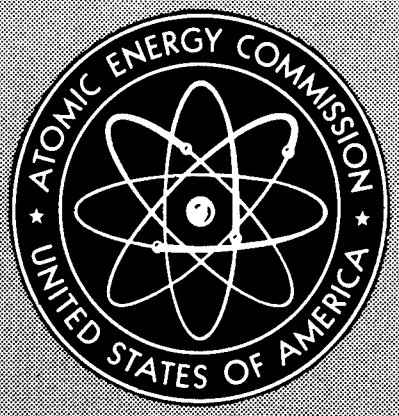

NYO-2181-4

EPIDEMIOLOGICAL FOLLOW-UP OF THE NEW JERSEY RADIUM CASES

I. REPORT OF THE EPIDEMIOLOGICAL AND MEDICAL STUDY GROUP AND THE PROJECT SUBCONTRACTORS
II. RESUME OF COOPERATIVE LABORATORY STUDIES ON PROJECT CASES AND SPECIMENS
III. RESUMES OF FINDINGS FROM INDIVIDUAL CASE STUDIES

Progress Report to October 1, 1966

March 1967
[DTIE Issuance Date]

Radium Research Project
New Jersey State Department of Health
West Orange, New Jersey

UNITED STATES ATOMIC ENERGY COMMISSION • DIVISION OF TECHNICAL INFORMATION

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BIOLOGY AND MEDICINE
(TID - 4500)

New Jersey State Department of Health
Radium Research Project
11 Washington Street
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Supported by
U. S. Atomic Energy Commission
Contract AT(30-1)-2181

*On loan from Division of Radiological Health
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supported by
U. S. Atomic Energy Commission
Contract AT(30-1)-3086

Breath Radon Measurements

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and staff of
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U. S. Atomic Energy Commission
Contract AT(30-1)-952

PREFACE

This is the final annual report of a series which describes the epidemiological follow-up of a group of dial painters and other radium workers exposed more than 40 years ago to radium-226 and/or radium-228 (mesothorium) used as the activator for radioluminous watch, clock and instrument dial paint. Many of these individuals still carry measureable body burdens of the isotopes.

Summaries of data from fifteen individual cases not previously reported continue the procedure established in prior reports (NYO-2760, NYO-10604, NYO-2181-2, NYO-2181-3). Additional information is known about each case but not all available data are presented, merely the highlights of the results of medical, dental and roentgenographic studies, and estimates of body burden of radium.

Additional data about the entire group of cases may be found in reports previously published, namely:

NYO-2759: The Epidemiological Follow-Up of the New Jersey Radium Dial Painters, Progress Report to January 31, 1962

NYO-2760: Résumés of Findings from Individual Case Studies, Epidemiological Follow-Up of Radium Cases, July 1, 1962

NYO-10604: Epidemiological Follow-Up of the New Jersey Radium Cases, Progress Report to July 1963

NYO-2761: Atlas of Current Roentgenographic Findings in the New Jersey Radium Cases, October 1963

NYO-2181-1: Current Data from the Epidemiological Follow-Up of the New Jersey Radium Cases, October 1, 1963

NYO-2181-2: Epidemiological Follow-Up of the New Jersey Radium Cases, Progress Report to April 1964

NYO-2181-3: Epidemiological Follow-Up of the New Jersey Radium Cases, Progress Report to September 1, 1965

Further information regarding the New Jersey Radium Research Project cases is contained in the complete file maintained on each case in the Project office. A group of approximately 100 controls has been recruited and is being studied by the same clinical and laboratory examinations as used for cases.

Field study and collection of data on the cases and controls of this Project will be completed about February 28, 1967. Statistical collation and evaluation of the data relating retained body burdens of radium to observed bio-medical effects is concurrently in progress. An evaluative report summarizing information collected over the ten years of the Project is being prepared for publication at conclusion of this U. S. Atomic Energy Commission Research Contract, approximately June 30, 1967.

Recognition is given to the individuals who performed the studies and prepared this report because the New Jersey Radium Research Project is an Epidemiological Field Office coordinating consultant medical, dental, radiographic and medical laboratory clinical studies and subcontracting or cooperating in histopathological, radiochemical and radiophysical laboratory studies of its cases, its controls and clinical and post-mortem specimens obtained from them.

Acknowledgement is made of contribution to the progress of this Project and to the preparation of this report by:

William G. Bernhard, M.D., St. Barnabas Medical Center
Gwilym S. Lodwick, M.D., University of Missouri School of Medicine
Hubert A. Sissons, M.B., F.C.Path., Royal National Orthopaedic Hospital, London

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and by the following staff involved in histopathology studies:

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Eugene Zimmerman
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ABSTRACT

The 1966 Progress Report of the New Jersey Radium Research Project gives a brief résumé of the goals and organization of the Project; summary of clinical, laboratory and statistical studies conducted during the reporting period; revised schema for coding x-ray bone lesions; and résumés of findings from fifteen cases not previously published.

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PART III
RÉSUMÉS OF FINDINGS FROM INDIVIDUAL CASE STUDIES

INTRODUCTION

This report deals with progress of the Radium Research Project of the New Jersey State Department of Health in epidemiological follow-up and special studies on radium dial painters, other radium workers and selected controls from September 1965 to October 1966.

Previous reports (See Preface) detail information on Project background, methods employed, résumés of cases, observations and impressions based on case finding; occupational and medical histories; medical, dental and roentgenographic examinations; clinical, pathological, radiochemical and radiophysical laboratory studies on cases; and analysis of samples of radioactive paints to which the cases were originally exposed.

As of October 1, 1966, 215 cases and 89 controls have undergone complete or partial study to estimate the long-term effects of a radium body burden in man. In previous reports, data from various phases of the Project have been tabulated and studied. At present, these listings are being brought up to date and additional listings are being prepared. Evaluation of accumulated data is under way. A final set of studies on all cooperating cases and controls will be completed about February 28, 1967. Addition of data from these studies will permit evaluation of most of the information collected by the Project.

Project Organization*

Purpose

The Radium Research Project of the New Jersey State Department of Health, supported by U. S. Atomic Energy Commission Contract AT(30-1)-2181, is reexamining through application of modern epidemiological methodology and reevaluating the low level, long-term, biomedical effects of retained body burdens of radioactive substances (radium-226 and radium-228) in former radium dial painters and other radium workers. The chief interest of the Project lies in refining radiation safety standards, especially for internal body burdens of radium and other bone-seeking isotopes.

This study concentrates on approximately 200 cooperative individuals from the slightly more than 1000 former workers of the radium dial painting industry in Northern New Jersey (See Exhibit 1). Most of these people were employed in the industry between 1913 and 1928. A selected group of presumptively unexposed sibling controls is also under study.

Overt diseased states such as pathological fracture, osteogenic sarcoma, paranasal sinus carcinoma and massive bone necrosis, while dramatic and of commanding interest in understanding biomedical effects of irradiation, are probably results of relatively obscure changes produced in cells or tissues by prolonged or repeated exposures. In the minds of the Project consultants and other Project scientific personnel, both the beginning change and the final disaster to the individual are equally important. If the radiation safety goal of the Project is to be approached, studies must concentrate on relatively low body burden cases with particular attention in them to the unexplained radiolucent areas in mandibles and long bones,

*Revised and reprinted this year to insure availability of this information to individuals not seeing previous Project publications or reports.

uneven thickening of bone cortices, changes in trabecular patterns and calcification, microanatomical changes in soft tissues or individual cells, and subclinical changes in blood cellular or serum components which may be precursors of later, fatal irradiation sequellae. The material appears favorable for this approach. Other studies are left to sister projects, such as the ones under Robley D. Evans, Department of Physics, Massachusetts Institute of Technology (AEC Contract AT(30-1)-952); Merril Eisenbud, Institute of Environmental Medicine, New York University Medical Center (AEC Contract AT(30-1)-3086); Asher J. Finkel, Director of Health Division and L. D. Marinelli, Director of Radiological Physics Division, Argonne National Laboratory; and Robert J. Hasterlik, Department of Medicine, Argonne Cancer Research Hospital.

Goals

Simply stated, the goals of the Project are four-fold:

1. Detection of the earliest possible biomedical changes associated with internal irradiation among radium workers which initiate series of events that culminate in grossly harmful or lethal injuries.

irradiation → biomedical effects + time → deleterious effect

2. Assessment of aggregate internal radiation exposures of tissues, cells and bodies of radium workers.

3. Collation of aggregate radiation exposures with objective biomedical effects observed in radium workers.

4. Evaluation of radiation doses (body burdens) and biomedical effects observed in radium workers in terms of radiological health or radiation safety standards applicable to radiation workers and to the populace.

Structure (See Exhibit 2)

The New Jersey Radium Research Project, operating under the general direction of the Commissioner, New Jersey State Department of Health, consists of a Project Director, a Project Medical and Dental Staff, a Field and Office Staff, several clinical laboratory consultants, several cooperating independent research groups and several scientific subcontractors.

Epidemiological activities such as case finding, field case follow-up, obtaining of occupational histories, compilation of record folders, storage and distribution of autopsy specimens, etc., are done in the Project office under direction of the Project Director. This immediate Project office group is responsible for general administration of the Project, obtaining vital statistics records on cases and controls, arranging for post-mortem examinations, coding and punching data for statistical processing, etc.

The Project Medical and Dental Staff together with the Project Director comprise the steering group for the Project. They also examine cases and controls, perform the roentgenographic surveys on them, evaluate the clinical findings, evaluate the roentgenograms and help advise on evaluation of data collected.

The clinical laboratory consultants are responsible for performing and reporting clinical laboratory tests on cases and controls.

Special radiation studies such as whole body counting and breath radon measurement for estimating body burdens, and radiochemical analysis of soft tissue and bone specimens for radioisotope content are performed at New York University Medical Center under cooperative arrangement with

Professor Merril Eisenbud and his staff. For interproject comparison purposes, breath radon measurements, and in the past, whole body counts, are done on selected cases under cooperative arrangement at the Massachusetts Institute of Technology Department of Physics with Professor Robley Evans and his staff. Special excretion studies have been done at New York University Medical Center and at Argonne National Laboratory, Radiological Physics Division.

Processing, reading and evaluating of surgical and post-mortem specimens from cases and controls are done under subcontract agreements. General pathological studies are done at the New Jersey College of Medicine and Dentistry where Dr. Hugh Grady and Dr. William Sharpe provide histopathologic interpretation of soft tissues and bone and conduct a special study of early radiation osteitis. Oral pathological studies are done at Georgetown University School of Dentistry where Dr. Joseph Bernier directs histopathologic interpretation of oral specimens with the assistance of Dr. Joseph Belzile.

Under subcontract at the Rutgers University Statistics Center, Professors Ellis Ott and Thomas Hayton provide consultation and data processing toward statistical evaluation of the data collected and recorded under the other activities of the Project.

Activities

The New Jersey Radium Research Project began in November 1957 as a feasibility study, converted to an ongoing epidemiological project in March 1958. Major effort during 1957 to 1960 went into identifying by name and locating by address the early dial painters and radium workers

of northern New Jersey. During 1959 to 1966 the Project collected medical, dental, x-ray and laboratory data on cases willing to cooperate. Current efforts are directed toward data collation and evaluation but with a final effort being expended in completing the data collection on cases and in developing and examining the selected control group.

Areas of data compilation and of clinical and laboratory study are as follows:

1. Studies performed on cases

    a. Occupational history
    b. Medical, family and spouse history
    c. Dental history
    d. Physical examination
    e. Dental examination
    f. X-Ray survey and examination
    g. Clinical laboratory series of tests
    h. Whole body gamma count (NYU)

Two sets of medical, dental, etc. studies plus three additional laboratory sets are planned for each case.

2. Studies performed on controls include one set of medical, dental, etc. plus four additional laboratory sets.

3. Additional special items as appropriate

    a. Copies of birth and death certificates
    b. Post-mortem examination at which extensive collection of bone specimens is done
    c. Histopathology on surgical, biopsy and post-mortem specimens
    d. A special research study of early radiation osteitis in bones of cases.

4. Development of objective recording systems for the data observed in (a) histopathology (general and oral) (b) roentgenograms and (c) clinical laboratory.

5. Collation of medical and other findings with gross body burdens.

6. Evaluation of clinical laboratory data for significant variations and comparison with body burden.

7. Radiochemical analysis of selected bone specimens from cases and controls:

   a. A standard six bones per case whenever appropriate specimens are available

   b. Special comparative study of radioisotope content (Ra-226, Ra-228, Pb-210) of multiple bone and soft tissue specimens from several selected cases.

8. With compilation of data nearing completion, attention is now being directed to the points of interest they delineate and to meaningful conclusions that may be drawn therefrom.

PART I

REPORT OF THE EPIDEMIOLOGICAL AND MEDICAL STUDY GROUP AND THE PROJECT SUBCONTRACTORS

I. CLINICAL STUDIES

Medical Studies

During this reporting period, three new radium case examinations and seven follow-up examinations on radium cases were performed by the Project Medical Director, as well as examinations of 34 controls cases. Partial medical examinations were performed on three cases.

Summaries of fifteen additional radium cases are presented as Part III of this report, supplementing previously reported case summaries.

Three radium cases who had been under study died during the period covered by this report. Post-mortem examination was performed on one of these. Ten radium cases who had not been under active study also died.

Malignancies Among Cases Under Study

Four malignancies among living radium cases under study have been brought to our attention; these have not been previously reported; and all diagnoses have been verified by histological reports.

Case No.	Malignancy
5153	Mucoepidermoid carcinoma of right parotid salivary gland (1963) (Bowen's Disease of skin of finger previously reported) Basal cell carcinoma of scrotum (1966)
5246	Basal cell carcinoma of forehead and chin (1964) (Squamous cell carcinomas of skin of fingers and basal cell carcinomas of skin of lip, left ear, nose previously reported)
5290	Basal cell epithelioma, left upper lip (1955) (Basal cell epithelioma of skin of temple previously reported)
5368	Squamous carcinoma of cervix (1951)

Deaths of Cases Who Died While Under Study

1. Case 5155. Case résumé is in NYO-2760. This patient died in December 1965. Post-mortem diagnoses were:

   History of automobile accident.
   Comminuted compound fracture, right tibia and fibula
   Lacerations, multiple, right and left knees, right temporal area
   Eccymoses, right ear lobe
   Multiple rib fractures, status post-surgical cut-down, ankle
   Acute pulmonary edema, myocardial hypertrophy
   Acromegaly
   Hirsutism
   Large face and hands
   Coarseness of skin, face
   Prominent mandible and supra-orbital ridges
   Generalized organomegaly
   History of exposure to radium
   Cavitations of tibial and humeral medulla
   Osteoporosis
   Status post hysterectomy

2. Case 5136. Case résumé is in NYO-2181-3. This patient died in July 1966 with death certificate diagnoses of coronary thrombosis due to hypertensive arteriosclerotic heart disease. No post-mortem examination was performed.

3. Case 5255. Case résumé is in NYO-2760. This patient died in August 1966 with death certificate diagnoses of myocardial infarction due to arteriosclerotic heart disease. No post-mortem examination was performed.

Data from Death Certificates

Five additional malignancies were diagnosed on newly received death certificates.

Case No.	Year of Birth	Year of Death	Causes of Death
5180	1898	1966	Carcinoma of lung with metastases
5497	1893	1965	Pulmonary embolus Generalized carcinomatosis Primary carcinoma of breast
5954	1892	1965	Post-operative infection and inanition Resection of cancer of sigmoid
5999	1893	1965	Carcinomatosis. Cancer of colon
6008	1908	1966	Multiple myeloma

Control Cases

No controls have died since the last report. In December 1965 a possible basal cell carcinoma, skin of left side of nasal bridge, was diagnosed on Control 6574.

Roentgenographic Studies

During the past year the roentgen examination has proceeded without change in basic policy or equipment. Forty-three complete bone surveys were made, nine of which were on former workers in the luminous dial industry, and the remainder on presumably unexposed controls. Studies were made on osseous material resulting from two autopsies.

As examination of workers and controls nears completion, the evaluation of data accumulated in the past seven years becomes of paramount importance. To be of maximum use, films must be minutely reexamined and carefully classified. The coding forms (See Exhibit 3) devised in 1964 and last revised October 15, 1965, have been used in 25 cases and found suitable. By means of these forms any designated deviations from the normal are classified by location, type, distribution, frequency and size. Record is kept of definite clinical and pathological entities present. The degree of osteoporosis is evaluated by measurement of the combined cortical thickness of the proximal radius and second metacarpal bones as detailed in previous report NYO-2181-3.

A second consultation was held with Dr. Gwilym Lodwick, Professor and Chairman of the Department of Radiology of the University of Missouri School of Medicine, an authority on radiological computer investigation. Agreement was found in the practical aspects of the coding. Dr. Lodwick offered us the facilities of his special computer for analyzing the frequency distributions of our findings. When this point has been reached the importance of the individual findings may be appraised, as well as their relationship to age, sex, exposure, body burden, medical, dental,

pathologic and radiochemical findings. The control material will prove invaluable in this study.

An exhibit was prepared and shown at the Annual Meeting of the Radiological Society of North America, November 28 to December 3, 1965. This exhibit demonstrated the most frequent changes found in the bones of radium workers and compared them with radiographs of the corresponding pathological specimens. It also demonstrated our findings in the measurement of the combined cortical thickness in the radii and hands of radium workers compared with the unexposed population.

While the process of coding appears to be the most important activity at the time of this report, and must be completed if minimal specific changes are to be recognized and evaluated, another important study to be undertaken is correlation of gross and histological pathology with the roentgen image. Seldom, if ever, has such a fund of documented and coordinated material been assembled and it is planned that full use will be made of this unusual opportunity. It is estimated that an additional two years would be required to make full use of the valuable radiological data that has been and is still being accumulated.

Dental Studies

During this reporting period 38 cases were examined clinically and dental radiographs were taken. This total number includes one initial examination of a known exposed case, six follow-up studies of known exposed cases and 30 initial examinations of control cases plus one control follow-up.

No attempt has been made to analyze these data or correlate them with cases previously studied. This will be the subject of our forthcoming final report.

Re Case 5281 (Body Burden .603μc Ra^{226} and .0019μc Ra^{228}), the x-ray views and histopathology studies of the defect, the bone and soft tissue contained therein, within the body of the mandible were presented and discussed at the April 18, 1966 AEC Group Meeting held in Washington, D.C. The initial impression of the tissue removed is that of a necrotic mass with scavenger cells and remnants of acute inflammatory cells. Additional considerations are some form of degenerated connective tissue, hyalin type of degeneration and plasma protein. As the histopathology studies progress and these findings can be compared to those found throughout the skeletal structure, Case 5281 will be the subject of a separate report.

The oral histopathology findings are summarized elsewhere in this report. While the microscopic slides of the specimens are being read by a pathologist who has no knowledge of retained body burdens of patients from whom the specimens were taken, the processing of the total findings; clinical, roentgenographic, histopathology, radiochemistry, retained body burdens, etc., will hopefully be completed within the coming year and an analysis tying together these independent observations will be contained in our final Project report.

II. LABORATORY STUDIES

Clinical Laboratory

The Clinical Laboratory, under the direction of Dr. Lester M. Goldman, Director of Laboratories, Newark Beth Israel Hospital, continued to perform its preselected battery of tests on cases and controls of the New Jersey Radium Research Project. During the reporting year, 54 sets of examinations were done on radium workers and 164 sets of examinations were done on controls. Collation and statistical testing evaluation of the results of the laboratory examinations are currently in process.

Histopathology (Soft Tissue and Bone)

General Pathology

Quantitative Report

Substantial progress was made between 1 September 1965 and 1 September 1966. 403 complete specimens representing 1215 tissue blocks (missing 23 blocks which are at least temporarily "not available") have been reported, and 121 bones from 23 cases have been examined in sufficient detail to begin the definition of changes. About 700 blocks have been described but are not yet assembled into complete specimen reports because of randomization necessary for blind study. No correlation has so far been attempted with radium burdens of any sort.

Limitation of Material

Because of the necessary delay between death and freezing of the tissues, much of the bone is poorly fixed, but the anatomic outline of various structures and lamellar architecture are satisfactory. Because osteocytic criteria for bone ischemia and metabolic injury, insofar as established, are not applicable, microradiographic evidence of occluded vessels and calcified osteocyte lacunae will be necessary to assess the presence and extent of bone infarction and death in borderline areas.

