PREPARATION OF 30 YEARS' PERSONNEL MONITORING DATA FROM A URANIUM FABRICATION PLANT FOR USE IN EPIDEMIOLOGIC STUDIES+

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ABSTRACT-- Dose assessment is the process of transforming radiation monitoring results ("dose" and "dose rate") into a form usable in epidemiologic studies (that is, machine-readable, annual individual dose equivalents (with variances) to selected target organs). Dose assessment issues include completeness of monitoring and records, quality factors, notional doses, minimum detectable doses, use of internal monitoring results, and accuracy and precision of doses.

Monitoring data were assessed for use in an on-going epidemiologic study of employees at a DOE uranium fabrication plant. External data (pocket chamber, film, TLD) were available from 1948-present, urinalysis data from 1950-present, and lung counting data from 1961-present.

Data were edited for completeness and validity. Monitoring was judged to be complete and state-of-the-art except for the earliest years of plant operation. A quality factor of 2 was used for high neutron doses; for alpha particles, dose equivalents were calculated using Q(alpha) = 10 and 20. Notional doses were generated for "damaged" dosimeter data by interpolation between adjacent results. Doses equal to the minimum detectable dose were replaced by notional doses generated from log-probit analysis. Dose equivalents to lung were inferred from uranium urinalysis and lung count data. Uncertainties (variances) were computed for each dose. Average coefficients of variation for annual lung doses ranged from 2 to 6.

External doses totaled 12,000 person-rems for 117,000 person-years of monitoring for 12,500 workers. Lung doses totaled 52,000 (Q(alpha)=10) person-rems for 42,000 person-years for 6,200 workers.

This work is part of the Health and Mortality Study of the U.S. Department of Energy (DOE) Workers being conducted by Oak Ridge Associated Universities (ORAU) with the collaboration of the Department of Epidemiology and the Department of Environmental Sciences and Engineering of the School of Public Health of the University of North Carolina (UNC). This work is supported in part by Contract No. DE-AC05-760R00033 between DOE and ORAU. The data on which the Health and Mortality Study are based are the porperty of DOE. They are included in DOE's System of Records No. 30 and are protected according to the requirements of the Privacy Act (1974).

Daniel J. Strom worked under appointment to the Nuclear Science and Engineering and Health Physics Fellowship Program administered by Oak Ridge Associated Universities for the U.S. Department of Energy.

I. Introduction

[Slide 1] The United States Department of Energy (DOE) Health and Mortality Studies are performed for DOE by several contractors, including the Center for Epidemiologic Research at Oak Ridge Associated Universities (ORAU). [Slide 2] The Department of Epidemiology at the University of North Carolina (UNC) at Chapel Hill is a subcontractor for part of the Health and Mortality Study efforts.

[Slide 3] The ORAU-UNC collaboration includes study of workers at many facilities, including over 16,000 who worked at the Y-12 plant in Oak Ridge, Tennessee, between 1947 and the present. Y-12 has been involved primarily with uranium work for DOE. Radiation hazards at Y-12 are primarily the inhalation of uranium aerosol and exposure to external radiation.

II. Dose Assessment

[Slide 4] Within the context of radiation epidemiology, dose assessment is the process of transforming occupational radiation monitoring results into a form useful for epidemiology. Results of occupational monitoring may be in the form of doses, such as the results of film badge readings, of in the form of records that are essentially dose rates, such as concentrations of radioactivity in air, concentrations in urine, and organ burdens. Dose rate type data cannot be used directly in epidemiology, but must be incorporated into dosimetric models and integrated over time to compute doses. Epidemiologic studies that attempt to classify workers into dose groups using dose rate data directly, without integration, cannot produce estimates of health risk per unit dose or dose equivalent, and risk the intorduction of serious misclassification of workers with respect to dose.

To be useful for epidemiology, occupational monitoring records must be in the form of machine-readable (that is, computer tapes) annual individual dose equivalents to selected target organs. Annual (as opposed to quarterly) doses provide the epidemiologist with sufficient time resolution to deal with latency in disease appearance and uncertainty in time of diagnosis. The choice of dose equivalent, rather than absorbed dose, is a compromise that permits the combining of doses due to radiations having different LET, such as gamma, alpha, and neutron. Ideally, the outcome of an epidemiologic study might be the determination of a relative biological effectiveness of the various types of radiations in human populations; in practice, however, collective doses and populations are too small to permit a realistic expectation of such outcomes. Finally, since cancers are associated with certain tissues or organs, doses to different organs from partial body or internal exposure must be kept separate for analysis.

III. A. Experience at Y-12

[Slide 5] Y-12 has been operated by Union Carbide Corporation for DOE from 1947 to the present. A prototype external monitoring program began in 1948, and was officially begun in 1950. For the period 1948 to 1980, this program produced some 449,000 records for 117,000 person-years of monitoring of about 12,500 individuals.

The uranium urinalysis program began in 1950, and produced some 432,000 records through 1980. The in vivo counting program began in 1961, and produced 40,700 records through 1978. The two bioassay programs combined accounted for 42,000 person-years of monitoring for about 6200 individuals.

[Slide 6 -- omitted] (One practical note bears mention here, and that is the problem of data management of so many records. In order to avoid future questions about what was done to the records we started with, and how and why it was done, a good deal of effort has been expended in the documentation of the dose assessment of the Y-12 project. While such documentation is slow and expensive, it has already proved its worth in resolving problems in the dose assessment process.)

