NRC FORM 313
(9-85)
10 CFR 30, 32, 33, 34, 35 and 40

U.S. NUCLEAR REGULATORY COMMISSION
APPROVED BY OMB
3150-0120
Expires: 5-31-87

APPLICATION FOR MATERIAL LICENSE

INSTRUCTIONS: SEE THE APPROPRIATE LICENSE APPLICATION GUIDE FOR DETAILED INSTRUCTIONS FOR COMPLETING APPLICATION. SEND TWO COPIES OF THE ENTIRE COMPLETED APPLICATION TO THE NRC OFFICE SPECIFIED BELOW.

FEDERAL AGENCIES FILE APPLICATIONS WITH:

U.S. NUCLEAR REGULATORY COMMISSION
DIVISION OF FUEL CYCLE AND MATERIAL SAFETY, NMSS
WASHINGTON, DC 20555

ALL OTHER PERSONS FILE APPLICATIONS AS FOLLOWS, IF YOU ARE LOCATED IN:

CONNECTICUT, DELAWARE, DISTRICT OF COLUMBIA, MAINE, MARYLAND, MASSACHUSETTS, NEW HAMPSHIRE, NEW JERSEY, NEW YORK, PENNSYLVANIA, RHODE ISLAND, OR VERMONT, SEND APPLICATIONS TO:

U.S. NUCLEAR REGULATORY COMMISSION, REGION I
NUCLEAR MATERIAL SECTION B
631 PARK AVENUE
KING OF PRUSSIA, PA 19406

ALABAMA, FLORIDA, GEORGIA, KENTUCKY, MISSISSIPPI, NORTH CAROLINA, PUERTO RICO, SOUTH CAROLINA, TENNESSEE, VIRGINIA, VIRGIN ISLANDS, OR WEST VIRGINIA, SEND APPLICATIONS TO:

U.S. NUCLEAR REGULATORY COMMISSION, REGION II
MATERIAL RADIATION PROTECTION SECTION
101 MARIETTA STREET, SUITE 2900
ATLANTA, GA 30323

IF YOU ARE LOCATED IN:

ILLINOIS, INDIANA, IOWA, MICHIGAN, MINNESOTA, MISSOURI, OHIO, OR WISCONSIN, SEND APPLICATIONS TO:

U.S. NUCLEAR REGULATORY COMMISSION, REGION III
MATERIALS LICENSING SECTION
799 ROOSEVELT ROAD
GLEN ELLYN, IL 60137

ARKANSAS, COLORADO, IDAHO, KANSAS, LOUISIANA, MONTANA, NEBRASKA, NEW MEXICO, NORTH DAKOTA, OKLAHOMA, SOUTH DAKOTA, TEXAS, UTAH, OR WYOMING, SEND APPLICATIONS TO:

U.S. NUCLEAR REGULATORY COMMISSION, REGION IV
MATERIAL RADIATION PROTECTION SECTION
611 RYAN PLAZA DRIVE, SUITE 1000
ARLINGTON, TX 76011

ALASKA, ARIZONA, CALIFORNIA, HAWAII, NEVADA, OREGON, WASHINGTON, AND U.S. TERRITORIES AND POSSESSIONS IN THE PACIFIC, SEND APPLICATIONS TO:

U.S. NUCLEAR REGULATORY COMMISSION, REGION V
MATERIAL RADIATION PROTECTION SECTION
1450 MARIA LANE, SUITE 210
WALNUT CREEK, CA 94596

PERSONS LOCATED IN AGREEMENT STATES SEND APPLICATIONS TO THE U.S. NUCLEAR REGULATORY COMMISSION ONLY IF THEY WISH TO POSSESS AND USE LICENSED MATERIAL IN STATES SUBJECT TO U.S. NUCLEAR REGULATORY COMMISSION JURISDICTION.

1. THIS IS AN APPLICATION FOR *(Check appropriate item)*

- [X] A. NEW LICENSE
- [ ] B. AMENDMENT TO LICENSE NUMBER ________
- [ ] C. RENEWAL OF LICENSE NUMBER ________

2. NAME AND MAILING ADDRESS OF APPLICANT *(Include Zip Code)*

Butkin Precision Manufacturing Corporation
67 Erna Avenue
Milford, Ct. 06460

3. ADDRESS(ES) WHERE LICENSED MATERIAL WILL BE USED OR POSSESSED.

a. 67 Erna Avenue, Milford, Ct. 06460
b. 6 Roberts Drive, North Adams, Ma. 01247

4. NAME OF PERSON TO BE CONTACTED ABOUT THIS APPLICATION: Halide J. Caine, Administrative Safety Officer

TELEPHONE NUMBER: (203) 878-2416

SUBMIT ITEMS 5 THROUGH 11 ON 8½ x 11" PAPER. THE TYPE AND SCOPE OF INFORMATION TO BE PROVIDED IS DESCRIBED IN THE LICENSE APPLICATION GUIDE.

5. RADIOACTIVE MATERIAL
a. Element and mass number, b. chemical and/or physical form, and c. maximum amount which will be possessed at any one time.

6. PURPOSE(S) FOR WHICH LICENSED MATERIAL WILL BE USED.

7. INDIVIDUAL(S) RESPONSIBLE FOR RADIATION SAFETY PROGRAM AND THEIR TRAINING AND EXPERIENCE.

8. TRAINING FOR INDIVIDUALS WORKING IN OR FREQUENTING RESTRICTED AREAS.

9. FACILITIES AND EQUIPMENT.

10. RADIATION SAFETY PROGRAM.

11. WASTE MANAGEMENT.

12. LICENSEE FEES *(See 10 CFR 170 and Section 170.31)*
FEE CATEGORY 2.G.
AMOUNT ENCLOSED $ 350.00

13. CERTIFICATION. *(Must be completed by applicant)* THE APPLICANT UNDERSTANDS THAT ALL STATEMENTS AND REPRESENTATIONS MADE IN THIS APPLICATION ARE BINDING UPON THE APPLICANT.

THE APPLICANT AND ANY OFFICIAL EXECUTING THIS CERTIFICATION ON BEHALF OF THE APPLICANT, NAMED IN ITEM 2, CERTIFY THAT THIS APPLICATION IS PREPARED IN CONFORMITY WITH TITLE 10, CODE OF FEDERAL REGULATIONS, PARTS 30, 32, 33, 34, 35, AND 40 AND THAT ALL INFORMATION CONTAINED HEREIN, IS TRUE AND CORRECT TO THE BEST OF THEIR KNOWLEDGE AND BELIEF.

WARNING: 18 U.S.C. SECTION 1001 ACT OF JUNE 25, 1948, 62 STAT. 749 MAKES IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OR REPRESENTATION TO ANY DEPARTMENT OR AGENCY OF THE UNITED STATES AS TO ANY MATTER WITHIN ITS JURISDICTION.

SIGNATURE—CERTIFYING OFFICER	TYPED/PRINTED NAME	TITLE	DATE
Halide J. Caine	Halide J. Caine	Administrative Safety Officer	

14. VOLUNTARY ECONOMIC DATA

a. ANNUAL RECEIPTS

[ ]	< $250K	[ ]	$1M–3.5M
[ ]	$250K–500K	[ ]	$3.5M–7M
[ ]	$500K–750K	[ ]	$7M–10M
[ ]	$750K–1M	[ ]	> $10M

b. NUMBER OF EMPLOYEES *(Total for entire facility excluding outside contractors)*: 70

c. NUMBER OF BEDS: N/A

d. WOULD YOU BE WILLING TO FURNISH COST INFORMATION *(dollar and/or staff hours)* ON THE ECONOMIC IMPACT OF CURRENT NRC REGULATIONS OR ANY FUTURE PROPOSED NRC REGULATIONS THAT MAY AFFECT YOU? *(NRC regulations permit it to protect confidential commercial or financial—proprietary—information furnished to the agency in confidence)*

[ ] YES [X] NO

FOR NRC USE ONLY

TYPE OF FEE	FEE LOG	FEE CATEGORY	COMMENTS	APPROVED BY
Application	Jan 10 I	2G		S. Kimberley
AMOUNT RECEIVED	CHECK NUMBER			DATE
$350	4716	verified by Doug	106654	1/28/87

PRIVACY ACT STATEMENT

8710070244 870422
REG1 LIC40
STB-1505 PDR

Item 8

Employee Radiation Safety Training

Training courses were presented to the employees at the North Adams, Massachusetts facility on September 2, 1986 and at the Milford, Connecticut facility on September 22, 1986. The training lectures were presented by George R. Holeman. Appendix C con ains the outline of the training sessions which cover the radiation safety material suggested in 10CFR Part 19. Employees were cffered the opportunity to ask questions without company management present.

Item 9

Facilities and Equipment

Floor plans are provided in Appendix D and include both the North Adams, Massachusetts site and the Milford, Connecticut site. Parts may move by company truck with trained drivers between facilities in accordance with applicable Department of Transportation regulations.

Item 10

Radiation Safety Program

The Butkin Precision Manufacturing Corporation Radiation Safety Program is provided in Appendix E.

Item 11

Waste Management

All scrap and chips are returned to the major customer, AVCO/Lycoming, Nuclear Regulatory Commission License No. STB 393 in Department of Transportation containers provided by AVCO/Lycoming.

Waste may also be transferred to other licensed vendors, if necessary.

APPENDIX A

EXPERIENCE OF PERSONNEL

Radiation Safety Officers

Halide J. Caine
Joseph J. Gwozdz
Claire V. Senecal

Radiation Safety Consultants

Kenneth W. Price
George R. Holeman

RESUME

HALIDE J. CAINE C.P.A.

EMPLOYMENT:

1972-1973 DIVINA PRODUCTS/DBA R&P INC., WASHINGTON AVE., WEST HAVEN, CT.
MANUFACTURER OF HEALTH & BEAUTY AIDS

QUALITY CONTROL TECHNICIAN

- RESPONSIBLE FOR ALL TESTING OF PRODUCT INCLUDING SPECIFIC GRAVITY PYCNOMETER METHOD, REFRACTOMETER METHOD, HEAT INDUCED TESTING.
- MAINTENENCE OF QUALITY RECORDS ETC.

1973 DIVINA PRODUCTS CONT.

QUALITY CONTROL MANAGER

- RESPONSIBLE FOR DAILY SUPERVISION OF QUALITY DEPT. INCLUDING THREE TECHNICIANS.

1973-1979 DIVINA PRODUCTS CONT.

QUALITY CONTROL DIRECTOR

- RESPONSIBLE FOR ESTABLISHMENT OF QUALITY STANDARDS AND SOPs (EXISTING STANDARDS FOUND UNACCEPTABLE BY FDA)
- COMPLETE IMPLEMENTATION AND MAINTENENCE OF NEW PROCEDURES INCLUDING TESTING AND TRACEABILITY.
- COMPILED QUALITY MANUAL AND STANDARD OPERATING PROCEDURE MANUALS FOR QUALITY AND PRODUCTION.
- WORKED DIRECTLY WITH FDA AND BUREAU OF ALCOHOL.TOBACCO AND FIREARMS INSPECTORS DURING ROUTINE INSPECTIONS AS WELL AS FOLLOW UP AUDITS.* IN ONE YEAR PERIOD REDUCED NUMBER OF MONETARY VIOLATIONS BY 30K.
- COMPLETE RESPONSIBILITY OF QUALITY DEPARTMENT AS WELL AS ASSISTANCE IN PRODUCTION PROBLEM SOLVING ETC.

1979-1980 BUTKIN PRECISION MFG. CORP., ERNA AVE., MILFORD, CT
MFGER. AIRCRAFT TURBINE ENGINE COMPONENTS

PURCHASING AGENT ANNUAL BUDGET 800K

- RESPONSIBLE FOR PURCHASING OF ALL SHOP TOOLS, EQUIPMENT, PAPER GOODS ETC.
- ADMINISTRATION OF PURCHASE ORDERS, REQUEST FOR QUOTATIONS, GENERAL CUSTOMER CONTACT.
- INTERIM RESPONSIBILITY AS QUALITY CONTROL MANAGER (1979-1981)

- UPDATED AND REVISED EXISTING QUALITY CONTROL MANUAL, IMPLEMENTED AND MAINTAINED QUALITY DEPARTMENT.
- UPDATED COMPANY FILES OF MILITARY AND CUSTOMER SPECIFICATIONS, AND DOD REQUIREMENTS.

1980-1982 BUTKIN PRECISION MFG. CORP. CONT.

