When using βray emitters, sometimes the glass container will provide adequate protection, if not secondary containers will do the job. It must be remembered that β ray emitters when unshielded may well provide dangerous levels. Thus, at the surface of a P-32 solution containing only 1μc/cc, the dose rate is ~ 800 mrep/hr.
Many a young radiochemist will think that adequate control of exposure can be attained by rapid manipulation. This, in theory, is true only if - by disregarding the higher probability of spillage - one can execute operations within milliseconds or microseconds - In view of the legitimate doubt that any amount of training will produce such dexterity, it might be well to cover the beaker, petri dishes and the like with sufficient material to stop the β radiation.

Control of contamination is attained by good housekeeping and work habits and by operating in a laboratory properly equipped. The work area should be free from equipment and materials not required for the experiment at hand and equipment used should be decontaminated and stored in a controlled location after use.
Supervision and working rules regarding food handling, checks of personnel activity, waste disposal, etc., are necessary. Main objective is education of worker to follow these necessary procedures for his own protection and the protection of others. It is to be realized that skill in radiation protection is as necessary as skill in chemical and biological manipulations.

Levels of maximum permissible contamination - Slide

Radiation hazards are best evaluated by means of instruments.

Hazard instrumentation:
1) Personnel
Pocket ion chambers — external exposure (total or partial) - Slide (cons-construction; calibrations)
Film ion chambers
Film badges
Finger rings (in state of development)

2) Beta-gamma survey meter
Contamination: counters (qualitative) Slide
radiation exposure: ionization chamber quantitative Slide

3) Beta-gamma ray hand counters & shoe counters Slide
4) Air samplers - Procedure for analysis, filter queen Slide

Waste disposal: Long lived isotopes should be concentrated and retained in proper location unless can be *isotopically* diluted to levels comparable to natural radioactivity - Practical considerations will dictate the procedure-
Short lived isotopes can be disposed by H20 dilution in clear alkaline solutions at low levels. This is a subject that calls for some experimentation and appraisal of procedures enacted. Levels suggested are 0.1 per liter of water for a total of less than 5 mcs per week - Other level suggested for I-131 - 100 grain of K I [?] for each mc of I-131 in K I solution.

It is well to realize that the word disposal or discard is a misleading one for many isotopes- Storing of waste is more appropriate.

Laboratory and equipment.
It may pay to have one lead lined hood for institutions in order to avoid duplication of facilities and stocking of large amounts of lead or other shielding material. Description of hood at Memorial [Hospital, N.Y.] --[written out measurements]--
Ventilation 100 f/m; provision for easy decontamination of hood and lab.

Detailed information to be found in bibliography. {Benches, walls, floors, waste container, sinks}
At millicurie level and below, almost all radioisotopes in powder form are hazardous--Handling in dry boxes Slide

Personnel Selection
Persons who are naturally neat and careful are preferred workers with radioisotopes. They shall be informed in detail of all known dangers involved. They shall be instructed regarding local rules and regulation for protection, and should be expected to observe them in all details - It is particularly important that all users of radioisotopes should be considered as potential full-time users.
The worker is by the most important factor in a successful program of hazard control; there is very little use in striving to design fool-proof instruments and enact fool-proof procedures. Human foolishness covers quite a wide range--Special attention should be paid to brilliant young scientists who in their enthusiastic pursuit of truth forget their personal safety and that of his fellow-man. Some of the best informed have been victim of regretful, but preventable, accidents.
Slides

9. April 7, 1949 [U of Chicago?]
"Seminar on Shielding [very mathematical] 8 handwritten pages + Bibliography (mimeograph) + Slides
PHOTONS
Gamma Rays (x rays) [equations] Auger effect. Interaction of gamma rays and matter.
a) Photoelectric effect: electron bound because.... [equations]
b) Compton effect: Laws of conservation of momentum explain character....
[many, many equations throughout]...conservation of energy and momentum....
cross sections....
pair production for low energies....disintegration of photon...neglect photo-disintegration....photo fission...
Elementary considerations in shielding...complications...1) Interest is not in flux....2) Instrument sensitivity....3) Scattered radiation.... 4) geometrical considerations - less elementary, suggest that....[equations...theoretical approach for parallel beam on thick slab...Hirschfelder et Al give [equations]...ratio of true intensity to logarithmic int. [equations, equations]...this is for that part of the attenuation due to Compton effect so that your thickness is given by solving: [equations]....
Bethe gives fraction of intensities as [equation] for a flat slab and similar conditions where [equations] and gamma function [equations]. [Also, M.E.V. tables]
Comparison with experiment is possible with large values of x and parallel beam. Wickoff et al - with x rays (not monochromatic). Experimental set-up [table, drawing]
This data can be translated into variation of beam thickness, namely instead of using [equation] we may write [equation] and get the % increase in shield thickness to compare to μ/μ^{-6}s
...plot N.B.S. and Hirschfelder
GEOMETRY
Scatter
a) Thin Scatter [equations, graphs]
b) Thick Scatter
c) Sky Shine (narrow angle)
Some solids no self absorption [equations, drawings]
Rod
Circular Plate
[Graph Paper on which is plotted a graph of shielding ...Compton...]
Photoelectric effect - Reaction between photon and [beam?] [brend?] electron where there is possibility of communicating total energy of photon (hv) to the kinetic energy of the

electron 1/2 mv^2... The atom takes most of momentum and the binding energy of the electron are involved. [equation]. If whole momentum were transferred to electron then $hv/c = 1/2\ mv^2$ which combined with $hv = 1/2\ mv^2$ would give an [absurdity?] $V = 2c$ [graph, equations]

