage can occur. The activity itself is covered by 2 mils of stainless steel and 10 mils of aluminum, which results in a total covering of about 100 mg/cm^2.

The source is mounted at the end of a 6¾" shaft. A 4" x ¼" circular Plexiglas shield is mounted on the shaft for the protection of the operator. It can be moved along the shaft to any desired position and will stop most of the radiation emitted by the source.

The applicator is housed in a walnut case into which it can be securely clipped. When the instrument is fastened in the case the source is completely shielded by means of a source shield. A second source shield is also provided for use with the applicator when set up on a table.

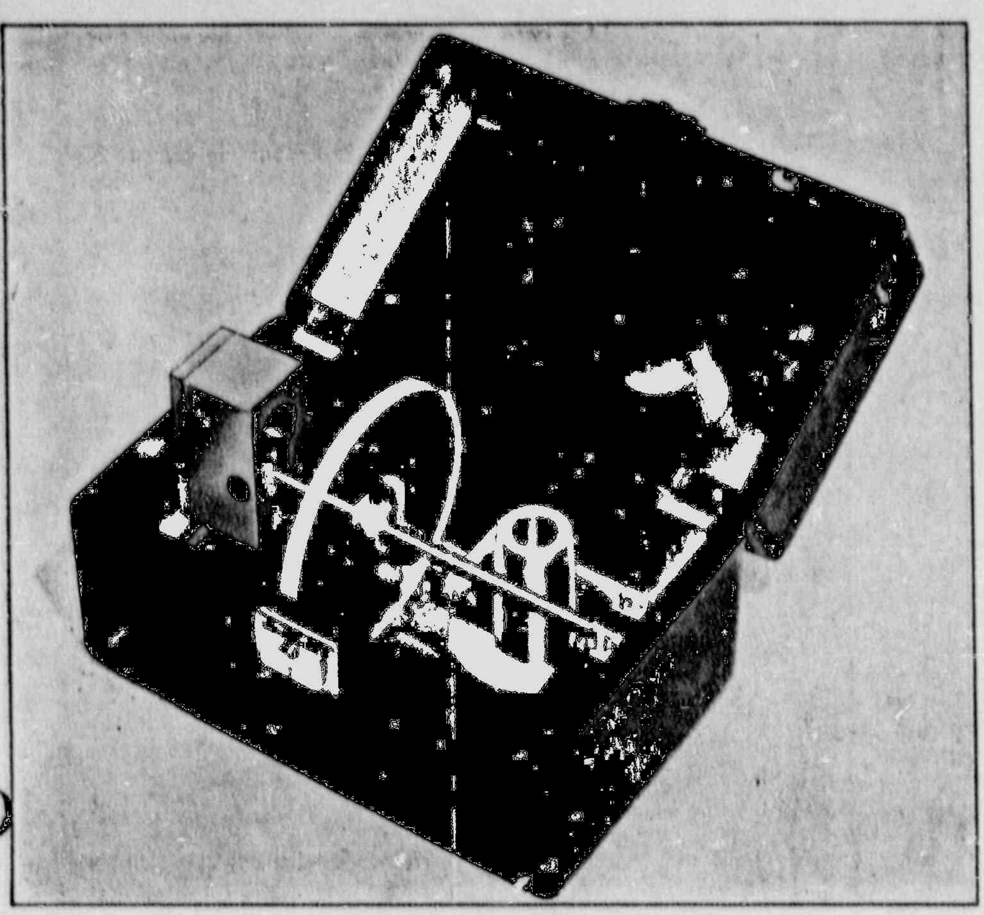
With each instrument Tracerlab supplies a radioautograph showing the uniformity of the activity on the source, a chart which shows the percentage reduction of the surface dosage rate as a function of the depth of Lucite, which is generally considered equivalent to tissue, and a chart which shows percentage reduction of surface dosage rate versus time to allow correction for source decay.

While special attention has been given by Tracerlab in the design and manufacture of the Strontium Medical Applicator to the safety of personnel using it in therapeutic work, the instrument must nevertheless be handled with due and reasonable care. The standard procedures which have been devised for Radium plaques might well be considered as a general guide for this purpose.

Before this applicator can be purchased from Tracerlab, it is necessary to obtain authorization from the U. S. Atomic Energy Commission by submitting three copies of Form AEC-313 to the Isotopes Division, U. S. Atomic Energy Commission, Post Office Box E, Oak Ridge, Tennessee. If authorization is granted, the U. S. Atomic Energy Commission will issue Form AEC-374 which must then be submitted with the purchase order. Furthermore, the following regulations pertaining to Beta-Ray Applicators have been issued by the U. S. Atomic Energy Commission:

> **"Before a beta-ray applicator is first used, the applicant must receive from the MANUFACTURER or from the National Bureau of Standards a certificate which states (1) the dosage rate of the applicator, and (2) that there is no detectable leak of activity to the exterior. The applicator must be identified by the name of its manufacturer and its serial number. A copy of the certificate must be filed with the Isotopes Division or with a person or agency designated by the Division.**
> **Each twelve months the applicant must similarly file a certificate, executed by the manufacturer, stating that the applicator still exhibits no detectable leak of activity to the exterior."**

Tracerlab will furnish the original certificate and submit the necessary copy to the Isotopes Division. Upon return of the applicator at the end of each year, Tracer-



RA-1 Strontium Medical Applicator in Walnut storage box with source fixed in shield and auxiliary shield at right.

lab will check the instrument for leakage, remeasure the surface dosage rate, and issue a new certificate, at a service charge of $25.00. After five years, the applicator will also be recalibrated when it is returned for its annual inspection.

SPECIFICATIONS

Source Material:
Strontium-90 in equilibrium with Yttrium-90.

Source Strength:
About 25 millicuries which yield a surface dosage rate at the aluminum surface of approximately 20 roentgens-beta equivalent per second as measured by a Vanishing Ion Chamber. Date and Calibrated value of surface dosage rate stamped on applicator.

Source Dimensions:
a) Active diameter—7.8 mm.
b) Outside diameter—12.7 mm.

Source Mounting:
Source covered by 2 mils of stainless steel and 10 mils of aluminum, and sealed by double hermetic seal.

Shield:
4" x ¼" circular Plexiglas which slides on shaft.

Shaft Length:
6¾".

Equipment Supplied:
a) Radioautograph showing uniformity of activity on source.
b) Chart which shows simulated tissue depth dosage curve based on measurements with Lucite absorbers.
c) Chart which shows percent reduction of surface dosage rate vs. time to allow correction for source decay.
d) Wooden storage box and shield.

Price:
F.O.B. Boston $300.00

BETA RAY THERAPY

Nuclear radiation has been used in a variety of applications in medical therapy. All types of ionizing radiation, such as alpha, beta, gamma, and X-rays, can be used in this way since they all cause ionization to take place in tissue. This is the phenomenon which results in biological effects. However, since in most cases the object is to achieve this effect in the diseased cells with as little harm to the normal ones as possible, it is not only necessary to use a great deal of caution but also to choose the proper type of radiation and dosage for each particular treatment.

Alpha radiation emitted by natural or artificial radioactive elements consists of a monoenergetic stream of Helium nuclei. These alpha particles, while highly energetic, are so large that their range in tissue is only a few thousands of a millimeter, or a few cell diameters. Hence they are generally not useful in therapeutic work unless the source of radiation can be brought directly in contact with the diseased cells. Even the outer skin usually prevents the penetration of alpha rays and, therefore, they are employed only when, for instance, it is possible to inject the emitting substance into the tissue in question.

Beta radiation consists of high energy electrons which are given off by radioactive substances with a spectral distribution of energies. The energy of the beta radiation emitted by a particular element is generally expressed in terms of the peak energy of the spectrum, which is usually three to four times the average energy. These energies are measured in millions of electron vólts (Mev) and electrons of this energy will penetrate on the order of several millimeters of tissue. Therefore this type of radiation is most useful in the treatment of conditions which lie near the surface. One of the most common applications of this type is to be found in the field of ophthalmology where it is desired to irradiate tissue just beneath the outer layer of cells covering the eye, without causing any damage to the underlying eye tissue.

Gamma rays and X-rays are a form of electromagnetic radiation. They have no rest mass, but they can be assigned specific energies and are frequently thought of in terms of quanta of energy. This type of radiation is much more poorly absorbed than alpha or beta radiation and generally has a range in tissue of a substantial number of centimeters. Thus a gamma ray having the same energy as a beta ray would cause less ionization, and hence have less biological effect, per unit volume. Therefore, the presence of some gamma rays in a beta ray source for the treatment of tissue near the surface of the skin is not very dangerous to the patient even though the gamma rays penetrate much further. However, the presence of gamma radiation requires more protection for the operators of the applicator and consequently a pure beta source is preferable for instruments which are to be used for the above purpose.

It is also pertinent to point out here that when it is desired to use gamma radiation for therapeutic purposes, much stronger sources are required to make up for the smaller ionization per unit volume produced by gamma rays. A more detailed discussion of this point can be found elsewhere in this issue.

From the foregoing discussion it can readily be seen that the most suitable radiation for the treatment by irradiation of tissue near the surface would usually be pure beta radiation of fairly high energy. The large variety of radioactive isotopes which can be obtained from the nuclear reactor at Oak Ridge permits, for the first time, a choice of such beta emitters, all of which are less expensive than radium and its decay products and, unlike the radium series, none of which emits gamma radiation. Of these artificial beta emitters, the one which is most suitable from the point of view of half life (the time during which half of the radioisotope decays into its daughter product) and which gives beta rays of sufficient energy is Strontium-90. It has a thirty year half life and decays to Yttrium-90 through the emission of 0.65 Mev beta rays. Yttrium-90 in turn has a half life of sixty-two hours and is thus in equilibrium with Strontium-90. It decays to stable Zirconium through the emission of 2.16 Mev beta rays which are the rays that are actually employed, since the 0.65 Mev beta rays are virtually completely absorbed by the covering of the source.

Using an experimental Strontium-90 applicator with a surface dosage of about 5 roentgens-beta equivalent, Drs. H. L. Friedell and C. I. Thomas, and Mr. J. S. Krohmer of Western Reserve University, Cleveland, Ohio report the following results[1]:

> **"Sr-90 beta rays have been applied clinically and a series of cases treated with this method were compared with another series in which beta rays from radon have been used. No demonstrable difference in the biological effectiveness in the two sources could be demonstrated—efforts being made to approximate the dosages in the two groups. In the case of the Sr-90 applicator, the treatment was applied in direct contact over a period of 60 seconds which gave a dose of approximately 325 roentgens. (The Sr-90 beta ray applicator emits 5.4 roentgens per second at the surface.) All treatments have been given by the direct contact technique since this is the only manner in which the actual dose to the tissue can be carefully regulated. The spray technique is believed to be inaccurate since the geometry (relationship of the radiating surface to the tissue to be irradiated) cannot be rigidly controlled.**
>
> **The conditions which appear favorable for radiation are:**
>
> ***1. Superficial tumors:***
>
> **Small benign tumors, especially papillomas of the lids and conjunctiva respond very well to beta irradiation. Bowen's disease or intra-epithelial epitheliomas can be destroyed with beta rays without risk of deeper damage. Angiomata of the lids and conjunctiva in infants respond to beta radiation if treated early. With this type of lesion the response is generally quite prompt and the cosmetic result excellent. (Usually one or two treatments are sufficient.)**
>
> **Pterygia, either true or of the pseudo variety, recurrent pterygia and enlarged pinguecula all respond very satisfactorily to beta irradiation. Several treatments of 300 roentgens each is usually all that is necessary to obliterate this type of lesion. (Our usual course has been 300 roentgens weekly for a total of 1200 roentgens.)**

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1. "Beta Ray Application to the Eye with Description of an Applicator Utilizing Strontium-90", H. L. Friedell, C. I. Thomas, and J. S. Krohmer, American Journal of Ophthalmology, 33, 525 (1950).