Histologic Abnormalities

Without knowledge of body or local bone burdens of radium at the time of interpretation of histologic preparations, many of the changes noted presumably represent only the usual and expected changes of aging: patchy and irregular loss of osteocytes from their lacunae, calcification of vascular channels and canals, increased porosity of both cortical and

cancellous bone, and structural changes in joints and periosteal surfaces. Changes consistent with varying stages and degrees of Paget's disease (osteitis deformans) have often been noted. Subsequent statistical analysis against a control population may define whether these changes are in fact accelerated in patients with higher than background radiation burdens.

Conferences with Dr. Hubert A. Sissons in London gave independent support to specific changes which have not been encountered in the enormous material seen at the Royal National Orthopaedic Hospital, which have apparently not hitherto been described, and which may tentatively be presumed related in some way to exposure to radiation. Other abnormalities may subsequently be identified, and only analysis of the whole material available will be able to assess possible relationship to radium burdens. Correlation of these histologic changes with whole body and fractional bone radiation burdens will require a larger sampling than has been accomplished to date.

For adequate scientific completion of the bone histopathology component of the Project, financial support is needed for at least two more years, and probably longer.

The time is probably ripe to initiate direct, fractional analyses of radium bearing bones, because the total radioactivity is so small that autoradiographs may prove wholly unreliable except for assessment of "hot spots." Exposure times for autoradiographs may approach two years, and direct analyses seem a more useful approach.

Current Queries

Review of current and past literature suggests that early bone infarction and "radium osteitis" were not distinguished by writers generally before World War II, and that confusion between these processes makes their reports subject to reinterpretation. The fibrillar cortical and granular basophilic material reported in early descriptions of both bone infarction and "radium osteitis" have never been adequately characterized. The special staining program which is under way may yield useful information along these lines, and further review of the literature will continue.

Oral Histopathology

Material studied during the reporting period includes fifteen individual specimens from nine cases. Specimens were from the oral cavity except for two cases where specimens were from the maxillary sinuses.

All tissues were processed in a conventional manner at the Department of Oral Pathology of Georgetown University. All sections were read blind with no knowledge of body burdens.

Serial sections of all specimens were prepared and every tenth section was stained with hematoxylin and eosin. All blocks were paraffin embedded; thus far no special staining has been found necessary. All unstained sections are mounted on glass slides, carefully protected by paraffin sheet film and stored.

The data are presented in condensed form in terms of geographical area. A more detailed report on each specimen has been recorded and is in the Project files. Specimens were examined from the following areas:

(1) Mucosa and bone of the maxillary sinus

(2) Mucosa of the oral cavity, including tongue, palate, cheek, alveolar mucosa and gingiva

(3) Bone of the mandible and maxilla

The histopathologic findings in the above areas were:

(1) Maxillary Sinus: The mucosa presented a non-specific inflammatory proliferative polyposis which, judging from the eosinophilia could be interpreted as allergic.

(2) Mucosa of the Oral Cavity: The findings in the oral cavity were inflammatory or benign, proliferative pseudo-tumors such as papilloma, fibromas, acanthosis, etc. Two specimens did, however, show epithelial dyskeratosis. Serial examination of these two specimens revealed no extension to carcinoma in situ or submucosal invasion. Reactions in mucosal adnexae, such as the minor salivary glands showed non-specific ductal ectasia, but no tumors were encountered.

(3) Bone: Specimens from two cases showed no unusual periosteal or endosteal changes and neither specimen presented any tumors. Trabecular spaces did, however, appear enlarged and Haversian systems in cortical bone were unusually prominent. Large empty spaces were encountered frequently in cortical bone.

As the study continues, soft tissue changes are still non-specific, but many specimens remain for examination and it is impossible at this time to correlate findings with body burdens. Bone lesions examined in two specimens are as previously reported, large empty spaces within cortical bone. It is, however, too soon to determine if this will be a constant finding. Unfortunately, due to the technical difficulties of processing, bone tissue examination does not progress as rapidly as soft tissue. No malignant changes have been uncovered thus far.

Body Burden Assessment

Through interproject cooperation the New York University Medical Center group, working under Merril Eisenbud and supported by U. S. Atomic Energy Commission Contract AT(30-1)-3086, has performed 73 whole body counts and 36 breath radon determinations on cases and controls of the Radium Research Project since September 1, 1965. Additionally, the Massachusetts Institute of Technology group, working under Robley Evans and supported by U. S. Atomic Energy Commission Contract AT(30-1)-952, has performed 13 breath radon determinations on Project cases.

As is reported in NYO-3086-6 (10/1/66), special additional studies on materials from Project cases were done by the New York University Medical Center group:

(1) "Estimates of Total Body Radium in the New Jersey Dial Painters" by H. Peterson, N. Cohen, and H. W. Berk.

(2) "A Study of the Distribution of Ra-226, Ra-228, Pb-210 and Th-228 in Bone and Soft Tissue of Radium Dial Painters" by Henry Petrow.

(3) "Discussion of Possible Mechanisms Involved in the Apparent Concentration of ^{226}Ra and ^{210}Pb in Aorta and Thyroid" by Norman Cohen.

Since the data presented in these three reports constitutes an integral part of the information about radium workers in the case group of the Radium Research Project, by permission of Dr. Eisenbud, Dr. Petrow and Mr. Cohen, the summaries of these three portions of NYO-3086-6 are reproduced here and copies of the full reports are included as Part II of this current progress report of the Project.

Summary

The effective half-life of radium-226, calculated from RaC retention, has been found to be approximately 11 years. It is believed that this value, which is shorter than the half-life proposed by others, might be due to a natural aging effect such as osteoporosis which results in increased bone resorption. No difference is apparent between the exponential and power function retention models.

A possible correlation between a respiratory parameter, minute volume (liters/min), and radon retention has been found. It is believed that this variation might explain short-term fluctuations in radon retention measurements. Additional data is needed to confirm this observation.

A study has been made of the distribution of Ra-226, Ra-228, Pb-210 and Th-228 in bone and soft tissue of two radium dial painters. The data are presented in a separate section of this report, available on microfilm from the AEC (NYO-3086-5). The results of this study showed the usual heterogeneous deposition pattern for radium in the skeleton. The average skeletal Pb-210 to Ra-226 ratios demonstrate that lead and radium have equal biological half-lives. The variation in the ratio were site dependent. Shafts of long bone and rib had high ratio values, while the ends of long bones and vertebrae had low ratios. In long bone, low ratios were associated with high Ra-226 concentrations. The cause of the ratio variations cannot be proven unequivocably, but is believed to be due to variations in the radon retention factor.

The Th-228 to Ra-228 ratios were also measured. These ratios vary considerably, but in a random manner. The cause of the variation is believed to be Th-228 translocation. The average skeletal ratio of Th-228 to Ra-228 offers a second method of estimating radium biological half-life over the last 5 - 10 years of life. This value is 10.4 years. The analysis of beagle bone obtained from an animal injected with Ra-228 indicated a similar ratio pattern, with large, random variations being observed. The radium biological half-life, as calculated from the data, is 16 years.

The analysis of tissues from an individual with a 50 year old radium burden indicated that 0.05% of the Ra-226 and 0.65% of the Pb-210 in the body is found in soft tissue. The aorta contained the most Ra-226 and Pb-210 of all soft tissues analyzed with the thyroid being the second highest.

Since, of all the soft tissues obtained from a deceased radium dial painter, the aorta had the highest concentrations of both Ra-226 and Pb-210, a survey of the literature concerned with the uptake of polyvalent cations by the aorta has been made, and consideration given to the radiobiological implications of the known facts, as they pertain to radium cases.

III. STATISTICAL STUDIES

The coding and punching of further data has proceeded through the year. Specifically the whole body counter determinations have been assigned a deck, likewise the breath radon and thoron determinations. A coding scheme has been devised for the revised x-ray scoring system pending the actual release of evaluations by the Project radiologist. For day-to-day working purposes average values have been promulgated of the clinical laboratory parameters.

In the expectation that Project pathologists will require statistical processing of their bone histological findings a preliminary study of these findings has been made to gain insight into the phenomena. On the basis of this, the pathologists' requirements can be rapidly executed. Likewise in the expectation of evaluations by the Project consultant on hematological data, a study of the interrelations of the components of the electrophoretic pattern of controls and subjects with less than detectable body burdens has been mounted.

With a view to final analysis, a review of radium retention data has been made. It has been possible to supplement this by the computations of certain parameters from the New Jersey data.

PART II

RÉSUMÉ OF COOPERATIVE LABORATORY STUDIES ON PROJECT CASES AND SPECIMENS

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PART I

Estimates of Total Body Radium in the New Jersey Dial Painters

H. Peterson, N. Cohen, H.W. Berk

Method of Whole Body Counting

In previous progress reports (1962 and 1965) the technique used to determine the breath radon estimates has been reviewed. This section will describe the procedures employed in the whole body gamma spectrometric analysis.

Figure (1a) illustrates the gamma ray spectrum of a normal individual measured with a 8" x 4" sodium iodide (Tl) detector and an energy calibration of 12 keV/channel. This represents the energy region 0 - 3 MeV when 255 channels are employed. The peak in channel 120 is due to the 1.46 MeV photon from ^{40}K which occurs naturally in potassium with a specific activity of 829 pCi ^{40}K per gram of potassium. The other prominent photopeak is due to ^{137}Cs (0.661 MeV) which is present due to fallout from nuclear weapons testing. In order to avoid interferences from these nuclides and from variations in their concentration from subject to subject only the energy region above 1.60 MeV is used for study.

Figure (1c) is the gamma spectra of a 1.0 μCi source of ^{226}Ra taken under the same conditions as Figure (1a). The prominent photopeak in the region above 1.60 MeV is due to

the 1.76 MeV gamma of ^{214}Bi(RaC). Since this nuclide is a daughter of the 3.83 day ^{222}Rn it represents only the fraction of the ^{226}Ra body burden due to retained radon. For most of our cases this fraction is approximately 0.33 (see Section2). The region containing this photopeak extends from channels 140 (1.68 MeV) to 159 (1.91 MeV) and is identified in Figure (1c) as the RaC region. Radium-228 (Mesothorium) is determined by measuring the 2.61 MeV gamma of its daughter ^{208}Tl (ThC"). The intervening radon isotope, ^{220}Rn (Thoron), has a half life of 56 seconds and therefore is presumed to decay entirely in the body.

Thallium-208, in equilibrium with Thorium-232, is used as a standard for the mesothorium estimation. Due to its short (5.7 yr) half life ^{228}Ra is not used as a standard, thus eliminating decay corrections. A correction is made, however, to take into account the equilibrium ratio of ^{208}Tl to ^{228}Ra. This is 0.5 for ^{228}Ra in equilibrium, whereas it is 0.33 for ^{232}Th . The gamma ray spectrum of ^{232}Th is shown in Figure (1d); the region encompassing the 2.61 MeV peak of ^{208}Tl (channels 206-229, 2.47-2.74 MeV) is indicated.

Figure (1b) is the gamma spectrum of case #5025 who has an estimated body burden of 0.085 μCi ^{226}Ra.

The principal decay products of importance in the two chains are: ^{232}Th____, ^{228}Ra 5.7 yr., ^{228}Th 1.9 yr., ... ^{208}Th 3.1 min., ^{228}Ra 5.7 yr., ^{228}Th 1.9 yr.,.... ^{208}Tl 3.1 min.

If the thorium chain is in equilibrium, the activity of any daughter equals that of the parent (secular equilibrium), and $A(^{232}Th) = A(^{228}Ra) = A(^{228}Th) = 3\ A(^{208}Tl)$. The factor of 3 is due to a branch in the decay chain such that the ^{208}Tl yield is 33%.

Under these conditions in the ^{228}Ra chain, however, transient equilibrium exists, therefore $3\ A(^{208}Tl) = A(^{228}Th) = \frac{\lambda^{228}Th}{\lambda^{228}Th - \lambda^{228}Ra} A(^{228}Ra) = 1.5\ A(^{228}Ra)$.

Therefore, $\frac{A(^{208}Tl) / A(^{228}Ra)}{A(^{208}Tl) / A(^{232}Th)} = 1.5$. However, it does not necessarily follow that the ratio of ^{228}Th to ^{228}Ra in the body is equal to 1.5, since this ratio is a function of the pertinent effective half lives. Petrow has measured the ratio of ^{228}Th to ^{228}Ra in a skeleton and found it to be 2.08, which reflects the fact that radium has a shorter biological half life than thorium (14). Since this ratio may vary from case to case, this is a possible source of error in any ^{228}Ra measurement.

The counting rate in the RaC and MsTh regions may be represented by

$$S_{RaC} = B_{RaC} + R_{RaC} + T_{Rac} \quad (1)$$

and

$$S_{MsTh} = B_{Msth} + R_{MsTh} + T_{MsTh} \quad (2)$$

where S_{RaC} = gross count rate in RaC region.

B_{RaC} = background count rate in RaC region.

R_{RaC} = count rate in RaC region due to ^{226}Ra and its daughters.

T_{RaC} = count rate in the RaC region due to ^{228}Ra and its daughters.

S_{MsTh} = gross count rate in Msth region.

B_{MsTh} = background count rate in MsTh region.

R_{MsTh} = count rate in the MsTh region due to ^{226}Ra.

T_{MsTh} = count rate in the MsTh region due to ^{228}Ra and its daughters.

An estimate of B can be made by determining the counting rate obtained under the same conditions but without the subject present. Because of variations in the cosmic ray intensity and in the radon-220 and radon-222 levels in the counting room and surrounding area as well as changes in the calibration (gain drift, etc.) the background measurement is made either immediately before or after the measurement of the subject.

The estimation of R and T is somewhat more difficult. As can be seen from Figures (1c) and (1d) there are counts contributed to the RaC region from thorium daughters and counts contributed to the MsTh region from radium-226 daughters. The most accurate method of determining these contributions would be to employ phantoms having the same anthropometric characteristics as the subject and containing known amounts of radium and thorium. In practice, however, this would be unsatisfactory for the following reasons:

1.) A large number of different sized phantoms would be required to simulate the variety of body sizes encountered in the subjects.

2.) Homogeneous phantoms generally contain aqueous solutions of the standards. The possibility of contamination from leakage as well as the difficulty of handling large phantoms limits their desirability. Also the deposition of radium in the skeleton is heterogeneous, but not reproducibily so.

3.) Leakage of radon would affect the concentration of ^{214}Bi in the phantom and result in the overestimation of the body burden.

The standards are in the form of sealed sources and are counted in the crook of the chair (see Figure 2). From these measurements the contribution to each region is determined. These factors are evaluated for each run and are approximately,

$$a = \frac{\sum_{140}^{159} \text{thorium}}{\sum_{206}^{229} \text{thorium}} = 0.23$$

$$b = \frac{\sum_{206}^{229} \text{radium}}{\sum_{140}^{159} \text{radium}} = 0.028$$

Differences between the Compton scattering contributions in the standard and the subject are assumed to be second order

effects.

Using these contribution factors equations 1 and 2 become

$$N_{RaC} = S_{RaC} - B_{RaC} = R_{RaC} + a\,T_{MsTh} \quad (3)$$

$$N_{MsTh} = S_{MsTh} - B_{MsTh} = bR_{RaC} + T_{MsTh}, \quad (4)$$

where N_{RaC} and N_{MsTh} are the net counting rates in the two regions.

These equations can be solved for T_{MsTh} and R_{RaC} giving

$$R_{RaC} = \frac{N_{RaC} - aN_{MsTh}}{1 - ab} \quad (5)$$

$$T_{MsTh} = N_{MsTh} - b\left(\frac{N_{RaC} - aN_{MsTh}}{1 - ab}\right) \quad (6)$$

If N_{MsTh} is negative, it is set equal to zero so as not to overestimate the radium counting rate.

The difference in the counting efficiency (geometry) between a point source and a human subject is compensated for by means of a chair factor. The chair factor is defined as

$$f = \frac{\text{Counting rate per unit known activity in a person}}{\text{Counting rate per unit activity of a standard source}} \quad (7)$$

and was found to be 1.2 by measuring 5 individuals having known ^{226}Ra burdens.

The body burdens of RaC and Mesothorium are given by

$$BB_{RaC} = \frac{R_{RaC}\ A_{Ra}}{f\ N_{RaC}} \quad (8)$$

and $$BB_{MsTh} = \frac{T_{MsTh} \; A_{Th}}{f\,(1.5)\,\overline{N+}_{MsTh}} \qquad (9)$$

Where A_{Ra} = activity of radium standard

A_{Th} = activity of thorium standard

f = chair factor = 1.2

1.5 = equilibrium correction factor (see pp. 1-2, 1-3)

$N+_{RaC}$ = net RaC counting rate of radium standard

$N+_{MsTh}$ = net MsTh counting rate of thorium standard

These calculations have been programmed for a Control Data 160-A computer in the program "BURDEN", which computes in addition to the estimates, the variance due to counting statistics and the MSA* (minimum significant amount) for each run.

Appendix II contains a listing of "BURDEN" and a sample output page.

Reproducibility of Whole Body Data

An additional study (6) of the reproducibility of whole body counter measurements was performed using four subjects having body burdens ranging from 0.003 to 0.083 μCi RaC. The body burdens were determined by two separate techniques: The "Burden" program with a radium point source standard which

*The MSA is the minimum amount of measured radioactivity of which it can be stated that, at the 0.10 level of significance, this measured activity is above background.

is used routinely for ^{226}Ra body burden determinations; and the integral stripping technique of Hallden and Harley (5). The variability of these two techniques, expressed as % standard error / estimated body burden of RaC, are plotted in Figure 3. The data reported in the 1965 report on two cases measured in 1962 at the New York City Facility are also plotted. The curve is the estimated percent standard deviation computed from counting statistics for individual measurements versus body burden RaC. The standard deviation used is the value currently reported as the error in the RaC measurements. It has been found that the variation in repeated measurements of an individual is less than the error predicted from counting statistics for most of the cases studied.

Breath Radon Measurement

The breath radon values obtained thus far in 1966 are the second series of measurements made on the group of dial painters studied in 1965.

The procedures for performing the radon measurements have remained essentially the same as previously described in the 1965 Annual Report (3). The only two modifications in procedure involved subject positioning during collection and a change in the gamma count summation region.

Since it is likely that the retained fractional radon is in some way related to the short term variation of the

respiratory pattern, every effort was taken to remove all emotional and physiological discomforts. Subjects were allowed to recline in a chaise lounge during sample collection, thereby providing a relaxed atmosphere and achieving a more reproducible breathing pattern. In addition, this procedure makes collection of larger samples more feasible, providing for better counting statistics.

In the 1965 annual report (3) two different counting procedures for the estimation of radon were described. One method involves gamma counting of a charcoal sample containing adsorbed radon. As originally described, only events occurring in the ^{214}Bi region were measured. In order to increase sensitivity and to minimize errors due to gain shift, summation is now performed over the energy continuum, 0.22-2.56 MeV. This results in a new MSA (minimium significant activity) (1) of 1.30 pCi for radon.

The second method is essentially that developed by Lucas and consists of desorbing the radon and collecting the gas in a scintillation bottle, and alpha counting radon and its other emitting daughters. This technique is considerably more sensitive than gamma counting and the MSA is 0.016 pCi of radon.

Based on a 100 liter breath sample from an individual with an average minute volume of 7.5 L/min, the minimum significant

body burdens corresponding to the above MSA values are 1.18 nCi and 14.5 pCi, assuming the fractional radon retention is 0.33. Since the chance of procedural error is less likely by the direct gamma counting technique, and the method is rapid, it is used for those cases where the body burden is high enough to allow for acceptable counting statistics. (See figure 4)

The results of 27 breath radon measurements made during the past two years are listed in Table 1. If the effective half life of ^{226}Ra is assumed to be 11 years, a decrease of approximately 6% in the 1965 body burdens would be expected. A change of this magnitude, however, would be masked by differences due to other factors contributing to the overall experimental error.

Fractional expired radon vs body burden for both 1965 and 1966 measurements is plotted in Figure 5. No significant correlation between body burden and the radon loss rate is evident. If the standard deviation of the outgassed radon values due to counting statistics is plotted against body burden, (Figure 6), it is obvious that the distribution in Figure 5 is a function of the associated counting error. The plot of percent counting error vs body burden (Figure 7), illustrates the statistical degree of uncertainty in the outgassed radon value as a function of body burden.