10. October 7, 1949

"The Significance of Ionization Measurements in Radiobiology" (Presented at ANL: Meteorology Site D)

"1. Growing importance of understanding biological effects of radiation: Radio therapy up to now: increasing number of people affected; economics of protection, public relations.

"2. Some general characteristics of the interaction between biological system and ionizing radiation: Sensitivity of living biological systems with respect to other materials. [He cites] Siegel showed changes of sensitivity from 4.6×10^{-6} ohm cm^2 to 10.1×10^6 by 3×10^{19} n/cm^2....for the mouse. Turning to living systems, biological effects show wide variation in sensitivity.

"3. In general, methods of measurement of radiation is determined by the fact that we are dealing with a form of energy. Specific purpose to which a radiation is used determines which of a number of quantities is of greatest importance to investigate. Left to a severely physical investigation of a beam of ionizing radiation, one might be tempted to concentrate on measurement of its intensity (flux; $ergs/cm^2$). But if the beam is used to evaluate biological responses, the absorbed energy should be the significant quantity.

"Among the many physical and chemical effects of ionizing radiation, ionization in air is most promising because a) of ion current [ ] wide range with fair accuracy [ ] the measurement itself is easy compared to decision on which conditions to measure and what it means; b) energy per ion formed nearly independently of particle velocity; atomic number of air [ ] advantage in x- gamma- rays, but useless in neutron measurement.

The fundamental concept in which the roentgen is based is:

$R \underset{\propto}{\square} E_{flux} (\text{Б}_{\underset{\gamma}{a}} + r+p) = N\ hv\ (\text{Б}_a + r+p)$

[and then he goes on to show slides and talk about "thimble" chambers.

So, it seems Dad was "teaching" the Midwest and west about the sensitivity of the biological organism with respect to ionizing radiation. He was teaching the reasons for the need to measure biological tissue differently form air... The method he showed them was the Marinelli method for finding the measurements in terms of roentgens.

11. January 5, 1951

"Energy Loss by Charged Particles" (5 pp. handwritten + Slides)
(Fermi, pp.27 & ff.)
[equations, graphs, tables]
<u>for electrons</u> - equation 1) holds approximately because preliminary assumptions hold only approx. [equation]
General character of Bragg curve holds along the path of the particle. If one considers, however, a given volume element....[drawing, equation] (without scatter) hence, loss per unit volume increases. Chance of scatter increases with decrease in energy...[drawing, graph] ...maximum range presupposes no scatter and checks fairly well with theoretical [formula?]
In conclusion, [table].

Dosimetry is expression of energy loss per unit mass or unit volume: it is a [drawing? graph?] differential dE/dVol specification of sources (strength, location, nature), their law of losses, their law of scatter.

For particles which are not scattered, contribution can be computed (as for α and p of fairly high energy) at microscopic level [drawing, equation, graph]
How must dE/dVol be specified? According to biological structure and inhomogeneity of sources.

It is obvious that for α , the homogeneity must be surveyed at [micron] distances to assure ourselves that it is so at cellular level.
For electrons, same principle applies, except that due to their range the volumes involved are much greater. In homogeneities are main problem and are worthy of detailed study. Problem complicated by spectrum of Bray isotope spectrum. Examples:
1) Brays in bottles of solution (homogenous with H-3, C-14, but not with P-32) [equation, drawing]
2) Brays in blood vessels and tissue of different concentration (N-24 in vascular and [exter?] [extra?]vascular system; A-41 in lung)
3) leukemic cells in blood
4) I-131 and thyroid follicle

Only practical method of establishing whether simplified calculations are valid is to test [whether?] inhomogeneity are valid is by radio-autograph of thickness equal to range of particle under consideration.

If homogeneity is established, then formula such as
r/day = 61 C □ c in μc/gram
□ in MEV per disintegration is valid

For inhomogeneous sources--especially β rays--problem is very complex due to straggling, scattering and different energies of β rays which one deals with in practice - α, p are somewhat easier, less straggling: α rays fairly homogenous in energy and scatter little, but protons released by neutrons are not the same energy, but little scatter. If parameter varied is density of ionization, average of dE/dx over track must be taken and therefore an uncertainty is already present if biological phenomenon is strongly dependent on it--
The partition between excitation and ionization - formula for energy loss gives total and, if ions formed are to be calculated, must divide by [W?] [N?] (per ion formed)
{this is a] little higher for α than for β and not very dependent on energy [ςrays ?] and ion clusters as studied by cloud chamber [drawing, fraction appearing scheme for + and -]
…assuming volume = $\underline{\qquad}^{3}$ and 32.5 e.v., we end up with ultimate event of ~180.000r
15 mμ
and if we should take into consideration time of formation $\simeq 10^{-10}$ minute rate is $1.8\text{x}10^{15}$r/minute. This should give us reason to ponder when we tend to extrapolate to zero volume.