This excerpt from the published article is printed here merely in the public interest; the conclusions and observations stated in it are solely those of the authors.

Reprints of the entire article may be obtained from Tracerlab upon request.

2. *Vernal conjunctivitis:*

Early cases of vernal conjunctivitis show an excellent therapeutic response to beta irradiation. In these early cases, the papilae consist of proliferating, young fibrous tissue, new vessels and lymphoid cells which are all very radiosensitive. The long standing cases showing the typical cobble-stone placques with hyaline degeneration, however, are more resistant to irradiation and often must be removed first by excision. Beta radiation may then be applied to this area. In applying the radiation, it must be remembered to give special attention to the upper edge of the tarsal cartilage as it is these follicles that cause the most troublesome symptoms. (We have used dosage totaling 1200 roentgens.)

Patients with the limbal lesions usually are seen at an early stage and consequently the response to therapy is very satisfactory. Recurrences in both the limbal and palpebral types of vernal conjunctivitis have been greatly decreased by radiation therapy.

3. *Anterior segment tuberculosis.*

The work of Woods has shown that anterior ocular tuberculosis is favorably treated in more than 50 per cent of the cases observed. Recurrences are not decreased, but the irradiation appears to have a beneficial effect on the immediate attack. The limbal type of follicle hypertrophy with corneal infiltration that has an appearance similar to phlyctenule responds to irradiation with special predisposition. The mode of action is not known, but it may be due to a radiosensitivity of the lymphoid and giant cells which degenerate and are replaced by fibrous tissue.

4. *Vascularization of the cornea.*

Beta irradiation is used both to prevent and also to obliterate corneal vascularization. It acts to inhibit the proliferation of capillary endothelium in newly forming vessels and infiltrating loops of vessels can be stopped short by beta radiation. Larger and well established vessels can also be obliterated by beta radiation in greater amounts applied over the limbus. The radiation induces an obliterative arteritis and resulting occlusion. (The dosage varies. We have administered radiation in courses, usually totaling 1200 roentgens in a period of one month. This may be repeated after an interval of one to two months.)

Vascular obliteration by means of beta irradiation has proven favorable in the following circumstances:

a. After superficial keratectomy to prevent a revascularization of the corneal stroma. In these cases the irradiation should be started after the first twenty-four hours and applied at the limbus.

b. As a preliminary procedure to corneal transplant where there are invading vessels in the cornea.

c. Following corneal transplant where there is a possibility of vessels re-infiltrating the graft from the surrounding cornea.

d. In vascularized corneal leukomas that are associated with symptoms of irritability, photophobia and lacrimation. Chemical burns of the cornea are often associated with this clinical picture and are greatly relieved by irradiation therapy.

5. *Corneal ulcers.*

There is no need for irradiation therapy in acute pyogenic corneal ulcers. This treatment is unsuccessful and may be followed by perforation of the cornea.

Certain forms of chronic ulcer are known to heal with irradiation therapy applied to the limbal region directly adjacent to the ulceration. There are no contraindications to this and it should be tried in stubborn or slow healing ulcers."

Another article, entitled "Description of a Strontium-90 Beta Ray Applicator and Its Use on the Eye", by the above authors will be published in the September issue of the American Journal of Roentgenology and Radium Therapy. Reprints of this article will also be available from Tracerlab.

CALIBRATION OF SOURCES

Terminology

The historical development of the physics and chemistry of radioactive materials lead unfortunately to the ambiguous use of several terms employed in the measurement of the strength and effects of radioisotopes. These ambiguities have been almost completely eliminated in recent years as knowledge of the properties of radioactive matter has increased; however, occasional misinterpretations still arise and radiological measurements are occasionally made in units which, strictly speaking, should not be employed. Sometimes difficulty of measurement makes use of the correct units almost impossible. In order to avoid possible confusion concerning the methods of measurement of the effects of irradiation used in describing the medical applicator, the appropriate units will be reviewed briefly.

The standard unit of radiological dose is the roentgen (r), which was defined by the 1937 Radiological Congress as that amount of X- or gamma-radiation which by the ionizing effects of its secondary electrons produces one esu of charge of either sign in one cc. of dry air at standard temperature and pressure. Equivalent measures of the roentgen are as follows:

$$
\begin{aligned}
1\ r &= 1 \text{ esu/cc. standard air} \\
&= 2.083 \times 10^{9} \text{ ion pairs/cc. standard air} \\
&= 1.61 \times 10^{12} \text{ ion pairs/gm. air} \\
&= 6.77 \times 10^{4} \text{ Mev/cc. standard air} \\
&= 83.8 \text{ ergs/gm. air} \\
&= 5.24 \times 10^{7} \text{ Mev/gm. air}
\end{aligned}
$$

The equivalent definitions in energy terms are based on the current experimental value of 32.5 electron volts required to form one ion pair in air.

In using the roentgen as a unit of quantity of gamma radiation we should remember that no precise physical information concerning the energy per photon, total number of photons, total energy of the beam or photons, or intensity of the beam of photons is presented. The "quantity" exactly referred to is the quantity of ionization (units of electric charge or ion pairs) produced in air as a standard substance by the secondary electrons which are photo, compton and pair-produced by the collisions of photons with atoms or free electrons in the air. The roentgen does not depend at all upon the time required for the production of ionization. As a result, gamma ray dosage rates must be measured in roentgens per unit time. The r per second, therefore, is a measure of the rate of formation of ionization in standard air or the "ionization intensity". It is not a measure of incident gamma ray energy intensity, but is a rate of energy dissipation.

When ionization is produced by radiations other than gamma rays, the dosage may not be expressed in terms of roentgens. For the important case of absorption

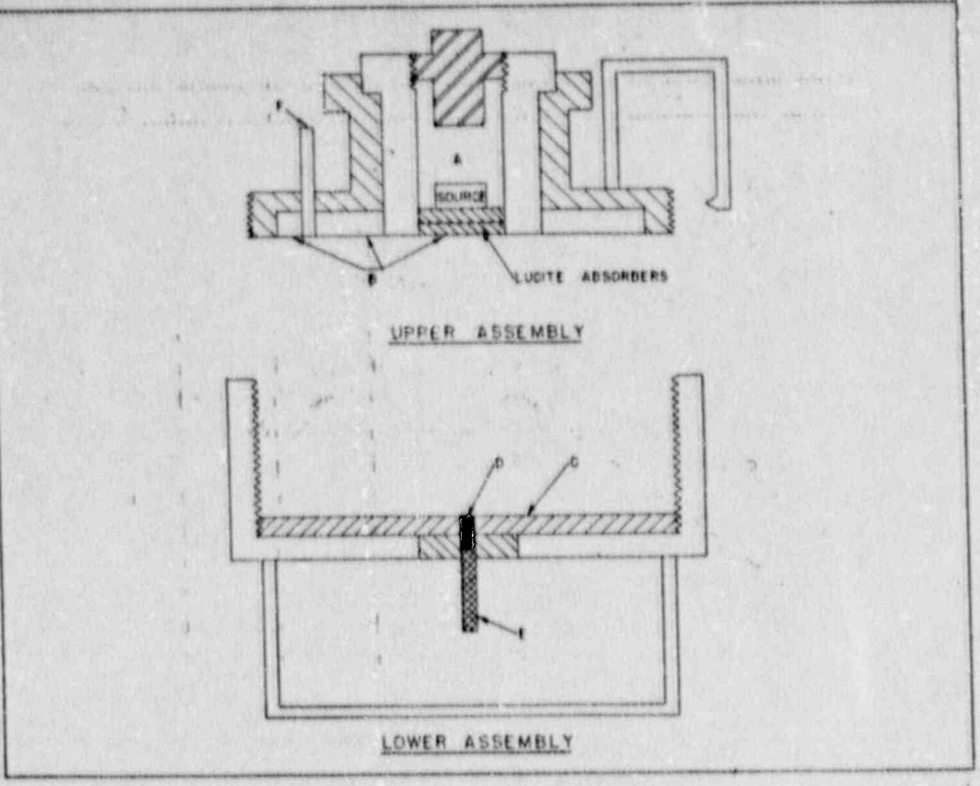

Figure 1.

Schematic diagram of the Tracerlab Vanishing Ion Chamber. This instrument is designed to measure the ionization in a layer of air, the thickness of which may be made vanishingly small. In this way, the dosage rate at the surface of a source or at a given depth of absorber may be obtained.

in tissue, however, a special unit has been defined in terms of comparable energy absorption. If the energy lost by ionization in tissue produced by any primary radiation is the same as the energy loss which has been computed for one roentgen of gamma radiation in water, namely 93 ergs/gm, the dose is defined as one roentgen-equivalent-physical (rep). Thus 1 rep = 93 ergs/gm tissue. It should be noted that the number of ergs produced in a gram of tissue by one roentgen (necessarily of photons since the r unit applies only to gamma radiation) varies considerably with gamma energy and tissue composition, thus making the usual statement 1 r of photons = 1 rep an approximation.

It has, naturally, been impossible to determine the radiological dosage rate as a function of tissue depth of a medical applicator source by measuring the energy dissipated in various layers of tissue. This is an unfortunate result of the fact that, although the definition of the rep is a logical extension of the roentgen, it is very difficult to measure. In the experimental arrangement used in calibrating medical applicator sources, the quantity actually measured is the ionization produced in air per unit volume by the Sr^{90}-Y^{90} beta particles after they have passed through various thicknesses of an absorber which is considered equivalent to tissue. If the ionization per unit volume amounts to 2.083×10^9 ion pairs per cc. of standard air (1 esu of charge), the dose may be defined as one roentgen-beta equivalent[1]. Due to the fact that the interaction of beta rays with matter is more nearly independent of atomic number than gamma rays, 1 roentgen-beta equivalent is about 0.9 rep.

Method of Measurement

Both the surface and the depth dosage rates of the medical applicator have been measured by means of a Vanishing Ion Chamber[2].

Resultant measurements should lead to a true value for the roentgen-beta equivalent dosage rate. However, certain other means of measuring the same phenomena have been devised and should also give accurate values. Unfortunately, this has not been the case and the discrepancy probably will not be resolved until further fundamental investigations have been made[3]. However, intercomparisons have been made by the various investigators who have Vanishing Ion Chamber type equipment and cross-calibrations have been made which are consistent. It is our belief that these vanishing ion chamber measurements lead to a true value for the roentgen-beta equivalent, but until this is finally proven it has been decided to call the roentgen-beta equivalent, as determined by a vanishing ion chamber, a radiation unit where it can be stated that one radiation unit = [K] x [roentgen-beta equivalent], where K is as yet unknown but probably is unity.

Figure 1 represents a vertical cross-section of the Vanishing Ion Chamber. The brass plug, A, holds the source to be tested as indicated. Since the density and chemical composition of Lucite are close to the density and composition of tissue, the tissue-equivalent absorbers used are of this material. The 0.001" aluminum window, B, serves as the upper plate of the ionization chamber. The lower plate consists of an aquadag coating on the upper surface of the polystyrene disk, C. This aquadag coating has been broken by inscribing a circular disk of inner radius 0.250 cm. and width 0.010 cm. in the center of the coating. This break serves to insulate the center area, which serves as the collector plate, from the rest of the coating, which serves as a guard ring. The collection volume of the chamber in cc. is thus evidently equal to $(0.250)^2\pi$ times the distance of separation between the aquadag coating and the aluminum window.