There appears, in the data accumulated to date, to be

a possible correlation ($\rho = 0.76$, significant at the 95% confidence level) between minute volume (l/m) and outgassed radon (Figure 8). It has been assumed in the past that radon retention may be affected by the respiratory pattern but until now there has been no evidence of correlation between expired radon and any respiratory parameter.

The rate of radon elimination from bone is considered to be the controlling factor in radon retention, (15) and while this process may be time dependent it can probably be considered constant for periods as short as one year for old radium burdens. Percent retention as a function of time may be possibly follow the slope illustrated in Figure 9 which was plotted from the data of several investigators (4,7,8,11, 13,15-17) of the retention factors for man, dogs and rats with body burdens of 11 days to 40 years duration. A comparison of several models of radon retention is presented in Table II.

Short term variation of the expired radon fraction on the other hand is much greater than that predicted from these models and may be a function of more immediate physiological parameters. Further experimentation is necessary to confirm the observed correlation between percent radon expired and minute volume.

Radium Retention

In the previous report (3) the effectivehalf-life of

radium was computed based on whole body measurements of the RaC daughter made in this laboratory from 1960 to 1965.

Re-analysis of 11 cases selected in 1965 with the addition of data obtained in 1966 gave the ^{226}Ra effective half-life estimates shown in Table III. The statistical techniques used for obtaining the pooled regression estimate are described in appendix I. The value thus obtained of the effective half-life of radium for these 11 cases was 15.7 ± 2.4 years in 1965 and 14.73 ± 2.31 years when the 1966 data were included. If the data are normalized to percentages of the initial measurement (taken as 100%), and are combined and fitted by least squares technique, the estimate of the effective half-life of radium is 14.2 ± 3.08 years when the 1966 data are added. Based on pooled regression analysis of 21 cases having body burdens greater than MSA (0.002 μCi RaC) an effective half-life of 11.1 ± 1.9 years was reported in 1965.

If more stringent conditions are imposed upon the selection of data by choosing only cases where the observations have been made over a period greater than three years, having more than two measurements, and having body burdens greater than 0.01 μCi RaC; only six cases would be included (5014, 5025, 5215, 5281, 5284, 5917) and a pooled half-life of 11.32 ± 0.94 years is obtained. These six cases represent 42 points.

On the other hand, if all cases having a body burden greater than MSA (0.002 μCi RaC) (1) are used, a value of 10.71 $\pm$ 2.58 years results. This study includes 124 points (30 cases). These data are given in Table IV.

The variation of the half-life estimate with RaC body burden is shown in Figure 10. No general trend is evident but it should be noted that the negative values are all for cases having a 1960 estimate body burden of less than 0.01 μCi RaC. Most of the half-life estimates in the region above 0.01 μCi that are less than 5 years are from cases represented by only a few points.

The pooled half-life estimate of 10.7 $\pm$ 2.58 years, although considerably lower than the 45 years presently assumed for radium, is in excellant agreement with a value of 10.4 years calculated by Petrow (14) for ^{228}Ra in bone (case 5281) from the $^{228}Th/^{228}Ra$ ratio. The reason for this rapid elimination is not known, but it should be noted that our population is an aged one (mean age 66.6 years) and all measurements made were made in the past 6 years. Hence, this relative short half-life may be due to an aging effect such as osteoporosis.

Due to an error in the 1965 report the power function model for radium elimination waserroneously thought to be inapplicable to our data. We now find that this conclusion

was based on a numerical miscalculation and that the power function does in fact yield estimates of elimination rates that are consistant with our data.

The power function retention model is

$$R(t) = a\, t^{-b}$$

where $a = R(1)$; then at some time later, x, let $R(t + x) = \frac{1}{2} R(t)$, therefore $\frac{1}{2} a\, t^{-b} = a\, (t + x)^{-b}$, and x should then be the apparent half-life.

then $-b\ln(t) = \ln 2^{-1} - b\ln(t + x)$

$$b\,(\ln(t + x) - \ln(t)) = \ln 2$$

$$b\left(\ln \frac{t + x}{t}\right) = \ln 2$$

$$\ln\left(1 + \frac{x}{t}\right) = \frac{1}{b} \ln 2$$

$$1 + \frac{x}{t} = 2^{1/b}$$

therefore $x = t\,(2^{1/b} - 1)$ (For the derivation used last year the 1 was assumed to be small compared with $2^{1/b}$.)

The principal error in the previous analysis was that the value of b (0.1518) was determined by employing the data of initial measurement as the initial date of exposure. Although this assumption is inconsequential when employing an exponential model it does lead to serious error when applied to the power function. The mean time of exposure is now used and is taken as the midpoint of the period of active exposure to radium. These data were obtained from the Radium Research Project files and are listed in Table V. When the analysis is redone using

this initial point a value of b of 2.78 results. Then

$x = 43.1\ (1.274 - 1) = 11.8$ years considerably more in agreement with the exponential values of 10.7 and 11.2 years than the value of 4140 years that would be obtained if $b = 0.1518$. Norris (12) has reported a more rigorous derivation of an apparent half-life based on setting the slopes of the two equations obtained after logarithmic transform equal to one another:

$$\frac{1}{R(t)} \frac{dR(t)}{dt} = -\frac{b}{t}$$ from the power function and

$$\frac{1}{R(t)} \frac{dR(t)}{dt} = -\lambda = \frac{-0.693}{T_{1/2}}$$ if the exponential is used;

then $T_{1/2}$ apparent $= \frac{0.693\ t}{b}$.

With $t = 43.1$ years and $b = 2.78$ this gives an apparent half-life of 10.78 years, in excellent agreement with the exponential values. Although radium retention in aged subjects can be described by a power function this function is quite different than that reported by Norris (11).

The fact that RaC and not ^{226}Ra is being measured produces a bias in the effective half-life estimate only if the fraction of retained radon is changing with time. Since the RaC produced in the body is directly proportional to this quantity:

RaC = (fractional Rn retention) (^{226}Ra), then if the radon retention is changing with time the true biological half-life of ^{226}Ra will be different than that inferred

from the RaC measurements.

If the equation describing increasing radon retention reported by Miller and Finkel (10) is used with the value we report for the power function exponent, the effective half-life of radium would be 10.1 years, in good agreement with the reported values.

One might expect the short term changes in radon retention described in the second section of this report to have an effect upon the measured half-life. However, if the changes in radon retention are related to the minute volume then one might assume that they are either random or produce a bias in one direction. In either of these cases the effects should be negligible when a large number of cases are used to compute the pooled slope, however they might contribute to the variability of the estimates obtained from individual cases.

Appendix I - Statistical Techniques

In testing the applicability of the exponential function the regression model is $B(t) = B_o e^{-\lambda_E t}$ (1) where T_E, the effective half-life is $T_E = \frac{\ln 2}{\lambda_E}$. This can be transformed into the linear equation

$$Y = a + bx \qquad (2)$$

letting $Y = \ln A(t)$, $a = \ln A_o$, $x = t$

and $b = -\lambda_E$.

For the power function the regression model is

$$A(t) = qt^{-p} \tag{3}$$

which can also be transformed into equation (2) with the following change of parameters.

$$\begin{aligned} Y &= \ln A(t) \\ a &= \ln q \\ x &= \ln t \\ b &= -p \end{aligned}$$

The parameters obtained are therefore those which give the best fit to equation 2 in the log - log plane and not to equation 3. It has been shown (9) that these parameters can be different than those obtained from iterative calculations based on equation 3 directly. However, most of the studies in the literature use the log - log transformation.

Keeping in mind the different transformations employed to obtain the linear equation the remaining techniques are the same for both cases.

If there are k cases having n_i points each then the estimate of the individual slope for each case is given by

$$b_i = \frac{S^i_{xy}}{S^i_{xx}} \tag{4}$$

$$\text{where } S^i_{xy} = \sum_{j=1}^{n_i} x_{ij}y_{ij} - \frac{\sum_{j=1}^{n_i} x_{ij} \sum_{j=1}^{n_i} y_{ij}}{n_i} \tag{5}$$

$$\text{and } S^i_{xx} = \sum_{j=1}^{n_i} x_{ij}^2 - \frac{\left(\sum_{j=1}^{n_i} x_{ij}\right)^2}{n_i} \tag{6}$$

The standard error of this estimate is

$$S.E.\ (b_i) = s_i \Big/ \sqrt{S^i_{xx}} \tag{7}$$

where S_i^2, is the mean square due to error,

$$S_i^2 = \frac{1}{n_i - 2} \left[S^i_{yy} - b_i \frac{S^i_{xy}}{S^i_{xx}} \right] \tag{8}$$

$$\text{and} \quad S^i_{yy} = \sum_{j=1}^{n_i} y_{i_j}^2 - \frac{\left(\sum_{j=1}^{n_i} y_{i_j} \right)^2}{n_i} \tag{9}$$

The pooled slope, $\bar{b}$, is estimated assuming parallel lines and is given by reference 2;

$$\bar{b} = \frac{\sum_i^k S^i_{xy}}{\sum_i^k S^i_{xx}} \tag{10}$$

The standard error of this estimate is given by

$$S.E.(\bar{b}) = S^+ \Big/ \sqrt{\sum_{i=1}^{k} S^i_{xx}} \tag{11}$$

where S^{+2} is given by

$$\frac{\sum_{i=1}^{k} S^i_{yy} - \sum_{i=1}^{k} \frac{\left(S^i_{xy} \right)^2}{S^i_{xx}}}{\sum_{i=1}^{k} n_i - 2k} \tag{12}$$

```
C      BURDEN II - PROGRAM FOR RADIUM AND THORIUM BODY BURDEN CALCULATIONS
C      DEVELOPED BY H. PETERSON AND H. BERK, NYU MEDICAL CENTER,
C      INSTITUTE OF ENVIRONMENTAL MEDICINE.
C      MODIFIED OCTOBER 18,1965 BY H.PETERSON AND G.LAURER TO INCLUDE
C      MSA DETERMINATIONS AND  CORRECTION OF PROCEDURAL ERROR
C      KA = 1 READ NEW SERIES STARTING WITH BACKGROUND
C      KA = 2 READ NEW SAMPLE CARD
       COMMON CMIN
       DIMENSION BKGD(256),RADS(256),THORS(256),SAM(256),TITLE(11)
       DIMENSION ANAME,8)
     2 READ 10,TMB,(TITLE(J),J=1,11)
    10 FORMAT(F6.1,11A6)
       PRINT 11,TMB,(TITLE(J),J=1,11)
    11 FORMAT(1H1,F6.1,11A6)
       READ 12,(BKGD(I),I=1,255)
    12 FORMAT(10F6.0)
     3 READ 10,TMR,(TITLE(J),J=1,11)
       PRINT 10,TMR,(TITLE(J),J=1,11)
       READ 12,(RADS(I),I=1,255)
     4 READ 10,TMT,(TITLE(J),J=1,11)
       PRINT 10,TMT,(TITLE(J),J=1,11)
       READ 12,(THORS(I),I=1,255)
   200 RARRA = 0.0
       RARTH =0.0
       RARBK = 0.0
       THRRA = 0.0
       THRBK = 0.0
       THRTH = 0.0
C      THORIUM REGION AT 12 KEV/CHANNEL = CHANNELS 206-229(2.59 MEV TO
C       2.75 MEV) ENCOMPASSING THE 2.61 MEV PEAK OF THORIUM C## TL-208).
       DO 20 I=206,229
       THRRA = THRRA + RADS(I)
       THRTH = THRTH + THORS(I)
    20 THRBK = THRBK + BKGD(I)
C      RADIUM REGION AT 12 KEV/CHANNEL = CHANNELS 140-159(1.68 MEV TO
C      1.91 MEV) ENCOMPASSING THE 1.76 MEV PEAK OF RAC(BI-214).
       DO 25 I=140,159
       RARTH = RARTH + THORS(I)
       RARRA = RARRA + RADS(I)
    25 RARBK = RARBK + BKGD(I)
C      MSA(SIGMIN) PROCEDURE FROM B.ALTSCHULER, B.PASTERNACK,HEALTH
C      PHYSICS,9,293,1963.
       CALL SIGMIN (RARBK)
       RMIN = CMIN
       CALL SIGMIN (THRBK)
       THMIN = CMIN
       PRINT 150
   150 FORMAT(1H0,25X,11HBACKGROUND ,15X,16HRADIUM STANDARD ,15X,17HTHORI
      1UM STANDARD   )
       PRINT 151,RARBK,RARRA,RARTH
   151 FORMAT(1H0,13H SUM 140-159 ,12X,F8.0,21X,F8.0,21X,F8.0 )
       RARBK = RARBK/TMB
       RARRA = RARRA/TMR
       RARTH = RARTH/TMT
       PRINT 140,RARBK,RARRA,RARTH
   140 FORMAT(1H0,15H COUNTS/MINUTE ,12X,F9.3,20X,F9.3,20X,F9.3)
       ERARBK = RARBK/TMB
       ERARRA = SQRTF(ABSF((RARRA/TMR) + ERARBK ))
       ERARTH = SQRTF(ABSF((RARTH/TMT) + ERARBK))
       RARRA = RARRA-RARBK
       RARTH = RARTH-RARBK
       PRINT 152,RARBK,RARRA,ERARRA,RARTH,ERARTH
```

```
  152 FORMAT(1H ,20H NET COUNTS/MINUTE ,7X,F9.3,9X,F9.2,3H+- ,F9.2,14X,F
     19.2,3H+- ,F9.2 )
      PRINT 153,THRBK,THRRA,THRTH
  153 FORMAT(1H0,13H SUM 206-229 ,12X,F8.0,21X,F8.0,21X,F8.0)
      THRBK = THRBK/TMB
      ETHRBK = THRBK/TMB
      THRTH = THRTH/TMT
      THRRA = THRRA/TMR
      ETHRRA = SQRTF(ABSF((THRRA/TMR) +ETHRBK))
      ETHRTH = SQRTF(ABSF((THRTH/TMT) + ETHRBK))
      PRINT 140,THRBK,THRRA,THRTH
      THRTH = THRTH-THRBK
      THRRA = THRRA-THRBK
      PRINT 152,THRBK,THRRA,ETHRRA,THRTH,ETHRTH
C     A = CONTRIBUTION OF THORIUM COMPTON GAMMA PHOTONS TO RADIUM REGION
      A = RARTH/THRTH
      EA = A*SQRTF((ERARTH/RARTH)**2  + (ETHRTH/THRTH)**2  )
C     B= CONTRIBUTION OF HIGHER RADIUM PEAKS TO THORIUM REGION.
      B = THRRA/RARRA
      EB = B*SQRTF((ETHRRA/THRRA)**2 + (ERARRA/RARRA) **2 )
      Q=1.0-(A*B)
      PRINT 154,A,EA,B,EB,Q
  154 FORMAT(1H0,5H A = ,F9.4,3H+- ,F9.4, 10X,5H B = ,F9.4,3H+- ,F9.4,10
     1X,10H 1-A*B = ,F9.4 ///)
      PRINT 155
      PRINT 143,RMIN,THMIN
C     MSC = MINIMIUM SIGNIFICANT COUNT
  143 FORMAT(1H0,7H  MSC  ,15X,F8.3,44X,F8.3)
      RMIN = RMIN/TMB
      THMIN = THMIN/TMB
      PRINT 144,RMIN,THMIN
C     MSCR = MINIMIUM SIGNIFICANT COUNTING RATE
  144 FORMAT(1H0,7H  MSCR ,15X,F8.3,44X,F8.3 )
      AMIN = RMIN/ ((1.0-(A*B))*(1.2*RARRA))
      BMIN = (THMIN*0.72)/(1.8*THRTH)
C     MSA = MINIMIUM SIGNIFICANT AMOUNT
      PRINT 145,AMIN,BMIN
  145 FORMAT(1H0,7H  MSA  ,13X,F8.5,3H UC,40X,F8.5,3H UC  ///)
    1 READ 6,KA
    6 FORMAT(I6)
    5 READ 14,TMS,CASE,(ANAME(J),J=1,8),IM,ID,IY,RUN
   14 FORMAT(F6.1,9A6,3I2,A6)
      IF(TMB-TMS) 174,301,174
  174 PRINT 175
  175 FORMAT(1H0,75H MSA NOT VALID FOR RUN. DIFFERENT COUNTING TIME USED
     1 FOR PATIENT AND BKGD.    /// )
      AMIN = 0.0
      BMIN = 0.0
  301 PRINT 16,TMS,CASE,(ANAME(J),J=1,8),IM,ID,IY,RUN
   16 FORMAT(1H0,F6.1,12H NJRRP CASE ,A6,5X,8A6,8H RUN ON ,I2,3H / ,I2,3
     1H / ,I2,4X,8H RUN  ,A6 )
      READ 12,(SAM(I),I=1,255)
  201 THRSAM = 0.0
      RARSAM = 0.0
      DO 30 I = 140,159
   30 RARSAM = RARSAM+SAM(I)
      DO 35 I=206,229
   35 THRSAM = THRSAM + SAM(I)
      PRINT 155
  155 FORMAT(1H0,20X,15H RADIUM REGION ,30X,16H THORIUM REGION  /25X, 9H
     1 140-159 ,35X,10H 206-229    )
      PRINT 156,RARSAM,THRSAM
```

```
  156 FORMAT(1HO,14H TOTAL COUNTS ,6X,F9.0,39X,F9.0  )
      RARSAM = RARSAM/TMS
      THRSAM = THRSAM/TMS
      PRINT 146,RARSAM,THRSAM
  146 FORMAT(1H ,12HCOUNTS/MIN  ,11X,F9.3,39X,F9.3)
      ERASAM = SQRTF(ABSF((RARSAM/TMS)+ERARBK))
      ETHSAM = SQRTF(ABSF((THRSAM/TMS) + ETHRBK))
      RARSAM = RARSAM-RARBK
      THRSAM = THRSAM-THRBK
      PRINT 157,RARSAM,ERASAM,THRSAM,ETHSAM
  157 FORMAT(1H ,13H NET COUNTS  ,4X,F8.3,3H+- ,F8.3,27X,F8.3,3H+- ,F8.3
     1)
      EAB = (A*B)*SQRTF((EA/A)**2 + (EB/B)**2)
      IF(THRSAM) 170,170,171
  170 TIRA = RARSAM
      E2RA = ERASAM
      GO TO 172
  171 TIRA = RARSAM-(A*THRSAM)
      EIRA = (A*THRSAM)*SQRTF((EA/A)**2 + (ETHSAM /THRSAM)**2)
      E2RA = SQRTF((ERASAM )**2 + (EIRA)**2 )
  172 T2RA = TIRA/(1.2-(A*B))
      TRA = T2RA/(1.2*RARRA)
C     ACTIVITY OF RADIUM STANDARD =  1.0 UC
C     1.2 = CHAIR FACTOR = RATIO OF ACTIVITY IN BODY TO SAME ACTIVITY A
C     POINT SOURCE DUE TO BETTER BODY CRYSTAL GEOMETRIC RELATION.
      ERA=ABSF(TRA)*SQRTF((E2RA/TIRA)**2+(EAB/(A*B))**2+(ERARRA/RARRA)**
     12)
      TITH = THRSAM-(B*T2RA)
      TTH = (TITH*0.72)/(1.8*THRTH)
C      0.72 = ACTIVITY IN UC OF THORIUM STANDARD.
C     1.8 = 1.2 CHAIR FACTOR * 1.5(RATIO OF TL-208 YIELD FROM TH-232
C     STANDARD TO THE TL-208 YIELD FROM RA-228 IN PATIENT
      EOTH = ABSF(B*T2RA)*SQRTF((EB/B)**2 + (E2RA/T2RA)**2  )
      EITH = SQRTF((ETHSAM)**2 + (EOTH)**2)
      ETH = ABSF(TTH)*SQRTF((EITH/TITH)**2 + (ETHRTH/THRTH)**2)
      PRINT 100
  100 FORMAT(1HO,19X,33H BODY BURDEN   MICROCURIES (UC)  )
      PRINT 50,TRA,ERA
   50 FORMAT(1HO,28H RADIUM C BODY BURDEN     = ,F12.6,4H +- ,F12.6)
      PRINT 51,TTH,ETH
   51 FORMAT(1HO,28H MESO THORIUM BODY BURDEN = ,F12.6,4H +- ,F12.6)
      IF(TRA-AMIN) 160,160,162
  160 PRINT 161
  161 FORMAT(1HO,22H RADIUM C BODY BURDEN ,5X,3H = ,14X,3HMSA  )
  162 IF(TTH-BMIN) 163,163,165
  163 PRINT 164
  164 FORMAT(1HO,28H MESO THORIUM BODY BURDEN = ,14X,3HMSA  )
  165 GO TO (2,1),KA
      END
      SUBROUTINE SIGMIN(S)
      COMMON CMIN
      SQ = SQRTF(2.0*S)
      SA = 8.0*S
      SB = SQRTF(SA)
      SC = 4.0*S
      ALPHA =  1.2816
       CMIN  = ALPHA*(SQ*(SQRTF(1.0 +(ALPHA**2)/SA) + (ALPHA/SB)))
      RETURN
      END
```