PURCHASING/ADMINISTRATIVE MANAGER ANNUAL BUDGET 1.5M+ **
- CREATED ALL PURCHASING, GENERAL ADMINISTRATIVE AND COMPANY POLICY PROCEDURES USED CURRENTLY.
- RESUMED RESPONSIBILITY FOR EXPEDITE OF ORDERS AND ASSISTED IN PRODUCTION PLANNING.

1982-PRESENT OPERATIONS MANAGER **

-COMPLETE RESPONSIBILITY FOR THE FOLLOWING DEPARTMENTS:
PURCHASING BUDGET 2.5M+
ADMINISTRATION
SALES
BOOKEEPING
CUSTOMER SERVICE
HEALTH & SAFETY
*DIRECT MIN. OF EIGHT EMPLOYEES AT ALL TIMES
-HEAVY CONTACT WITH FIELD REPS., DEPT. HEADS AND OTHER MANAGERS.
-REPORT DIRECTLY TO PRESIDENT OF CORPORATION
-HEAVY CUSTOMER AND VENDOR CONTACT
-MAINTAIN ALL COMPANY POLICIES AND REVIEW ANNUALLY.
-GENERALLY OVERSEE DAILY ACTIVITY OF PLANT OPERATIONS.
*HEAVY ATTENTION TO FEDERAL, DOD, OSHA, STATE AND CUSTOMER REGULATIONS, INTERPRETATION AND IMPLEMENTATION THEREOF.

EDUCATION:

GRADUATE NORTHWEST CONNECTICUT COLLEGE
ASSOCIATES DEGREE, LIBERAL ARTS

CURRENTLY ATTENDING SOUTHERN CONNECTICUT STATE COLLEGE (EVENING DIV.)
PURSUING DEGREE IN BUSINESS MANAGEMENT

MISC. COURSES IN COST ANALYSIS, MANAGEMENT SKILLS, MILITARY ACCOUNTING PRACTICES, SMALL BUSINESS SEMINARS ETC.
UNIVERSITY OF NEW HAVEN, QUINNIPIAC COLLEGE, US GOVERNMENT SPONSORED AND CUSTOMER SPONSORED.
SUCCESSFULLY COMPLETED 40 HOUR TRAINING COURSE IN RADIATION SAFETY

** MANAGEMENT INCLUDES THAT OF OUR FACILITY LOCATED IN NORTH ADAMS, MASS.

Certificate of Radiation Safety Training

We Certify That

Halide J. Caine

Has Satisfactorily Completed 40 Hours Of Radiation Safety Training

June 18, 1986

Kenneth W. Price, C.H.P.

George R. Holeman, C.H.P.

U.S. Small Business Administration
Administrator's Award for Excellence

Presented to

Butkin Precision Manufacturing Company

In recognition of outstanding contribution and service to the nation by a small business in satisfying the needs of the Federal procurement system.

May 10 1983

JOSEPH J. GWOZDZ
Fales Road
Cheshire, Ma.

(413) 743-4401

EDUCATION:

Hoosac Valley High School, 1973

Berkshire Community College, 1975
Associates Degree in Environmental Science

Radiation Safety Program, 1986
40 hour radiation safety program
Butkin Precision Mfg, Milford, Ct.

WORK EXPERIENCE:

Eagle Mold & Tool, Cheshire, Ma. 1973
General Machine Practice

S & M Precision, Pittsfield, Ma. 1973-1980
Developed machining skills
Became lead machinist and foreman

Butkin Precision, Inc., North Adams, Ma.
1980 - Present
Hired as jig bore operator
Promoted to foreman and am now
shop manager

Certificate of Radiation Safety Training

We Certify That

Joseph Gwozdz

Has Satisfactorily Completed 40 Hours Of

Radiation Safety Training

June 18, 1986

Kenneth W. Price, C.H.P. | George R. Holeman, C.H.P.

RESUME OF

CLAIRE V. SENECAL

PERSONAL DATA: 11 Woodlawn Avenue, North Adams, Ma. 01247
(413) 663-9334

STRENGTHS: I am career motivated, willing to work hard. Can Accept supervision, abse to work under stress. Can work equally well alone or with others. Put forward an aggressive effort to achieve goals set by the administration. I am sincere and determined to do well.

EDUCATION: College of Our Lady of the Elms, Chicopee, Ma.

North Adams State College, North Adams, Ma.
B.A. Business Administration - 1982

EMPLOYMENT: Butkin Precision Inc., Roberts Drive, North Adams, Ma.
October 1981 to Present
Office Manager

Penn Coal Stove Company, River Road, Clarksburg, Ma.
August 1980 to October 1981
Office Manager

Cecile Industries, Beaver Street, North Adams, Ma.
March 1980 to August 1980
Quality Control Manager / Office Manager

Inflated Products Company, Union Street, North Adams, Ma.
June 1974 to December 1979
Office Manager / Quality Control Assistant Manager

Mammoth Mart, Curran Highway, North Adams, Ma.
March 1974 to June 1974
Cashier

R.J. Widen Tannery, Ashton Avenue, North Adams, Ma.
May 1973 to February 1974
Packer

CLAIRE V. SENECAL

SUMMARY OF EXPERIENCES

ADMINISTRATION: I have had a variety of experience in administration. They have included preparation of government bids and follow ups, general office work, record keeping. As an Office Manager, I was responsible for the operation of all office procedures and personnel.

FINANCE: Preparation of weekly budgets. Responsible for the payroll and the accounts payable and receivable ledgers. Also trial balance and end of the month schedules for management. Was responsible for payroll taxes, monthly, quarterly, and yearly. I have prepared W2 forms for the employees.

PERSONNEL: Assisted in hiring employees for the company. Exercised sensitivity with workers in order to help them with problems which might impede their work performance.

PUBLIC RELATIONS: This has been a day to day routine. As a receptionist, I handle all phone calls and sales representatives coming into the office.

PURCHASING AGENT: Was responsible for purchasing materials to keep operations going smoothly. Have experience of purchasing materials for government contracts as well as components for aircraft engines.

OTHER: In 1986, I completed a forty hour training course for Radiation Safety, since we presently manufacture aircraft components containing a small amount of radioactive material.

REFERENCES: Available upon request.

Certificate
of
Radiation Safety Training

We Certify That

Claire V. Senecal

Has Satisfactorily Completed 40 Hours Of

Radiation Safety Training

June 18, 1986

Kenneth W. Price, C.H.P.	George R. Holeman, C.H.P.

KENNETH W. PRICE, M.P.H.,C.H.P.

Business Address:

Yale University
Health Physics Division
314 Wright Nuclear Structure
Laboratory, West
P. O. Box 6666
New Haven, Ct. 06520
Phone: 203/436-0570

Home Address:

59 Kaye Vue Drive
Apartment B
Hamden, Ct. 06514
Phone: 203/287-0250

EXPERIENCE - EDUCATIONAL

Degree/Year	Institution	Field Study
B.S. - 1966	California St. College California, Pa.	Physics/Math California, Pa.
M.P.H. - 1968	Yale University New Haven, Ct.	Radiological Health New Haven, Ct.

EXPERIENCE - PROFESSIONAL

Northeastern Regional Health Laboratory Winchester, Ma.	1967	U.S.P.H.S. Fellow
Lawrence Livermore Laboratory Mercury, Nv.	1968 - 1974	Health Physicist Nuclear Weapons Testing
Nevada Nuclear Test Site Mercury, Nv.	1972 - 1973	Consultant to the U.S.A.E.C. in conjunction with the Los Alamos Scientific Laboratory
Yale University University Health Services New Haven, Ct.	1974 - Present	Health Physicist
Yale University School of Medicine Dept. of Epidemiology and Public Health New Haven, Ct.	1979 - Present	Appointed Lecturer in Public Health: Radiological Health
Yale Univeristy University Health Services New Haven, Ct.	1979 - Present	Deputy Director, Health Physics Div.

State of Connecticut Governor's Independent Risk Assessment Team (IRAT) Hartford, Ct.	1981 - Present	To advise governor in event of nuclear power plant emergency
Radiation Consultant	1982 - Present	Legal work,training license preparation and dosimetry calculations
Member, American Association of Physicists in Medicine (AAPM) Special Task Group 27, "Neutron Measurements Around High Energy X-Ray Radiotherapy Machines"	1984 - Present	To prepare a guidance document for surveying High Energy Linear Accelerator
Radiation Accident Laboratory	1984 - Present	On 24 hour alert for the evaluation of internal and external personal absorbed doses due to nuclear power accidents involving radioactive materials. Work also included lab analyses of contaminated items and biological samples for activity and assessing the impact.
Consultant for Northeastern Utilities Nuclear Power Co.	1984 - Present	Work involves the preparation and observation of medical nuclear accident emergency scenarios for two nuclear reactor sites. Work also includes training of plant technicians and ambulance personnel, and hospital emergency room personnel.
Consultant, Victoreen-Nuclear Associates	1985 - Present	To prepare a document describing the function and use of an extrapolation chamber for beta dosimetry in nuclear power plants

SOCIETIES

Member, Connecticut Chapter of the Health Physics Society
Member, Board of Directors of Connecticut Chapter of the Health Physics Society
Member, National Chapter of the Health Physics Society

CERTIFICATION

Certified by the American Board of Health Physics on June 21, 1981.

PUBLICATIONS

K W. Price, "Determination of Neutron Spectra and Dose at the Yale MP Tandem Van de Graaff Accelerator," Master's Thesis, 1968.

G. R. Holeman, D. McM. Shaw and K. W. Price, "Stray Neutron Spectra and Comparison of Measurement with Discrete Ordinates Calculations," Proceedings of the Second International Conference on Accelerator Dosimetry and Experience, 553, 1969.

K. W. Price and W. C. King, "An Estimate of the Release from the Baneberry Event," University of California Report, UCRL-51095, Classified, 1970.

K.W. Price, G. R. Holeman, "A Technique for Rapid Determination of Dose Equivalent Rates at Particle Accelerators Using the Bonner Spectrometer," Health Physics Operational Monitoring, Vol. 1, 429, 1972.

K. Buset and K. W. Price, "Lightning Flash Densities and Calculations of Strike Probabilities to Certain Vulnerable Installations at the Nevada Test Site (NTS)." April 14, 1975. (Published in the Proceedings.)

K. W. Price and G. R. Holeman, "Drift Tube Activation in a Heavy Ion Accelerator," presented at the Health Physics Society Meeting, San Francisco, California, June 28-July 7, 1976. (Not published)

K. W. Price and G. R. Holeman, "Health Physics Aspects of the Yale Heavy Ion Linear Accelerator Dismantling Project," Operational Health Physics, Proceedings of the Ninth Mid-Year Topical Symposium of the Health Physics Society, 499, 1976.

M. M. Gabel, K. W. Price and G. R. Holeman, "Thyroid Monitoring and Minimizing I-125 Uptake", Published in the Proceedings of the Campus Radiation Safety Officers Conference, N.B.S., SP-456, 1976.

G. R. Holeman, K. W. Price, L. F. Friedman and R. Nath, "Neutron Spectra from a Sagittaire Medical Accelerator," Proceedings of the Fourth International Conference of the International Radiation Protection Association, Vol. 3, 827, 1977.

G. R. Holeman, K. W. Price, L. F. Friedman and R. Nath, "Neutron Spectral Measurements in an Intense Photon Field Associated with a High Energy X-Ray Radiotherapy Machine," Medical Physics, Vol. 4, No. 6, 1977.

K.W. Price and G. R. Holeman, "An Economical Liquid Scintillation Counting Procedure for the Determination of I-125 Airborne Concentrations Using Charcoal Filters in Nalge Liquid Scintillation Tubes", Sixth Annual Campus Radiation Safety Officers Conference, University of Houston, Houston, Texas, July 11-13, 1977.

K. W. Price, G. R. Holeman, R. Nath and L. Friedman, "A Neutron Survey of a 25 MV X-Ray Clinical Linac Treatment Room," Health Physics Society 1978 Annual Meeting, July, 1978.

K. W. Price, R.Nath and G. R. Holeman, "Fast and Thermal Neutron Profiles for a 25 MV X-Ray Beam," Medical Physics Journal, July/August, 1978.

K. W. Price, G.R. Holeman, and R. Nath, "A Technique for Determining Fast and Thermal Neutron Flux Densities in Intense High Energy (8-30 MEV) Photon Fields," Health Physics Journal, Vol. 35, August, 1978.