The entire upper assembly is screwed into the lower assembly. The distance between the aluminum window and the aquadag coating can thus be varied smoothly from 0.000" to 0.050", since one revolution of the upper assembly changes the separation by 0.050". A pointer is attached to the upper assembly and a scale is provided on the lower assembly; separation distances can be read accurately to 0.0001".

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1. "Actions of Radiation of Living Cells", by D. E. Lee, page 16, MacMillan Company, N. Y., 1947.

2. This apparatus is based upon a design originated by G. Failla ("The Measurement of Tissue Dose in Terms of the Same Unit for All Ionizing Radiations", Radiology, 29, 202 (1937). Tracerlab is indebted to Dr. Friedell, Mr. Krohmer and Mr. McCarthy of University Hospitals, Cleveland, for allowing us to examine a somewhat improved version of Failla's original design previous to our designing the instrument described.

3. Private communication from Robley D. Evans, Professor of Physics, Massachusetts Institute of Technology.

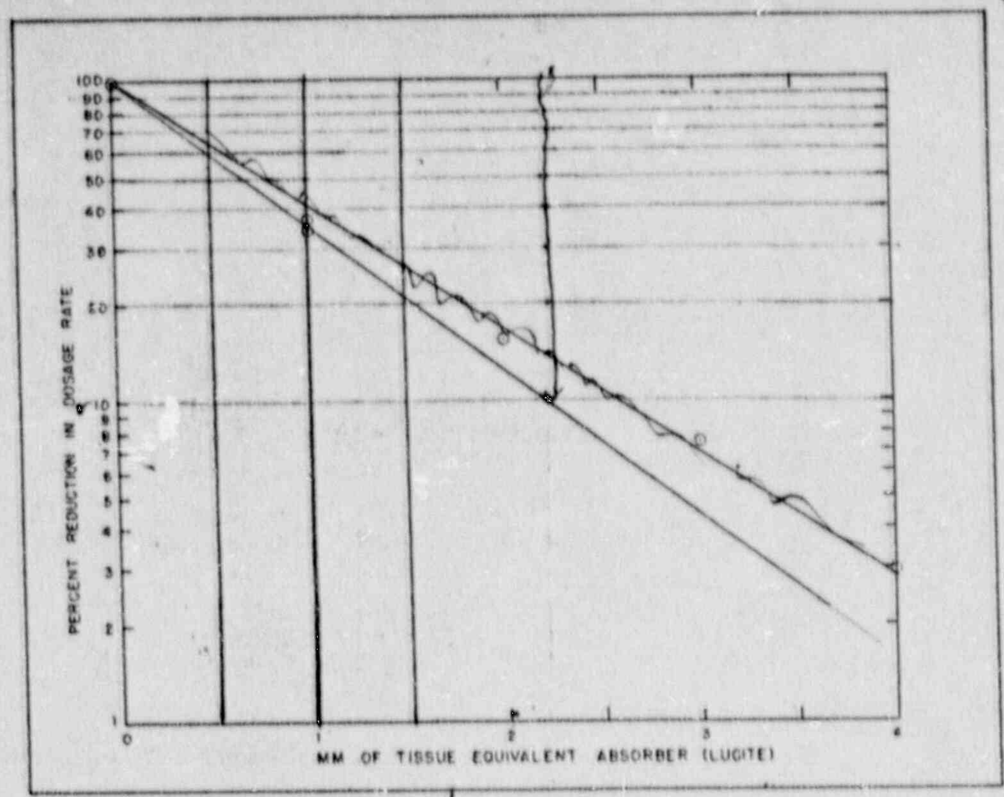


Figure 2.

A sample depth dosage curve for the RA-1 Strontium Medical Applicator as determined with the Tracerlab Vanishing Ion Chamber using 1 mm thick Lucite disks as absorbers. Lucite (specific gravity = 1.2) is generally considered to be approximately tissue equivalent.

One end of the graphite rod, D, through the center of the polystyrene disk makes contact with the center area of the graphite coating and the other end is attached to the brass rod, E. This serves as the sensitive electrode of the ionization chamber. The box below E contains the preamplifier. Electrical contact to the aluminum window is made through the brass rod, F.

A standard electrometer circuit with the meter used as a null instrument is employed in these measurements. Any voltage built up by the flow of ionization current through a "hi-meg" resistor (3×10^{10} ohms) may be bucked out by applying an equal and opposite voltage across part of a ten turn helical potentiometer. This potentiometer has a calibrated dial on its shaft; the circuit is arranged so that the readings of the dial are proportional to the ionization current.

When the chamber is in use, some of the beta particles emitted by the source are stopped in the center area of the aquadag coating. Reversing switches are used to reverse the direction of the ionization current through the "hi-meg" resistor, thereby providing a method for separating the true ionization current from the beta particle current.

The true ionization current is measured under given absorber conditions as a function of the separation distance between the ionization chamber plates. This data is then plotted and the resulting curve extrapolated back to zero separation. The following symbols are introduced:

S == initial slope of curve of ionization current vs. separation distance units of potentiometer turns per 0.001".

V == voltage across potentiometer in volts.

R == resistance of "hi-meg" resistor in ohms.

A == center area of graphite in cm^2.

W == weight in mg. of 1 cc. of air at time of measurement.

Knowledge of these quantities and the thickness of tissue equivalent absorber is sufficient for the calculation of the dosage rate experienced at a given tissue depth. A simple calculation reveals that the number of radiation units/sec. as measured by the vanishing ion chamber, which for reasons stated above has been defined as (K) x (roentgen-beta equivalents/sec.) is equal to $\frac{1.52 \times 10^{11} \times V S}{W R A}$.

A typical depth dosage curve for the Tracerlab RA-1 Strontium Medical Applicator, based on measurements with Lucite absorbers, is shown in Figure 2.

GEORGE F. PIEPER.

Bibliography

1. R. D. Evans, "Radioactivity Units and Standards", *Nucleonics*, 1, No. 2, 32, October, 1947.

2. D. E. Lea, "Actions of Radiations on Living Cells", MacMillan Co., New York, 1947.

3. J. H. Lawrence and J. G. Hamilton, Ed., "Advances in Biological and Medical Physics", Academic Press, Inc., New York, 1948.

4. N. Howard-Jones, Ed., "Applied Biophysics", Chemical Publishing Co., Brooklyn, N. Y., 1949.

5. Lapp and Andrews, "Nuclear Radiation Physics", Chapter 18, Prentiss-Hall, Inc., New York, 1948.

PRICE REDUCTION ON "64" SCALER

As a result of simplified assembly methods and economies resulting from volume production, it has become possible to reduce the price of the SC-2A "64" Scaler to $355.00 f.o.b. Boston, effective June 1, 1950.

ADDITIONAL PRICES ON CARBON-14 TAGGED COMPOUNDS AND CHANGES IN MINIMUM ORDER

Prices have been set and specific activities have been determined for three more Carbon-14 tagged compounds which were listed in Catalog B, and the price of one compound has been corrected as follows:

L2-3	Ethylene	1 mc./1-2 m.mole	$300.00/mc.
L5-9	dl-Lysine-2-C-14 Mono Hydrochloride	1 mc./2-3 m.mole	500.00/mc. (corrected price)
L5-7	dl-Methionine-2-C-14	1 mc./2-3 m.mole	750.00/mc.
L5-9	dl-Lysine-2-C-14	1 mc./2-3 m.mole	725.00/mc.

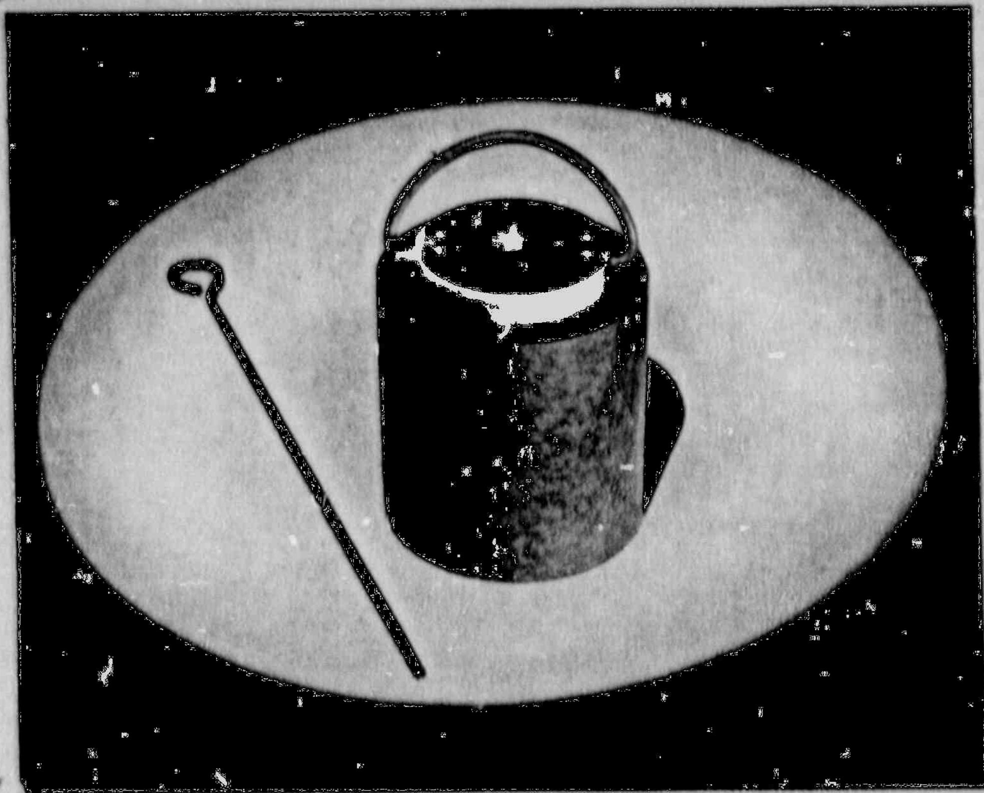
Also, one additional compound has been synthesized and added to the list of available radiochemicals:

L4-13	Succinic Acid-2-C-14	1 mc./1-3 m.mole	$475.00/mc.

Furthermore, Tracerlab has recently received a number of requests for smaller minimum quantities of amino acid compounds and certain other compounds of biological interest, and in an endeavor to be of greater service to our customers, we have reduced the minimum quantities to 0.1 millicurie on the following compounds:

		Price Per Millicurie	Price Per 0.1 Millicurie
L4-9	Phenylacetic Acid-1-C-14	$425.00	$ 77.50
L4-10	2, 4-Dichlorophenoxyacetic Acid-1-C-14	650.00	100.00
L4-11	Ethyl Acetaminocyanoacetate-2-C-14	550.00	90.00
L4-12	Ethyl Cyanoacetate-2-C-14	425.00	77.50
L4-13	Succinic Acid-2-C-14	475.00	82.50
L5-1	Glycine-1-C-14	450.00	80.00
L5-2	Glycine-2-C-14	600.00	95.00
L5-3	dl-Alanine-1-C-14	450.00	80.00
L5-4	dl-Phenylalanine-2-C-14 Hydrochloride	675.00	102.50
L5-6	dl-Phenylalanine-3-C-14 Hydrochloride	500.00	85.00
L5-7	dl-Methionine-2-C-14	750.00	110.00
L5-8	dl-Tryptophan-2-C-14	700.00	105.00
L5-9	dl-Lysine-2-C-14 Mono Hydrochloride	725.00	107.50
L6-1	Benzoic Acid-1-C-14	550.00	90.00
L5-2	Toluene-1-C-14	500.00	85.00
L6-3	Benzene	600.00	95.00
L6-4	Chlorobenzene-1-C-14	800.00	115.00
L6-5	Aniline-1-C-14	650.00	100.00
L6-6	Phenol-1-C-14	800.00	115.00

The price for 0.2, 0.3, and 0.4 millicuries of these compounds will be 2/10, 3/10, and 4/10 respectively of the price per millicurie plus a $35.00 handling charge. For 1/2 millicurie and more, the price will simply be the appropriate fraction of the millicurie price. For example, L5-2 Glycine-2-C-14 which is priced at $600/mc. will sell for $155.00 for 2/10 millicurie and $360.00 for 6/10 millicurie.