SAMPLE OUTPUT PAGE FROM BURDEN

30.0 BACKGROUND RUN 1443 10/7/65
15.0 RADIUM 226 1.0 UC RUN 1445 10/M/65
15.0 THORIUM 232 0.72 UC RUN 1444 10/7/65

	BACKGROUND	RADIUM STANDARD	THORIUM STANDARD
SUM 140-159	939.	15738.	3518.
COUNTS/MINUTE	31.300	1049.200	234.533
NET COUNTS/MINUTE ,	31.300	1017.90+- 8.42	203.23+- 4.08
SUM 206-229	680.	654.	13243.
COUNTS/MINUTE	22.666	43.600	882.866
NET COUNTS/MINUTE ,	22.666	20.93+- 1.91	860.19+- 7.72

A = .2362+- .0051 B = .0205+- .0018 1-A*B = , .9951

	RADIUM REGION 140-159	THORIUM REGION 206-229
MSC	56.366	48.091
MSCR	1.878	1.603
MSA	.00154 UC	.00074 UC

30.0 NJRRP CASE 5001 RUN ON 10 / 7 / 65 RUN

	RADIUM REGION 140-159	THORIUM REGION 206-229
TOTAL COUNTS	1856.	639.
COUNTS/MIN	61.866	21.300
NET COUNTS	30.566+- 1.762	-1.366+- 1.210

BODY BURDEN MICROCURIES (UC)

RADIUM C BODY BURDEN = .025146 +- .002789

MESO THORIUM BODY BURDEN = -.000929 +- .000563

MESO THORIUM BODY BURDEN = MSA

TABLE I

RADIUM DIAL PAINTER BODY BURDEN MEASUREMENTS 1965 - 1966

CASE NUMBER	DATE	^{226}Ra Yielding Expired Rn(c)		RaC(MC) BY WHOLE BODY COUNTING		TOTAL BODY BURDEN (c)		FRACTIONAL RADON EXPIRED		MINUTE VOLUME
5021	3/15/65	.0134+-	.0026	.0036+-	.0009	.0170+-	.0027	.7882+-	.1991	10.35
5284	3/10/65	.1472+-	.0031	.0886+-	.0018	.2358+-	.0035	.6242+-	.0162	6.44
5014	4 14/65	.0895+-	.0094	.0569+-	.0034	.1464+-	.0099	.6113+-	.0765	8.09
5551	4/28/65	.0147+-	.0061	.0079+-	.0011	.0226+-	.0061	.6504+-	.3235	7.26
5818	6/02 65	.0132+-	.0037	.0101+-	.0012	.0233+-	.0038	.5665+-	.1848	7.15
5413	5/11 65	.0108+-	.0080	.0036+-	.0007	.0144+-	.0080	.7500+-	.6954	8.55
5321	5 19/65	.0147+-	.0026	.0089+-	.0008	.0236+-	.0027	.6228+-	.1314	5.37
5040	7 13/65	.0077+-	.0012	.0056+-	.0012	.0133+-	.0016	.5789+-	.1166	6.54
5121	5 18/65	.0066+-	.0027	.0035+-	.0007	.0101+-	.0027	.6534+-	.3225	7.06
5358	5 04/65	.2513+-	.0175	.0868+-	.0074	.3381+-	.0190	.7432+-	.0665	11.10
5251	9 29/65	.0315+-	.0028	.0156+-	.0014	.0471+-	.0031	.6687+-	.0742	8.25
5001	10/07/65	.0430+-	.0024	.0251+-	.0010	.0681+-	.0025	.6314+-	.0426	7.10
5025	11/09 65	.0492+-	.0009	.0355+-	.0034	.0847+-	.0035	.5808+-	.0263	6.50
5358	6 23/66	.2040+-	.0028	.0772+-	.0047	.2812+-	.0054	.7254+-	.0172	9.10
5121	6 15/66	.0085+-	.0001	.0041+-	.0018	.0126+-	.0018	.6746+-	.0968	7.24
5040	6 10/66	.0080+-	.0002	.0053+-	.0019	.0133+-	.0019	.6015+-	.0877	6.86
5321	6 07/66	.0183+-	.0011	.0131+-	.0020	.0314+-	.0022	.5828+-	.0549	6.12
5025	6/01 66	.0503+-	.0015	.0330+-	.0029	.0833+-	.0032	.6038+-	.0297	7.00
5413	5/26 66	.0090+-	.0011	.0048+-	.0018	.0138+-	.0021	.6521+-	.1276	7.30
5818	5/11 66	.0193+-	.0012	.0101+-	.0020	.0294+-	.0023	.6564+-	.0661	7.70
5215	4/06 66	1.1209+-	.0069	.4280+-	.0289	1.5489+-	.0297	.7236+-	.0145	7.78
5551	4 01/66	.0175+-	.0017	.0067+-	.0016	.0242+-	.0023	.7231+-	.0990	11.40
5014	3 31/66	.0819+-	.0012	.0459+-	.0036	.1278+-	.0037	.6408+-	.0212	6.26
5021	3/25/66	.0137+-	.0014	.0022+-	.0015	.0159+-	.0020	.8616+-	.1418	8.96
5284	3/23/66	.1510+-	.0017	.0862+-	.0060	.2372+-	.0062	.6365+-	.0182	5.47
5119	6 28/66	.0277+-	.0026	.0051+-	.0018	.0328+-	.0031	.8445+-	.1136	8.39
5917	8/10/66	.0416+-	.0004	.0412+-	.0035	.0828+-	.0035	.5024+-	.0219	3.82

AVERAGE O.G.F. = .662967 +- 0.082656

Error reported as is based on counting statistics only.

TABLE II

COMPARISON OF MODELS FOR RADON RETENTION

Test Subject	% Retention (t in days)	Predicted Radon Retention %			Reference
		29 yrs	35 yrs	46 yrs.	
Mice	$5.8\ t^{0.1804}$	30.9	31.8	33.2	10
Dogs	$5.7\ t^{0.20}$	36.2	37.8	40.0	8
Mice	$5.16\ t^{0.208}$	36.1	37.9	39.5	7
Mice	$4.95\ t^{0.224}$	39.3	41.0	43.9	4
Dogs(RaC) Humans(Ra)	$3.89\ t^{0.24}$	35.9	37.9	40.8	11,16
Humans	Measured(8 cases)	31.2	--	--	10
Humans	Measured(6 cases)	--	34.4	--	10
Humans	Measured(2 cases)	26.5	--	--	This report
Humans	Measured(28 cases)	--	--	33.7	This report

TABLE III

COMPARISON OF 1965 AND 1966 EFFECTIVE HALF LIFE ESTIMATES

	1965		1966	
Case #	No. Points	Estimated $T_{\frac{1}{2}}$ (years)	No. Points	Estimated $T_{\frac{1}{2}}$ (years)
5001	4	-37.73 ± 74.57	6	$+ 19.91 \pm 22.14$**
5014	5	25.19 ± 11.92	7	13.60 ± 3.78
5025	7	18.88 ± 5.97	11	12.50 ± 1.92
5096	2	14.03 ± 0.31*	2	14.03 ± 0.31*
5251	2	-5.55 ± 0.046*	4	$- 9.12 \pm 6.17$
5278	2	10.16 ± 0.052*	2	10.16 ± 0.052*
5281	4	18.71 ± 15.73	4	18.71 ± 15.73
5284	6	6.80 ± 1.57	9	8.61 ± 1.40
5818	2	-4.15 ± 0.011*	4	$- 40.0 \pm 120$***
5917	4	10.74 ± 2.39	5	9.04 ± 0.89
5962	2	7.46 ± 0.020*	2	7.46 ± 0.020*
Pooled Mean	38	15.7 ± 2.4	56	14.73 ± 2.31

Notes:

* Underestimate of standard error when only two points are used.

** Negative half life reported in 1965 is mainly due to 1 point which is out of line.

*** Large value due to very small change in body burden from 1965 to 1966.

TABLE IV

COMPARISON OF HALF LIVES RESULTING FROM AN EXPONENTIAL MODEL AND THE APPARENT HALF LIFE PREDICTED BY FITTING A POWER FUNCTION TO THE DATA

Case #	Number of Points	$T_{\frac{1}{2}}$ Exponential (years)	T_{app} Power Funct. (years)
5001	6	19.91 ± 22.12	20.32 ± 23.03
5014	7	13.60 ± 3.78	13.64 ± 3.88
5021	6	3.86 ± 1.19	3.91 ± 1.24
5025	11	12.50 ± 1.92	12.55 ± 1.96
5040	4	-81.35 ± 748	-97.06 ± 1042
5089	2	-8.36 ± 0.54	-8.34 ± 0.61
5096	2	14.03 ± 0.17	14.05 ± 0.51
5102	2	5.95 ± 0.12	5.93 ± 0.38
5118	2	1.42 ± 0.02	1.41 ± 0.07
5119	4	13.58 ± 17.97	13.50 ± 17.64
5121	5	43.69 ± 178	39.82 ± 147
5153	6	4.91 ± 3.09	4.93 ± 3.15
5184	3	4.10 ± 0.62	4.15 ± 0.58
5215	5	15.37 ± 0.68	15.15 ± 0.61
5251	4	-9.12 ± 6.17	-9.38 ± 6.56
5257	2	0.77 ± 0.011	0.77 ± 0.016
5278	2	10.16 ± 0.052	10.17 ± 0.15
5281	4	18.71 ± 15.73	18.54 ± 15.32
5284	9	8.61 ± 1.40	8.61 ± 1.38

Continued

TABLE IV (Contd.)

Case #	Number of Points	$T_{\frac{1}{2}}$ Exponential (years)	$T_{app.}$ Power Funct. (years)
5307	2	6.52 ± 0.04	6.55 ± 0.03
5321	5	-12.91 ± 15.39	-13.49 ± 16.75
5358	2	6.66 ± 0.07	6.66 ± 0.16
5369	3	7.28 ± 19.24	7.51 ± 20.38
5413	4	3.84 ± 2.22	3.88 ± 2.24
5541	3	0.46 ± 0.47	0.47 ± 0.48
5551	4	23.82 ± 17.0	24.32 ± 17.63
5631	4	31.72 ± 125	30.95 ± 119
5818	4	-40.0 ± 120	-39.13 ± 114
5917	5	9.04 ± 0.89	8.96 ± 0.93
5962	2	7.46 ± 0.02	7.46 ± 0.10
Pooled Mean	124	10.71 ± 2.58	10.40 ± 2.32

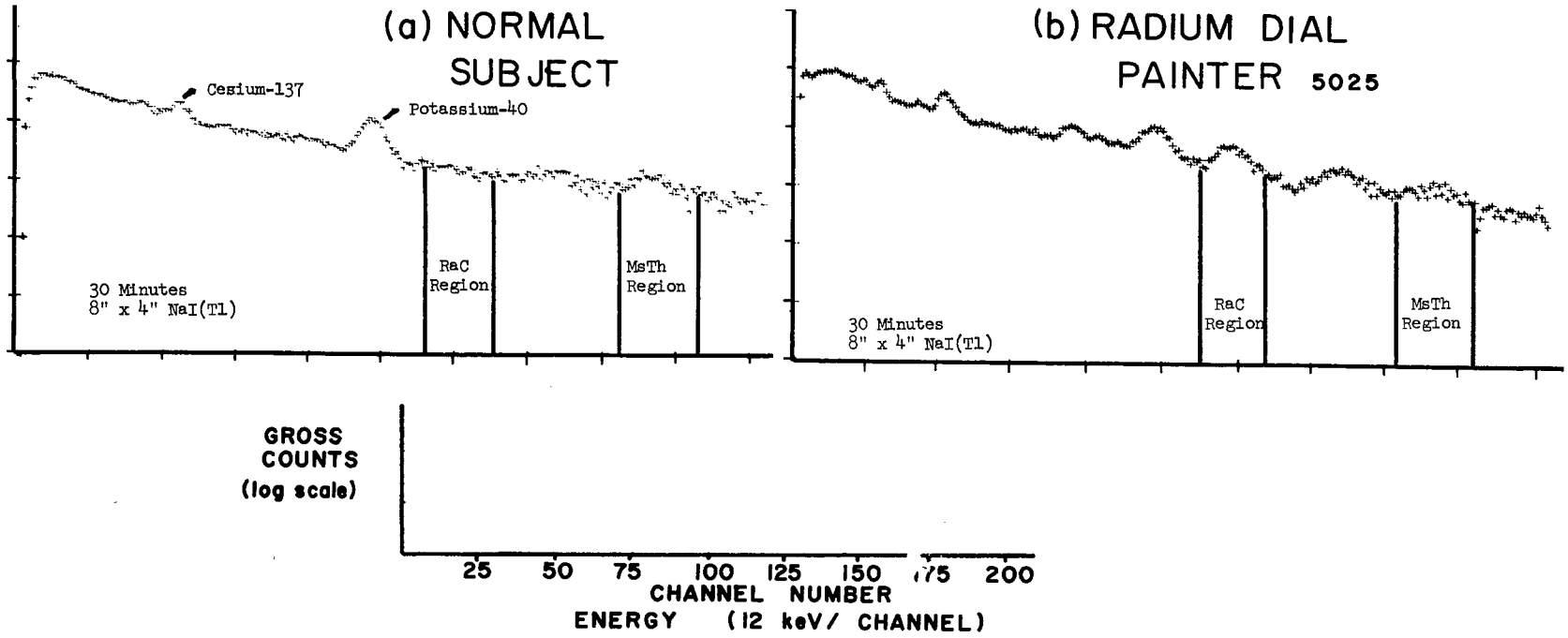
TABLE V

EXPOSURE HISTORY OF CASES STUDIED

Case #	Initial Exposure Year	Duration (years)	Zero Time for Calculation	Years Elapsed to 1963
5001	1917	2.92	1918.5	45.97
5014	1916	3.00	1917.5	46.00
5021	1917	0.33	1917.2	47.34
5025	1917	1.83	1917.92	46.12
5040	1917	1.00	1917.50	46.80
5089	1917	0.500	1917.25	46.55
5096	1918	0.50	1918.25	43.49
5102	1916	6.00	1919.60	42.24
5118	1917	1.333	1917.67	44.18
5119	1924	3.17	1925.58	38.10
5121	1921	0.67	1921.33	42.49
5153	1923	2.50	1924.25	39.29
5184	1922	3.00	1923.50	39.74
5215	1917	1.50	1917.75	45.13
5251	1917	8.25	1921.12	42.40
5257	1932	23.33	1943.67	17.23
5278	1917	1.00	1917.50	45.62
5281	1916	2.92	1917.46	44.80
5284	1917	1.50	1917.75	45.95
5307	1944	1.33	1944.67	18.30
5321	1916	0.25	1916.12	48.13
5358	1923	28.33	1937.16	28.75
5369	1919	0.50	1919.25	44.24

TABLE V cont

5413	1916	1.00	1916.50	48.05
5541	1937	7.00	1940.50	24.40
5551	1918	0.75	1918.38	46.42
5631	1917	0.42	1917.21	46.12
5818	1916	2.00	1917.00	48.00
5917	1918	0.75	1918.38	45.52
5962	1932	1.83	1932.92	31.02
			mean	43.13


(a) NORMAL SUBJECT
Cesium-137
Potassium-40
RaC Region
MsTh Region
30 Minutes
8" x 4" NaI(Tl)
(b) RADIUM DIAL PAINTER 5025
RaC Region
MsTh Region
30 Minutes
8" x 4" NaI(Tl)
GROSS COUNTS (log scale)
25 50 75 100 125 150 175 200
CHANNEL NUMBER
ENERGY (12 keV/ CHANNEL)

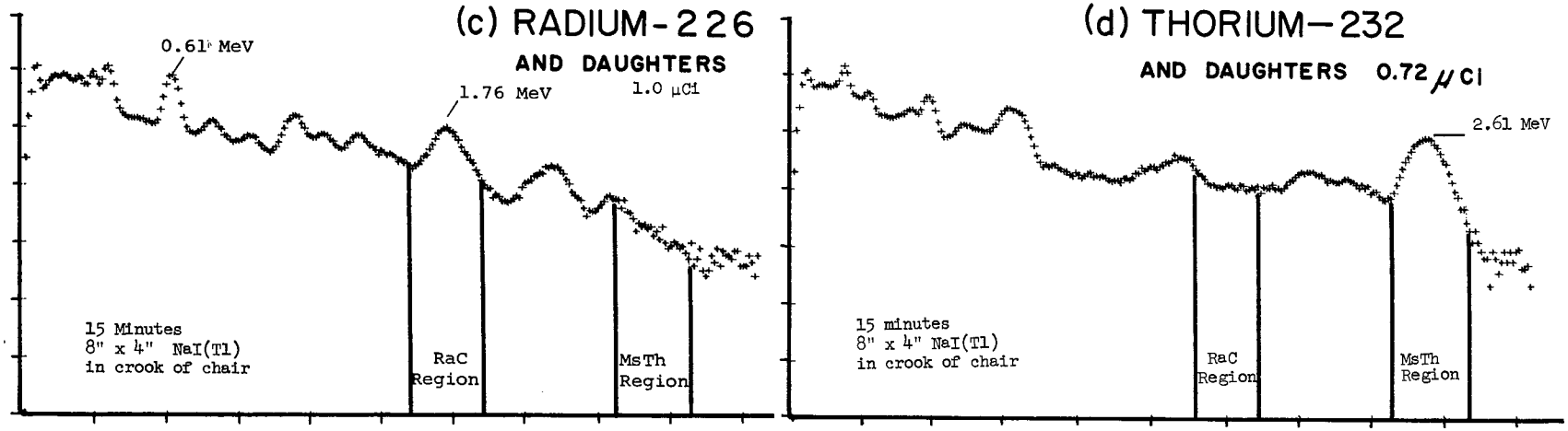

(c) RADIUM-226 AND DAUGHTERS 1.0 μCi
0.61 MeV
1.76 MeV
15 Minutes
8" x 4" NaI(Tl)
in crook of chair
RaC Region
MsTh Region
(d) THORIUM-232 AND DAUGHTERS 0.72 μCi
2.61 MeV
15 minutes
8" x 4" NaI(Tl)
in crook of chair
RaC Region
MsTh Region