[Slide 7] A number of things must be done with the raw data as received from an occupational health physics program. First, research must be done to determine what records are available, and what form they are in. Records must be retrieved from the facility under study, and it must be determined what each field means and the units in which it is expressed. Hardcopy records (that is, paper, microfilm, etc.) must be keyed into machine-readable form and verified for accuracy of keying. Each record must be linked with a person known to the study, and when positive identification is achieved, personal identifiers are removed and replaced with a unique ID number to ensure the protection of privacy.

Extensive editing of the raw data is done to check for valid values, ranges, and internal consistency. Preliminary summary statistics are computed, such as means, medians, minima and maxima; outliers are examined. Frequency tables or plots are made of variables by year and sometimes as a function of other variables as well, in order to get a feeling for the data and to identify problems.

Problem codes often accompany data (for example, "damaged film" or "surface contamination"). An analysis of these codes is necessary to ensure the validity of the data.

During the years 1948-49, external doses less than or equal to the minimum detectable dose of 30 mrem were recorded as 30 mrem. A log-probit analysis of the data was done, revealing that they were lognormally distributed. From this analysis, it was shown that the average exposure received by persons receiving doses of 30 mrem or less was about 9 mrem, assuming that the shape of the lognormal curve below 30 mrem was the same as that above 30 mrem. Thus, in order to avoid injecting a positive bias into the data set by leaving the 30's in, and to avoid injecting a negative bias into the data set by setting the 30's to zero, a value of 9 mrem was substituted for a reading of 30 in the years 1948-49. The MDD problem did not occur in 1950 or later, due to the use of a curve fitting routine at Y-12 that permitted the recording of external doses as low as 1 mrem.

Dose values on records determined to be flawed and unusable, such as "damaged film" records, were replaced with notional doses generated by linear interpolation between an individual's adjacent records. (This "nearby" interpolation routine could accept any of 12 different combinations of adjacent unflawed records, provided that the unflawed records were within one or two calendar quarters of the flawed record and were for the same individual. The procedure was tested on randomly selected unflawed records, and it proved to predict the test record dose very accurately on the average. All but 300 of some 3300 flawed records were replaced in this manner.)

Results from the 1958 criticality accident were not on the film badge tape we received, because the victims were not wearing film badges. We added these results from the literature.

Dummy and useless records were removed from the tapes. In some cases, a monitoring record had been generated for administrative reasons, and contained no dosimetric information. In other cases, calibration records were found on the tapes, and these were removed.

Uncertainties, in the form of variances, were computed and entered into the dataset. For external results, Y-12 made available to us calibration data for their film badge program dating back to 1963. A variety of methods were uesd to assign variances to inferences of lung doses from urinalyses and lung counts; a discussion of these would require more time than is available here.

III. B. External Monitoring

[Slide 8] For external monitoring results, daily, weekly, or quarterly results were added to produce annual totals and variances. Counts were made of notional doses and problem codes for each individual. Summary statistics were compiled and plotted.

[Slide 9] The annual collective gamma dose equivalent (in rems) at Y-12 is shown in this slide. Note the large rise in 1961, when a four-fold increase in the number of badges issued occurred, with a two-fold increase in the collective dose. This could indicate that some real doses had gone unmonitored, or it could indicate that problems of minimum detectable doses had shown up: thousands of workers times four MDD's per year amounts to a lot of collective dose.

[Slide 10] Cumulative percentages of workers and of collective doses are shown in this slide for the year 1967, plotted on a logarithmic dose scale. Both curves are well fit by smooth sigmoids. It can be seen that while 90% of the workers received doses less than about 100 mrem, they accounted for only about 35% of the collective dose. This simply means that the more highly exposed workers account for a large proportion of the collective dose.

[Slide 11] The percent of Y-12 workers receiving **individual gamma doses** less that the dose on the "dose" axis is shown in this slide for Y-12 by year, from 1948 through 1979. One feature is immediately evident: there were significant differences in the cumulative profiles from one year to another. Another significant feature is the trend towards fewer and fewer high doses as time went on. This plot does not, however, give much insight into the number of persons above about 0.5 rem. Also note that the 1958 accident cases are not included on this or any subsequent plots, since they would obscure all other doses for 1958.

[Slide 12] The cumulative **collective dose** profiles by year are shown in this slide. The clear trend seen here is that the collective dose was received predominately by workers receiving lower and lower doses as time went on, in keeping with the lowered standards in 1961 and the ever-increasing emphasis on ALARA. Note the heavy lines at 0.5, 1.5, and 5 rems, and how they tend to be found at higher and higher elevations as time goes on.

[Slide 13] The external monitoring data from 1967 are shown in this slide, with the vertical axis being probit units (that is, standard deviations from the median). The straight portions of the curves indicate that the data are well described by a lognormal function up to 1000 mrem, where the effects of dose limits and ALARA may be invoked to explain the upward trends in the curves.

[Slide 14] The same probit transformation has been used for the following two figures. This slide shows probits of the cumulative number of workers recieving **individual** doses below that marked on the dose axis, by year. The increasing slopes of the 0.5 and 1.5 rem isodose contours indicate the tendency for workers to recieve lower and lower doses as time went on. It is also easy to see that 1967 was one of the very few years during which the number of workers was distributed normally with respect to the logarithm of dose. It seems that in some years, very few low doses were recieved, while in others, up to half of the annual totals were very low.