R-30 ONE MILLICURIE COBALT-60 GAMMA SOURCE

In response to considerable demand for a gamma source of millicurie strength, Tracerlab has developed a one millicurie Cobalt-60 source. This source is particularly useful in the calibration and checking of instruments and film, and can be used for experimental work with Geiger tubes, ionization chambers, and scintillation counters. It is also very helpful in spot checking the effectiveness of protective shielding.

The R-30 Cobalt source consists of a hermetically sealed point source and a heavy lead shield in which it can be inserted and securely fastened. The shield, which is provided with a handle, is made of two inches of lead and thus affords complete protection against the 1.16 Mev and 1.30 Mev gamma rays given off by Cobalt-60. When the source is to be used it is unfastened with the end of a wrench which is supplied with the source, and is taken out of the shield with a special remote handling tool, which is also supplied. This special tool permits completely safe manipulation of the source.

Approval must be obtained from the U. S. Atomic Energy Commission before this source may be purchased.

SPECIFICATIONS

SOURCE MATERIAL:
Hermetically sealed point source of Cobalt-60.

SOURCE STRENGTH:
1 millicurie

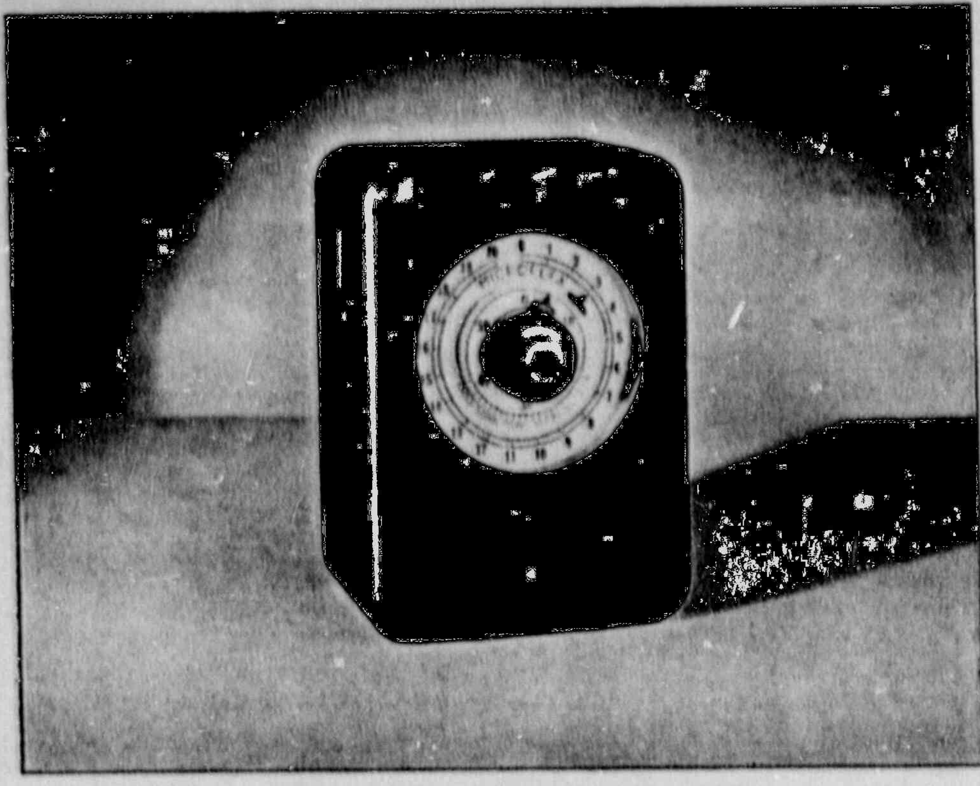
SHIELDING:
2 inches of lead with carrying handle.

DIMENSIONS:
4" diameter by 4½" high.

ADDITIONAL EQUIPMENT SUPPLIED:
a) Remote handling tool.
b) Wrench

WEIGHT:
23 lbs.

PRICE:
F.O.B. Boston $40.00



SC-25 EAGLE AUTOMATIC TIMER

For the convenience of its customers Tracerlab has adopted the Eagle Automatic Timer for use with the "64" Scaler and the "100" Scaler. When properly connected to these scalers this automatic timer makes it possible to count for a predetermined time interval without attention on the part of the operator.

The timer has two concentric dials on which the predetermined count can be set anywhere between two seconds and twenty minutes with an accuracy for ± 1 second. At the end of the selected time interval it will interrupt the pulses from the Geiger-Mueller tube and thus stop the counting of the scaler. Then when the reset switch on the scaler is thrown, the timer and the scaler are both reset and are ready for the next counting run.

The Eagle Automatic Timer is connected to the "64" Scaler and the "100" Scaler by means of a regular plug which uses the same outlet on the scaler as is used by the SM-60A clock, and by a special cable which connects to the oscilloscope viewing jack on the back of the scaler. All cables and plugs are provided with the instrument.

SPECIFICATIONS

Time Scale:
two seconds to twenty minutes

Dial Divisions:
one second

Accuracy
±1 second

Power
110 V A.C., 60 cps. Available on special order for 220 V A.C., 50 cps.

Dimensions:
5¾" x 8" x 5⅛"

Connections:
1 A.C. line cord to connect to timer plug on rear of scaler, and one 4 foot length of RG-58/U coaxial cable equipped with General Radio type 274-M double plug for attachment to oscilloscope viewing jack on scaler.

Weight:
12 pounds

Price:
F.O.B. Boston $75.00

FOREIGN DISTRIBUTORS

Austria:
Otto Hardung,
Kohlgasse 33,
Vienna, Austria.

Denmark:
Torben Soderberg,
12, N Y Ostergade,
Copenhagen, Denmark.

Greece:
K. Karayannis & Co.,
Karitsi Square,
Athens, Greece.

India:
Raj-der-Kar & Co.,
Commissariat Building, Hornby Road,
Fort-Bombay, India.

Norway:
Aksjeselskapet Proton,
Rosenkrantzgen 11,
Oslo, Norway.

South Africa:
A. F. H. Devors & Co. (Pty.) Ltd.,
3, Village Road, Selby,
Johannesburg, South Africa.

Spain:
Compania para la Fabricacion de
Contradores y Material Industrial
Apartado 159
Barcelona 8, Spain

Belgium:
Bureau d'Etudes E. R. V. A.,
215, Avenue Brugmann,
Brussels, Belgium.

France:
Saphymo,
9, Place des Etats-Unis,
Paris 16, France.

Holland:
Adr. van der Kuip,
Oude Gracht 258,
Utrecht, Holland.

Italy:
Ing. S. Belotti & Co. S. A.,
Piazza Trento 8,
Milan VII, Italy.

Portugal:
Equipamentos de Laboratorio Lda.,
Apartado 458,
Lisbon, Portugal.

Sweden:
LKB-Produkter
Fabriksaktiebolag,
Stockholm 12, Sweden.

Switzerland:
Seyffer & Co., Inc.,
Kanzleistrasse 126,
Zurich 4, Switzerland.

AUTHORIZED SERVICE STATIONS

Colorado:	Technical Equipment Corp., P. O. Box 11, Highlands Station, Denver 11.
Eastern Canada:	Electrodesign, 445 St. Peter Street, Montreal, Quebec.
Illinois:	Television Engineers, Inc., 1539 West Harrison St., Chicago 7.
Louisiana:	Delta Electronic Equipment Co., P. O. Box 476, New Orleans.
Missouri:	Industrial Service Laboratories, 1602 Locust St., St. Louis 3.
New York:	Video Television, Inc., 239 E. 127 Street, New York.
Pennsylvania:	J. F. Griffin & Co., 1431 North Fifth St., Philadelphia 20.
Southern California:	Dawkins Espy Electronic Corporation, 11747 West Pico Blvd., Los Angeles 34.
Texas:	Southwestern Industrial Electronic Co., P. O. Box 13058, Houston 19.

TRACERLAB PRODUCTS AND SERVICES

Catalog No.		
SU-1B	Radiation Survey Meter	$275.00
SU-3A	Laboratory Monitor with TGC-1 G-M Tube	275.00
SU-4A	Radioactivity Demonstrator with G-M Tube	112.50
SU-5	Beta-Gamma Survey Meter	235.00
SU-7	Ore Detector	112.50
SC-1B	Autoscaler with Preamplifier	650.00
SC-2A	The "64" Scaler	355.00
SC-3A	Duoscale $20 ea., 6 for	100.00
SC-4	Eagle Preset Counter	80.00
SC-5A	Printing Interval Timer	450.00
SC-6A	Automatic Sample Changer	950.00
SC-7	The "100" Scaler	425.00
SC-8	Autoscaler Cart	38.00
SC-9C	Shielded Manual Sample Changer	200.00
SC-10A	Radioassay Sample Holder	60.00
SC-11	Decascale	50.00
SC-12	Discriminator Input Circuit	35.00
SC-13	Radioactive Ore Analyzer	200.00
SC-17	Mechanical Register	175.00
SC-25	Eagle Automatic Timer	75.00
P-4	Preamplifier for TGC Tubes	25.00
P-5	Tube Mount for TGC Tubes	12.50
P-6	Short Lead Medical Shield	27.50
P-7	Long Lead Medical Shield	37.50
P-12	Alpha Scintillation Detector	135.00
V-1	Victoreen Minometer	160.00
V-2	Victoreen Pocket Dosage Meter	12.50
SM 60A	Electric Timing Clock	55.00

G-M Tubes

TGC-1	Tracerlab G-M Tube, 3-4 mg/cm², mica window	37.50
TGC-2	Tracerlab G-M Tube, less than 2.0 mg./cm², mica window	47.50
TGC-3	Mica Window X-ray GM tube with Be and Cu filters	87.50
TGC-3A	Mica Window X-ray GM tube without filters	47.50
TGC-4	Glass Gamma G-M Tube	12.00
TGC-5	Glass Beta-Gamma G-M Tube	14.00
TGC-6	Small Glass Beta-Gamma G-M Tube with 3 pin base	10.50

Equipment

Catalog No.		
E-1	Sample Trays (8½" x 11")	1.50
E-2A	Sample Storage Cabinet	25.00
E-3A	Aluminum Absorbers	50.00
E-4A	Flat Copper Planchets	10.00/M
E-5	Cupped Planchets	2.00/C
E-6	Ashing Dishes, $.50 ea.	5.00/dz.
E-7	Brass Ring and Disc, $1.25 ea.	12.00/dz.
E-8A	Precipitation Apparatus	15.00
E-10	Decay Charts	1.00
E-11	Lead Brick	9.60
E-12	Rectangular Lead Container (2" wall 4" x 4" x 6" I.D.)	135.00
E-13A	Rectangular Lead Container (1" wall 6" x 6" x 8" I.D.)	90.00
E-14	Rectangular Lead Container (½" wall 7" x 7" x 9" I.D.)	60.00
E-15	Cylindrical Lead Container (1" wall 2 1/16" x 4⅝" I.D.)	25.00
E-16	Electroplating Cell	15.00
E-17	Remote Handling Tongs	35.00
E-18A	Remote Pipetting Device	75.00
E-19	Planchet Holders	2.50/dz.
E-20	Stainless Steel Cupped Planchets	5.00/C
E-21A	Copper Planchets for R11 & R12	10.00/M
E-22A	Aluminum Absorbers for R11 & R 12	5.00/C
E-23A	Full Interlocking Lead Brick	10.00
E-23B	Half Interlocking Lead Brick	7.50
E-23 C, D, E, F	Interlocking Lead Bricks 90° & 120° Corners, Male and Female Ends	5.00 ea.
E-24	Stainless Steel Flat Planchets	3.00/C
E-26	Plastic Shield (9½" x 12")	8.50
E-27	Plastic Shield (12" x 19½")	12.50
E-28	Plastic Shield (19½" x 24½")	20.00

Radioactive Reference Sources

R-1	Calibrated Radiocobalt Beta	15.00
R-2	Uncalibrated Radiocobalt Beta	7.50
R-3	Calibrated Radiolead Beta	15.00
R-4	Uncalibrated Radiolead Beta	7.50
R-5	Calibrated Uranium X Beta	15.00
R-6	Uncalibrated Uranium X Beta	7.50
R-7	Calibrated Radiocobalt Gamma	15.00
R-8	Uncalibrated Radiocobalt Gamma	7.50
R-10	Uncalibrated Radiocarbon Beta	7.50
R-11	Simulated I-131 Reference Source Set	50.00
R-12	Simulated P-32 Reference Source Set	50.00
R-30	1 Millicurie Cobalt-60 Source	40.00

Tagged Chemicals

About 400 Inorganic and Organic Compounds Tagged with Radioactive Isotopes are available from stock. Catalog B contains a complete list.