FIGURE 1

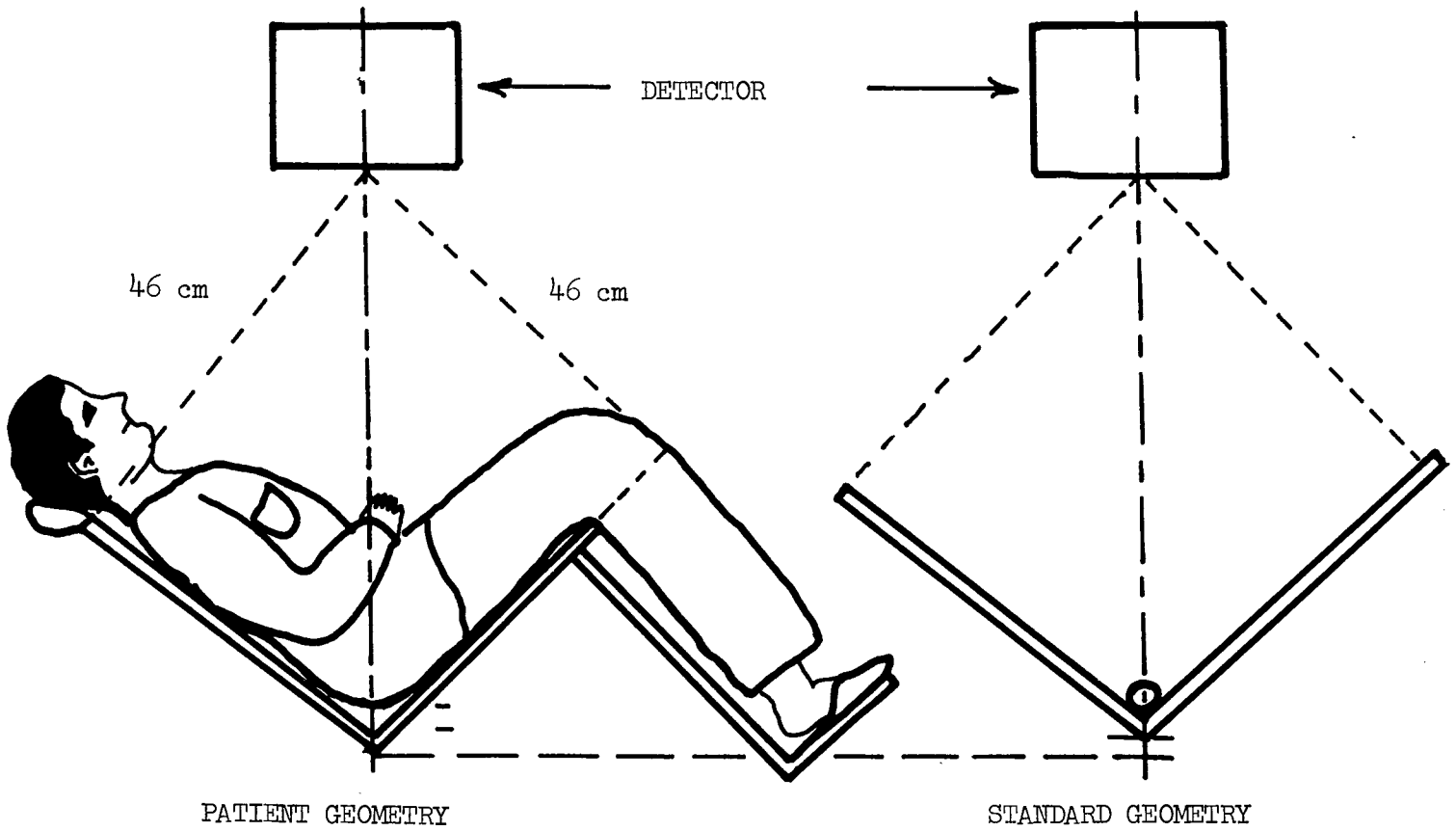


FIGURE 2

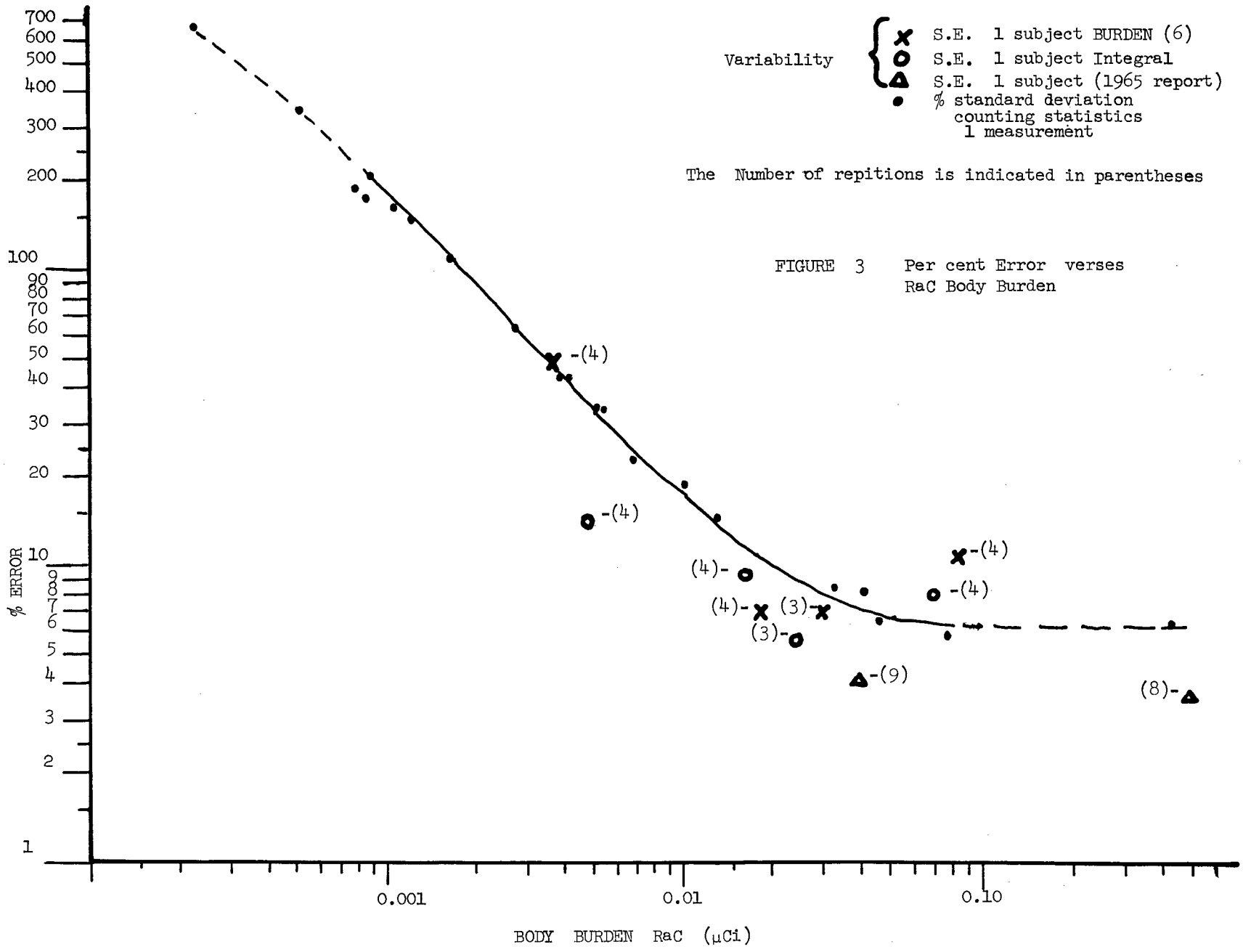


FIGURE 3 Per cent Error verses RaC Body Burden

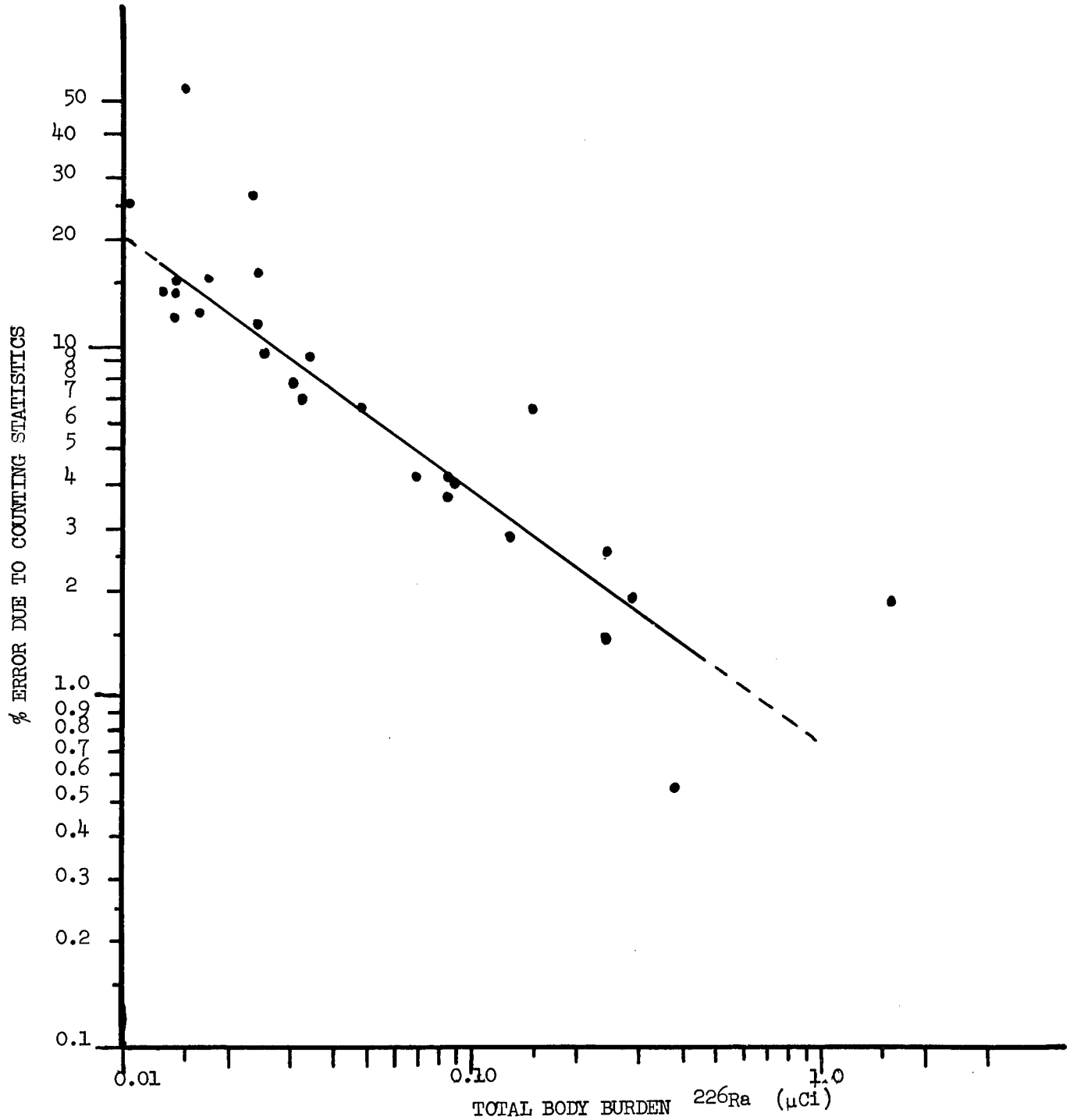


FIGURE 4. Per Cent Error due to Counting Statistics Verses Radium Body Burden

FIG. 5

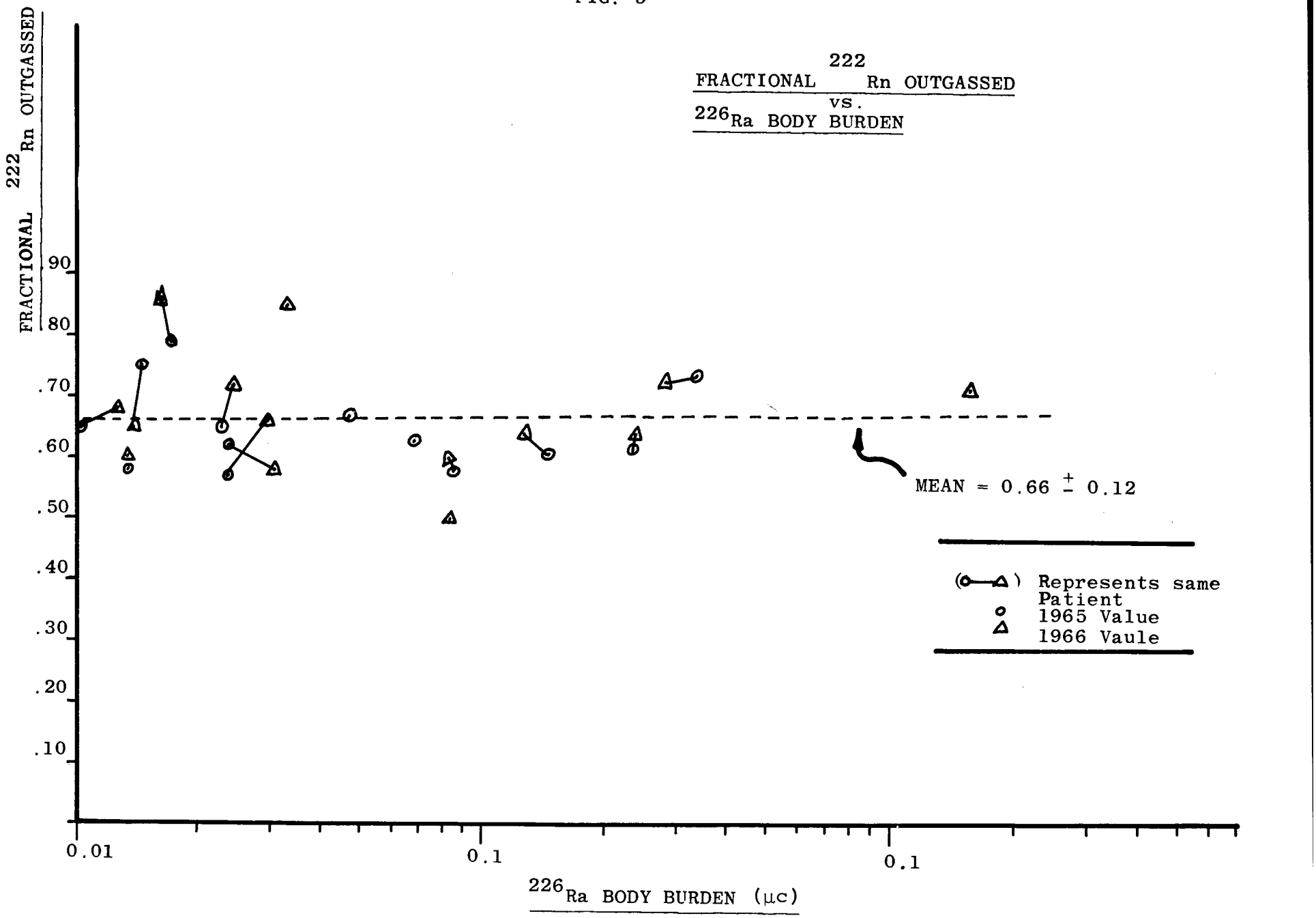
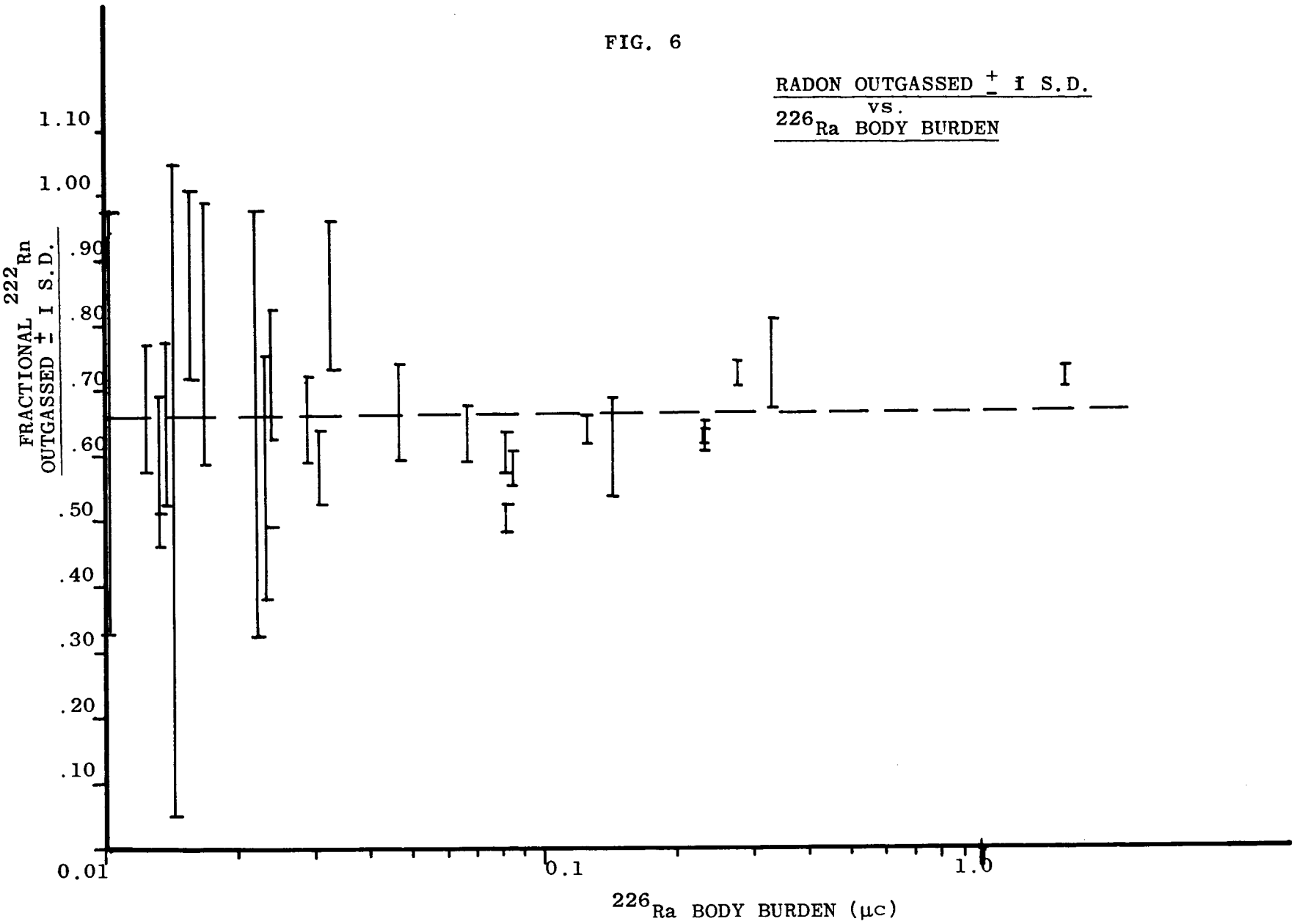

FRACTIONAL 222Rn OUTGASSED
FRACTIONAL 222Rn OUTGASSED vs. 226Ra BODY BURDEN
.90
.80
.70
.60
.50
.40
.30
.20
.10
MEAN = 0.66 ± 0.12
(o—Δ) Represents same Patient
o 1965 Value
Δ 1966 Vaule
0.01
0.1
0.1
226Ra BODY BURDEN (μc)

FIG. 6


RADON OUTGASSED ± 1 S.D.
vs.
226Ra BODY BURDEN
FRACTIONAL 222Rn OUTGASSED ± 1 S.D.
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
0.01
0.1
1.0
226Ra BODY BURDEN (μc)