R. Nath, K. W. Price and G. R. Holeman, "Mixed Field Dosimetry, Proceedings of a Conference on Neutrons from Electron Medical Accelerators," NBS Special Publication, 554, United States Department of Commerce, National Bureau of Standards, September, 1979.

R. Nath, K. W. Price and G. R. Holeman, "An Intercomparison of Neutron Measurements for a 25 MV X-Ray, Radiotherapy Accelerator," Medical Physics, 7 (5) September/October, 1980.

K. W. Price, R. Nath and G. R. Holeman, "High Energy X-Ray Spectrum Measurements Using Photo Nuclear Activation Detectors," submitted to the 25th Annual Meeting of the Health Physics Society, February, 1980.

K. W. Price and G. R. Holeman, "Dynamics of Maternal and Fetal Iodine Uptake and Assessing Fetal Thyroid Absorbed Dose," presented at the Fourteenth Health Physics Society Mid-Year Topical Symposium on Medical Physics, and published in proceedings, December, 1980.

K. W. Price, "Using a Business Computer to Compile Scientific Data," presented at the Joint Chapter Meeting of the Health Physics Society on "The Use of Small Computers for Emergency Planning, Collection of Scientific Data, and Health Physics Record Keeping," May 1, 1981.

K. W. Price, G. R. Holeman and Ravinder Nath, "Measurement of Neutron Dose Equivalent with Phosphorous Activation Dectectors," presented at the 15th Mid-Year Topical Meeting of the Health Physics Society, 1982.

K. W. Price and G. R. Holeman, "Investigation into the Use of a Victoreen Model 651 250 R-Chamber to Measure Beta Absorbed Dose in Air," presented at the 27th Annual Meeting of the Health Physics Society, June, 1982.

K. W. Price and G. R. Holeman, "Applicability of the Victoreen Model 651 250 R-Chamber for Measurement of Beta Absorbed Dose in Air (and Tissue)," presented at 29th Annual Meeting of the Health Physics Society, June,1984.

GEORGE R. HOLEMAN

Business Address:	Home Address
Yale University Radiation Safety Department 314 Wright Nuclear Structure Laboratory, West 260 Whitney Avenue New Haven, Ct. 06520 203/432-3036	351 Monticello Drive Jefferson Woods Branford, Ct. 06405 203/488-3774

EXPERIENCE - EDUCATIONAL

Degree/Year	Institution	Field of Study
B. A. - 1960	Centre College of Kentucky Danville, Ky.	Physics/Mathematics
A. M. - 1961	Harvard University Cambridge, Ma.	Engineering/ Health Physics

EXPERIENCE - PROFESSIONAL

Organization	Years	Position
Harvard University Cambridge, Ma.	1960 - 1961	U. S. Atomic Energy Commission (AEC) Health Physics Fellow
Brookhaven National Laboratory Upton, Long Island, N. Y.	1961	U. S. Atomic Energy Commission (AEC) Health Physics Fellow
General Electric Company Knolls Atomic Power Laboratory Schenectady, N. Y.	1961 - 1963	Health Physicist
Yale University Dept. of University Health New Haven, Ct.	1963 - 1971	Health Physicist (Responsible for Yale University Radiation Protection Program)
Yale University Dept. of Epidemiology and Public Health School of Medicine New Haven, Ct.	1963 - 1985	Lecturer in Public Health (Environmental Health)
Yale University Dept. of Epidemiology and Public Health School of Medicine New Haven, Ct.	1964 - 1970	Co-Director - Graduate Radiological Health Training Project
Yale University University Health Services New Haven, Ct.	1971 - 1986	Director, Health Physics Division

Yale University School of Medicine Cancer Center New Haven, Ct.	1974 - 1977	Program Director Radioisotope Facility
United States Veterans Administration Medical Center West Haven, Ct.	1976 - Present 1986 - Present	Attending Health Physicist Radiation Safety Officer
State of New Mexico Environmental Evaluation Group Santa Fe, New Mexico	1979 - Present	Consultant Evaluation of U.S. Department of Energy (DOE) Waste Isolation Pilot Project
State of Connecticut Governor's Office Hartford, Ct.	1980 - Present	Member Independent Risk Assessment Team (Radiological)
State of Connecticut Connecticut Hazardous Waste Management Service Hartford, Ct.	1983 - Present 1983 - Present	Board Member (Gubernatorial Appt.) Vice Chairman
Yale University Dept. of Epidemiology and Public Health School of Medicine New Haven, Ct.	1985 - Present	Lecturer in Epidemiology (Environmental Health)
Yale University University Health Services New Haven, Ct.	1986 - Present	Director Radiation Safety Department

SOCIETIES and AGENCIES

American Association of Physicists in Medicine:

- Chairman, Radiation Protection Committee, (1980-1985)
- Member, Science Council, (1980-1985)
- Member, Public Education Committee, (1984-Present)
- Consultant, Radiation Protection Committee, (1986-Present)

American Nuclear Society:

- Member, Executive Council, Connecticut Chapter, (1975-1977)

American Public Health Association:

- Member, Committee on Status of Radiation Protection Personnel, (Chairman, University Sub-committee), (1968-1970)
- Chairman, Radiological Health Section Nominating Committee, (1969-1970)
- Chairman, Radiological Health Section Program Committee, (1984)
- Chairman-Elect, Radiological Health Section, (1985)
- Chairman, Radiological Health Section, (1986)
- Member, (Ex-Officio) Governing Council, (1986)
- Member, Action Board, (1986-Present)

Connecticut Academy of Science and Engineering:

Member, Committee on Video Display Terminal Radiation Health Effects, (1983-1984)

Health Physics Society:

Member, Education and Training Committee, (1968-1971)
Chairman, Education and Training Committee, (1970-1971)
Consultant, Education and Training Committee, (1971-1972)
Member, Membership Committee, (1974-1977)
Member, Program Committee, (1979-1980)
Secretary, (1980-1982); Member, Executive Committee, (1980-1982)
Member, Board of Directors, (1980-1983)
Member, Ad Hoc Committee on Insurance, (1982-1985)
Delegate, International Radiation Protection Association Congress, (1984-1988)

Health Physics Society - Connecticut Chapter:

President, Connecticut Chapter, (1967-1968)
President-Elect, Connecticut Chapter, (1974-1975)
President, Connecticut Chapter, (1975-1976)
Secretary/Treasurer, Connecticut Chapter, (1977-1983)

National Council on Radiation Protection and Measurements (NCRP):

Member, Scientific Committee No. 60, Dosimetry of Neutrons from Medical Accelerators, (1979-Present)
Member, Task Group on Low-Level Waste, Scientific Committee No. 38, Radioactive Waste Disposal, (1982-Present)
Chairman, Task Group on Emergency Planning, Scientific Committee No. 46, Operational Radiation Safety, (1985-Present)

National Governors' Association (NGA):

Member, Advisory Committee on the Agreement State Program, (1982)

New England Congressional Institute:

Member, Hazardous Waste Management Project Consensus Group, (1985-Present)

The New England Council, Inc.:

Member, Task Group on Hazardous Waste Management, (1984-1986)
Member, Task Group on Hazardous Waste Management, Public Authorities, (1984-1986)

New York Academy of Science:

Member, (1986-Present)

Northeast Interstate Low-Level Radioactive Waste Commission:

Member, Technical Advisory Committee (1986-Present)

State of Connecticut:

Member, Advisory Committee on Low-Level Radioactive Waste, (1980-1986)
Member, Sub-committee on Public Information, (1982-1983)

State of Connecticut Legislature:

Member, Academic Advisory Board to the Connecticut Legislature's Energy and Public Utilities Committee, (1983-1984)

United States Atomic Energy Commission:

Member, Advisory Panel on Accelerator Radiation Safety, (1969-1972)

Western Governors Policy Office (WESTPO):

Member, Technical Advisory Committee (1984-1986)

PUBLICATIONS

G. R. Holeman, USAEC REPORT KAPL-Int-230, "Practical Radiation Protection Course," April, 1963.

J. C. Overly, G. R. Holeman, P. D. Parker and D. A. Bromley, "Radiation Shielding for an MP Tandem Accelerator Installation," Nucl. Inst. and Method, 53 (1967) 56.

G. R. Holeman, "A Method for Inferring Quality Factor Using the Bonner Spectrometer," USAEC Report, CONF-670305, Symposium on Biological Interpretation of Dose from Accelerator Produced Radiation, (1967) 225.

G. L. Watkins and G. R. Holeman, "The Evaluation of an Iterative Technique's Use in Unfolding Neutron Spectra Data," Health Phys.,17 (1968) 158.

G. R. Holeman, D. McM. Shaw and K. W. Price, "Stray Neutron Spectra and Comparison of Measurements with Discrete Ordinates Calculations," USAEC Report, CONF-691101, Second International Symposium on Accelerator Radiation Dosimetry and Experience, (1970) 552.

G. R. Holeman, "Measurement of Accelerator Produced Stray Neutron Spectra," A.J.P.H., 60 (1970) 1824.

K. W. Price and G. R. Holeman, "A Technique for Rapid Determination of Dose Equivalent Rates at Particle Accelerators Using the Bonner Spectrometer," in Health Physics Operational Monitoring, Edited by C. A. Willis and J. Handloser, Gordon & Breach, (1972) 429.

G. R. Holeman and D. McM. Shaw, "Radiation Exposure Record-Keeping by Time Sharing Computer," Health Phys., 27 (1974) 396.

K. W. Price and G. R. Holeman, "Health Physics Aspects of the Yale Heavy Ion Linear Accelerator Dismantling Project," Operational Health Physics, (Symposium Proceedings). Compiled by P. L. Carson, W. R. Hendee and D. C. Hunt, (1976) 499.

M. M. Gabel, K. W. Price and G. R. Holeman, "Thyroid Monitoring and Minimizing I-125 Uptake", Timely Topics (Proceedings of Campus Radiation Safety Officers' Conference, University of California, Irvine, California, August, 1975), Edited by William W. Wadman, III., (1976) 110.

M. M. Gabel, K. W. Price and G. R. Holeman, "Thyroid Monitoring and Minimizing I-125 Uptake," Measurements for the Safe Use of Radiation, NBS Special Publication 456, Edited by Sherman P. Fivozinsky, (1976) 371.

G. R. Holeman, K. W. Price, L. F. Friedman and R. Nath, "Neutron Spectra from a Sagittaire Medical Accelerator," Proceedings of IV. International Radiation Protection Association Congress, (1977) 827.

G. R. Holeman, K. W. Price, L. F. Friedman and R. Nath, "Neutron Spectral Measurements in an Intense Photon Field Associated with a High-Energy X-Ray Radiotherapy Machine," Med. Phys. 4 (1977) 508.

K. W. Price, R.Nath and G. R. Holeman, "Fast and Thermal Neutron Profiles for a 25-MV X-Ray Beam," Med. Phys. 5 (1978) 285.

K. W. Price, G. R. Holeman and R. Nath, "A Liquid Scintillation Counting Activation Technique for Determination of Fast and Slow Neutron Fluxes in Intense High Energy (8-30 MeV) Gamma Fields," Health Phys., 35 (1978) 341.

K. W. Price and G. R. Holeman, "An Economical Liquid Scintillation Counting Procedure for the Determination of ^{125}I Airborne Concentration Using Charcoal Filters in Nagle Liquid Scintillation Tubes," Proceddings of Sixth Campus Radiation Safety Officers Conference, University of Houston, Houston, Texas. July 1977 (1979) 169.

R. Nath, K. W. Price and G. R. Holeman, "Mixed Photon-Neutron Field Measurements," Proceedings of a Conference on Neutrons from Electron Medical Accelerators, NBS Special Publication 554, Edited by H. T. Heaton, II and R. Jacobs, (1979) 87.

R. Nath, K. W. Price and G. R. Holeman, "An Intercomparison of Neutron Measurements for a 25 MV X-Ray Radiotherapy Accelerator," Med. Phys., 7 (1980) 545.

K. W. Price and G. R. Holeman, "Dynamics of Maternal and Fetal Iodine Uptake and Assessing Fetal Thyroid Absorbed Dose," Medical Health Physics, (Proceedings of the Health Physics Society Fourteenth Mid-Year Topical Symposium, Hyannis, Massachusetts, December, 1980), Edited by T. G. Martin and K. W. Price, (1980) 49.