Beta Gauges

Price information on absorption and back-scattering type Beta Gauges is available upon request.

Complete descriptions of all Tracerlog products are contained in Catalog B and past issues of Tracelog which are available on request.

Add 10% for Foreign orders. All prices quoted F. O. B. Boston. Prices subject to change without notice.

SALES OFFICES

Chicago: Tracerlab, Inc., 221 North LaSalle St., Chicago, Ill., Franklin 2-4197.

New York: Tracerlab, Inc., 1775 Broadway, New York 19, Plaza 7-6133.

Western Division: Tracerlab, Inc., 2295 San Pablo Ave., Berkeley 2, California, Thornwall 3-2527.

TRAINING PROGRAM: Important Topics

- Self Assessment -

1. The ratio of proton mass to electron mass is approximately:

   (a) 1000/1; (b) 2000/1; (c) 3000/1

2. An isotope has a constant number of:

   (a) neutrons; (b) protons; (c) nucleons

3. If there is an excess of neutrons, the radioactive emission will be:

   (a) positive beta; (b) negative beta; (c) neutron

4. As the wavelength of a photon increases, the energy:

   (a) increases; (b) decreases; (c) remains unchanged

5. Given the same energy, an alpha particle produces ______ ionization than an electron:

   (a) more; (b) less; (c) the same

6. The primary advantage of Sr-90 over that of Radium and Radon is that Sr-90 has:

   (a) betas only; (b) gammas only; (c) both

7. Roentgen equivalent betas (reb's) _______ to rads, the absorbed dose unit.

   (a) are equal; (b) are not equal; (c) unrelated

8. Percent Depth Dose relates:

   (a) the dose at the tissue surface to the exposure at the applicator surface.

   (b) the dose at any depth to the dose at the tissue surface.

   (c) parity and inflation in supply side economics.

9. Of the two betas from a Sr-90 applicator, the more penetrating is the energy of:

   (a) 0.55 MeV; (b) 2.27 MeV; (c) a 60/40 percent combination

SELF-EVALUATION QUESTIONS: True or False

Exposure and Absorbed Dose Units

The Rad is a measure of absorbed energy while the Roentgen is a measure of ionization produced in a volume. T___ F___

When dealing with alpha particles, the dose equivalent (rem) is approximately the same as the absorbed dose (rad). T___ F___

The natural background radiation in the mountains is higher than at sea level. This may account for altitude sickness. T___ F___

For high energy photons with energies above 3 MeV, the roentgen and rad are no longer equivalent. This is because the electrons released in the target mass do not deposit all their energy in that same mass. T___ F___

SELF-EVALUATION QUESTIONS: Match each characteristic with one or both of the survey meter types.

Survey Meters	Characteristics
(a) Ion Chamber	___ filled with air.
(b) Geiger Mueller Tube	___ filled with noble gas.
	___ requires ultra-thin window to detect charged particles.
	___ biased at 600 V.
	___ biased at 1200 V.
	___ measures exposure reliably.
	___ increased sensitivity because of "avalanche" principle.
	___ requires calibration at 6-month intervals.
	___ suitable for determining exposure rate around ^{90}Sr applicator.

G L O S S A R Y   O F   T E R M S

Roentgen -	The unit of exposure, which is a measure of the ionization produced in air by x-rays.
mR -	milliroentgen; 1/1000 of a Roentgen.
rad -	The unit of absorbed dose equal to 100 ergs of any kind of energy absorbed 1 gram of any kind of material. The exposure in Roentgens can be converted to the absorbed dose in rads by use of the Roentgens to rad f factor.
mrad -	millirad; 1/1000 of a rad.
rem -	The unit of dose equivalent, a quantity used in radiation protection work. The rad is modified by a quality factor (QF) to convert it to a rem where the QF takes into account the difference in biological effectiveness. Because neutrons, for example, are 10 times more efficient in producing biological damage to the lens of the eye than x-rays, the QF = 10 and 1 rad of neutrons = 10 rems. For x-rays and most electron energies, QF = 1.
mrem -	millirem; 1/1000 of a rem.
Curie -	The unit of activity. One Curie is defined as 37 billion disintegrations per second.
mCi -	millicurie; 1/1000 of a Curie.
μCi -	microcurie; 1/1,000,000 of a Curie or 37,000 disintegrations per second.
NCRP -	National Council on Radiation Protection; makes, among other things, recommendations in the field of radiation protection.
ICRU -	International Commission on Radiation Units and Measurements; makes, among other things, recommendations in the field of radiation protection.
Maximum Permissible Dose -	The maximum dose equivalent that the body of a person, or specific parts thereof, shall be allowed to receive in a stated period of time.

Exposure	Tissue	Mammal	Effect
100 rads	Bone Marrow	Human	Neoplasia
	Stomach	Human	Neoplasia
	Lung	Human	Neoplasia
	Breast	Human	Neoplasia
50-100 rads	Fetus	Human	Mental retardation and reduced head size
50 rads	Skin	Human	Chromosome aberrations
50 rads	Testis	Human	Temporary sterility
50 rads	Ovary	Human	Temporary sterility
25 rads	Testis	Human	Transient reduction of sperm count
25 rads	Embryo and fetus	Mouse & rat	Neuroskeletal developmental abnormalities
10 rads	Lens	Mouse	Cataract
10 rads	Lymphocytes	Human	Bilobe nuclear abnormality
5 rads	Leukocytes	Human	Chromosomal aberrations
3 rads	Testis	Immature mouse	Temporary depression of spermatogonia
3 rads	Ovary	Immature mouse	Oocytes
2-4 rads	Fetus	Human	Childhood leukemia and other neoplasms

The purpose of this section is not to draw conclusions, but to give some indication of the criteria on which modern radiation protection is based. For a further examination, the reader is referred to NCRP Report No. 39 entitled, "Basic Radiation Protection Criteria" and Eric Halls' book entitled, "Radiobiology For the Radiologist" (Harper & Row, 1973).

D. Current Recommendations Regarding Dose Limitations

The following is an excerpt from NCRP Report No. 39, "Basic Radiation Protection Criteria" that is designed to inform with regard to the NCRP's position on dose limits applicable to individual members of the public.

TABLE 1

Dose-limiting recommendations for occupational exposure from NCRP Report No. 39 entitled, "Basic Radiation Protection Criteria."

Category	Maximum Permissible Dose Equivalent
1. Whole body long-term accumulation to age N years	(N - 18) x 5 rems*
2. Skin	15 rems in any one year
3. Hands	75 rems in any one year
4. Forearms	30 rems in any one year
5. Other organs, tissues and organ system	15 rems in any one year
6. Fertile women	0.5 rem in gestation period
7. General public	0.5 rem in any one year
8. Family of radioactive patients	
a. Individuals under 45	0.5 rem in any one year
b. Individuals over 45	5 rems in any one year

* This is an average of 5 rems per year.

SUGGESTED GENERAL REFERENCES

1. "Medical Radiation Biology," by Pizzarello and Witcofski; Lea and Febiger, Philadelphia, 1972.

2. "Medical Radiation Biology," by Dalrymple-Gaulden-Kollmorgen-Vogel; W.B. Saunders Company, Philadelphia·London·Toronto, 1973.

3. "Radiobiology for the Radiologist," by Hall; Harper and Row, New York·Evanston·San Francisco·London, 1973.

4. "Radiation Exposure in Pregnancy," by Brent and Gorson, in "Current Problems in Radiology," Vol. II, Number 5, Year Book Medical Publishers, Inc., Chicago; September-October 1972.

5. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, Division of Medical Sciences, National Academy of Sciences, National Research Council, Washington, D.C. 20006, 1972.

6. "Ionizing Radiation: Levels and Effects," A Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, Volume II: Effects, United Nations, New York, 1972.

7. "Your Body and Radiation," Frigerio; U.S. Energy Research and Development Administration, Technical Information Center, Oak Ridge, Tennessee 37830, 1967.

8. "The Genetic Effects of Radiation," Asimov and Dobzhansky, U.S. Energy Research and Development Administration, Technical Information Center, Oak Ridge, Tennessee 37830, 1966.

9. "Basic Radiation Protection Criteria," National Council on Radiation Protection and Measurements, Washington, D.C., 1971.

10. "Radiation Protection for Radiologic Technologists," by Frankel; McGraw-Hill, New York, 1976.

☆U.S. GOVERNMENT PRINTING OFFICE: 1979 O—633-471/407 REGION 3-1

Health Physics Vol. 36 (June) pp. 707-722
Pergamon Press Ltd., 1979. Printed in Great Britain

A CATALOG OF RISKS

BERNARD L. COHEN and I-SING LEE
Department of Physics and Astronomy, University of Pittsburgh,
Pittsburgh, PA 15620

Table 16. − ΔE(M, Q), increase of life expectancy in years relative to all white males for special groups

Group	Age range				
	40–55	55–70	70–85	85–∞	40–∞
Corporation executives	0.16	0.81	1.8	2.2	4.7
Business executives	0.25	1.1	1.2	0.15	4.3
Baseball players	0.13	0.57	1.0	0.96	2.9

Table 17. Average lifetime of twentieth century U.S. political leaders as compared with contemporary U.S. white males

Office	Additional longevity (yr)
Presidents	−5.1
Mayors of New York City	−1.3
Congressmen	+0.2
Senators	+0.4
Governors	+0.3
Supreme Court Justices	+1.4

Table 21. Loss of life expectancy due to catastrophic events, averaged over the U.S. population

Catastrophic events	Total lost life expectancy (days)
Hurricanes	0.3
Tornadoes	0.3
Earthquakes	0.1
Airline crashes (passengers)	1.0
Airline crashes (people on ground)	0.1
Major explosions	0.2
Dam failures	0.3
Major fires	0.3
Chemical releases	0.1
Nuclear reactor accidents	
within following 50 years	0.02–2*
noticeable, within first year	0.0004–0.1*

*Assumes all U.S. power nuclear. First figure from Rasmussen Report, second figure from Union of Concerned Scientists.