[Slide 15] A log-probit plot of annual **collective** gamma dose equivalents is shown here. Again note the increasing height of the isodose contours as time goes on. This indicates that a greater and greater fraction of the collective dose was received by workers receiving lower and lower individual doses.

[Slide 16] The following two figures depict four isodose contours from the three-dimensional percent plots of workers and collective doses, by year. These are referred to as "UNSCEAR Fractions," because they were described in the 1977 UNSCEAR Report. This slide shows the fractions of workers having **individual** annual doses less than 30, 500, 1500, and 5000 mrem, by year. The UNSCEAR Report specified that such fractions gave a good idea of the dose distribution in a population; in their "reference distribution", only 0.1% of workers were to be found above 5 rems. Note that after 1961, virtually everyone received doses less than 0.5 rem.

[Slide 17] The percent of **collective** gamma dose among workers having individual doses less than 30, 500, 1500, and 5000 mrem, by year, is shown in this figure. From 1961 on, the vast majority of the collective dose was recieved by individuals with annual doses between 30 mrem and 500 mrem, with very little contribution to collectve dose from persons receiving greater than 1500 mrem.

III. C. Internal Doses

[Slide 18] At Y-12, urinalysis results are recorded in net uranium alpha disintegrations per minute per 24 hours of urine excretion. Lung count results are recorded in net micrograms of U-235 in lung.

From urinalysis and lung count results, it is necessary to infer a lung burden of total uranium alpha activity using dosimetric models.

Without going into the details, we chose to use a **linear relationship** between **urinary excretion** and **lung burden,** assuming an instantaneous lung burden equal to 300 times the daily urinary excretion rate.

[Slide 19] Because lung counts were recorded in micrograms of U-235, it is necessary to make some guess about the degree of enrichment of the uranium to infer **total U** lung burdens. Since information for individuals about enrichment was not available, other than whether their urinalyses were done radiometrically (for natural or enriched uranium) or fluorometrically (for natural or depleted uranium), conversion factors representing central tendencies for three categories of urinalysis results were used. Note that over the spectrum from depleted to natural to highly enriched uranium, the fraction of total uranium activity due to U-235 is bounded by numbers within a factor of 1.9 of our central number of 165 dpm total uranium per microgram of U-235. Uncertainty in enrichment is not the largest uncertainity in lung dose computations.

A MODEL is needed to integrate the lung burden over each year. Based on study of clearance times published for selected cases from Y-12, we chose to use a clearance half time of 80 days, recognizing that this value is a median for a very broad population distribution.

[Slide 20] This slide shows three organ burden scenarios that are consistent with two equal lung burden measurements separated in time by 2 and one half effective clearance times. The shaded area is proportional to dose. The top curve shows a single intake immediately following the first measurement. The middle curve shows a single intake just before the second measurement. These two represent extremes of intake scenarios. The bottom curve represents a series of small intakes just adequate to maintain a constant organ burden. This is the scenario assumed by a linear interpolation.

[Slide 21] We chose to use a linear interpolation between adjacent lung burden inferences,provided they were separated in time by less than 2 1/2 effective clearance times (7 months). Note that the Y-12 data include many negative urinalysis and lung count results that result in negative organ burden inferences. Such negative calues arise when the gross counting value was less than the best available background. In order not to inject a positive bias into the collective data set, we kept the negative data intact. We are fully aware that there is generally no physical meaning to a negative dose, but we believe that spurious negative doses statistically counter balance spurious positive doses.

[Slide 22] Lung dose equivalent is simply calculated by multiplying the cumulated activity by the S-Factor (dose per unit cumulated activity) for uranium in the lung.

Contributions to the variance in an individual annual lung dose value come from both measurement uncertainty and individual deviations from the parameters used in the models. Some individual deviations are systematic, others random, most a combination of both intersubject and intrasubject variability. Doses based on lung counts have a geometric standard deviation (GSD) of 3, while those based on urinalysis results have a GSD of 5. At low dose values, dose uncertainty is dominated by measurement error, while at higher doses, it is dominated by model parameter variability or intersubject differences.

[Slide 23] The mean coefficient of variation of individual lung dose inferences is shown here, as a function of year. The range is over a factor of 2 to 6. These values are probably underestimates, because the calculational method employed allowed only random uncertainties, which tend to decrease with increasing numbers of measurements in a given year. Repeated measurements do not improve accuracy for individuals whose exposure and biological parameters deviate significantly and systematically from those assumed by our model.

[Slide 24] The annual collective lung dose equivalent for Q = 10 is displayed in this Figure. The lower values at early times probably reflect a smaller number of workers being monitored. At later times, the decrease is probably due to decreased numbers of workers and better ALARA programs.

[Slide 25] The differential frequency distribution of Y-12 lung doses is shown here by year and by dose interval. Note the highly non-linear vertical scale, and linear dose scale at low doses, etc. The mode is the 0-1 rem range for every year. The highest doses are seen to decrease as time goes on, and as precision improved, the most negative doses also disappeared.