G. R. Holeman, R. Fields, C. Nelson and J. Stolwijk, "Interim Storage of Low-Level Radioactive Wastes", Report prepared for E G and G Idaho, Inc. under sub-contract No. K-1984, February, 1981.

G. R. Holeman, "Quantitative Risk in Standards Setting", National Council on Radiation Protection and Measurements, 1980. Book Review published in American Journal of Roentgenology 140, (1983) 572.

G. R. Holeman, "Nuclear Magnetic Resonance: Usage Guidelines", Physics News in 1983, P. F. Schewe, Editor,(1983) 101 and Physics Today 37 (1984) S36.

G. R. Holeman, "Low-Level Radioactive Waste Disposal: Prospects for 1986", Proceedings of National Institutes of Health Symposium on Radiation Safety Issues in Laboratory and Clinical Research Institutions, December, 1985 (in press).

G. R. Holeman and L. M. Gibbs, "Low-Level Radioactive Waste Dilemma: One Institution's Approach", Chapter in Low Level Radioactive Waste, Edited by M. E. Burns, American Chemical Society (in press).

HONORS

Listed in Outstanding Young Men of America, 1968 Edition.
Listed in Community Leaders of America, 1969 Edition.
Listed in Two Thousand Men of Achievement, 1969 Edition, 1970 Edition.
Listed in American Men and Women of Science, 1976 Edition.
World Health Organization (WHO) Fellowship, 1985 (Study of Radioactive Waste Plans in Sweden, Federal Republic of Germany, and United Kingdom).

CERTIFICATIONS

Certified Health Physicist, American Board of Health Physics, 1969; Recertified, 1979; Recertified 1986.
Certified Radiation Equipment Safety Officer, Department of Health, State of New York, 1973.

0155C

APPENDIX B

RADIATION SAFETY OFFICER COURSE

Presented to Butkin Precision Manufacturing Corporation
by Kenneth E. Price and George R. Holeman

Outline and Handouts

Low-Level Effects of Radiation

Objective

Definition of Low-Level Radiation Exposure

- List Exposure Rates in US

Risks

- Genetic
- Induction of Cancer
- Effects on Embryo

Genetic Mutations

- Mutations
  - domminant
  - resessive
- Animal data
- Estimation of Genetic risks
- Doubling dose

Cancer Induction

- A bomb cancers
- Latent period
- Cancer risks
- Radiosensitivity
  - absolute risks
  - relative risks
- Dose rate effect
- Linear extrapolation
- Effect of sample size
- Models
- Somatic effects
- Suceptable individuals

Effects on Embryo

- Classical Effects
  - growth retardation
  - embryonic death
  - congenital malformations
- Variable Factors
  - radiation dose
  - dose rate
  - stage of gestation
- Radiation Protection Guides
- Threshold
- Occupational Risks

Risks

Life expectancy
Cancer risks
Comparable risks

Effects of Accidental High Level Exposures

Acute Radiation Syndrome
Slides of damage

N. COMPOSITION AND FLOW OF NASAL SECRETION

The concentration of inorganic ions in nasal secretion is inversely related to the daily volume. Data on the elemental composition of nasal secretion is presented in Table 131. Flow ranges from 500 to 1000 ml/day (ref. 423, p. 322). The bulk of the secretion will find its way to the GI tract.

TABLE 131. SOME MAJOR ELEMENTS IN NASAL SECRETION (ref. 354)

Water	95–97 g per 100 ml
Calcium	11 mg per 100 ml
Chlorine	425 mg per 100 ml
Potassium	69 mg per 100 ml
Sodium	295 mg per 100 ml

O. SUMMARY OF MODEL VALUES FOR DAILY BALANCE OF ELEMENTS IN REFERENCE MAN

Page ref.	Element	Intake: Food and Fluids	Intake: Airborne	Losses: Urine	Losses: Feces	Losses: Others	Units
367	Aluminium	45	0.10	0.10	43	1 sweat 0.0006 hair	mg
368	Antimony	~50	0.05	~40	~9	1 hair	μg
369	Arsenic	1.0	0.0014	0.05	0.8	0.5×10^{-3} hair and nails 0.15 other losses	mg
370	Barium	0.75	$0.09\text{–}26 \times 10^{-3}$	0.05	0.69	0.01 sweat 0.075 hair	mg
371	Beryllium	12	<0.01	1.0	10	1 other losses	μg
371	Bismuth	20	<0.01	1.6	18	Not known	μg
372	Boron	1.3		1.0	0.27	<0.001 hair	mg
372	Bromine	7.5		7.0	0.07	0.19 sweat 0.01 other fluids 0.002 hair	mg
373	Cadmium	150	<1	100	50		μg
374	Calcium	1.1		0.18	0.74	0.032–0.15 sweat Trace other fluids and hair	g
377	Carbon	300		5.0	7.0	270 exhaled 18 other losses	g
378	Cesium	10	0.025	9.0	<1.0	Sweat	μg
378	Chlorine	5.2		4.4	0.05	0.78 sweat 0.05 other fluids	g
380	Chromium	150	0.1	70	80	1 sweat 0.6 hair Trace other fluids	μg
381	Cobalt	300	<0.1	200	90	4.0 sweat 2.4 hair Trace other fluids	μg
382	Copper	3.5	0.02	0.05	3.4	0.010–0.10 sweat 0.003 hair and nails 0.020 menstrual loss Trace other fluids	mg
383	Fluorine	1.8		1.0	0.15	0.65 sweat Trace other fluids	mg

Continued

O. SUMMARY OF MODEL VALUES FOR DAILY BALANCE OF ELEMENTS IN REFERENCE MAN (*continued*)

Page ref.	Element	Intake: Food and Fluids	Intake: Airborne	Losses: Urine	Losses: Feces	Losses: Others	Units
385	Germanium	1.5		1.4	0.10	Sweat	mg
385	Hydrogen	350		160	13	72 sweat 95 insensible loss 10 unspecified losses	g
386	Iodine	200	0.5–35	170	20	6 sweat 2.3 hair Trace other fluids	μg
387	Iron, ♂	16	0.03	0.25	15	0.50 sweat, ♂, ♀ 0.013 hair, ♂, ♀	mg
	♀	12	0.03	0.20	11	0.60 menstrual losses	
390	Lead	0.44	0.01	0.015	0.3	0.065 sweat 0.03 hair	mg
391	Lithium	2.0		0.8	1.2	Trace hair, nails, milk, sweat	mg
392	Magnesium						
	♂	0.34		0.13	0.21	0.0015 sweat, ♂, ♀	g
	♀	0.27		0.11	0.16	Trace hair, other fluids, ♂, ♀	
393	Manganese	3.7	0.002	0.03	3.6	0.039 sweat 0.002 hair and nails	mg
394	Mercury	15	1	0–35	10	Trace sweat 0.9 hair	μg
396	Molybdenum	300	<0.1	150	120	20 sweat 0.01 hair Trace other fluids	μg
397	Nickel	400	0.6	11	370	20 sweat 1 hair	μg
398	Niobium	620		360	260	Trace sweat 0.3 hair	μg
398	Nitrogen, ♂	16		15	1.5	0.3 sweat, ♂, ♀ Trace hair, nails, ♂, ♀	g
	♀	13		13	1.3	Trace other fluids, ♂, ♀	
400	Oxygen, ♂	2600	920	1300	100	720 exhaled 580 sweat 760 insensible sweat loss	g
	♀	1800	640	1100	90	510 exhaled 370 sweat 530 insensible sweat loss	
400	Phosphorus	1.4		0.90	0.50	0.001 sweat 0.0001 hair Trace other fluids	g
402	Polonium-210	3.2	<0.01	0.011	3.2	Trace sweat, hair	pCi
403	Potassium	3.3		2.8	0.36	0.13 sweat Trace other fluids	g
404	Radium-226	2.3		0.08	2.2	Not known	pCi
405	Rubidium	2.2		1.9	0.3	0.05 sweat and other fluids	mg
406	Selenium	150		50	20	80 sweat 0.3 hair Trace other fluids	μg
407	Silicon	3.5	15?	10	10	0.3 hair	mg
407	Silver	70		9	60	0.4 sweat 0.6 hair	μg
408	Sodium	4.4		3.3	0.1	0.87 sweat 0.13 other fluids 0.1×10^{-3} hair	g
409	Strontium	1.9		0.34	1.5	0.02 sweat 0.2×10^{-3} hair Trace other fluids	mg
411	Sulfur	0.85	0.54×10^{-3}	0.8	0.14	0.026 sweat 0.032 hair, nails 0.003 other fluids	g

O. SUMMARY OF MODEL VALUES FOR DAILY BALANCE OF ELEMENTS IN REFERENCE MAN (*continued*)

Page ref.	Element	Intake		Losses			Units
		Food and Fluids	Airborne	Urine	Feces	Others	
412	Tellurium	0.6	0	0.53	0.10	0.01 exhaled	mg
412	Thallium	1.5	0.05	0.5	1.0	0.1×10^{-3} hair Trace sweat, milk	μg
413	Thorium	3		0.1	2.9		μg
413	Tin	4	0.34×10^{-3}	0.02	3.5	0.5 sweat	mg
414	Titanium	0.85	1×10^{-3}	0.33	0.52	0.8×10^{-3} hair	mg
415	Uranium	1.5	7×10^{-3}	0.05–0.5	1.4–1.8	0.02 hair	μg
416	Vanadium	2	0.2×10^{-3}	0.015	2		mg
416	Zinc	13	<0.1	0.5	11	0.78 sweat 0.03 hair, nails 1 menstrual loss	mg
418	Zirconium	4.2		0.15	4		mg

1. ALUMINIUM, ATOMIC NO. 13

Aluminium balance for reference man (mg/day)

Intake		Losses		
Food and fluids	Airborne	Urine	Feces	Others
45	0.10	0.10	43	1 sweat 0.0006 hair

Aluminium is ubiquitous, but little is known about its daily metabolic balance in man.

Aluminium in food and fluids is reported to vary between 7 and 500 mg/day. Whether much of this variability is due to analytical errors, contamination of samples, or environmental origin is unknown (refs. 553, p. 325; 553a, p. 426). Aluminium is derived principally from plant foods, baking powders, cooking vessels, and metal foils, so that the type of diet and customs of cooking can alter intake considerably (refs. 85; 293; 315; 549, p. 1684; 577). A reasonable intake in a "Western-type" diet is about 45 mg Al/day, with a maximum of about 135 mg Al/day (ref. 85, pp. 399, 429). No data have been found for the intake of aluminium by children, but estimates could be based on the total weight of food eaten.

Almost all dietary aluminium appears in the feces (97–102%; refs. 85, p. 410; 553a, p. 427), but not all of this represents unabsorbed material since aluminium is found in bile (ref. 85, p. 411). Absorption of aluminium in food or of soluble aluminium in experimental mammals is low (refs. 553, p. 326; 553a, p. 426). In a balance study for a single individual during a 28-day period, fecal loss was 42 ± 47† mg Al/day, while the diet contained 36 ± 62† mg Al/day (ref. 293, p. 586, table 6).

The concentration of aluminium in urine is low and scarcely affected by changes in dietary aluminium, even when large amounts are ingested (ref. 85, p. 409). However, a wide range of values have been reported, 0.02–1.00 mg Al/day (refs. 85, pp. 409–10; 293; 549, p. 1684).

In some soft tissues (i.e., lung) the concentration of aluminium increases with age (ref. 545, p. 65).

† Standard deviation.

from 0.2 to 0.8 μg/day for three normal subjects (nonsmokers and nonvegetarians) (ref. 589, p. 269, table 6). The model figure of 0.5 μg Tl/day represents one-third of the postulated intake of 1.5 μg Tl/day. Smokers (three subjects) excreted about 1.4 μg/day and vegetarians about 1.9 μg/day (ref. 589, p. 269).

No estimates have been found for the fecal loss of thallium. On the basis of experimentally established urine values, fecal loss (estimated at 50% that of urine loss) would be about 1.0 μg Tl/day. Thus this figure was chosen to achieve balance in the model. Secretion of thallium also takes place in milk (ref. 568, pp. 1765–6), and thallium is excreted in hair and nails (refs. 198, pp. 63–64; 522, p. 1141; 589, p. 167, table 5; 605, pp. 157–8); but these losses are insignificant in the daily balance. Since thallium is present in blood (standard error of the mean, 0.01 mg/l; ref. 103, p. 107) and is excreted in urine, it is expected to be in sweat also.