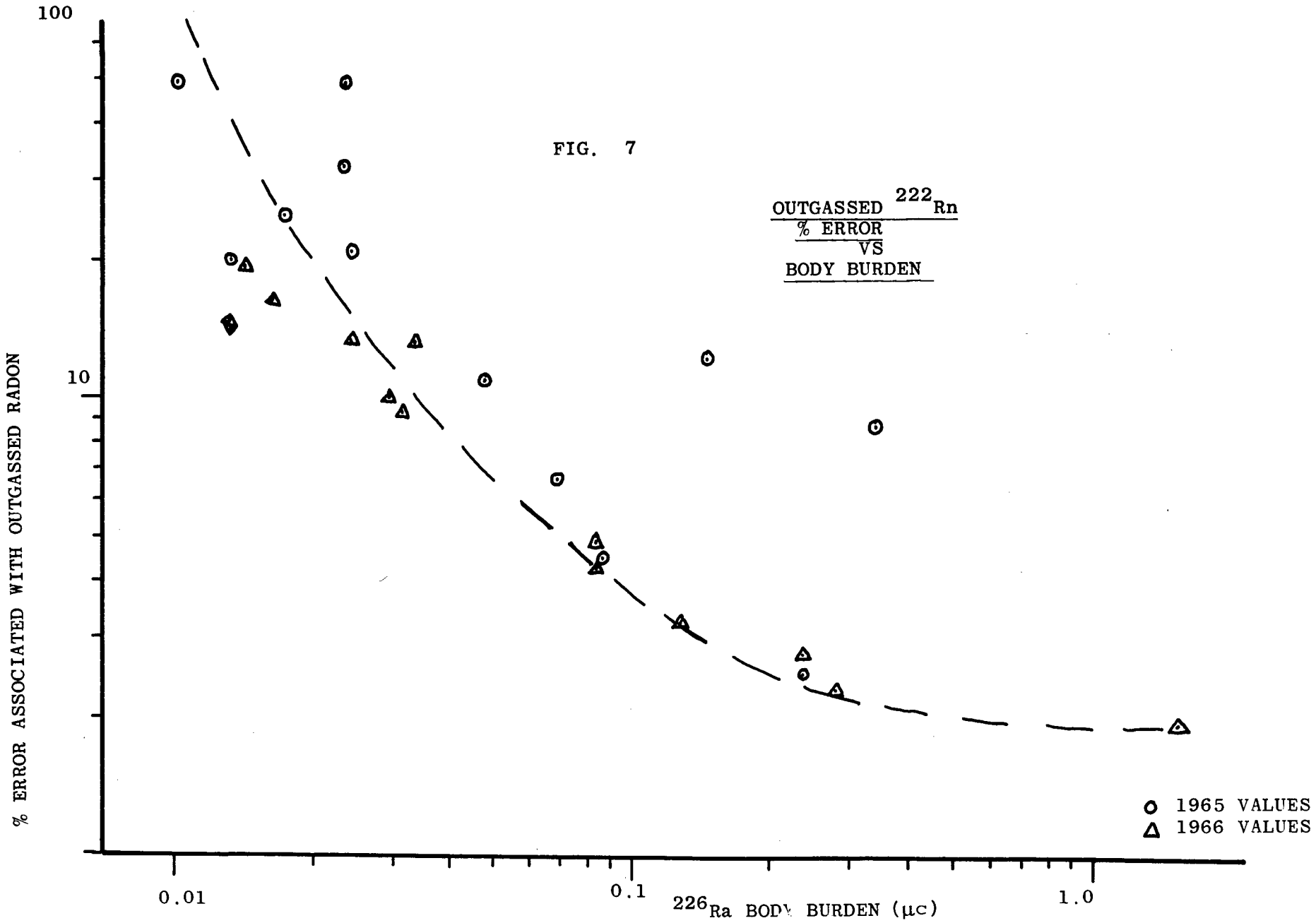


FIG. 7

OUTGASSED ^{222}Rn
% ERROR
VS
BODY BURDEN

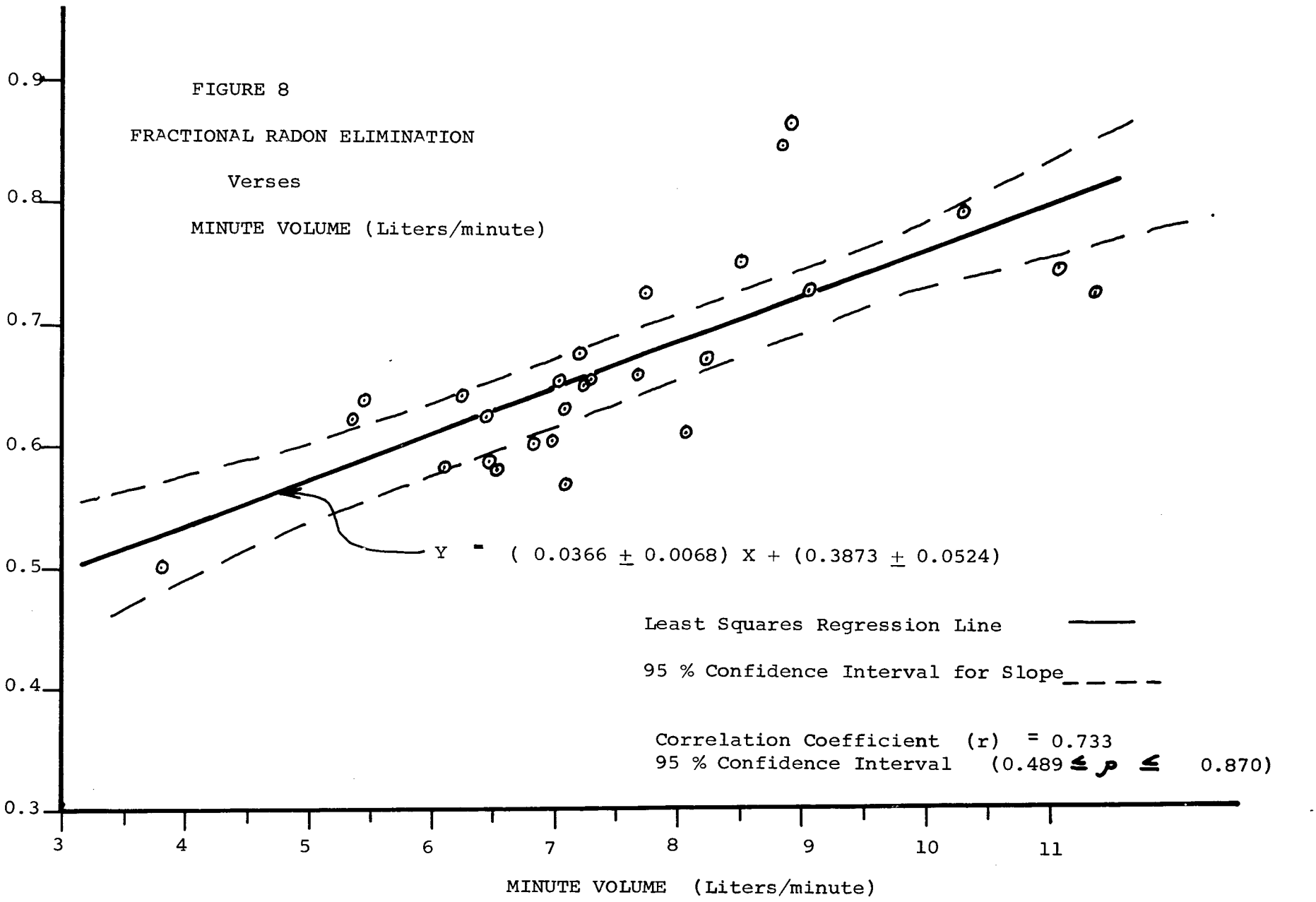


FIGURE 8
FRACTIONAL RADON ELIMINATION
Verses
MINUTE VOLUME (Liters/minute)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Y = (0.0366 ± 0.0068) X + (0.3873 ± 0.0524)
Least Squares Regression Line
95 % Confidence Interval for Slope
Correlation Coefficient (r) = 0.733
95 % Confidence Interval (0.489 ≤ ρ ≤ 0.870)
3
4
5
6
7
8
9
10
11
MINUTE VOLUME (Liters/minute)

FIGURE 9

% RADON RETENTION Vs. TIME

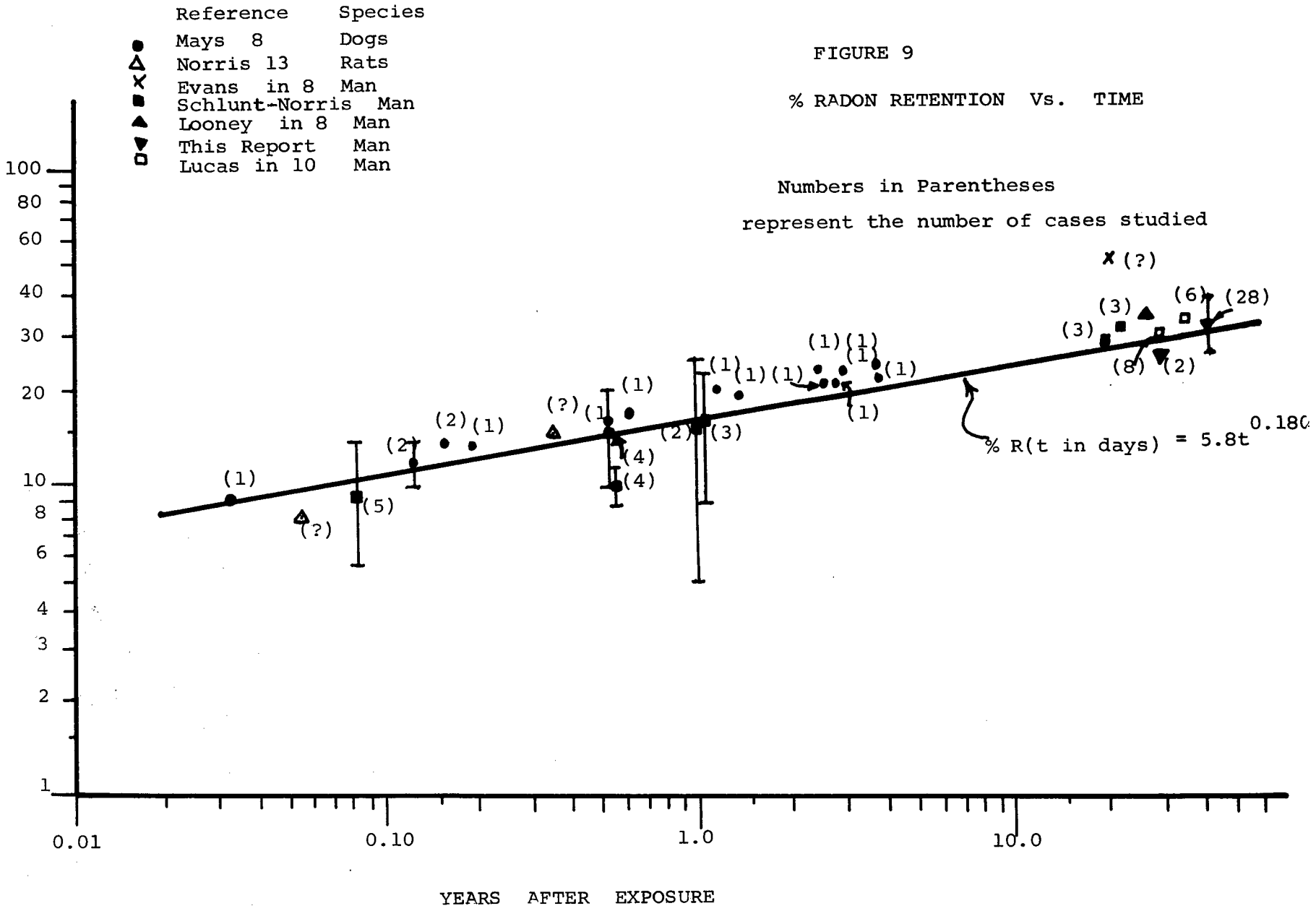
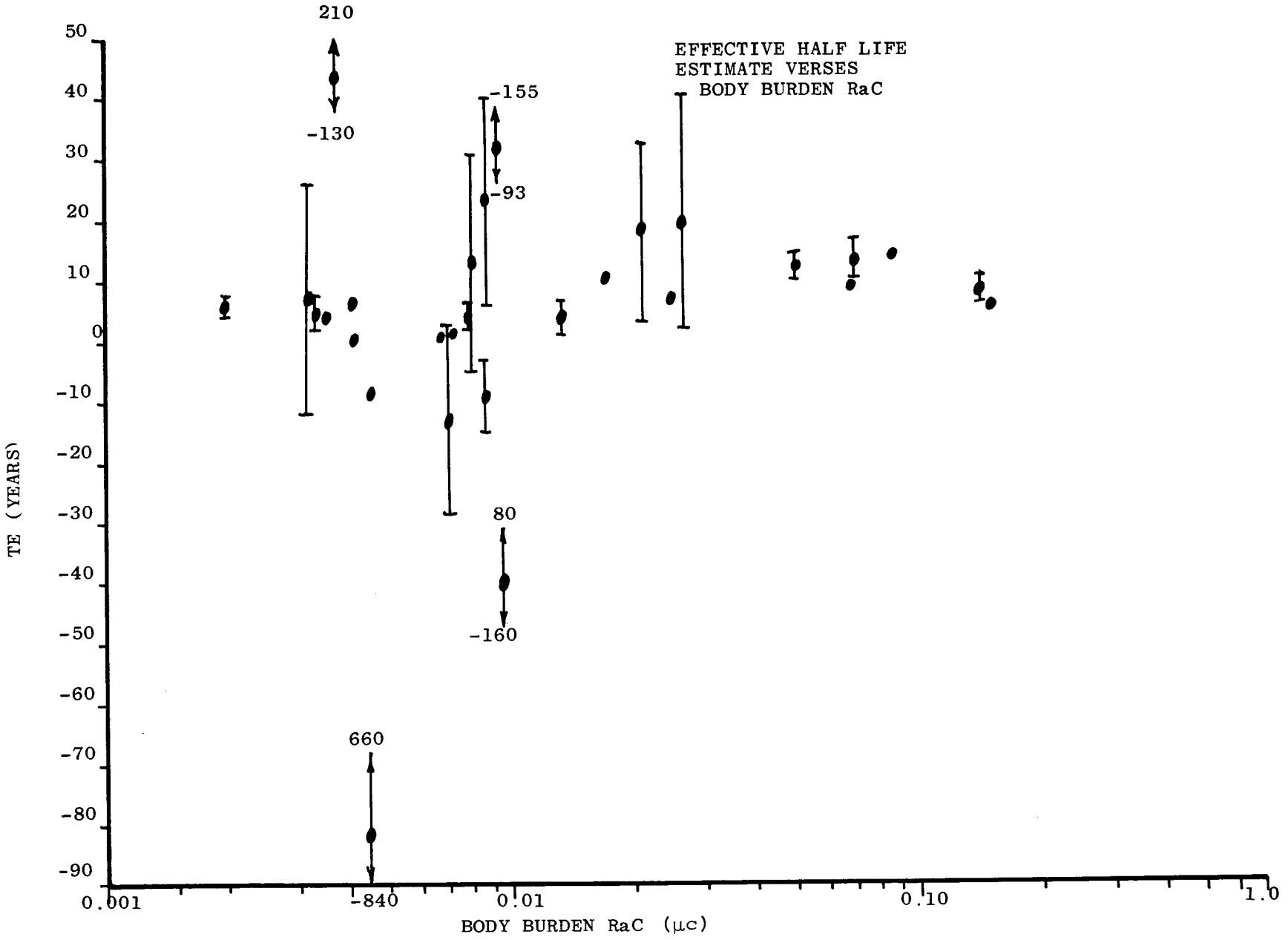


FIG. 10


EFFECTIVE HALF LIFE
ESTIMATE VERSES
BODY BURDEN RaC
210
-130
-155
-93
80
-160
660
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
TE (YEARS)
0.001
-840
0.01
0.10
1.0
BODY BURDEN RaC (μc)

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PART II

A Study of the Distribution of Ra-226, Ra-228 Pb-210 and Th-228 in Bone and Soft Tissue of Radium Dial Painters

Henry G. Petrow

This section is reported here ir summary only. The full report (147 pages), which constitutes the doctoral disertation submitted by the author in partial fulfillment of the requirements for the degree of Doctor of Philosophy, is on file with the Division of Biology and Medicine, and is available from the AEC in microfilm form (NYO-3086-5).

Summary

Bone and soft tissue samples from two radium dial painters, who died approximately 50 years after being exposed to Ra-226 and Ra-228, were analyzed for Pb-210 and Ra-226, and in the case of bone tissue, for Ra-228 and Th-228 as well. In addition bone obtained from a beagle injected with pure Ra-228 was analyzed for Ra-228 and Th-228. The purpose of the study was to determine what fraction of an old Ra-226 burden resided in soft tissue, and through measurement of Pb-210 to Ra-226 and Th-228 to Ra-228 ratios, to determine the metabolic behavior of Pb-210 and Th-228 relative to their radium parents; to determine if possible, the relationships of Rn-222 retention factors to the locus of Ra-226 deposition;

to determine the maximum amount of radium, lead, and thorium translocation in the skeleton; to estimate the biological half-life of radium through measurement of the Th-228 to Ra-228 ratio; and to assess the dosimetric significance of the findings.

The soft tissue study for one of the two dial painters indicated that 0.05% of the Ra-226 and 0.65% of the Pb-210 present at death were in soft tissue. The largest concentrations of both of these radionuclides were in the aorta and the thyroid. The dose to both of these organs was low provided their radioactivity content maintained a constant relationship to the skeletal burden throughout exposure and subsequent life. The possibility exists, however, that during exposure, where radium blood levels were undoubtedly high, the dose to both the thyroid and the aorta was high.

The average skeletal ratio of Pb-210 to Ra-226 for both dial painters indicates that these two radionuclides are eliminated from the skeleton with the same biological half-life. The analysis of excreta obtained from one of the dial painters supports this hypothesis.

The variability of the Pb-210 to Ra-226 ratio from site to site in the skeleton follows a distinct, reproducible pattern. For a given bone, the magnitude of the ratio is correlated with the Ra-226 concentration, with low ratios

being found in the region of high radium concentrations. For long bones, the identical correlation was found with respect to ratio value and locus of radium deposition. Low ratios were found in the end pieces of long bone, and high ratios in the shaft. Low ratios were found in vertebra and high ratios in rib.

Two mechanisms have been suggested to explain the variability in the Pb-210 to Ra-226 ratios. Translocation, as the result of radium and lead resorption followed by partial redeposition of the resorbed material is one possibility. If translocation is the sole cause of ratio variability, then the pattern of redeposition must be selective. That is, the redeposition of Pb-210 must proceed preferentially, relative to radium, in the shafts of long bones and in rib. The maximum amount of resorbed radium or lead redeposition is 4% of the terminal body burden. If both radionuclides are redeposited to the same extent, then 2% of the terminal body burden of Ra-226 and Pb-210 was redeposited.

An alternative hypothesis that could explain ratio variability is differences in Rn-222 retention factors. For long bones, this hypothesis is supported by our current knowledge of long bone structure and the mechanism of Rn-222 escape from bone, in that one could expect greater Rn-222

retention in the shaft, relative to the end pieces, and hence, ratios should be higher in the shaft than in the ends. This is the pattern of ratio variability found in long bone. Animal data, to some extent, corrobrate these findings. The reasons for high ratios in rib and low ratios in vertebra are not clear, but may result from differences in bone crystal size, or amorphous mineral content. If Rn-222 retention is the cause of ratio differences, as a consequence of the fact that Pb-210 and Ra-226 have equal biological half-lives, Rn-222 retention factors can be calculated for each ratio. The range of ratios was such for the two cases, that Rn-222 retention varied from 20% to 57%, if ratio differences are ascribed solely to differences in Rn-222 retention.

The study of Th-228 to Ra-228 ratios in the bone of one of the dial painters and in the beagle's bone indicated that this ratio was variable as was that of the Pb-210 to Ra-226 ratio, without, however, showing any discernible pattern. It is suggested that Th-228 translocation was the cause of the variability, and that 27% of the Th-228 translocated for the dial painter and 10% for the beagle. The average skeletal ratio of Th-228 to Ra-228 allows the calculation of the Ra-228 biological half-life, assuming that the effective half-life of Th-228 is equal to its physical half-life. The calculated Ra-228 biological half-life was 10.4 years for the dial painter and 16 years for the beagle.

Using the findings of the study, it is estimated that both dial painters had equal burdens of Ra-226 and Ra-228 after exposure. The alpha dose received from each chain was nearly identical after 50 years. About 5% of the alpha dose from the Ra-226 chain was received from Po-210, the alpha emitting daughter of Pb-210.

PART VII

Discussion of Possible Mechanisms Involved in the Apparent Concentration of ^{226}Ra and ^{210}Pb in Aorta and Thyroid

Norman Cohen

Introduction

The ^{226}Ra and ^{210}Pb content of various soft tissues from two former radium dial painters has been measured to determine what portion of the total body burden is found in soft tissues of individuals with old burdens, what organs concentrate radium and, finally, whether the soft tissue dose is significant relative to the skeletal dose (1). The dosimetric significance of these findings is discussed in Chapter II. In addition the biochemical mechanism responsible for concentration of these nuclides and the associated radiobiological implications will be discussed.

Experimental Results

In Table I are presented the data for 33 soft tissue samples from N.J. Case No. 5281 (estimated body burden at death = 0.6 μc) and 5 soft tissue samples from N.J. Case No. 5278 (estimated body burden at death = 0.05μ c). The important organs, as regards both ^{226}Ra and ^{210}Pb concentrations are the aorta and thyroid.

In Case No. 5281, the ^{226}Ra concentration of the aorta was at least 8 times as great as the next highest value obtained, excluding the thyroid. The aortic tissue is more than 43 times the average of the soft tissues other than thyroid.