[Slide 26] In summary, whole body collective doses at Y-12 totaled about 12,000 person-rems for 117,000 person years of monitoring of 12,500 workers. Lung doses totaled 52,000 person rems for 42,000 person years of monitoring of 6,200 workers. The collective lung dose total is probably within a factor of 3 of the true value; this is probably considerably better than the dosimetric information used in uranium miner studies.

REFERENCE

Strom, D.J., "A Strategy for Assessing Occupational Radiation Monitoring Data from Many Facilities for Use in Epidemiologic Studies," doctoral dissertation, Department of Environmental Sciences and Engineering, School of Public Health, University of North Carolina, Chapel Hill, North Carolina, 1984. Available from University Microfilms, Ann Arbor, MI.

A more detailed presentation of these results is being prepared for submission to <u>Health Physics</u>.

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Slide 1

Work supported by U.S. Department of Energy Contract DE-AC05-760R00033.

Dr. Strom supported by USDOE Health Physics Fellowship. Current address: Department of Radiation Health, University of Pittsburgh.

Slide 2

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The ORAU-UNC collaboration includes study of workers at many facilities, including over **16,000** who worked at the **Y-12** Uranium Plant in Oak Ridge, Tennessee, between **1947** and the **present.**

Slide 3

Within the context of radiation epidemiology, DOSE ASSESSMENT is the process of transforming occupational radiation monitoring results into a form useful for epidemiology, that is,

- **--machine-readable**
- **--annual**
- **--individual dose equivalents**
- **--to selected target organs.**

Slide 4

Between 1947 and 1980, occupational radiation monitoring results from Y-12 include

-- **449,000 external** monitoring records
-- **432,000** uranium **urinalysis** records
-- **40,700** ***in vivo* lung count** records

Slide 5

The three rules of data management:

1. Document
2. Document
3. Document

Slide 6

RAW MONITORING RESULTS

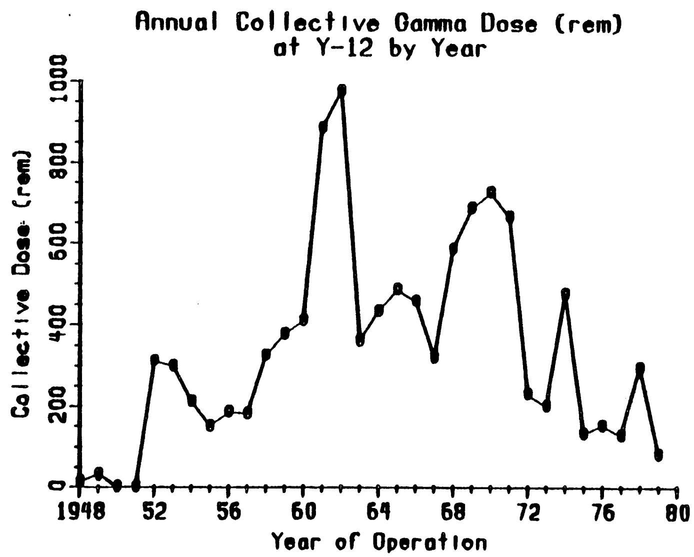
Key, verify non-machine-readable data
Replace personal identifiers with ID #
Edit for valid value, range, consistency
Compute summary statistics and plots
Analyze problem codes
Replace MDD's & flawed records with notional doses
Add accident results
Delete dummy & useless records
Assign uncertainties (variances)

Slide 7

EXTERNAL MONITORING RESULTS

Cumulate annual individual totals, variances
Count problem codes, notional doses
Compute summary statistics and plot

Slide 8



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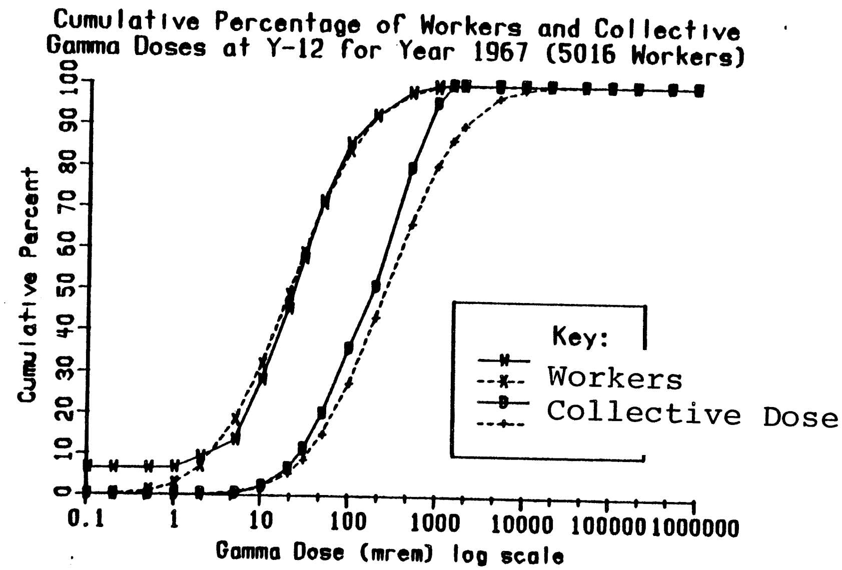