45. THORIUM, ATOMIC NO. 90

Thorium balance for reference man (μg/day)

Intake	Losses	
Food and fluids	Urine	Feces
3	0.1	2.9

Thorium is widely distributed in rocks and soils, but it is scarcely soluble, and, consequently, very little is incorporated by plants. Generally, its concentration in ash of the aerial parts of plants will be about half that in soil (ref. 571, p. 320). Little is known of the amount of thorium in diet or foodstuffs. Drinking water usually contains low concentrations (refs. 308; 417, p. 135) so that the daily intake of thorium in water (2 liters drunk) would be about 0.05 μg (ref. 417, p. 135) or 4 μg (ref. 308).

Absorption of orally administered thorium appears to be low; in laboratory experiments on rats with soluble thorium salts and small doses (< 30 mg/kg W), a retention of 0.06–0.6% was observed. For insoluble preparations, a still lower retention was found (refs. 16, pp. 91–93; 444, p. 32).

Daily urinary excretion is estimated to be 0.1–2 μg (refs. 408, p. 29; 417, p. 135) and daily fecal loss, 3.2 μg (ref. 408, p. 29). After inhalation or intravenous administration (in dogs and rats), only part of the dose appears in the urine; the remainder is in feces (refs. 48, p. 165; 523, pp. 660–2; 541, p. 160). For this reason and because of low absorption from the GI tract, fecal loss is higher than urinary loss.

46. TIN, ATOMIC NO. 50

Tin balance for reference man (mg/day)

Intake		Losses		
Food and fluids	Airborne	Urine	Feces	Others
4	0.34×10^{-3}	0.02	3.5	0.5 sweat

The trace metal tin has long been a contaminant of the human environment, first when bronze was developed, then with the relatively modern development of preserving

Chapter 9

Radiobiological Data

Radiation protection requires an understanding of the prompt and long-term biological effects of radiation and numerical estimates of radiation risks. This chapter presents the characteristics of the "acute radiation syndrome" which can occur if an individual is exposed to high doses of radiation, and the effects of high levels of radiation on the skin. It also describes the long term bioeffects of low levels of radiation on population groups. These risks are quantified and are put in prospective by comparison to other societal hazards.

The physical characteristics of different types of radiation influence the radiation dose the body or an organ receive as a consequence of exposure to different radioactive materials and/or different types of radiation. These physical parameters such as the relative biological effectiveness, the stopping power, the effective half-life and others are discussed within the context of calculations for internal doses from radionuclides. Several methods for the calculation of internal dose are presented in the context of this chapter.

These calculation methods for estimation of internal radiation dose require models for the intake, uptake, and elimination of radionuclides from the body. Models are presented for inhalation and ingestion of radioactive materials and are illustrated graphically and by mathematical equations. Biological parameters such as fractional uptake by various organs of the body for different radionuclides, organ weights, and physiological characteristics of biological processes by age and sex appear in several tables throughout this chapter.

All of the above material provides a basis for an understanding of the biological effects of radiation and methods by which radiation doses to specific organs and tissues may be discerned.

Table 9.1. Phases of the Acute Radiation Syndrome

Phase	Duration	Symptoms
Prodromal	1 - 4 days	Anorexia Nausea and vomiting Fatigue
Latent Period	2 - 3 weeks	No symptoms
Main Illness	2 - 6 weeks	Hemorrhage Susceptability to Infections Epilation Diarrhea Tremor and convulsions
Recovery	Variable	--

Table 9.2. Acute Clinical Effects of Single High Dose Rate Exposures of Whole-Body Irradiation to Healthy Adults

Phase of response	Dose (range)					
	0-100 rads (subclinical range)	LD_0 - LD_{98} range ~100-800 rads (low lethal range)			LD_{99}+ Over 800 rads (supralethal range)	
		100-200 rads	200-600 rads	600-800 rads	800-3000 rads	Over 3000 rads
Initial response						
Incidence of nausea and vomiting	none - 5%	5 - 50%	50 - 100%	75 - 100%	100%	100%
Time of onset	--	~ 3 - 6 hr	~ 2 - 4 hr	~ 1 - 2 hr	<1 hr	<1 hr
Duration	--	<24 hr	<24 hr	<48 hr	<48 hr	~ 48 hr
Combat effectiveness	100%	>80%	can perform routine tasks; sustained combat or comparable activities hampered for 6 - 20 hr	can perform only simple routine tasks; significant incapacitation in upper part of range; lasts more than 24 hr	progressive incapacitation following an early capability for intermittent heroic response	progressive incapacitation following an early capability for intermittent heroic response
Latent phase						
Duration	--	more than 2 weeks	approximately 7 - 15 days	none to approximately 7 days	none to approximately 2 days	none
Secondary response						
Signs and symptoms	none	moderate leukopenia	severe leukopenia; purpura, hemorrhage; infection; epilation after about 300 rads and above		diarrhea; fever; disturbance of electrolyte balance	convulsions; tremor; ataxia; lethargy
Time of onset postexposure	--	2 weeks or more	several days to 2 weeks		2 - 3 days	--
Critical period postexposure	--	none	4 - 6 weeks		5 - 14 days	1 - 48 hr
Organ system responsible	none	hematopoietic system			gastrointestinal tract	central nervous system
Hospitalization						
Percentage	none	<10%	up to 90%	100%	100%	100%
Duration	--	45 - 60 days	60 - 90 days	90 - 120 days	2 weeks	2 days
Incidence of death	none	none	0 - 80%	80 - 100%	90 - 100%	90 - 100%
Average time of death	--	--	3 weeks to 2 months		1 - 2 weeks	2 days
Therapy	none	hematologic surveillance	blood transfusion, antibiotics, rest		maintenance of electrolyte balance	supportive treatment

(From NATO Amed P-6, Part 1, 1973)

Table 9.3. Classification of Acute Radiation Injury

Group	Whole Body	Character	Symptoms
I	[50-200R]	Mild-Transient	Most of these patients are asymptomatic; a few may have minimal prodromal symptoms.
II	[200-450R]	Hematopoetic	These patients develop the acute radiation syndrome in a mild form. After transient prodromal nausea and vomiting, laboratory and mild clinical evidence of hematopoietic derangement dominates the picture.
III	[450-600R]	Hematopoetic	A serious course occurs in these patients. Complications of hematologic malfunction are severe and, in the upper part of the group, some evidence of gastrointestinal damage may also be present.
IV	[600-1000R]	Gastrointestinal	An accelerated version of the acute radiation syndrome occurs. Complications of gastrointestinal injury dominate the clinical picture. The severity of hematopoietic disturbances are related to the length of survival time following exposure.
V	[Several 1000R]	CNS	Fulminating course with marked central nervous system impairment occurs in this group.

(From The Acute Radiation Syndrome in Man (After George E. Thoma, Jr., M.D. and Niel Wald, M.D., BRH Training Publication No. 3n)

Table 9.4. Radiation Injury to the Skin

Dose (Rads to Skin)	Effect
200-300	Epilation
> 300	Radiation dermititis and erythema
1000-2000	Transdermal injury
> 2000 (single exposure)	Radionecrosis
> 5000 (over extended period)	Chronic dermititis

(After NCRP Report No. 29)

Table 9.5. Tissue Dose Rate at Various Distances from a 1-mCi Alpha Emitter

Distance (μm)	Dose rate at distance (rads/hr)
10	1.7×10^8
20	5.2×10^7
25	--
30	0
35	0

Table 9.7 Definition of Genetic and Somatic Effects of Low-Level Radiation

I. Genetic: Effects passed on from generation to generation
Somatic: Effects manifested in exposed individuals themselves

II. Radiation effects also characterized as:
Non-Stochastic (NS) - Severity proportional to dose.
Stochastic (S) - Probability of occurrence proportional to dose.

III. Radiation Effects

Genetic	Due to mutation of genetic material (S)
Somatic	Developmental abnormalities in the fetus
	Growth retardation
	Cataracts (NS)
	Effects on fertility (NS)
	Aging
	Cancer induction (S)
	. Female breast
	. Thyroid
	. Hematopoetic
	. Lung
	. GI organs
	. Bone
	. Skin (NS)

(S) = Stochastic
(NS) = Non-Stochastic

Table 9.8. Genetic Risks of Low-Level Ionizing Radiation

- One rem before conception is expected to produce 5-75 additional serious genetic disorders per 1 million live-births (First generation)
- This is small in relationship to the usual incidence of serious genetic disorder of about 10% of liveborn off-spring ($90,000/10^6$ live-births)

Table 9.9. Cancer Risk from Radiation Exposure (From Regulatory Guide 8.29, U.S. Nuclear Regulatory Commission)

The cancer risk estimates are presented below:

Estimates of Excess Cancer Incidence From Exposure to Low-level Radiation

Source	Number of Additional[a] Cancers Estimated to Occur in 1 Million People After Exposure of 1 Rem of Radiation to Each
BEIR, 1980	160-450[b]
ICRP, 1977	200
UNSCEAR, 1977	150-350

[a]Additional means above the normal incidence of cancer.

[b]All three groups estimated premature deaths from radiation-induced cancers. The American Cancer Society has recently stated that only about one-half of all cancer cases are fatal. Thus, to estimate incidence of cancer, the published numbers were multipled by 2. Note that the three groups are in close agreement on the risk of radiation-induced cancer.

In an effort to explain the significance of these estimates, we will use an approximate average of 300 excess cancer cases per million people, each exposed to 1 rem of ionizing radiation. If in a group of 10,000 workers each receives 1 rem, we could estimate that three would develop cancer because of that exposure, although the actual number could be more or less than three.

The American Cancer Society has reported that approximately 25 percent of all adults in the 20- to 65-year age bracket will develop cancer at some time from all possible causes such as smoking, food, alcohol, drugs, air pollutants, and natural background radiation. Thus in any group of 10,000 workers not exposed to radiation on the job, we can expect about 2,500 to develop cancer. If this entire group of 10,000 workers were to receive an occupational radiation dose of 1 rem each, we could estimate that three additional cases might occur which would give a total of about 2,503. This means that a 1-rem dose to each of 10,000 workers might increase the cancer rate from 25 percent to 25.03 percent, an increase of about 3 hundreths of one percent.

As an individual, if your cumulative occupational radiation dose is 1 rem, your chances of eventually developing cancer during your entire lifetime may have increased from 25 percent to 25.03 percent. If your lifetime occupational dose is 10 rems, we could estimate a 25.3 percent chance of developing cancer. Using a simple linear model, a lifetime dose of 100 rems may have increased your chances of cancer from 25 to 28 percent.

Table 9.9. Cancer Risk from Radiation Exposure (Continued)

The normal chance of developing cancer if you receive no occupational radiation dose is about equal to your chance of getting any spade on a single draw from a full deck of playing cards, which is one chance out of four. The additional chance of developing cancer from an occupational exposure of 1 rem is less than your chances of drawing an ace from a full deck of cards three times in a row.

Since cancer resulting from exposure to radiation usually occurs 5 to 25 years after the exposure and since not all cancers are fatal, another useful measure of risk is years of life expectancy lost on the average from a radiation-induced cancer. It has been estimated in several studies that the average loss of life expectancy from exposure to radiation is about 1 day per rem of exposure. In other words, a person exposed to 1 rem of radiation may, on the average lose 1 day of life. The words "on the average" are important, however, because the person who gets cancer from radiation may lose several years of life expectancy while his coworkers suffer no loss. The ICRP estimated that the average number of years of life lost from fatal industrial accidents is 30 while the average number of years of life lost from a fatal radiation-induced cancer is 10. The shorter loss of life expectancy is due to the delayed onset of cancer.

It is important to realize that these risk numbers are only estimates. Many difficulties are involved in designing research studies that can accurately measure the small increases in cancer cases due to low exposures to radiation as compared to the normal rate of cancer. There is still uncertainty and a great deal of controversy with regard to estimates of radiation risk. The numbers used here result from studies involving high doses and high dose rates, and they may not apply to doses at the lower occupational levels of exposure. The NRC and other agencies both in the United States and abroad are continuing extensive long-range research programs on radiation risk.

Some members of the National Academy of Sciences BEIR Advisory Committee and others feel that risk estimates shown above are higher than would actually occur and represent an upper limit on the risk. Other scientists believe that the estimates are low and that the risk could be higher. However, these estimates are considered by the NRC staff to be the best available that the worker can use to make an informed decision concerning acceptance of the risks associated with exposure to radiation. A worker who decides to accept this risk should make every effort to keep exposure to radiation ALARA to avoid unnecessary risk. The worker, after all, has the first line responsibility for protecting himself from radiation hazards.