In Case No. 5278, the ^{226}Ra in the aorta was more than 18 times the average ^{226}Ra content of the soft tissues and at least 9 times as

Table I

The analysis of Soft Tissues From Case 5281 and Case 5278 for Pb-210 and Ra-226

	Organ	Ra-226 pc/wet gram	Pb-210
Case 5281	Lung, Left	0.037 ± 0.004	0.044 ± 0.004
	Right Kidney	0.011 ± 0.001	0.031 ± 0.003
	Brain	0.027 ± 0.002	0.030 ± 0.001
	Liver	0.002 ± 0.001	0.076 ± 0.010
	Lung, Right	0.008 ± 0.003	0.056 ± 0.020
	Colon	0.003 ± 0.007	0.008 ± 0.004
	Left Adrenal	0.053 ± 0.004	0.050 ± 0.010
	Breast, Left & Rt.	Not Detectable	0.011 ± 0.005
	Right Adrenal	0.017 ± 0.003	0.046 ± 0.015
	Stomach	0.006 ± 0.002	0.029 ± 0.015
	Duodenum	0.010 ± 0.006	0.035 ± 0.035
	Brain	0.009 ± 0.001	0.022 ± 0.007
	Urinary Bladder	0.003 ± 0.001	0.009 ± 0.005
	Uterus and Adnexa	0.004 ± 0.001	0.020 ± 0.003
	Finger Tissue, left ring and middle	0.030 ± 0.002	0.050 ± 0.005
	Femoral Lymph Nodes	Not Detectable	Not Detectable
	Pancreas	0.009 ± 0.001	0.010 ± 0.010
	Spleen	0.044 ± 0.003	0.024 ± 0.012
	Heart	0.011 ± 0.001	0.073 ± 0.003
	Pituitary	Not Detectable	Not Detectable
	Rector Sigmoid	0.018 ± 0.004	0.003 ± 0.003
	Vagina	Not Detectable	Not Detectable
	Illeum	Not Detectable	Not Detectable
	Esophagus	Not Detectable	Not Detectable
	*Thyroid	0.110 ± 0.005	0.180 ± 0.020
	Diaphragm	Not Detectable	0.600 ± 0.100
	Larynx	Not Detectable	Not Detectable
	Gall Bladder	Not Detectable	Not Detectable
	Appendix	Not Detectable	Not Detectable
	Jejunum	Not Detectable	Not Detectable
	*Aorta	0.430 ± 0.020	1.010 ± 0.050
	Tracheal Lymph Nodes	Not Detectable	0.070 ± 0.020
	Liver	Not Detectable	0.080 ± 0.010
Case 5278	Uterus	0.003 ± 0.000	0.004 ± 0.000
	Left Kidney	0.004 ± 0.000	0.012 ± 0.001
	Right Kidney	0.010 ± 0.000	0.009 ± 0.000
	Heart	0.003 ± 0.000	0.012 ± 0.001
	*Aorta	0.089 ± 0.008	1.01 ± 0.050

great as the next highest soft tissue measured.

The concentration of ^{226}Ra obtained for thyroid tissue in Case No. 5281 was 11 times greater than the average but still 4 times smaller than the concentration in the aorta. Thyroid tissue for Case No. 5278 was not available for analysis.

The concentration of ^{210}Pb in the aorta of Case No. 5281 was about 39 times as great as the average ^{210}Pb concentration excluding values for the thyroid, (approximately 7 times greater than the average) and the diaphragm, (approximately 23 times greater than the average).

Van Middlesworth (11) reported that some cattle thyroids contained sufficiently high concentrations of ^{226}Ra and ^{228}Ra to be detectable by gamma spectrometry. Workers at MIT have confirmed this estimate that as much as 50pc each of ^{226}Ra and ^{228}Ra are present in some cattle thyroids. Tipton (6) has shown concentrations of lead, calcium, barium, and strontium in the thyroid and aorta which are higher than most other soft tissues in the body.

In the case of the aorta, the anomanously high lead and radium values may be explained by cationic binding by mucopolysaccharides. Bunting and Bunting (1953) (2) showed that arterial connective tissue consists chiefly of collagen, elastin and mucopolysaccharides (chondroitin sulfate and hyaluronic acid). Both elastin and mucopolysaccharides might be suspected as binding agents on the basis of histologic distribution: however, biological considerations (3) favor the mucopolysaccharides as the potential cation binding agent. The mucopolysaccharide molecule is a polyanion containing multiple carboxyl and sulfate radicals. Rothstein in 1957 (4) was the first to propose that the mucopolysaccharides in vivo behave as ion exchanges, that is, the binding is mainly electro-

static, of a type not depending on the specific properties of the anionic groups. In the chondroitin polysulfates the binding is shared equally by weakly acidic carboxyl groups and strongly acidic o-sulfate ester groups. It has also been shown (5) that different cations exhibit varying degrees of affinity for the acid mucopolysaccharides. This further supports the idea that, in general the reactions are of the ion exchange type with nonspecific electrostatic binding, rather than of the more specific chelate type.

The common order of affinity for some of the alkaline earths has been given (5) as $Mg^{+2} < Ca^{+2} < Sr^{+2} < Ba^{+2}$. It has been demonstrated that calcium ion has an essential role in the concentration of arterial smooth muscle. The studies of both Waugh (7) and Bohr (8) indicate that calcium is a vital link in the coupling of excitation and contraction in vascular muscle. It also appears to have an effect on membrane excitability in arterial muscle (8).

Lamberts and Van Andel (9) have demonstrated the high bivalent cation affinity by the inner arterial intima membrane using barium and strontium. One hundred rats, each subcutaneously injected with 30 μc of $^{140}BaSO_4$ and 30 μc $^{85}SrSO_4$ were measured for bone, aortic wall, skin and lung activity at various times up to 15 weeks after injection. Their data clearly indicate specific soft tissue deposition for the aortic wall. After 14 weeks this tissue on a per gram basis represented 43% of the barium activity present per gram of bone tissue. For strontium the maximum occurred after 7 weeks when the aortic wall represented 1.25% of the activity present per gram of bone. The difference in aortic concentration of barium and strontium may be due to the ion exchange

order of affinity previously noted. The barium deposition displayed periodicity which will be discussed in the next section.

From the foregoing evidence it appears quite reasonable that radium, a bivalent element of the alkaline earth series, should likewise deposit on the aortic wall. In fact, considering the common cation exchange affinity for the alkaline earths, the chondroitin sulfates should have even greater affinity for radium than for barium.

Lead has also been shown to be present in the normal aorta in concentrations exceeding that for most other soft tissues in the body. It is probable that the same biochemical ion exchange mechanism is responsible for this specific site deposition. In fact Schroeder (10) et. al. has demonstrated a rather large increase in lead concentration with age in the normal human aorta. This is not surprising in the light of the fact that the mucopolysaccharide concentration of the human aorta also increases with age.

There is less information presently available to explain the rather high ^{226}Ra and ^{210}Pb concentrations found in the thyroid gland. At present it is not known whether or not mucopolysaccharides are present in the thyroid.

Radiobiological Implications

The high sensitivity of mucopolysaccharides to X-rays has been demonstrated by both Lamberts and deBoer (12) and Brinkman et.al. (13) in several ways; the immediate drop of the injection pressure in mucoid and connective tissue, viscosity changes in fresh synovial fluid and the increased permeability of the connective membranes.

Viscosity changes in synovial fluid, (which contains a large proportion of mucopolysaccharides), is explained by an irradiation depolymerization mechanism of the chondroitin sulfates. The hypothesis thus emerges that the periodic type of ^{140}Ba noted previously is a consequence of the radiation reaching a value sufficient for destruction of deposition factors and its elimination from the wall tissue, (9). The effect of the increased permeability as a result of depolymerization may result in degenerative changes in the mucopolysaccharide matrix leading to infiltration of plasma lipoprotein complexes into the membrane wall. Infiltration of fat in the intimal and medial layers of the arterial wall causes deposition of fat charged macrophages which may lead to the formation of atheromatous plaques (12). Lindsay, et. al. (1962) (14) irradiated the abdominal part of the aorta in dogs and found atherosclerosis in the irradiated vessel in 2 to 48 weeks which could not be distinguished from the "natural" process. Likewise Lamberts and deBoer (12) have described the development of atheromatosis in the carotid artery of hypercholeserolaemic rabbits within a few weeks after X-irradiation of 500-3000r.

From these observations it is evident that elastic arteries do show extensive changes a short time after irradiation with doses of X-rays on the order of 500r. Under hypercholesterolaemic conditions these changes are easily demonstrable by the penetration of fat into the wall and the deposition of lipophages on the intima. The mechanism by which these lesions develop might be explained as follows: the formation and destruction of elastic and reticular fibers, a continuous process, is closely related to an intact mucopolysaccharide matrix.

Changes in this matrix e.g. depolymerization by X-irradiation, will cause changes in the formation of these fibers, leading up to an impairment of the filter barrier function of the arterial wall. This becomes evident by the changes in elastic fibers and fat infiltration into the wall (12).

It is interesting to note that a very large number of the radium dial painters examined at autopsy showed evidence of sclerotic lesions in the arteries (15). Since arterial sclerosis is so common among the aged as almost to be considered "normal", there can be little said concerning this observation. Further experimental and epidemiologic evidence is necessary, including comparison with a control group, before any statement can be made concerning causal effects.

The dose received by the aortic linings are currently being considered. It is clear that most of the dose received by these cases was early in life when the radium was freshly injected and relatively labile. It may be necessary to resort to animal experiments to obtain information about the dose to the aorta from freshly ingested radium.

Acknowledgement:

I would like to thank Dr. Henry G. Petrow for the initiation and supervision of this preliminary study of the radium and lead distributions in the soft tissues of exposed individuals. In addition, Dr. Petrow performed all of the ^{210}Pb determinations reported here.

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PART III

RÉSUMÉS OF FINDINGS FROM INDIVIDUAL CASE STUDIES

Previously published résumés appear in
Reports NYO-2760, NYO-10604, NYO-2181-2
and NYO-2181-3

VITAL STATISTICS

Living female
Born 28 September 1901; Orange, New Jersey

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

First exposure 1917 at age 18, New Jersey
Radium Luminous Material Corporation as packer

ESTIMATED BODY BURDEN

MSA radium-226, NYU Whole Body Counter, November 23, 1965
MSA radium-228, NYU Whole Body Counter, November 23, 1965

FAMILY HISTORY

Mother:	Died age 78 following gall bladder surgery
Father:	Died age 83, automobile accident
Brother:	(1) Died age 66, heart failure
	(2) Died age 69, heart failure
	(3) Died age 33, World War I
	(4) Living and well, age 62 (RRP Control 6581)
	(5) Living and well, age 60 (RRP Control 6563)
	(6) Living and well, age 55 (RRP Control 6548)
Sister:	(1) Died age 34, radium poisoning (RRP Case 5056)
	(2) Living and well, age 58
	(3) Living and well, age 53 (RRP Control 6568)
Son:	Living and well, born 1922
Daughter:	(1) Living and well, born 1923
	(2) Living and well, born 1924

MEDICAL HISTORY

Obstetrical: Para 3 Gravida 3
Scarlet fever, childhood (050)
Appendectomy, 1929 (551)
Pneumonia (490) and bronchitis (501), 1946
Bladder surgery, 1948
Phlebitis, 1956 (464)
Arthritis (725)

DIAGNOSES AND IMPRESSIONS FROM MEDICAL, CLINICAL LABORATORY, X-RAY AND DENTAL EXAMINATIONS AS OF 11/22/65

Apparent health: Good Fair Poor

Edentulous (533.7)
Slight osteoarthritis of lower cervical spine (723.1)

Moderate osteoarthritis of mid-dorsal spine (723.1)
Fairly advanced osteoarthritis of lumbo-sacral spine with thinning of 4th and 5th intervertebral discs (723.1)
Degenerative changes of greater tuberosities of humeri at tendon attachments (733)
Osteoarthritis of right acromio-clavicular joint (723)
Fairly advanced osteoarthritis of both knees (723)
Symmetrical deformities with chronic dislocation of 1st and 2nd metatarso-phalangeal joints of both feet
Obesity (287)
Bilateral arcus senilis (388)
Hemangioma right hand, congenital (228)
Mild retinal and peripheral arteriosclerosis (450.0)

VITAL STATISTICS

Male (last known to be alive 1962)
Born 7 November 1891

MEANS OF DISCOVERY

Referred by another case

OCCUPATIONAL HISTORY

No information on date of first exposure, age at first exposure or job description
Radium Luminous Material Corporation, New Jersey

ESTIMATED BODY BURDEN

1.73×10^{-12} curies per litre, Breath Radon by Dr. Hess, April 27, 1958

FAMILY HISTORY

Mother: No information
Father: No information
Brother: Last known to be alive in 1960 (RRP Case 5108)

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Dead Female
Born 9 October 1898; Steinbach, Germany
Died 15 November 1945; Los Angeles, California

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

First exposure 1918 at age 21, New Jersey
Radium Luminous Material Corporation as dial painter

ESTIMATED BODY BURDEN

3.4 micrograms radium-226, Geiger-Müeller Counter, H. S. Martland, M.D., August 24, 1940

FAMILY HISTORY

Mother:	Died age 72, heart disease
Father:	Died age 79, stroke
Brother:	(1) Died age 54, coronary
	(2) Living and well, age 66 (RRP Case 5322)
	(3) Living and well, age 56 (RRP Control 6510)
	(4) Died age 19, accidental fall in home (RRP Case 5182)
Sister:	(1) Died age 2, burns
	(2) Living and well, age 60 (RRP Control 6511)
	(3) Living and well, age 59 (RRP Control 6509)
Daughter:	(1) Living, age and status of health unknown
	(2) Living, age and status of health unknown

MEDICAL HISTORY

No information available

DIAGNOSES AND IMPRESSIONS

No studies performed

DATA FROM DEATH CERTIFICATE 11/15/45:

Ulcerative osteogenic sarcoma of left leg (196.9)
Metastasis to the lungs (165) due to radium osteitis (E961.3)

VITAL STATISTICS

Female (last known to be alive in 1961)
No birthdate available

MEANS OF DISCOVERY

Referred by another case

OCCUPATIONAL HISTORY

No information on date of first exposure or age at first exposure
United States Radium Corporation, New York as dial painter

ESTIMATED BODY BURDEN

0.564×10^{-12} curies per litre, Breath Radon by Dr. Hess, October 26, 1959

FAMILY HISTORY

Mother: No information
Father: No information
Sister: (1) No information
(2) No information

MEDICAL HISTORY

Obstetrical: Para 0 Gravida 0
Hypertensive cardiovascular disease, 1961 (443)
Herpes Zoster, left chest, 1961 (088)
Enlarged heart, 1961 (434.4)
Mild myocardial damage, 1961
Infected teeth, 1961 (532.3)

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Living female
Born 30 March 1901; Montclair, New Jersey

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

First exposure 1917 at age 16, New Jersey
Radium Luminous Material Corporation as clerk

ESTIMATED BODY BURDEN

MSA radium-226, NYU Whole Body Counter, October 25, 1965
MSA radium-228, NYU Whole Body Counter, October 25, 1965

FAMILY HISTORY

Mother:	Died at age 76, cardio-renal failure
Father:	Died at age 78, heart failure
Brother:	Living, age 50, peritonitis in 1966 (RRP Control 6573)
Sister:	(1) Living and well
	(2) Living and well, age 54 (RRP Control 6572)
Son:	Living and well, born 1926
Daughter:	(1) Living and well, born 1922
	(2) Living and well, born 1925

MEDICAL HISTORY

Obstetrical: Para 3 Gravida 3
Arthritis (725)
Squamous cell carcinoma of the uterus, 1951 (171)

DIAGNOSES AND IMPRESSIONS FROM MEDICAL, CLINICAL LABORATORY, X-RAY AND DENTAL EXAMINATIONS AS OF 10/25/65

Apparent health: Good Fair Poor

Edentulous maxilla (533.7)
6 remaining mandibular teeth
Generalized osteoporosis (733)
Degenerative disc disease (735)
Degenerative joint disease (723.1)
Peritendinitis calcarea (741)
Bilateral Morton's toes (733)
Tumor right lower eyelid, type undetermined (238)
Mild varicose vein, right greater saphenous (460)
Probable HCVD (443)

VITAL STATISTICS

Male (last known to be alive in 1950)
No birthdate available

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

No information on date of first exposure or age at first exposure
United States Radium Corporation, New York as purchasing agent

ESTIMATED BODY BURDEN

0.337×10^{-12} curies per litre, Breath Radon by Dr. Hess, February 27, 1950

FAMILY HISTORY

No information

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Female (last known to be alive in 1961)
No birthdate available

MEANS OF DISCOVERY

Referred by another case

OCCUPATIONAL HISTORY

No information on date of first exposure or age at first exposure
Ansonia Clock Company as dial painter

ESTIMATED BODY BURDEN

0.62×10^{-12} curies per litre, Breath Radon by Dr. Hess, October 7, 1954

FAMILY HISTORY

No information

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Living female
Born 16 March 1887, Orange, New Jersey

MEANS OF DISCOVERY

Referred by her physician

OCCUPATIONAL HISTORY

First exposure 1918 at age 31, New Jersey
Radium Luminous Material Corporation as dial painter

ESTIMATED BODY BURDEN

1.25 microcurie radium-226, MIT Breath Radon, December 8, 1965

FAMILY HISTORY

Mother: Dead, age and cause unknown
Father: Dead, age and cause unknown
Sister: Dead, age and cause unknown
No further information

MEDICAL HISTORY

Obstetrical: Para 0 Gravida 0
Pathological fracture, left femur, 1946 (N821)
Pathological fracture, right femur, 1951 (N821)
Pathological fracture, left elbow, 1964 (N821)

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Male (last known to be alive in 1957)
No birthdate available

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

No information on date of first exposure, age at first exposure or job description
United States Radium Corporation, New York

ESTIMATED BODY BURDEN

1.54×10^{-12} curies per litre, Breath Radon by Dr. Hess, October 7, 1957

FAMILY HISTORY

No information

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Male (last known to be alive in 1951)
No birthdate available

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

No information on date of first exposure, age at first exposure or job description
United States Radium Corporation, New York

ESTIMATED BODY BURDEN

0.49×10^{-12} curies per litre, Breath Radon by Dr. Hess, October 14, 1951

FAMILY HISTORY

No information

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Living male
Born 8 September 1922; Reading, Pennsylvania

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

First exposure 1946 at age 25, New York
United States Radium Corporation as chemist

ESTIMATED BODY BURDEN

0.0045 microcurie radium-226, NYU Whole Body Counter, September 16, 1965
0.0008 microcurie radium-228, NYU Whole Body Counter, September 16, 1965

FAMILY HISTORY

Mother:	Living and well, age 64
Father:	Living and well, age 65
Sister:	Living and well, age 31
Son:	Living and well, age 19

MEDICAL HISTORY

Pertussis, childhood (056.0)
Diphtheria, childhood (055)
Tonsillectomy and adenoidectomy, childhood (510.1)
Submucous resection of nose, 1942 (514)
Fracture, nose, traumatic, 1964 (N802)

DIAGNOSES AND IMPRESSIONS FROM MEDICAL, CLINICAL LABORATORY, X-RAY AND DENTAL EXAMINATIONS AS OF 10/28/65

Apparent health: Good Fair Poor

29 remaining teeth
Chronic dental pathology, periapical
Functional gastric disturbance (544.2)
Borderline hypertension (BP 156/96) (444)
One centimeter mass above left testicle, probable hydrocele (613)
Deviated nasal septum (514)
Degenerative disc disease (735)

VITAL STATISTICS

Living male
No birthdate available

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

No information on date of first exposure, age at first exposure or job description
United States Radium Corporation, New York

ESTIMATED BODY BURDEN

0.738×10^{-12} curies per litre, Breath Radon by Dr. Hess, September 23, 1963

FAMILY HISTORY

No information

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Male (last known to be alive in 1958)
No birthdate available

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

No information on date of first exposure, age at first exposure or job description
United States Radium Corporation, New York

ESTIMATED BODY BURDEN

0.28×10^{-12} curies per litre, Breath Radon by Dr. Hess, March 31, 1958

FAMILY HISTORY

No information

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Living male
No birthdate available

MEANS OF DISCOVERY

Search by case finding group

OCCUPATIONAL HISTORY

No information on date of first exposure, age at first exposure or job description
United States Radium Corporation, New York

ESTIMATED BODY BURDEN

4.55×10^{-12} curies per litre, Breath Radon by Dr. Hess, May 1, 1951

FAMILY HISTORY

No information

MEDICAL HISTORY

No information

DIAGNOSES AND IMPRESSIONS

No studies performed

VITAL STATISTICS

Female (last known to be alive in 1962)
Born 24 August 1922; Kulpmont, Pennsylvania

MEANS OF DISCOVERY

Referred by another case

OCCUPATIONAL HISTORY

First exposure 1941 at age 19, United States Radium Corporation, New York
No information on job description

ESTIMATED BODY BURDEN

"Inactive" Breath radon by Dr. Hess, February 14, 1950

FAMILY HISTORY

Mother:	Dead, age and cause unknown
Father:	Dead, age and cause unknown
Brother:	Last known to be alive in 1962
Son:	(1) Born 1950, last known to be alive in 1962
	(2) Born 1954, last known to be alive in 1962
	(3) Born 1957, last known to be alive in 1962

MEDICAL HISTORY

Obstetrical: Para 3 Gravida 3
No further information

DIAGNOSES AND IMPRESSIONS

No studies performed

APPENDIX

EXHIBIT 1

Case Finding and Follow-Up Progress Report to October 1, 1966

I. Estimated potential number of radium cases who were exposed in New Jersey or the metropolitan areas of New York or Philadelphia....1000

II. Number of names of all radium cases identified who were exposed in the State of New Jersey or the metropolitan areas of New York or Philadelphia..... 978

A. Number of radium cases living..... 332

1. Within New Jersey or the metropolitan areas of New York or Philadelphia..... 300

2. Outside of this area..... 32

B. Number of radium cases known to have deceased..... 259

C. Number of radium cases whose current status has not yet been determined..... 387

III. Number of radium cases contacted..... 362

A. Basic medical and radiation evaluation completed..... 150

1. Number of cases currently living..... 114

2. Number of cases deceased..... 36

B. Number of cases currently undergoing studies..... 50

C. Number of cases not studied..... 161

1. Living..... 139

2. Dead..... 22

IV. To date 53 cases have been completed and are on "standby" (with the exception of a yearly whole body count in some instances).