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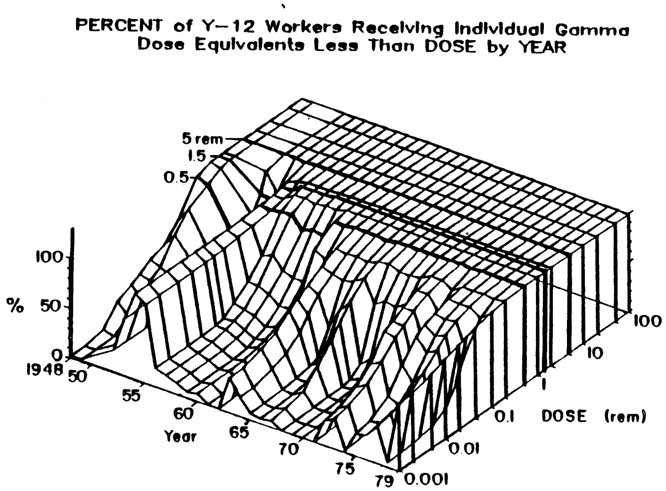

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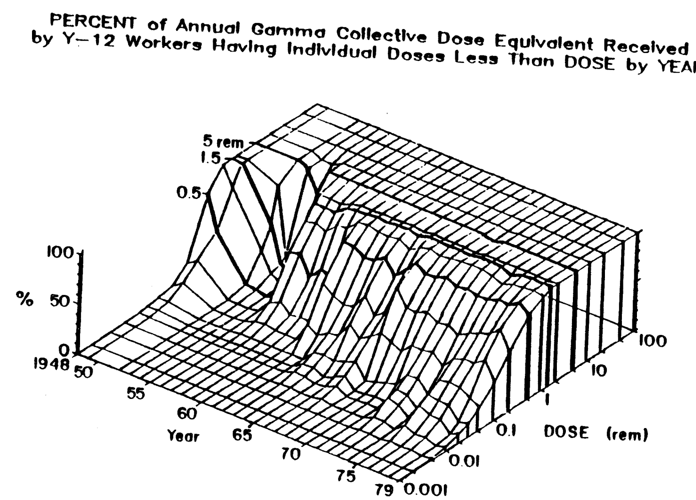

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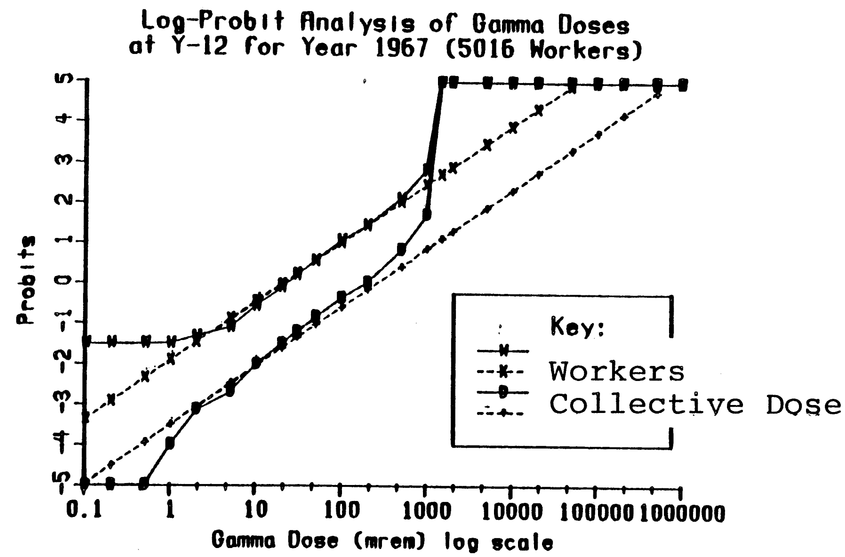

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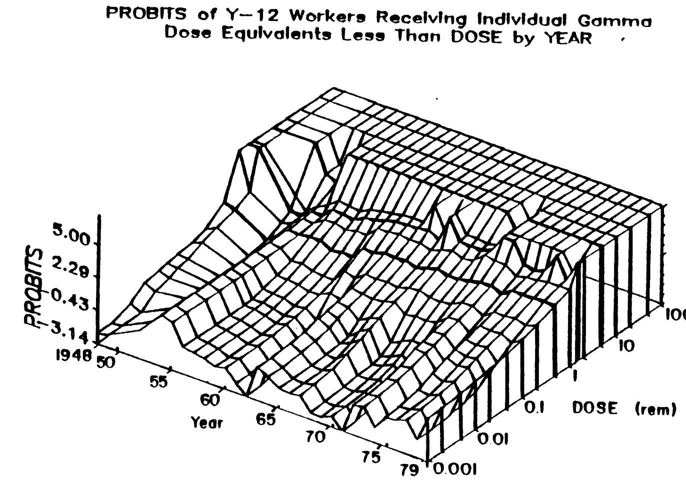