Table 9.10. Risk Estimates for Whole-Body Low-Level Low-LET Radiation (Cancer Mortality) (After BEIR III)

100	Excess cancer deaths over a life-time per 10^6 persons exposed to 1 rad of radiation
Risk	1×10^{-4} per person per rad over a lifetime
Risk	1.4×10^{-6} per persons per rad per year

- In a population of 10.000 persons - 1 excess cancer death over a lifetime would be expected from an exposure of 1 rad to each person.
- The expected deaths from cancer for 10,000 persons over a lifetime is normally 1600.

Table 9.11. Site Specific Cancer Risk (After NCRP No. 43)

Cancer	Lifetime Risk (Mortality) Per Person/rad "Best Value" $\times 10^{-5}$
Leukemia	2
Thyroid	1
Breast	5
Lung	2.5
Bone	0.5
Other	~1

Table 9.12. BEIR III Summary Results

(From Report of the Committee on the Biological Effects of Ionizing Radiation, National Academy of Science, 1980). (Courtesy of the National Academy Press, Washington, D.C.)

Estimated Excess Mortality Per Million Persons from all Forms of Cancer, Linear-Quadrative Dose Response Model for Low-LET Radiation

	Absolute-Risk Projection Model	Relative-Risk Projection Model
Single Exposure to 10 Rads		
Normal Expectation	163,800	163,800
Excess Cancer: Number	766	2,255
% of Normal	0.47	1.4
Continuous Exposure to 1 rad/year, lifetime		
Normal Expectation	167,300	167,300
Excess Cancer: Number	4,751	11,970
% of Normal	2.8	7.2
Continuous Exposure to 1 rad/year, age 20-65		
Excess Cancer: % of Normal	1.9	3.2

Table 9.13. Estimated Loss of Life Expectancy from Health Risks

(Adapted from Cohen and Lee, "A Catalogue of Risks," Health Physics, Vol. 36, June 1979). (Courtesy of The Journal of The Health Physics Society).

Health Risk	Estimates of Days of Life Expectancy Lost, Average
Smoking 20 cigarettes/day	2370 (6.5 years)
Overweight (by 20%)	985 (2.7 years)
All accidents combined	435 (1.2 years)
Auto accidents	200
Alcohol consumption (U.S. average)	130
Home accidents	95
Drowning	41
Natural background radiation, calculated	8
Medical diagnostic x-rays (U.S. average), calculated	6
All catastrophes (earthquake, etc.)	3.5
1 rem occupational radiation dose, calculated (industry average for the higher-dose job categories is 0.65 rem/yr)	1
1 rem/yr for 30 years, calculated	30

Table 9.14. Estimated Loss of Life Expectancy from Industrial Hazards

(Adapted from Cohen and Lee, "A Catalogue of Risk," Health Physics, Vol. 36, June 1979; and World Health Organization, Health Implications of Nuclear Power Production, December 1975.)

Industry Type	Estimates of Days of Life Expectancy Lost, Average
All industry	74
Trade	30
Manufacturing	43
Service	47
Government	55
Transportation and utilities	164
Agriculture	277
Construction	302
Mining and quarrying	328
Radiation accidents, death from exposure	1
Radiation dose of 0.65 rem/yr (industry average) for 30 years, calculated	20
Radiation dose of 5 rems/yr for 50 years	250
Industrial accidents at nuclear facilities (nonradiation)	58

Table 9.15. Probability of Accidental Death by Type of Occupation

(Adapted from National Safety Council, Accident Facts, 1979; and Atomic Energy Commission, Operational Accidents and Radiation Exposure Experience, WASH-1192, 1975.)

Occupation	Number of Accidental Deaths for 10,000 Workers for 40 Years
Mining	252
Construction	228
Agriculture	216
Transportation and public utilities	116
All industries	56
Government	44
Nuclear industry (1975 data excluding construction)	40
Manufacturing	36
Services	28
Wholesale and trade	24

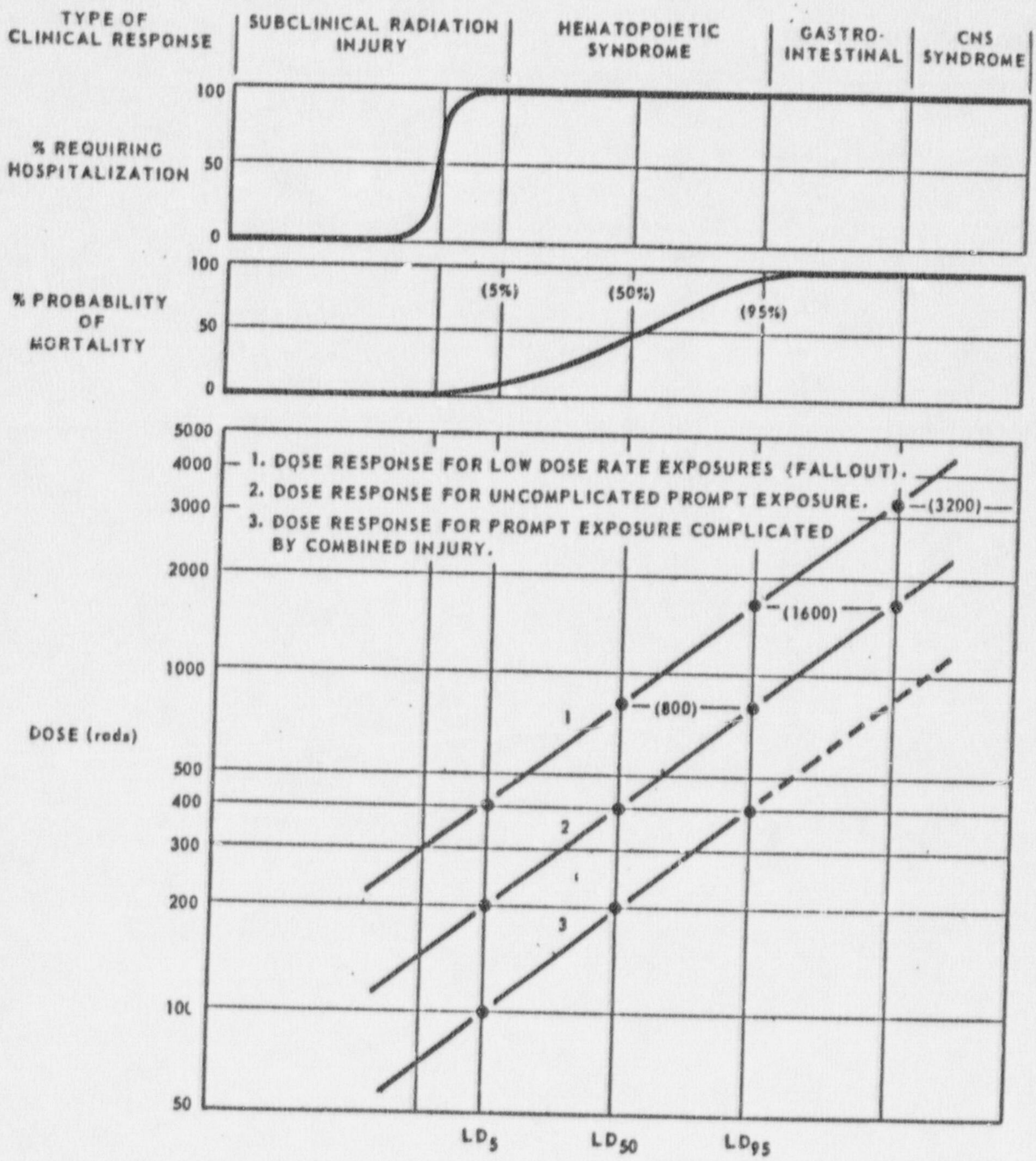


Figure 9.1. Clinical Effects of Whole-Body Irradiation in Man
(From NATO AMedP-6, Part 1, 19)

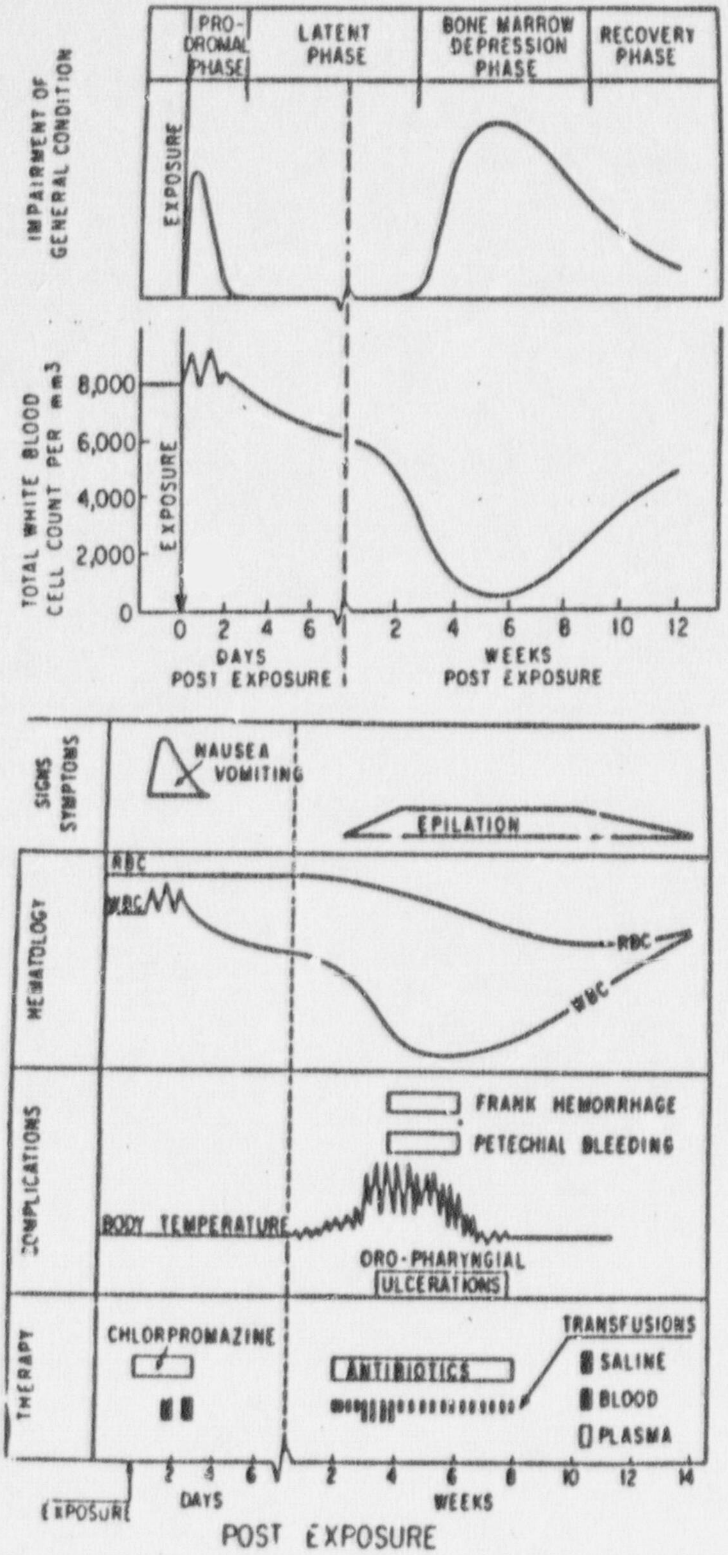
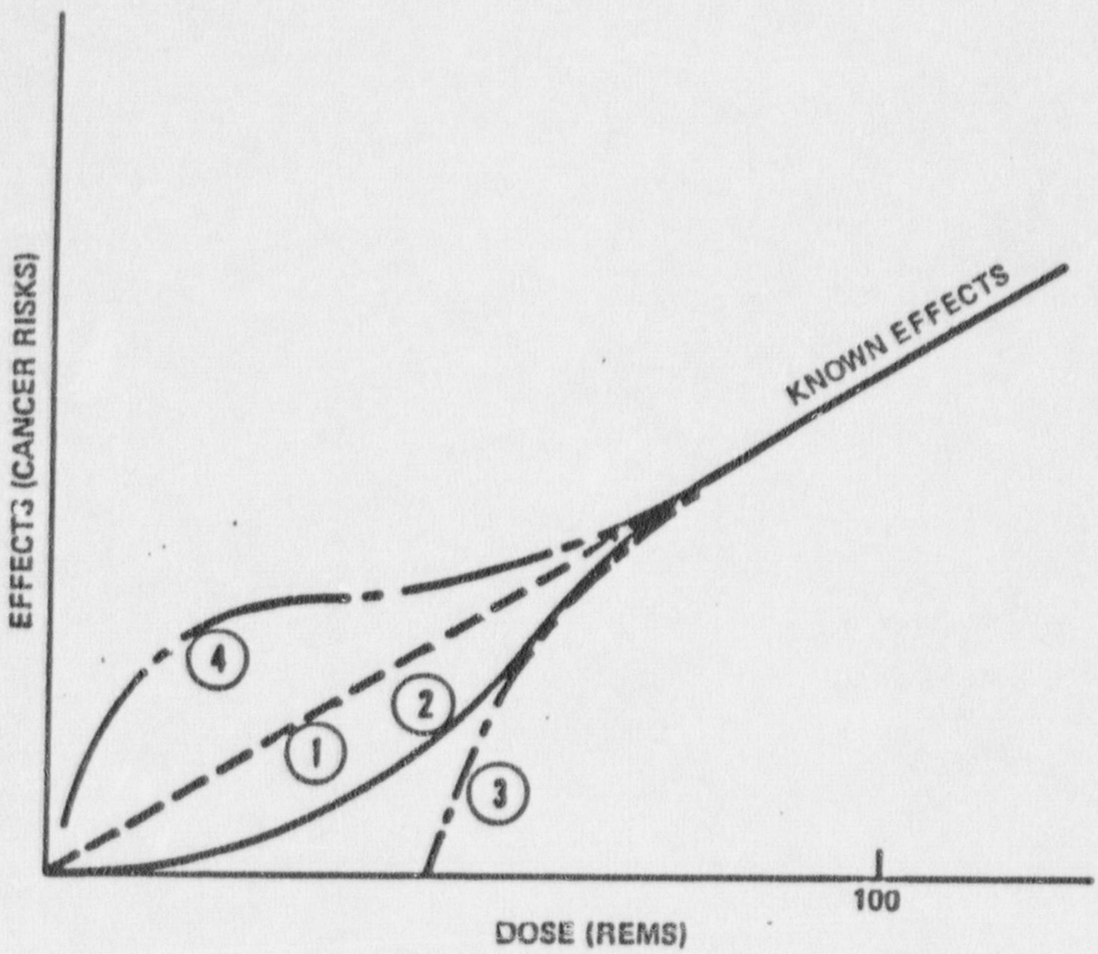