In biological material, since in general [equation with letters and numbers, including the words "Energy in element Z = Roentgens in equations and fractions, in material, air"). …air, water and some elements in the body. …
However, range of effectiveness becomes smaller and smaller around structure of interest…
Of greater interest because of greater density of ionization, local importance may be density of ionization, is N & H in neutrons because of N(n,p)C reaction and recoil protons.
The importance of scatter in biological experiments…[equations with Greek? letters]
importance of phantom (imitate conditions of radiotherapy)
glass influence depends on size of glass vessel [drawings]

Marinelli defines "Dosimetry," names "Law of Losses" and "Law of Scatter." He was laying down the theory for radiation dosimetry, for determining the amount of energy absorbed in human tissue in practical clinical situations. He defines [the theory of] Dosimetry as the expression of energy loss per unit mass or unit volume…as a … differential…. specification of sources (strength, location, nature), their law of losses and their law of scatter.

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12. March 14, 1951
"Lecture: Human Tolerance to Ionizing Radiations" University of Chicago. Radiochemistry class
References: Nucleonics, Jan, 1951, Feb. 1951
Am J RR Therapy, Jan, 1951

I. Historical Sketch: early experience led soon to 0.2 r/day $\simeq$ 1 r/week. (Before was radium and xray. Late developments led to a focused attention - 6th Sect. [recommendations?] on radiological protection, July 1950. Initiated some closer analysis of the problem:
Injuries
  a. superficial injuries
  b. general effects of the body, particularly the blood and blood forming organs (leukemia and anemias
  c. induction of malignant tumors
  d. deleterious effects such as cataracts, obesity, impaired fertility, reduction of life span
  e. genetic effects
How to measure exposure: Before roentgen sufficient. Now, not so much. Advantage of using energy/ gram of tissue

EXPOSURE TO INTERNAL RADIATION

Whole Body Exposure
Most dangerous effect on blood forming organs (data on man & experimental animals). To be exact, it is the most frequent phenomenon observed in irradiated mammals including man. For chronic exposure of mice: $T = T_o e^{-Kr}$ in which r = dose and $K \simeq 10^{-4} r^{-1}$ For x ray $\simeq 10^{-3} r_{ap}^{-1}$ for neutrons. This may not apply for very small doses and experiments are very difficult to perform at those levels.
Recommendations: I. in circumstances under which the whole body may be exposed even an indefinite period to x or gamma radiation of hv = 3 MEV, the maximum permissible dose received by the body shall be 0.5r/ in any one week = 0.3 r in free air = 0.3 to blood forming organs at average level of 5 cm depth.
II. In the case of high energy B rays, the max. permissible exposure of the surface of the body in any one week shall be the energy flux of beta radiation such that the absorption in grams of superficial tissue is equivalent to the energy absorption from 1.5 r of gamma rays. Calculation at basal layer of epidermis. $7 mg/cm^2$: To be taken with a grain of salt and should not be taken to apply to beta rays or greater range that a few mms. Not to Betatron electrons.
III. Partial exposure - In the case of exposure of the hands and forearms to x, gamma, and B radiation, maximum permissible does = 1.5 r or its energy equivalent/week at basal layer of epidermis.
IV. Neutrons - Maximum permissible energy absorption should not be greater than 1/10 of that permitted for high hv. This would be equivalent to about 1500 $n/s/cm^2$ slow neutrons and ~40 $n/s/cm^2$ fast neutrons.

INTERNAL EXPOSURE: Max. Permissible Amounts of Radioactive Isotopes

On the assumption that the Maximum permissible energy absorption is that equivalent of 0.3 r/week $\simeq$ $3/erg/cm^2$ at the point of maximum absorption, the maximum permissible levels in the body can be calculated when no experimental data are available. General formulae for alpha and beta emitters: [equations]
Ra-226 - Bone-seekers ; compared to Radium; [equations] Average half life and concentration in initial tissues. Others await information of metabolic data which are as yet to be established.

Experience on chronic radium poisoning in may indicates the most serious effects are anemia and damage to bone, including osteogenic sarcoma. Detected threshold ~ 1/µc
Maximum permissible amount in body = 0.1/µc [.... equations]....if safety factor is put 20 0.02
Average mean live 10^4 days ($\simeq 1 \times 10^{-4} = 10^{-5}$ µc
Absorption in gut 0.1 ....[equations]
Absorption in lung 0.06 [...equations]
Pu-239 - Ratio in animals for equal effects at low doses is criterion for choosing maximum permissible amount in body. Follow test from p I on-