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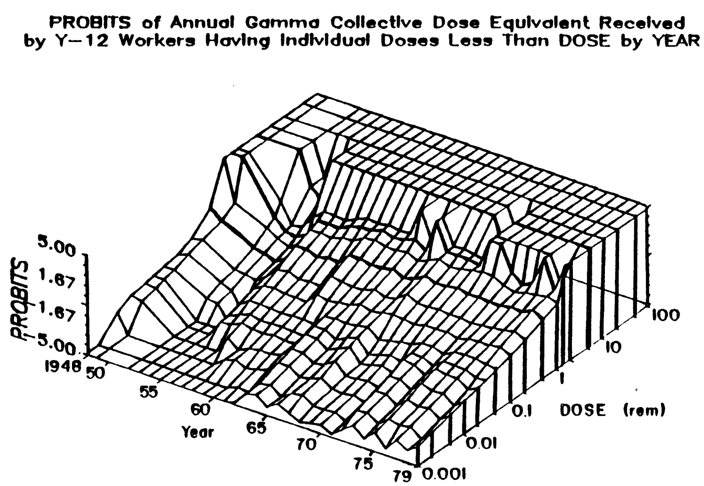

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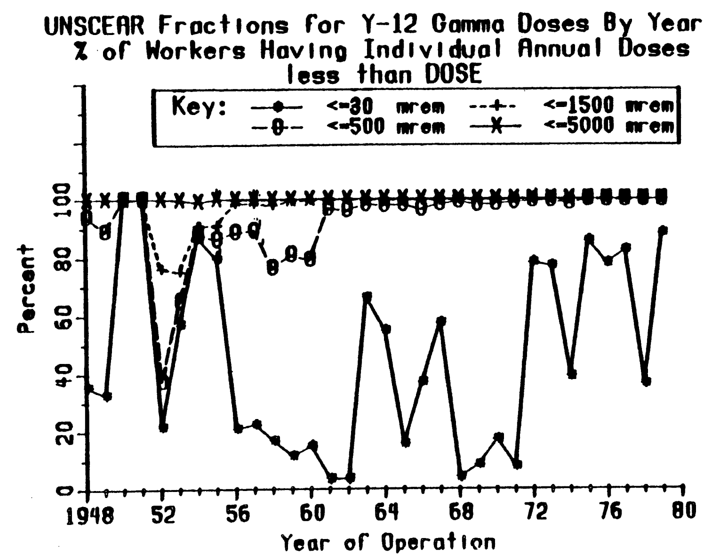
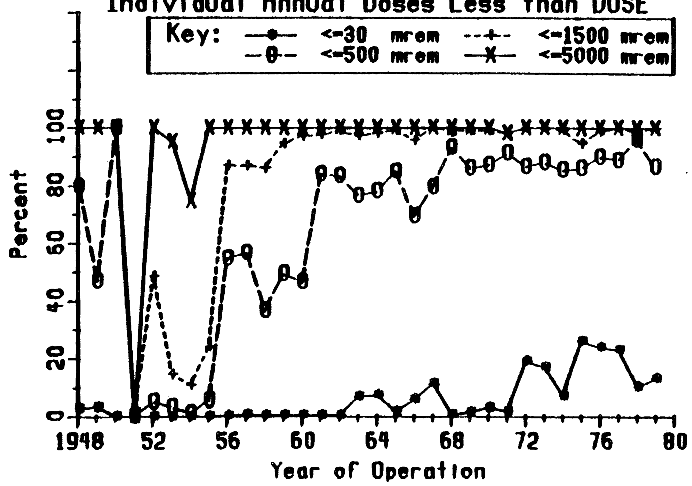


Slide 16

UNSCEAR Fractions For Y-12 Gamma Doses by Year: % of Coll. Dose Among Workers Having Individual Annual Doses Less than DOSE



Slide 17

INTERNAL MONITORING RESULTS (1)

Urinalysis results: net **dpm/24 h** total U alpha
Lung count results: net **ug U-235** in lung

Need MODEL to infer lung burden from urinalysis:
Total U lung burden = 300 X daily excretion rate

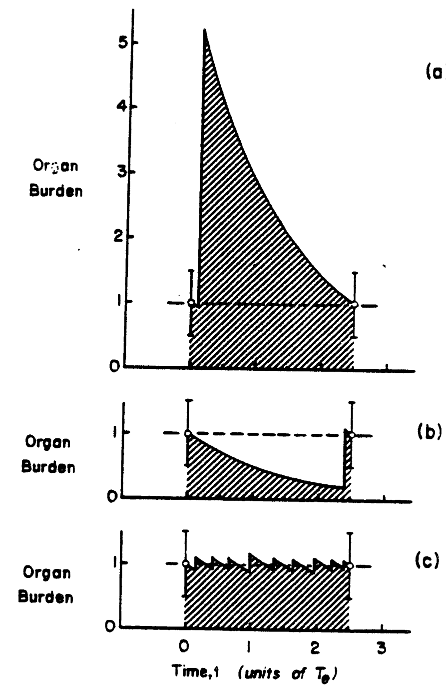
Slide 18

INTERNAL MONITORING RESULTS (2)

Need MODEL to infer enrichment for conversion of **ug of U-235 to total U alpha: 128(R), 267(F), 165(?)**

Need MODEL to integrate lung burden over year: **linear interpolation** or $\mathbf{T_{eff}}$ **= 80 days**