Figure 9.2. Clinical Course of Acute Radiation Syndrome (From BRH Training Publication No. 3n)



Radiation is like most substances that cause cancer in that the effects can be seen clearly only at high doses. Estimates of the risks of cancer at low levels of exposure are derived from data available for exposures at high dose levels and high dose rates. Generally, for radiation protection purposes these estimates are made using the linear model (Curve 1 in Figure 1). We have data on health effects at high doses as shown by the solid line in Figure 1. Below about 100 rems, studies have not been able to accurately measure the risk, primarily because of the small numbers of exposed people and because the effect is small compared to differences in the normal incidence from year to year and place to place. Most scientists believe that there is some degree of risk no matter how small the dose (Curves 1 and 2). Some scientists believe that the risk drops off to zero at some low dose (Curve 3), the threshold effect. A few believe that risk levels off so that even very small doses imply a significant risk (Curve 4). The majority of scientists today endorse either the linear model (Curve 1) or the linear-quadratic model (Curve 2). The NRC endorses the linear model (Curve 1), which shows the number of effects decreasing as the dose decreases, for radiation protection purposes.

Figure 9.3. Some proposed models for how the cancer risks of radiation vary with doses at low levels.

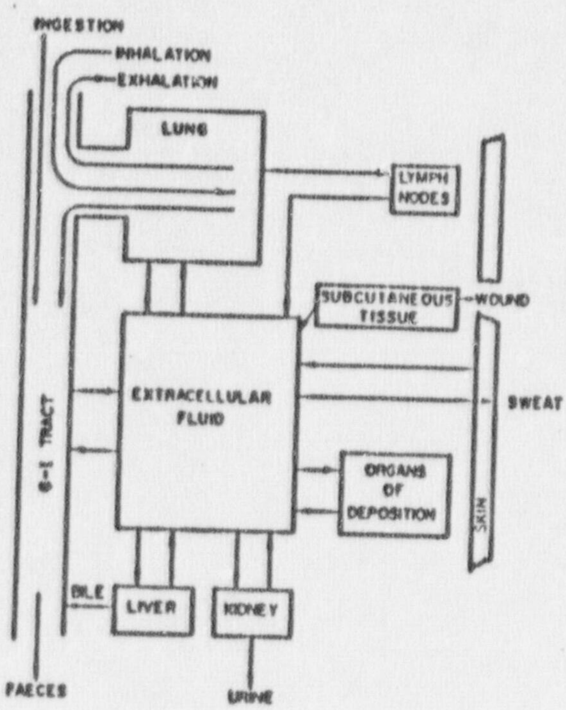


Figure 9.4. Principal Metabolic Pathways of Radionuclides in the body. (From ICRP 10)

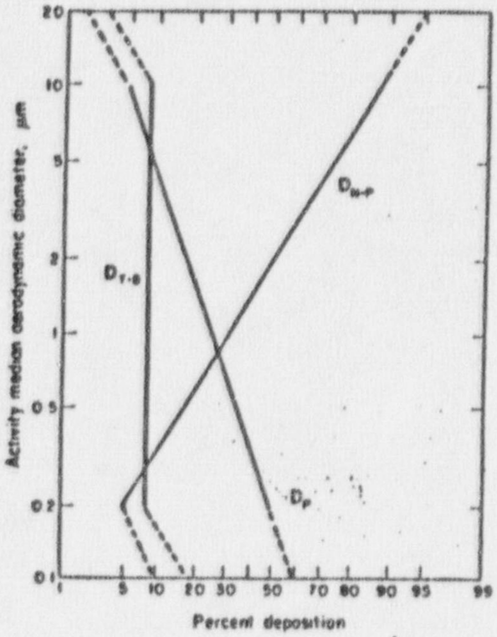


Figure 9.5. Deposition of dust in the respiratory system. The percentage of activity or mass of an aerosol, which is deposited in the N-P, T-B and P regions is given in relation to the Activity Median Aerodynamic Diameter (AMAD) of the aerosol distribution. The model is intended for use with aerosol distributions with AMADs between 0.2 and 10 μm and with geometric standard deviations of less than 4.5 Provisional estimates of deposition further extending the size range are given by the dashed lines. For an unusual distribution with an AMAD of greater than 20 μm, complete deposition in N-P can be assumed. The model does not apply to aerosols with AMADs of less than 0.1 μm. (From ICRP 30, Part 1, Addendum Part 3)

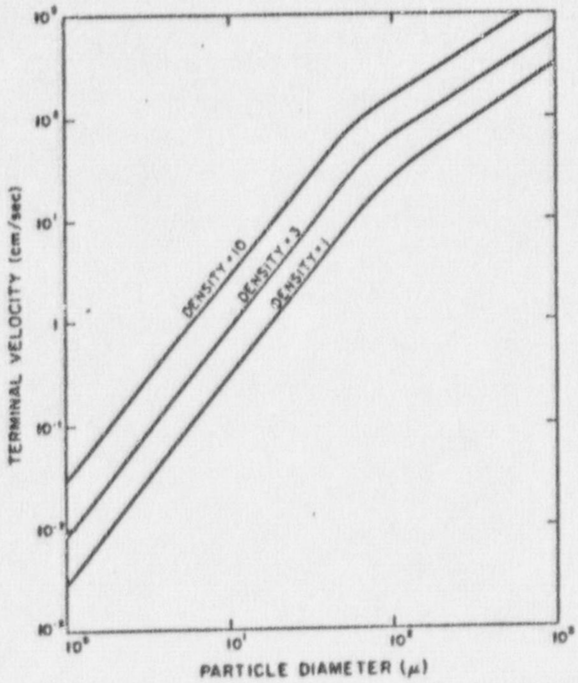


Figure 9.6. Terminal velocities for spheres of various sizes and densities in air at S.T.P. (From Meteorology and Atomic Energy, U.S. Atomic Energy Commission, 1966).

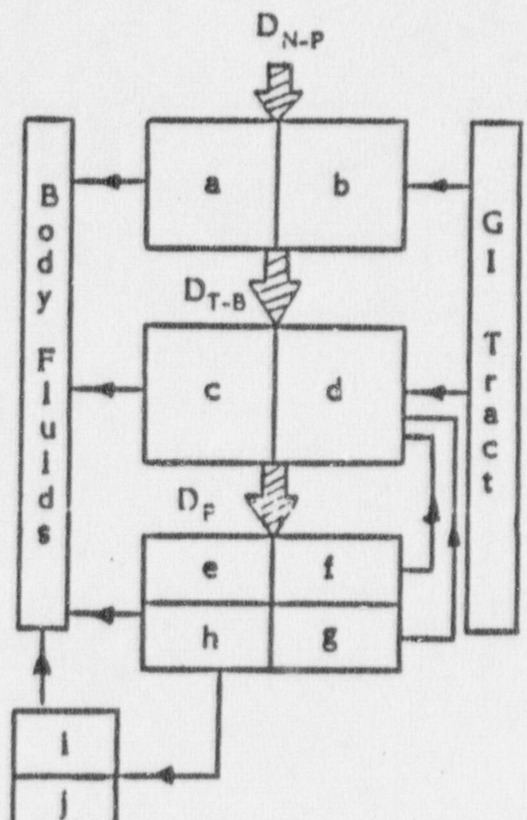


Figure 9.7. Respiratory Tract Model-Metabolic Pathways (From ICRP 30) (See Table 9.21 for numerical contents)

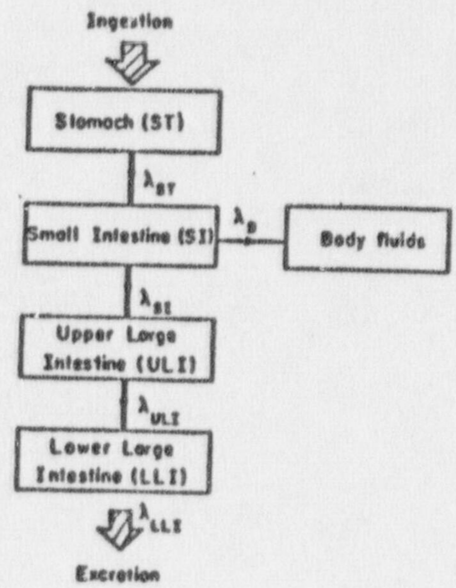


Table 9.8. Schematic of the GI Tract Model
(From ICRP 30)

0061p

RADIATION PHYSICS COURSE OUTLINE

EXTERNAL EXPOSURES

I. Basic Math

- A. Exponentials
- B. Scientific notation
- C. Units and dimensional analysis

STUDY GUIDE PROBLEMS

II. Activity

- A. Radioactive decay- the disintegration and per second
- B. Curie , millicurie, microcurie, becquerel

1 Curie = 1 Ci = 3.70×10^{10} dps

millicuries = Curies X 1000

microcuries = Curies X 1000000

Becquerel (Bq) = 1 disintegration / second

STUDY GUIDE PROBLEMS

III. Radioactive Decay

- A. Alpha, beta, gamma, internal conversion, fission
- B. Radioactive half life and decay computations

to compute activity that will be present after a time t

$$A = A_0 e^{-\frac{.693 t}{T_{1/2}}}$$

A_0 = initial activity $T_{1/2}$ = half life t = elapsed time.
$T_{1/2}$ and t must be in the same units

to compute activity that was present t time before

$$A_0 = A e^{\frac{.693 t}{T_{1/2}}}$$

STUDY GUIDE PROBLEMS

C. Emission frequency of radiation, branching ratio or abundance

1. Table look up for number of each type of radiiation per disintegration. Table I.

   a. examples of emissions from table I and explanation of table.