Table 22. Average number of years between catastrophes of given type which cause 1000 or more fatalities

Type catastrophe	Av. years between
Hurricanes	20
Earthquakes	40
Air pollution episodes	20
Dam failures	50
Explosions	150
Fires	200
Poison gas releases	1000
Airline crash	5000
Nuclear plants (400 GW)	
fatalities within months	200,000–1000*
fatalities within 50 yr	500–10 (?)*

*First numbers are from Rasmussen Study; second numbers from Union of Concerned Scientists. The 10 (?) is based on their estimate of one meltdown every 5 yr; to produce many fatalities, such a meltdown must be followed by a containment failure, the probability of which they do not estimate but we take their estimate to be 50%.

Table 26. Loss of life expectancy (ΔE) due to various causes

Cause	days
Being unmarried—male	3500
Cigarette smoking—male	2250
Heart disease	2100
Being unmarried—female	1600
Being 30% overweight	1300
Being a coal miner	1100
Cancer	980
20% Overweight	900
< 8th Grade education	850
Cigarette smoking—female	800
Low socioeconomic status	700
Stroke	520
Living in unfavorable state	500
Army in Vietnam	400
Cigar smoking	330
Dangerous job—accidents	300
Pipe smoking	220
Increasing food intake 100 cal/day	210
Motor vehicle accidents	207
Pneumonia—influenza	141
Alcohol (U.S. average)	130
Accidents in home	95
Suicide	95
Diabetes	95
Being murdered (homicide)	90
Legal drug misuse	90
Average job—accidents	74
Drowning	41
Job with radiation exposure	40
Falls	39
Accidents to pedestrians	37
Safest jobs—accidents	30
Fire—burns	27
Generation of energy	24
Illicit drugs (U.S. aver.)	18
Poison (solid, liquid)	17
Suffocation	13
Firearms accidents	11
Natural radiation (BEIR)	8
Medical X-rays	6
Poisonous gases	7
Coffee	6
Oral contraceptives	5
Accidents to pedalcycles	5
All catastrophes combined	3.5
Diet drinks	2
Reactor accidents—UCS	2*
Reactor accidents—Rasmussen	0.02*
Radiation from nuc. industry	0.02*
PAP test	−4
Smoke alarm in home	−10
Air bags in car	−50
Mobile coronary care units	−125
Safety improvements 1966–76	−110

*These items assume that all U.S. power is nuclear. UCS is Union of Concerned Scientists, the most prominent group of nuclear critics.

Table 25. Days of life expectancy added by various actions

Action	Added life exp. (days)
Using seat belts	50
Installing air bags in car	50
Buying larger cars*	50
Smoke alarm in home	10
Training family in resuscitation	≥100
Annual PAP test	4

*Standard rather than sub-compacts, or large rather than standard.

Table 27. Risks in individual actions

Individual action	Minutes life expectancy lost
Smoking a cigarette	10
Calorie-rich dessert	50
Non-diet soft drink	15
Diet soft drink	0.15
Crossing a street	0.4
Extra driving	0.4/mile
Not fastening seat belt	0.1/mile
1 mrem of radiation	1.5
Coast to coast drive	1000
Coast to coast flight	100
Skipping annual PAP test	6000
Moving to unfavorable state	800,000
Buying a small car	7000
Choose Vietnam army duty	600,000

ESTIMATED LOSS OF LIFE EXPECTANCY FROM HEALTH RISKS

Health Risk	Estimates of Days of Life Expectancy Lost, Average
Smoking 20 cigarettes/day	2370 (6.5 years)
Overweight (by 20%)	985 (2.7 years)
All accidents combined	435 (1.2 years)
Auto accidents	200
Alcohol consumption (U.S. average)	130
Home accidents	95
Drowning	41
Safest jobs (such as teaching)	30
Natural background radiation, calculated	8
Medical X-rays (U.S. average), calculated	6
All catastrophes (earthquake, etc.)	3.5
1 rem occupational radiation dose, calculated (industry average is 0.34 rem/yr)	1
1 rem/yr for 30 years, calculated	30
5 rems/yr for 30 years, calculated	150

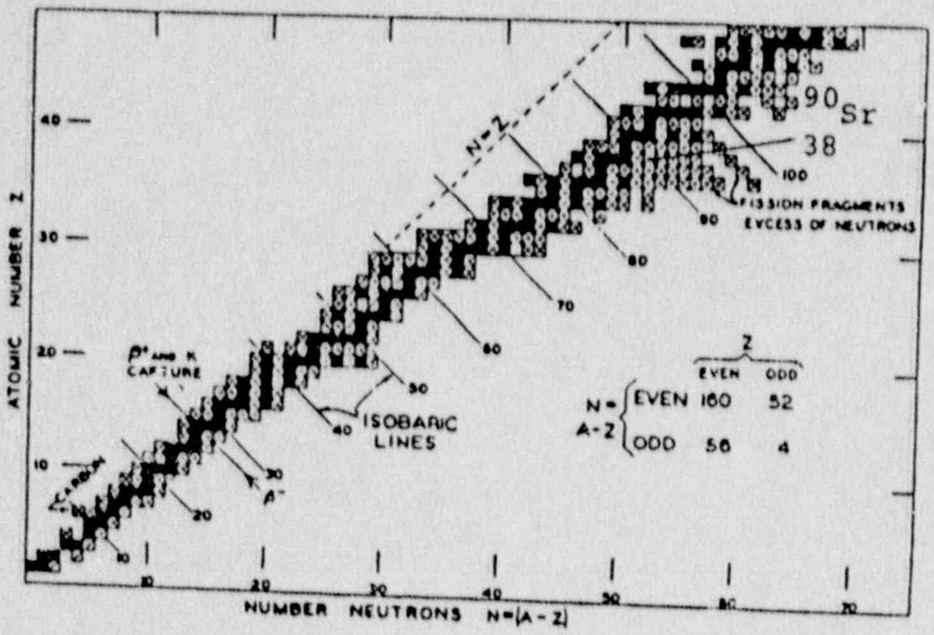
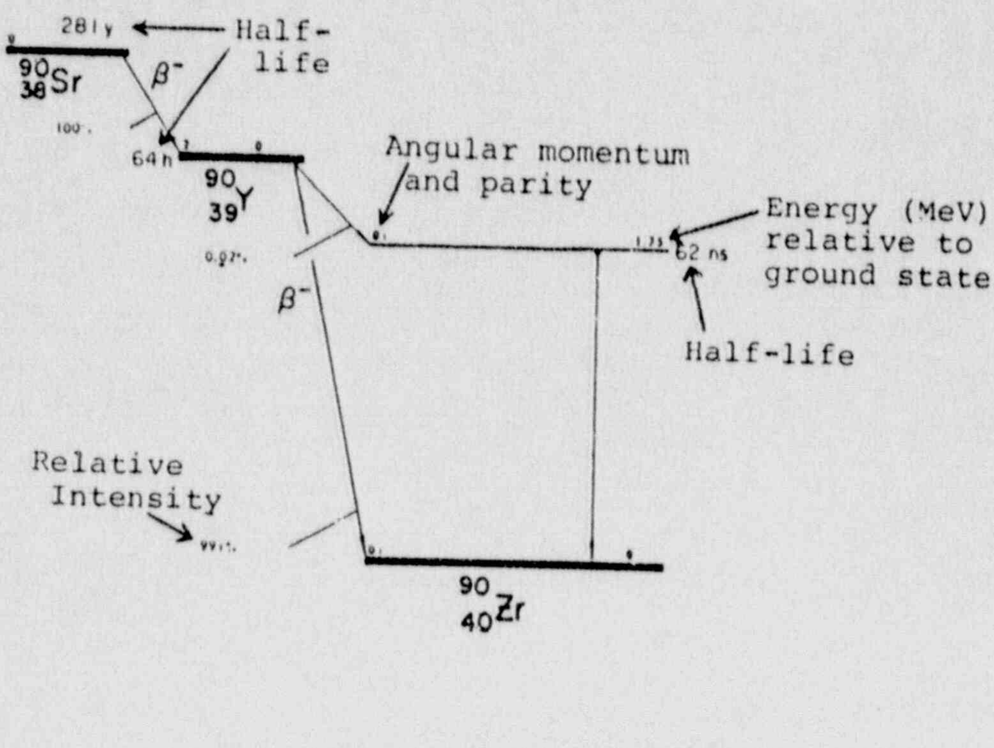
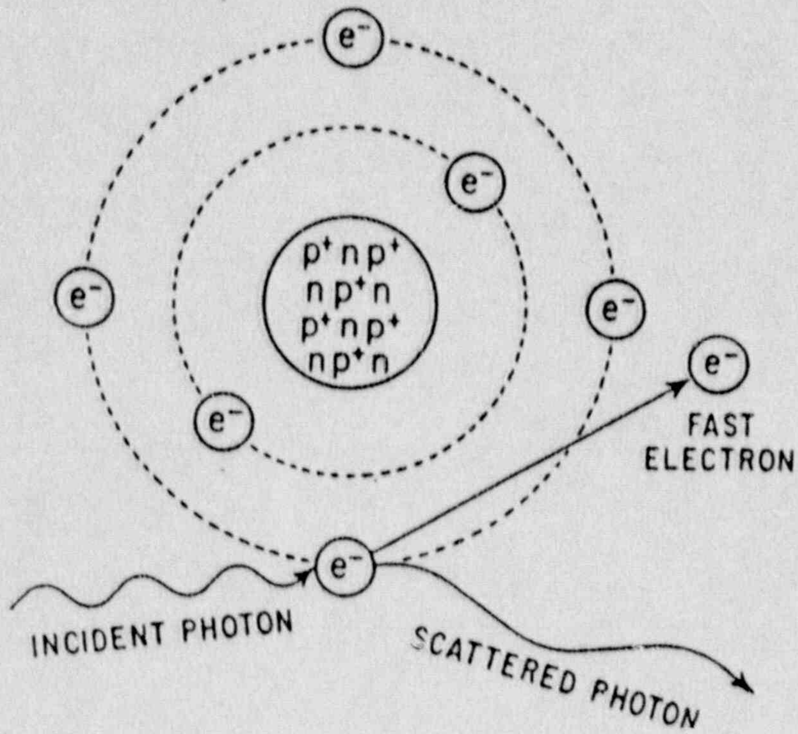


Chart showing the proportion of protons and neutrons in nuclei. Stable nuclei are represented by solid squares, radioactive nuclei by crosses. Nuclei with equal numbers of neutrons and protons lie along the N=Z line.