Slide 19



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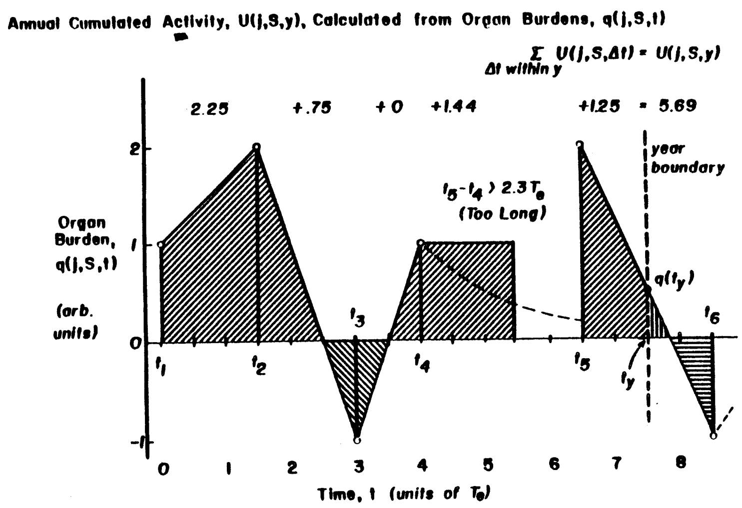


Slide 21

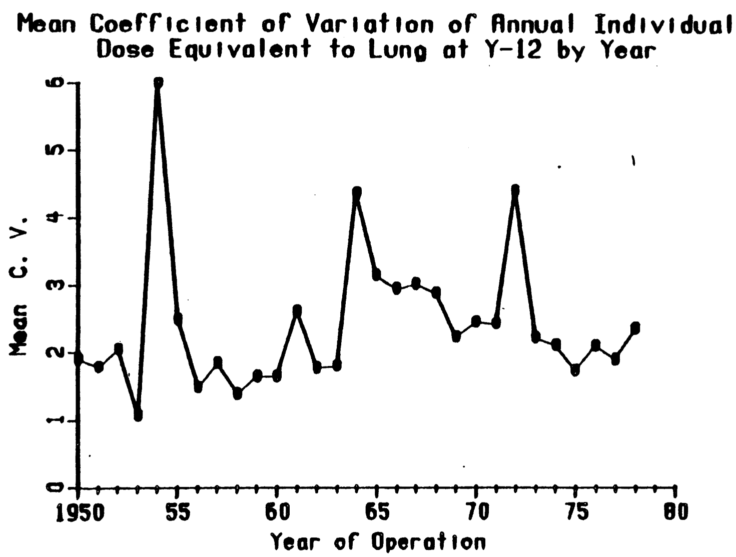
INTERNAL MONITORING RESULTS (3)

Dose Equivalent in Year y = $\tilde{A}_y \cdot$**(S-factor)**

Contributions to variance:
    Model: **Lung count, GSD = 3**
            Urinalysis, GSD = 5
Measurement: Depends on year, methods.

Compute summary statistics, plot.

Slide 22



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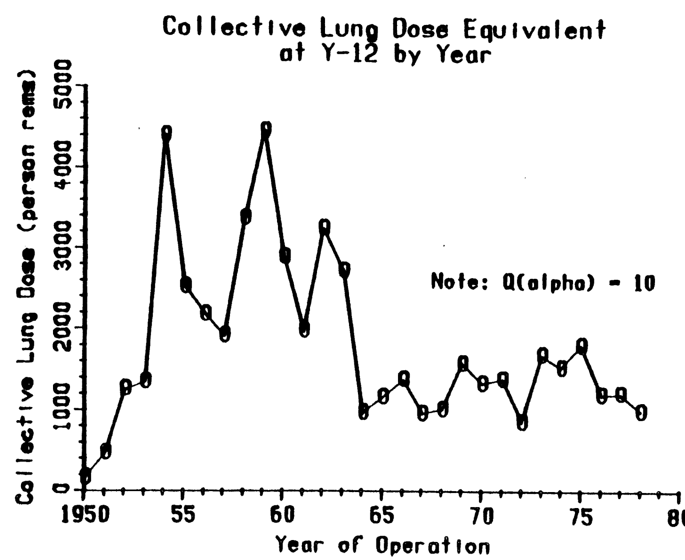
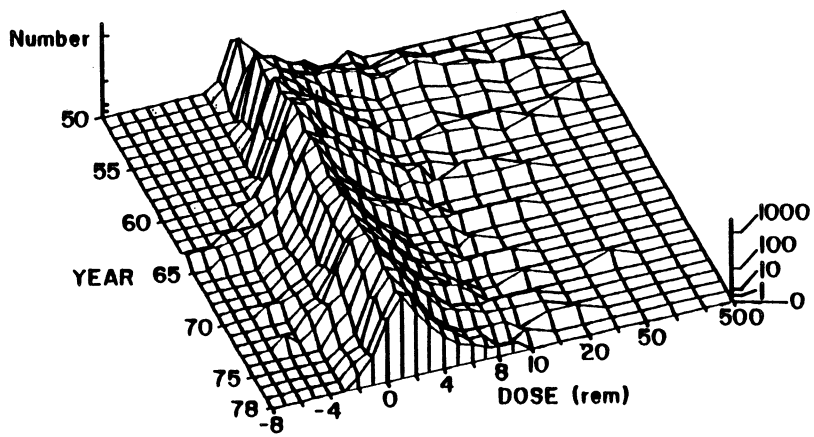


Slide 24

Frequency of Annual Uranium Lung Doses at Y-12 by Year and Dose Category



Slide 25

COLLECTIVE DOSE EQUIVALENTS AT Y-12, 1948-78

Target Organ	Number of Workers	Person-Years	Person-rems
Whole Body	12,500	117,000	12,000
Lung	6,200	42,000	52,000 (Q=10) 104,000 (Q=20)