V. Controls

A. Initial studies completed.....82
B. Completed all studies (including four additional laboratory examinations).....29
C. Undergoing initial study..... 7
D. Numbered but not yet started..... 5

U. S. Atomic Energy Commission
Division of Biology & Medicine

N. J. State Department of Health
Dr. Roscoe P. Kandle, Commissioner

Scientific Advisory Committee

Radium Research Project
Dr. Samuel C. Ingraham 2nd, Project Director

Consultants
Dr. Lester Goldman, Clinical Laboratory
Dr. William Bernhard, Special Laboratory

Cooperating Agencies for special radiation studies
WBC, Br Ra, Radiochemistry
New York University Medical Center
Drs. Merril Eisenbud & Henry Petrow

Breath Radon
Massachusetts Institute of Technology
Dr. Robley Evans

Subcontractors

General Pathology & Special Radio-osteitis Study
New Jersey College of Medicine & Dentistry
Drs. Hugh Grady & William Sharpe

Oral Pathology
Georgetown University Dental School
Drs. Joseph Bernier & Joseph Belzile

Statistical Consultation & Data Processing
Rutgers University Statistics Center
Drs. Ellis Ott & Thomas Hayton

Project Medical & Dental Staff
Dr. Hyman W. Fisher, Project Medical Director
Dr. Carye-Belle Henle, Project Radiologist
Dr. Robert Bonda, Project Dentist

Case Follow-Up
Nancy Manner, Nurse Supervisor
Mary Rallo, Field Nurse

Data Collection & Processing
Elizabeth Stewart
Catharine Rowland

Storage & Processing of Specimens
Ann Johnson

Fiscal & Clerical
Medora MacLaren, Administrative Assistant
Mary Cull, Medical Secretary

EXHIBIT 2

Table of Organization

EXHIBIT 3 - Lodwick Schema for Coding X-Rays

FORM NO.	DATE OF EXAM (Mo Day Yr)	EXAM NO.	CASE NO.
1			
(1)	(2) (3) (4) (5) (6) (7)	(8) (9)	(77)(78)(79)(80)

(10) Check if Specimens

(11) Radiologist Assn'd. No.

(12) 2 Taken by RRP
3 Taken for RRP
4 Other

DO NOT USE	PAIRED TUBULAR		Check if x-ray interpreted	CHANGES IN CATEGORIES LISTED: *Prox Epiph 1	Prox Met 2	Shaft 3	Distal Met 4	Distal Epiph 5	No changes in categories listed
	01 Clavicle	L							
	02	R							
	* 03 Femur	L							
	* 04	R							
	05 Tibia	L							
	06	R							
	07 Fibula	L							
	08	R							
	09 Foot	L							
	10	R							
	11 Humerus	L							
	12	R							
	13 Radius	L							
	14	R							
	15 Ulna	L							
	16	R							
	17 Hand	L							
	18	R							

*For femur the capital epiphysis is considered to be the "proximal epiphysis" and the two trochanters are included in the "metaphysis"

(Revised 10/15/65)

FORM NO. | DATE OF EXAM (Mo, Day, Yr) | EXAM NO. | CASE NO.

1																			
(1)	(2)		(3)		(4)		(5)		(6)		(7)	(8)		(9)	(77)		(78)	(79)	(80)

DO NOT USE		PAIRED FLAT		Check if x-ray interpreted	Changes in categories listed	No changes in categories listed
		19 Ilium	L			
		20	R			
		21 Ischium	L			
		22	R			
		23 Pubis	L			
		24	R			
		25 Ribs	L			
		26	R			
		27 Scapula	L			
		28	R			

DO NOT USE		UNPAIRED FLAT & SPONGY	Check if x-ray interpreted	Changes in categories listed	No changes in categories listed
		29 Skull (vault)			
		30 Skull (base)			
		31 Maxilla L			
		32 Maxilla R			
		33 Mandible (lt side)			
		34 Mandible (rt side)			
		35 Cervical spine			
		36 Dorsal spine			
		37 Lumbar spine			
		38 Sacrum & Coccyx			
		39 Sternum			

BONE DESTRUCTION

(Revised 10/15/65)

Complete this form for each different Area Code wherein destruction is present

FORM NO.	DATE OF EXAM (Mo Day Yr)	EXAM NO.	AREA CODE	CASE NO.
2				
(1)	(2) (3) (4) (5) (6) (7)	(8) (9)	(13)(14)(15)	(77)(78)(79)(80)

1. DIFFUSE CORTICAL POROSIS (See 1, 2, 3)

(CHECK ONE)

(16)
1 Coarse (holes present 10 mm or greater)
2 Fine (holes present 2 mm or greater but none 10 mm or greater)
3 Questionable or border line of normal (all holes less than 2 mm)

(17)(18) Greatest number of defects per Cm^2

% (19)(20)(21) % of area involved

2. CORTICAL DEFECTS (See 4, 5, 7, 15)

(22)(23)(24) No. of defects in area

% (25)(26)(27) % of area involved

mm x mm (28)(29)(30)(31) Large

mm x mm (32)(33)(34)(35) Small

} Range of size of defects (mm)

3. SUBCORTICAL (ENDOSTEAL) DEFECTS (See 4, 5, 6)

(36)(37)(38) No. of defects in area

% (39)(40)(41) % of area involved

mm x mm (42)(43)(44)(45) Large

mm x mm (46)(47)(48)(49) Small

} Range of size of defects (mm)

4. MEDULLARY DEFECT (See 8)

mm N.A. (50)(51) Length

(52)(53) Width

(54)(55) Depth

(56) MARGIN
1 Distinct
2 Less Distinct (CHECK ONE)
3 Indistinct

% (57)(58)(59) % of area involved

BONE PROLIFERATION (Revised 10/15/65)

Complete this form for each different Area Code wherein proliferation is present

FORM NO.	DATE OF EXAM (Mo / Day / Yr)	EXAM NO.	AREA CODE	CASE NO.
3				
(1)	(2) (3) (4) (5) (6) (7)	(8) (9)	(13)(14)(15)	(77)(78)(79)(80)

1. DIFFUSE MEDULLARY SCLEROSIS (See 10, 17)

%		% of area involved
(16)(17)(18)		
Cm^2		Size of lesion (Cm^2)
(19)(20)(21)(22)		
%		Degree of solidity (% area sclerosed)
(23)(24)(25)		

MARGIN

(26)

- 1 Distinct
- 2 Less Distinct
- 3 Indistinct

(CHECK ONE)

2. FOCAL TRABECULAR SCLEROSIS (See 11, 12, 13, 14, 16)

		Number of foci in area
(27)(28)(29)		
mm mm		Large
(30)(31)(32)(33)(34)(35)		} Range of size of foci (mm)
mm mm		Small
(36)(37)(38)(39)(40)(41)		
%		Degree of solidity (% area sclerosed)
(42)(43)(44)		

MARGIN

(45)

- 1 Distinct
- 2 Less Distinct
- 3 Indistinct

(CHECK ONE)

3. PERIOSTEAL THICKENING (See 15)

mm mm		Degree of thickening (mm)
(46)(47) (48)(49)		
%		% of length of area
(50)(51)(52)		

- 1 Regular
- 2 Irregular

(CHECK ONE) (53)

BONE PROLIFERATION (2) (Revised 10/15/65)

FORM NO.	DATE OF EXAM (Mo Day Yr)	EXAM NO.	AREA CODE	CASE NO.
3				
(1)	(2) (3) (4) (5) (6) (7)	(8) (9)	(13)(14)(15)	(77)(78)(79)(80)

4. CORTICAL THICKENING

mm mm

(16)(17) (18)(19) Degree of thickening (mm)

%

(20)(21)(22) % of length of area

(23) 1 Regular 2 Irregular (CHECK ONE)

5. ENDOSTEAL THICKENING (See 5)

mm mm

(24)(25) (26)(27) Degree of thickening (mm)

%

(28)(29)(30) % of length of area

(31) 1 Regular 2 Irregular (CHECK ONE)

6. SEQUESTRAE (See 9)

(32) 1 Present 2 Absent (CHECK ONE)

7. CORTEX INSIDE OF CORTEX (See 4, 6, 15)

(33) 1 Present 2 Absent (CHECK ONE)

8. TRANSVERSE LINEAR DENSITIES

(34) 1 Present 2 Absent (CHECK ONE)

(35)(36) If present, number of lines

9. OBLIQUE LINEAR DENSITIES

(37) 1 Present 2 Absent (CHECK ONE)

(38)(39) If present, number of lines

SPECIAL STANDARD MEASUREMENTS (Revised 10/15/65)

FORM NO. | DATE OF EXAM (Mo, Day, Yr) | EXAM NO. | CASE NO.

FORM NO.	DATE OF EXAM (Mo Day Yr)	EXAM NO.	CASE NO.
4			
(1)	(2) (3) (4) (5) (6) (7)	(8) (9)	(77)(78)(79)(80)

1. Radius (in AP film): Number of defects in 1 Cm^2 at distal end of shaft and distal metaphysis at point of greatest slope.

LEFT		RIGHT	
	(16)(17)(18)		(19)(20)(21)

2. Combined thickness (medial and lateral) of cortex of radius at point below radial tuberosity where cortices of radius and ulna become parallel (measured to nearest 0.1 mm).

	mm		mm
LEFT AP	(22)(23)(24)	RIGHT AP	(28)(29)(30)
LEFT LATERAL	(25)(26)(27)	RIGHT LATERAL	(31)(32)(33)

3. Total width (thickness) of radius at point below radial tuberosity where cortices of radius and ulna become parallel (measured to nearest 0.1 mm).

	mm		mm
LEFT AP	(34)(35)(36)	RIGHT AP	(40)(41)(42)
LEFT LATERAL	(37)(38)(39)	RIGHT LATERAL	(43)(44)(45)

4. Combined cortical thickness (medial and lateral) of second metacarpal bone (in AP film) through thickest area of cortex (measured to nearest 0.1 mm).

	mm		mm
LEFT	(46)(47)(48)	RIGHT	(49)(50)(51)

CLINICAL ENTITY AFFECTING BONE

(Revised 10/15/65)

FORM NO. 5 (1)

DATE OF EXAM (Mo Day Yr) (2) (3) (4) (5) (6) (7)

EXAM NO. (8) (9)

CASE NO. (77)(78)(79)(80)

(CHECK ONE) (16)

1 Present

2 Absent

DEGREE OF CERTAINTY (17)

1 Possible

2 Probable (CHECK ONE)

3 Definite

METHOD OF ESTABLISHING DIAGNOSIS (CHECK ONE OR MORE)

(18) Clinical

(19) Laboratory

(20) Pathology

(21) Radiography

If present, specify: _____

USE SEPARATE SHEET FOR EACH DIAGNOSIS PERTINENT TO BONE

WHO Code No. _____

INSTRUCTIONS AND DEFINITIONS FOR USE WITH X-RAY CODING FORMS

FORM 1

Form 1 (consisting of two pages) is used to code all bones and portions of bones containing changes in categories listed on Forms 2 and 3. Each set of x-rays on a case will have one Form 1.

Basic information

1. Enter month, day and year of x-ray film set being interpreted.
2. Enter examination number, also checking block 10 if x-rays are of specimens rather than of case.
3. Enter assigned number of radiologist doing the interpretation (Dr. Henle #1, Dr. Bonda #2, etc.).
4. Enter source of x-rays (2 Taken by RRP, 3 Taken for RRP, 3 Other).
5. Enter case number.

Interpretation

1. Check appropriate space for each bone interpreted.
2. Check area or areas in which changes of categories listed on Forms 2 (Destruction) and 3 (Proliferation) are located or check appropriate "no changes" block if there are no changes of categories listed on Forms 2 and 3.

n.b. The blocks marked "DO NOT USE" are for coding at the Project office preparatory to punching IBM cards for this deck.

FORM 2

Form 2 is for coding destructive lesions in bones or portions of bones. There will be a Form 2 or Form 3 or both for each entry in the "changes" columns of Form 1. Normally there will be no Forms 2 or 3 to match entries in the "no changes" columns of Form 1.

Basic Information

1. Enter month, day and year of x-ray film set being interpreted.
2. Enter examination number.
3. Enter case number.
4. Enter Area Code number which is comprised of...

   On page 1 of Form 1: the two digits to the left of the name of the bone being interpreted plus the digit above the portion of the bone being interpreted ie. the Area Code for a change in the shaft of the Left Clavicle would be "013".

   On page 2 of Form 1: the two digits to the left of the name of the bone being interpreted ie. the Area Code for a change in the Skull (vault) would be "29". Since there is no third digit, box 15 of the Area Code is left blank.

   When the interpretation is "no changes" in categories listed, no Form 2 or Form 3 will be prepared.

Interpretation

1. DIFFUSE CORTICAL POROSIS (See 1, 2, 3)

   (16) Check one only.

   (17)-(18) "Greatest number of defects per Cm^2" - to quantitate greatest occurrence of cortical defects, select most involved area of bone or bone segment covered by Form 2 and count defects in 1 Cm^2.

   (19)-(21) "% of area involved" is to be a visual estimate of % of bone or bone segment covered by Form 2 that the defects constitute.

2. CORTICAL DEFECTS seen in profile (See 4, 5, 7, 15)

   (22)-(24) "No. of defects in area" is to be an actual count or, if defects are very numerous, a best estimate of number of defects in the bone or bone segment described by the Form 2.

   (25)-(27) "% of area involved" is to be a visual estimate of % of bone or bone segment covered by Form 2 that the defects constitute.

   (28)-(35) "Range of size of defects" is to be actual measurements (rounded off to the nearest 0.1 mm) of the dimensions of the defects visually selected as being the largest and smallest ones present.

3. SUBCORTICAL (ENDOSTEAL) DEFECTS seen in profile (See 4, 5, 6) as for CORTICAL DEFECTS.

4. MEDULLARY DEFECTS (See 8)

   (50)-(55) Length (longest dimension of defect), width (measure at right angle to length of defect) and depth (seen on lateral film, if available) are the three dimensions of a defect mutually at right angles to each other but not necessarily in line with any axis of the bone or bone segment being described. Normally only two of these dimensions are recordable from the available films. N.A. means "Not Applicable".

   (56) "Margin": Distinct - margin of the lesion is clearly and easily determined.
   Less Distinct - margin of the lesion is reasonably clearly and easily determined.
   Indistinct - margin of the lesion is quite vague.

   n.b. These terms refer to determinability of the margin, not its contour.

   (57)-(59) "% of area involved" is to be a visual estimate of the % of the study area represented by the Form 2 that appears to be involved.

FORM 3

Form 3 (consisting of two pages) is for coding proliferative lesions in bones or portions of bones. There will be a Form 3 or Form 2 or both for each entry in the "changes columns of Form 1. Normally there will be no Forms 3 or 2 to match entries in the "no changes" columns of Form 1.

Basic Information as for Form 2.

Interpretation

1. DIFFUSE MEDULLARY SCLEROSIS (See 10, 17)

   (16)-(18) "% of area involved" is to be a visual estimate of degree of involvement of bone or bone segment covered by the Form 3.

   (19)-(22) "Size of lesion" is to be the best reasonable estimate of the size in square centimeters of the area involved.

   (23)-(25) "Degree of solidity" is to be a visual estimate of the % of the coded area represented by the Form 3 that appears to be sclerosed.

   (26) "Margin": Distinct - margin of the lesion is clearly and easily determined.
   Less Distinct - margin of the lesion is reasonably clearly and easily determined.
   Indistinct - margin of the lesion is quite vague.

   n.b. These terms refer to determinability of the margin, not its contour

2. FOCAL TRABECULAR SCLEROSIS (See 11, 12, 13, 14, 16)

   (27)-(29) "Number of foci in area" is to be an actual count or, if foci are very numerous, a best estimate of number of defects in the bone or bone segment described by the Form 3.

   (30)-(41) "Range of size of foci" is to be actual measurements (rounded off to the nearest mm) of the dimensions of the foci visually selected as being the largest and smallest ones present.

   (42)-(44) "Degree of solidity" - See (23)-(25) above.

   (45) "Margin" - See (26) above.

3. PERIOSTEAL THICKENING (See 15)

   (46)-(49) "Degree of thickening" is to be a measure (rounded off to the nearest mm) of the maximum thickness of major area of periosteal thickening.

   (50)-(52) "% of length of area" is to be the best visual estimate.

   (53) "Regular" and "Irregular" refer to contour of periosteal thickening.

4. CORTICAL THICKENING as for PERIOSTEAL THICKENING.

5. ENDOSTEAL THICKENING (See 5) as for PERIOSTEAL THICKENING.

FORM 3 (CONTINUED)

6. SEQUESTRAE (See 9) - Check as indicated.

7. CORTEX INSIDE OF CORTEX (See 4, 6, 15) - Check as indicated.

8. TRANSVERSE LINEAR DENSITIES - Check as indicated.

9. OBLIQUE LINEAR DENSITIES - Check as indicated.

FORM 4

Form 4 is for coding special standard measurements made on x-rays of designated bones. There will be a Form 4 for each Form 1.

Basic Information as for Form 2 (Omit Area Code)

Interpretation

1. Record number of defects in 1 Cm^2 in AP film at junction of distal end of shaft of radius and distal metaphysis at point of greatest angle. Right radius is preferred. If both right and left AP views are available, both may be recorded.

2. Record combined thickness (medial and lateral) of cortex of radius at point below radial tuberosity where cortices of radius and ulna become parallel. Left radius is preferred. Both AP and lateral views should be measured and recorded if films are available. All measurements are rounded off to the nearest 0.1 mm.

3. Record total width (thickness) of radius at point below radial tuberosity where cortices of radius and ulna become parallel. Left radius is preferred. Both AP and lateral views should be measured and recorded if films are available. All measurements are rounded off to the nearest 0.1 mm.

4. Record combined thickness of medial and lateral cortex of second metacarpal bone through thickest area. Both measurements are to be made at the same level in the bone. Left second metacarpal is preferred. All measurements are to be rounded off to the nearest 0.1 mm. If both right and left AP views are available, both may be recorded.

FORM 5

Form 5 is for recording each clinical entity affecting bone that is diagnosed for a set of x-rays. A separate Form 5 is used for each diagnosis.

Basic Information as for Form 2 (Omit Area Code)

Interpretation

(16) Check as appropriate. If there is no Definite Clinical Entity Affecting Bone, there will be only one Form 5 with block (16) checked "Absent".

(17) "Degree of certainty" - Check appropriate block.

(18)-(21) "Method(s) of Establishing Diagnosis" - Check appropriate block or blocks.

"Diagnosis" - Enter name of each diagnosis pertinent to bone. The International Code Number for the diagnosis will be entered prior to the punching of the appropriate IBM card.