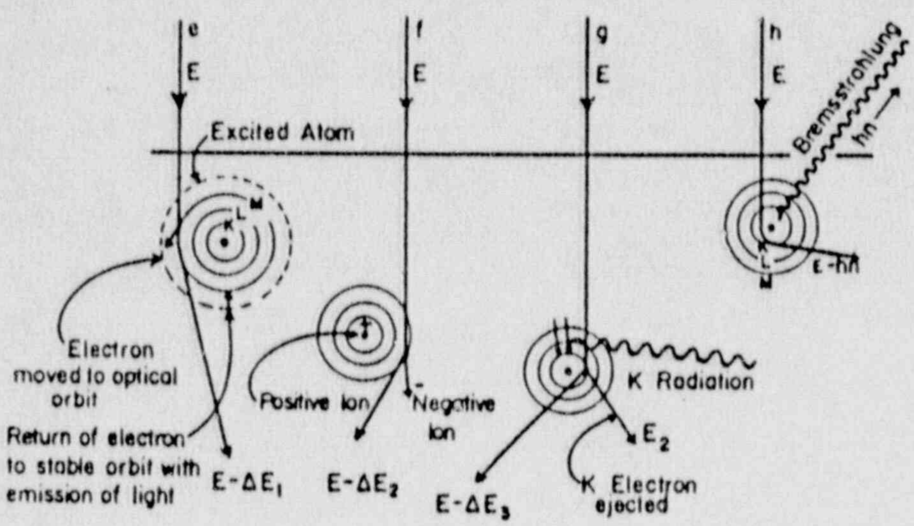


TRAINING PROGRAM: Energy Deposition

- Photons -



- Electrons -



REPRESENTATIVE EXPOSURES

Exposure	Significance
0.100 R/year	Background Radiation in Honolulu
0.200 R/year	Background Radiation in Denver
0.020 R/exposure	Typical Skin Exposure for Chest X-Ray
0.600 R/exposure	Typical Skin Exposure for Abdominal X-Ray
0.500 R/year	Limit for Occupational Exposure of Whole Body
1 R/exposure	Risk of Cancer 1 in 50,000
20 R/exposure	Leukemia Induction
100 R/exposure	Mild Irradiation Sickness
500 R/exposure	Temporary Loss of Hair
600 R/exposure	Radiation Cataract
2000 R/7 days	Threshhold Erythema
4500 R/5 weeks	Treatment of Radiosensitive Tumor

TRAINING PROGRAM: Dosimetry

Conversion From reb/sec to rads/sec For Sr-90 Beta Applicators:

Dose Rate in Tissue (rads/sec) = $f \times (S_w/S_a)$

$\times$ Exposure Rate (reb/sec)

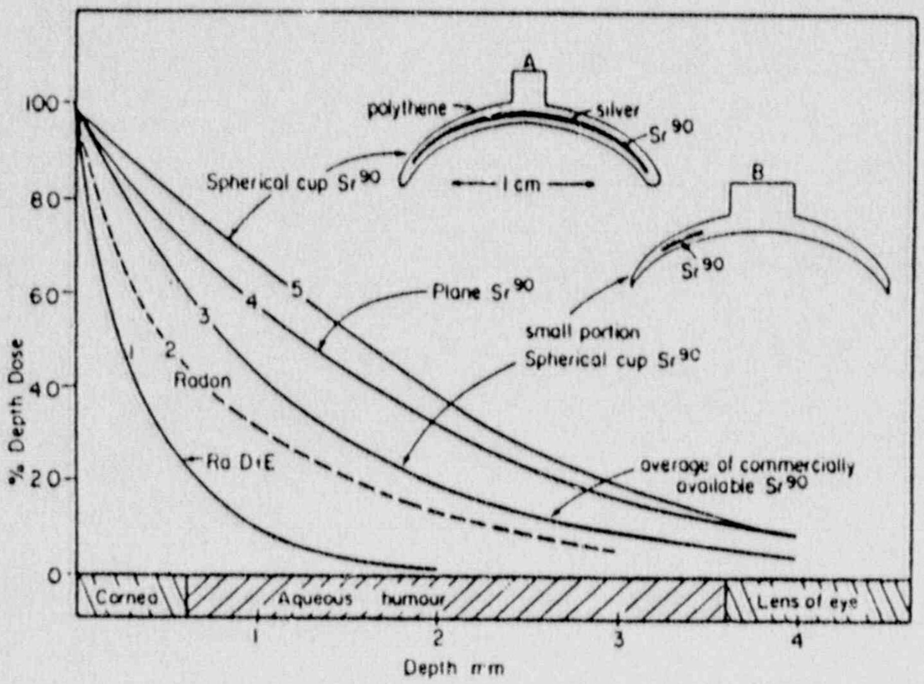
= $\underbrace{0.87 \times 1.13}_{0.98} \times$ Exp. Rate (reb/sec)

where --

f = Roentgen to rad conversion factor for air

S_w= Mass stopping power in water for 2.27 MeV betas

S_a= Mass stopping power in air for 2.27 MeV betas



Depth dose for beta applicators. Curve 1, RaD + RaE; Curve 2, Radon - average of 3 applicators; Curve 3, ^{90}Sr - average of 9 commercially available applicators, also for the type 4, 6 mm circular spot on spherical shell; Curve 4, ^{90}Sr - plane applicator 16 mm diameter; Curve 5, ^{90}Sr - spherical cup, 20 mm diameter.

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TRAINING PROGRAM: Dosimetry

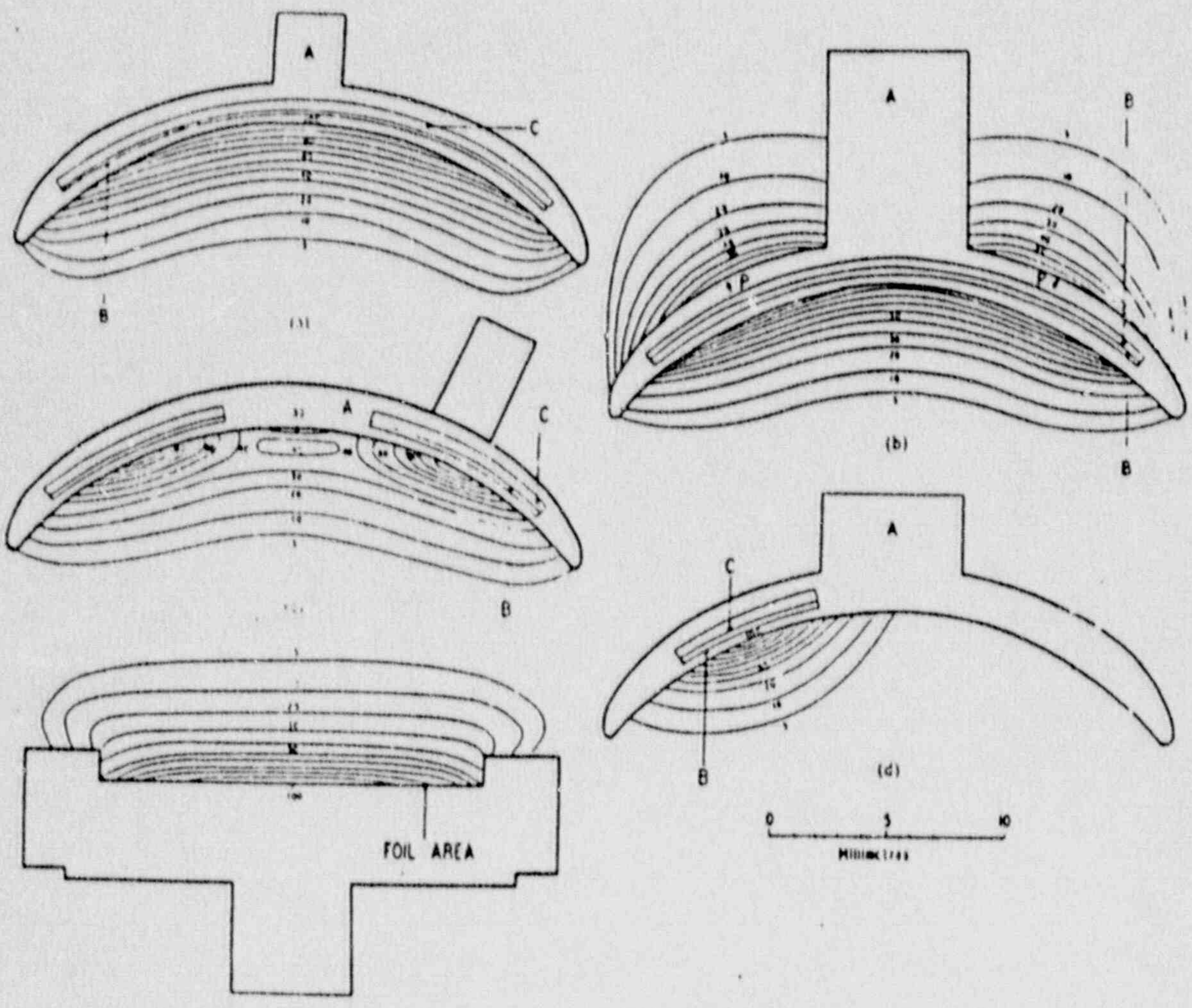
Calculation of Treatment Time:

Treatment Time (seconds) =

$$\frac{\text{Dose At Depth d}}{(\%DD(d)/100) \times \text{Surface Tissue Dose Rate (rads/sec)}}$$

where --

%DD(d) = Percent Depth Dose at depth d



Dose rate distribution in tissue in contact with Sr-90 foil applicators. Dose rates for particular curves are expressed as percentages of the surface dose rate at a convenient point. For each diagram: A-plastic only; B-active foil; C-silver foil.

SUGGESTED READING LIST:

1. "An Evaluation of the Clinical Use of a Strontium-90 Beta-Ray Applicator With a Review of the Under-lying Principles" by H. L. Friedell, C. I. Thomas, and J. S. Krohmer. Amer. J. Roentgen, 71(1954)25.

2. "Physical Study of Strontium-90 Beta Ray Applicator" by S. J. Supe, and J. R. Cunningham. Amer. J. Roentgenal., Rad. Therapy & Nuclear Medicine, 89(1963)570.

TRAINING PROGRAM FOR
PROSPECTIVE AUTHORIZED USERS OF
Sr-90 OPHTHALMIC EYE APPLICATORS

A. Radiation Physics & Instrumentation (6 hours):

1. Review of atomic/nuclear structure.
2. Physics of ionization, excitation and energy deposition.
3. Detection of atomic/nuclear radiations.
4. Exposure and absorbed dose units.
5. Physical description and dosimetry of beta ray applicators.
6. Physics of clinical applications.

B. Radiation Protection (6 hours):

1. Units, nomenclature and their use in expression of protection formalism.
2. Criteria of radiation safety.
3. Data base for human biological effects from radiation exposure.
4. Recommendation/regulation sources and assumptions.
5. Summary of biological effects.
6. Risks from radiation exposure and its comparison with other environmental insults.

C. Mathematics Pertaining to the Use and Measurement of Radioactivity:

1. Review of basic algebra.
2. Review of the use of graphs.
3. Simple inverse and inverse square proportion.
4. Exponential decay, use of half-life, average life, etc.

D. Radiation Biology:

1. Biological interaction of radiation with tissue.
2. Cell survival curves.
3. Oxygen effect.
4. Radiosensitivity, cell age in mitotic cycle.
5. Dose fractionation and repair.
6. LET and RBE
7. Tumor/normal tissue response to radiation and complications.

action of beta rays with matter. Thus, from a health point of view this Medical Applicator must be considered as a high intensity source of beta radiation and a low intensity source of X-rays. A radiation survey of the Medical Applicator under typical conditions of usage and storage is presented below. These data were obtained with Tracerlab SU-1H Portable Radiation Survey Meter. They are only approximate and are presented solely for informational purposes.

Medical Applicator Housed in the Storage Box (see Figure 2)

Left side of storage box (adjacent to shield).