Slide 26

Cumulated Activity Calculation Using Lung Burden Data

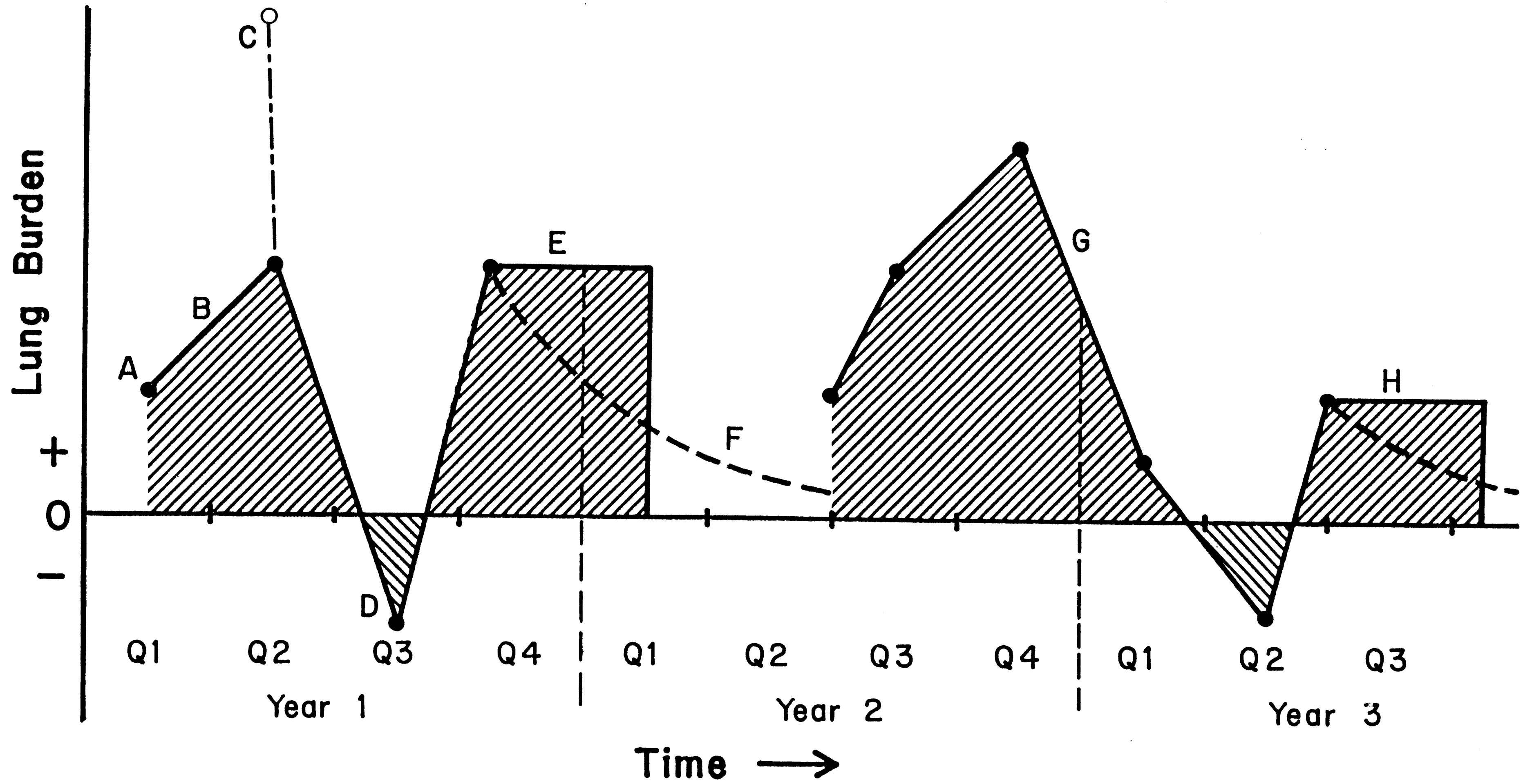


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Figure 6. An example of the calculation of an individual's cumulated activity (dpm-days) from lung burden data (dpm in lung associated with a date) assuming an effective clearance halftime of 80 days. The annual cumulated activity is proportional to the shaded area above zero minus that below for each year. Q1 = first calendar quarter, Q2 = second calendar quarter, etc. Point labeled "A" is worker's first measurement, taken at date of hire; an instantaneous lung burden equal to this value is assumed. Line at "B" is the straight line interpolation that follows from the chronic intake assumption. Point labeled "C" is rejected by the criterion that T_{eff} > 15 days. Point at "D" is a negative value; cumulated activity below the zero line is subtracted from that above the line. Horizontal line at "E" results from the use of the "TOOLONG" procedure (see text), that is, the following data point is more than 210 days later, so the cumulated activity is 115 days times the lung burden at the beginning of the interval, and is assigned to the year in which that lung burden occurred. The dashed curve labeled "F" is clearance with an 80 day halftime. The points on either side of "G" occur in different calendar years; the cumulated activity is assigned to each year in appropriate proportions. At point "H", the last data point for this individual, "TOOLONG" is again invoked, and the cumulated activity is assigned to the year in which the data point occurred.