	40 mc	100 mc
Beta Radiation -	none	none
X-Radiation -	5 mrem/hr	12 mrem/hr

All other surfaces of storage box:

Beta Radiation -	none	none
X-Radiation -	<1 mrem/hr	3 mrem/hr

1 ft. away from storage box:

Beta Radiation -	none	none
X-Radiation -	none	<1 mrem/hr

Medical Applicator in Auxilary Housing (with plexiglas shield adjacent to housing)

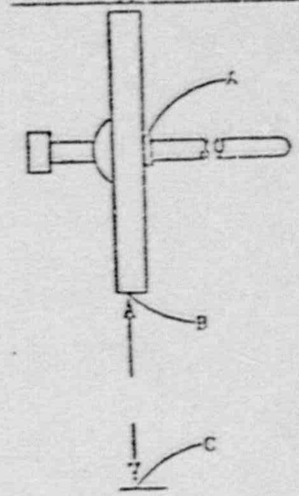
Surface of auxilary housing

	40mc	100 mc
Beta Radiation -	none	none
X-Radiation -	3 mrem/hr	25 mrem/hr

1 ft. away

Beta Radiation -	none	none
X-Radiation -	0.05 mrem/hr	3 mrem/hr

Medical Applicator in Air



Position A (In Back of Shield)

	40 mc	100 mc
Beta Radiation	none	none
X-Radiation	8 mrem/hr	20 mrem/hr

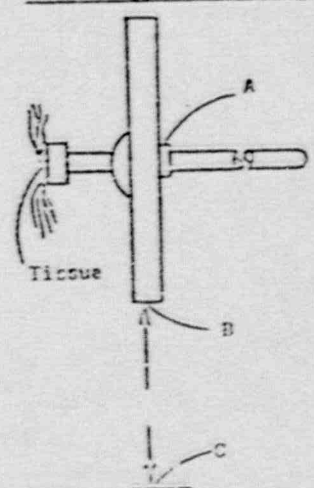
Position B (Adjacent to Edge of Shield)

	40 mc	100 mc
Beta Radiation (Scattered)	400 mrem/hr	1000 mrem/hr
X-Radiation	12 mrem/hr	40 mrem/hr

Position C (1ft. from Edge of Shield)

	40 mc	100 mc
Beta Radiation (Scattered)	50 mrem/hr	125 mrem/hr
X-Radiation	0.05 mrem/hr	10 mrem/hr

Medical Applicator in Usage



Position A

	40mc	100 mc
Beta Radiation	none	none
X-Radiation	10 mrem/hr	20 mrem/hr

Position B

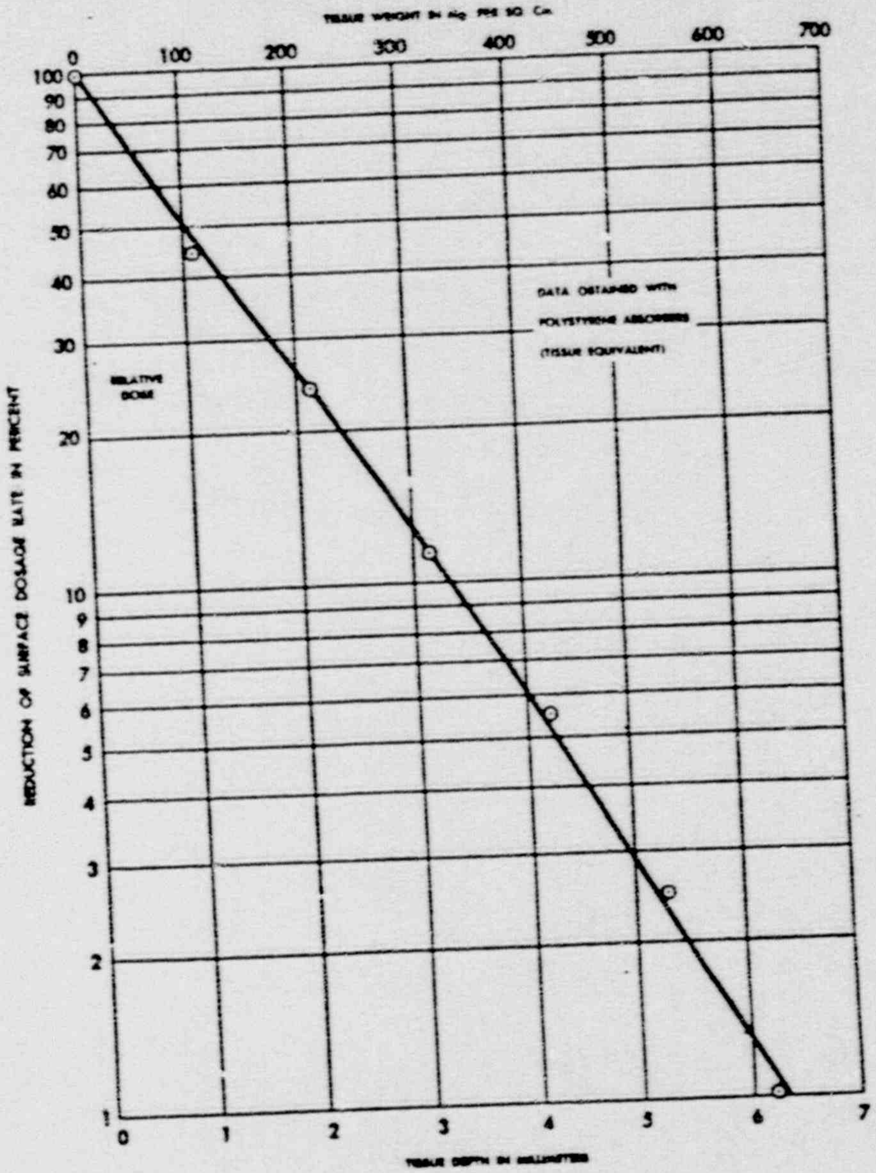
	40mc	100 mc
Beta Radiation (Scattered)	240 mrem/hr	800 mrem/hr
X-Radiation	15 mrem/hr	50 mrem/hr

Position C

	40 mc	100 mc
Beta Radiation (Scattered)	6 mrem/hr	14 mrem/hr
X-Radiation	0.05 mrem/hr	0.5 mrem/hr

FIGURE 5

PERCENT REDUCTION OF SURFACE DOSAGE RATE OF THE MEDICAL APPLICATOR AS A FUNCTION OF TISSUE DEPTH



Thus, for example, if 0.9 gram of tissue completely absorbs the beta particles (0.7 mev average energy) emitted by one millicurie (37×10^6 betas per sec.) of yttrium-90, the dosage rate is

$$\frac{37 \times 10^6 \times 0.7 \text{ mev}}{0.9 \text{ gm}}/\text{sec.} = 28.8 \times 10^6 \text{ mev/gm-sec.}$$

OR

$$0.55 \text{ rep/sec.}$$

This computation states nothing about the distribution of the dosage rate as a function of tissue depth. If the one millicurie of yttrium-90 were uniformly distributed throughout the 0.9 gram, the tissue would be receiving a uniform dosage of 0.55 rep per second throughout. If the yttrium-90 were a plaque placed on the surface of the tissue, the rep dosage rate would be greatest at the front surface and would be essentially zero at a depth of 9mm. For this case the measurement of the rep dosage rate as a function of tissue depth cannot be determined directly by an simple means. What can be experimentally ascertained is a quantity which is a simple extension of the definition of the roentgen and which has been designated by Lea[3] as a roentgen-equivalent-beta. This quantity can be quantitatively related to the rep, provided that the respective dissipation of the energy of the beta rays in air and tissue are identical. It is unfortunate that this needless ambiguity exists.

Roentgen-equivalent-beta

A roentgen (r) is a measure of the resultant ionization produced by secondary electrons in standard air, the electrons resulting from the interaction of air with gamma radiation. If the quality of ionization is such that one electrostatic unit of charge is produced per cc of dry air at 0°C and 760 mm Hg (Standard air) then that quantity of ionization is one roentgen (1 r).

Lea[3] has extended this definition to include beta radiation by defining one roentgen-equivalent-beta as that quantity of beta radiation which in passage through standard air produces by ionizing the air one electrostatic unit of charge per cc. From this basic definition, it can be computed that

(3) 1 Roentgen-equivalent-beta = 2.08×10^9 ion pairs per cc of standard air

(4) 1 roentgen-equivalent-beta per sec. = 3.33×10^{-10} amperes per cc of standard air

I INTRODUCTION

A. General

The Medical Applicator, shown in Figure 1, is a beta emitting plaque which contains the radioactive nuclides strontium-90 in equilibrium with yttrium-90. It has been designed for the therapeutic usage by qualified physicians primarily for certain diseases of the eye. It, however, can be used as a localized source of beta radiation for other surface irradiations whenever a low degree of tissue preparation is desired.

Strontium-90 has a half-life of 28.5 years and disintegrates through the emission of a beta particle with maximum energy of 0.65 million electron volts to form yttrium-90. Yttrium-90 has a half-life of 62 hours and emits beta particles with a maximum energy of 2.16 mev to form the stable isotope of zircondum, namely zircondum-90. No significant gamma radiation is present. Thus it can be seen that a plaque containing strontium-90 is a source of pure beta radiation with two continuous spectra, namely that of strontium-90 and yittrium-90 respectively, and has a half-life of 28.5 years. This means that in about 28.5 years the intensity of radiation which is emitted by the plaque will be one-half of its present value. The number and origin of the beta particles emitted from the surface of the plaque and the radiation intensity resulting therefrom are dependent upon the millicurie strength, area of the radioactive deposit, and the degree of filtration which results from the metallic protective covering. This protective covering (approximately 100 mg. per sq. cm.) is sufficient to reduce the number of beta particles which result from the disintegration of strontium-90 and yttrium-90 to approximately 3% and 60% of their original value, respectively. Thus it can be seen that the beta particles being emitted from this plaque will have essentially the characteristics of a pure yttrium-90 spectrum after it is passed through 100 mg. per sq. cm. of filtration.

B. Therapy

It is well known that the biological effect of nuclear radiation is due to its ionizing effect. In the case of gamma - or X-rays, this ionization is not produced by the rays per se. In the passage of this radiation through matter, the gamma ray interacts primarily through Compton effect and imparts an appreciable fraction of its energy to an orbital electron. This energy appears as kinetic energy (electron translational motion). This electron loses its kinetic energy in passing through matter and finally comes to rest. An appreciable fraction of this loss of kinetic energy results in ionization and it is the production of these ion pairs in biological material which results ultimately in pathological changes. The precise mechanism by which these biological effects are brought about,

due to the presence of ion pairs, is yet unknown. The therapeutic value of such radiation probably depends upon one or both of the following: increased sensitivity to ionization of diseased cells and thus preferential destruction over normal cells; the fact that upon the partial or complete destruction of tissue cells the recovery mechanism of the tissue is such that predominantly normal cells will be regenerated.

In the case of beta radiation (high speed electrons), the ionization is produced directly through the slowing down and ultimate stoppage of these particles in matter, in a manner identical with that of the secondary eleccrons described above. Thus, any biological differences to be expected from the effects of either gamma or beta radiation are quantitative rather than qualitative and can be attributed only to distributional differences of the ion pairs present in the tissue subjected to either kind of radiation. These distributional differences in the resultant ionization can be quite marked. For example, if one had a parallel beam of 1 mev gamma or X-radiation striking tissue, the resultant distribution of ionization throughout the skin would be essentially constant while if one had a parallel beam of 1 mev beta radiation striking the skin tissue 1 cm deep the resultant distribution of ionization would be greatest at the skin surface and would decrease approximately exponentially until the energy of the beta rays was nearly expended; this would take place at about a depth of 4 mm and hance the remaining 6mm of skin tissue would be unaffected.

C. Medical Applicator Specifications

Source Material:	Strontium-90 in equilibrium with yttrium-90, firmly bonded in silver foil
Source Dimensions:	(a) Active diameter - 6.5 mm (b) Outside diameter - 13mm
Source Mounting:	Source covered by 1.5 mil of stainless steel (inner container), 1.5 mils of stainless steel (outer container) and sealed by a double hermetic seal.
Source Strength:	40 to 100 mc which yields a surface dosage rate in roentgen-equivalent-beta per second as stated on the Certificate, on the plate attached to the storage box.
Shaft Length:	6 inches. Serial number of Medical Applicator engraved on shaft.
Shield:	4" x 3/8" circular Plexiglas which slides on shaft.