2. Explain figures 1,2,3,4 as decay schemes for isotopes

STUDY GUIDE PROBLEMS

D. Radioactive Series--Thorium Series

1. Explain the concept of decay into daughters
   a. Explain equilibrium (secular, transient, and none)

2. Explain table 2-10 and thorium series. ^{220}Rn also.

STUDY GUIDE PROBLEM

IV. INTERACTION OF RADIATION WITH MATTER

A. Specification of particle energy, Mev.
   1. Particle or radiation energy and general penetration-eV,KeV,MeV

B. Ionization processes

   1. Beta and alpha particle direct ionization

   2. Photon, gamma, x-ray indirect ionization.

C. Show photon interaction processes in a shield.

   1. photoelectric , Compton, and pair production.

V. RADIATION INTENSITY AND INVERSE SQUARE LAW

A. Explain radiation fluence rate .... particles or photons/ cm^2 - sec

B. The inverse square law for computation of fluence rate at a distance

$$\phi_r = \frac{S}{4\pi R^2} \quad \text{particles}/\text{cm}^2\text{-sec}$$

S = dps * particles/dps
R = distance in cm
π = 3.1416

or, if the fluence is known at one distance and it it desired to compute it at another

$$\frac{\phi_1}{\phi_2} = \frac{R_2^{\,2}}{R_1^{\,2}}$$

ϕ_1 = fluence rate or dose at Distance R_1

ϕ_2 = fluence rate or dose at Distance R_2

STUDY GUIDE PROBLEMS

VI. UNITS OF RADIATION EXPOSURE, DOSE, AND DOSE EQUIVALENT.

A. SLIDE OF Roentgen - explain what it is--specifies ionization in air

B. SLIDE of RAD-explain what it is and the problems with mixed fields

C. SLIDE of REM- explain what it is, the QF, and implications

VII. GAMMA AND PHOTON EXPOSURE CALCULATION FROM FLUENCE RATE

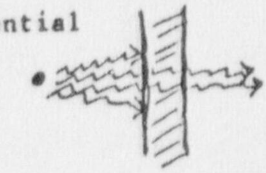
A. Referring to figure 6.1 explain the curve of φ versus photon energy.

STUDY GUIDE PROBLEMS

$$R/HR = \frac{\Phi}{\varphi}$$

VIII. PHOTON SHIELDING

A. Explain by the use of a diagram the derivation of the exponential attenuation of a narrow beam of photons for a SINGLE ENERGY.



B. SLIDE of the mass attenuation curve for lead versus energy. Energy dependance

IX. SHIELD THICKNESS IN MASS PER UNIT AREA

A. Explain the concept of mass / area expression of shield thickness.

If "p" is the density of the shield in gm/cm^3 and "d" the thickness in cm, then the shield thickness in gm/cm^2 is

$$x = p * d \quad gm/cm^2 \quad (\text{times } 1000 \text{ for } mg/cm^2)$$

If a piece of material with measured area "A" cm^2 is weighed and found to have a mass of "w" grams, the equivalent shield thickness is

$$x = w / A \quad gm/cm^2 \quad (\text{times } 1000 \text{ for } mg/cm^2)$$

STUDY GUIDE PROBLEMS

X. CALCULATING PHOTON ATTENUATION IN A SHIELD OF KNOWN THICKNESS

A. The equation for computing photon absorption is

$$I = I_o B e^{-ux}$$

$$B \hat{=} 1 + ux$$

I_o = fluence rate or exposure rate without shield.
I = fluence rate or exposure rate with shield.
x = shield thickness, mg/cm^2
u = mass attenuation coefficient, cm^2/gm,
B = buildup factor

where "u" , the mass attenuation coefficient is obtained from table 5.1 for the energy and material used for shielding. Units of u are cm^2/gm.

B. Explain the buildup factor and the approximation B= 1 + u*x.

C. Explain the photon HVL (half value layer) and explain figure 5.

D. Explain the use of the gamma constant Γ, and Table 6.1.

STUDY GUIDE PROBLEMS

XI. BETA PARTICLE DOSE TO SKIN AND EYES

A. Beta dosimetry is difficult. Main differences between beta dosimetry and photon dosimetry are

1. Beta dose is generally not a deep dose, and usually the skin and eyes are effected.

2. Air and other materials significantly absord betas. Must account for this in dose calculations.

3. Betas have a definite range in materials.

4. One can only approximate the dose rate in a calculation.

B. Refer to figures 6.11 for ranges, 6.12 for ranges in mg/cm^2, and figure 6.13 for half thickness.

C. Explain the skin and the dead layer assumed depth of 7.0 mg/cm^2. Explain the eye and the lens depth of 300 mg/cm^2.

1. Calculate the beta energy needed to penetrate the dead layer and the lens using figure 6.12.

7mg/cm^2 on figure 6.12 = 68 KeV , 0.068 MeV

300mg/cm^2 on figure 6.12 = .80 Mev or 800 KeV

STUDY GUIDE PROBLEMS

XII BETA PARTICLE HALF VALUE THICKNESS(LAYER)

A. Using figure 6.13 one may approximate the effectiveness of placing a shield in a beta field. The beta dose rate resulting from placing a shield in a beta field is given by the following equation

$$D = D_o e^{\frac{-.693\,X}{HVL}}$$

$X <$ Range of Beta

D_o = dose Rate without shield
D = dose Rate with shield
X = shield thickness, mg/cm²
HVL = half value thickness or Layer, mg/cm², figure 6.13

The thickness "x" of the material must be less than the range of the beta in the material as obtained from figure 6.12.

B. One may use the half value thickness directly if the number of shield half value layers are known.

$$D = D_o \left(\frac{1}{2}\right)^n$$

n = number of Half-value Layers of shield.

STUDY GUIDE PROBLEM

XIII. BETA DOSE CALCULATIONS FROM A POINT SOURCE OF RADIOACTIVE MATERIAL

A. An approximate skin dose conversion factor is

10 betas/ cm^2 - sec per mrad/hr

B. The equation for computing the beta dose rate from a point source of radioactive material is

$$\phi_B = \frac{S}{4\pi R^2} e^{\frac{-.693\,X_{air}}{HVL_{air}}} \quad \text{Betas/cm}^2\text{-sec}$$

$X_{air} <$ Range of Betas

$$D_B \cong \frac{\phi_B}{10} \quad \text{mrad/hr to SKIN}$$

S = Betas per second from source.
R = Distance in cm from Source.
$X_{air} = R * 0.001243 \text{ mg/cm}^3$
HVL_{air} = from figure 6.13, mg/cm²
π = 3.1416

XIV. ALPHA PARTICLE DOSE TO SKIN AND TISSUE

A. An alpha particle of greater than 7.5 Mev is required to penetrate the dead layer of the skin, which is 7 mg/cm^2.

B. Use plot 6.13 to determine the range of alphas in air.

C. The plot may be used to compute the range in other materials by ratio of the densities.

1. The density of air is about 0.001293 gm/cm^3, and that of tissue is 1.0 gm/cm^3. Find the range in air from figure 6.13 and then use the following equation to estimate the range in skin.

$$\text{RANGE TISSUE} \approx \text{RANGE AIR} * 0.001293$$

2. The thickness of skin on the body varies with area

AREA	THICKNESS, mg/cm2
palms, soles	40
forearms	8
remainder	4
inside of body	0

STUDY GUIDE PROBLEMS

XVI. HOMEWORK PROBLEM

A. Compute the photon exposure rate and the beta absorbed dose rate at a distance of 30 cm from a point source of ^{60}Co. If a 1 cm thick lead shield is placed over the source what would be the resulting exposure and absorbed dose rates at 30 cm from gamma and beta radiation? What would be the unshield exposure rate at 30 cm 10 years from now?

0060p

RADIATION PHYSICS STUDY GUIDE

BASIC MATH

evaluate

$e^{-1.0}$ ____________

$e^{1.0}$ ____________

$e^{1.92}$ ____________

$e^{-1.92}$ ____________

express in scientific notation

1456.23 ____________

1000000.0 ____________

0.000001234 ____________

express in floating point

1.567×10^{5} ____________

4.567×10^{-3} ____________

3.67000×10^{8} ____________

3.70×10^{10} ____________

ACTIVITY

Convert 3.0 curies (Ci) to dps : ____________

Convert 2.1×10^{5} dps to Ci : ____________

to mCi : ____________

to uCi : ____________

to Bq : ____________

RADIOACTIVE DECAY

Initially you have 100 mCi of a radioactive material which has a half life of 5 days. How much activity would be present

10 days later : ________________

20 days later : ________________

If at the present time you have 5 mCi of a radioactive material, how much was present 2 weeks ago? The radioactive material has a half life of 60 days.

____

RADIATION EMISSION INTENSITY

If you have 1.5 mCi of ^{149}Pm, what would be the

dps : ________________

betas / sec : ________________

gammas / sec : ________________

If you had 1.5 mCi of ^{146}Pm what is the

dps :____________________

betas / sec :____________________

gammas / sec :____________________

NOTICE THAT EVEN THOUGH THE ACTIVITIES ARE EQUAL, THE RADIATION EMISSION FROM THE TWO ARE NOT

THORIUM SERIES

The table below indicates the melting points and boiling points of the daughters of the thorium series. Describe in detail the radioactive envirionment one might expect if a fire occurred and the temperature was 2200 degrees centigrade.

ISOTOPE	MELTING POINT, oC	BOILING POINT, oC
Thorium	1845	4500
Radium	700	1440
Lead	327	1620
Bismuth	271	1420-1560
Thallium	302	1457

INVERSE SQUARE LAW

Compute the photon (gamma ray) fluence rate from 5 mCi of a radioactive source which emits a photon 80% of the time with an energy of 0.51 MeV at

1 cm distance:____________________

10 cm distance:____________________

100 cm distance:____________________

PHOTON FLUENCE RATE
TO
ROENTGEN/HOUR (R/HR)

Using the results of the above study guide section on inverse,square law, compute the roentgen per hour at the same distances. Express the results in milliroentgen per hour also. What would be the total exposure at each distance for an exposure time of 20 minutes?

1 cm distance:_______________R/hr
_______________mR/hr
Total Exposure:_______________mr

10 cm distance:_______________R/hr
_______________mR/hr
Total Exposure:_______________mr

100 cm distance:_______________R/hr
_______________mR/hr
Total Exposure:_______________mr

EXPRESSING SHIELD
THICKNESS IN
MASS / UNIT AREA

What is the g / cm^2 and mg / cm^2 of a 0.118 inch piece of lead sheet, lead has a density of 11.35 gm / cm^3?

thickness mg/cm^2:__________

thickness g/ cm^2:__________

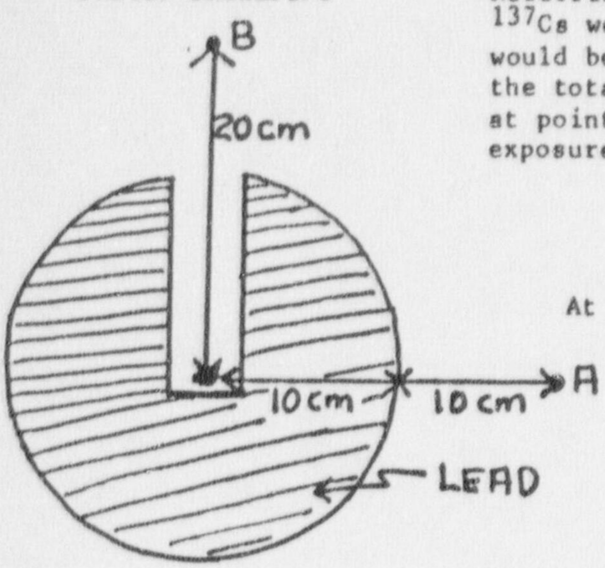
A sheet of aluminum has dimensions of 3.94 inch by 1.97 inch and is found to weigh 135 grams. What is the thickness in

mg / cm^2:__________

g / cm^2:__________

PHOTON SHIELDING

Referring to the sketch below, if 6.7 mCi of ^{137}Cs were placed at the point indicated what would be exposure rates at A and B and what would be the total exposure for an exposure time of 45 minutes at points A and B. How serious would you consider the exposures at each point?



At point B exposure rate : ____________ mr/hr
total exposure : ____________ mr
Effect : ____________
____
____

At point A exposure rate : ____________ mr/hr
total exposure : ____________ mr
Effect : ____________
____
____

BETA PARTICLE RANGE

Compute the range of beta particles in air and water from ^{151}Pm.

range in air: ____________ cm

range in water: ____________ cm

BETA SHIELDING AND HVL - RANGE

A beta source emits beta particles of maximum energy 0.6 MeV. If the beta particle fluence rate is known to be 1000 beta / cm^2 - sec without a shield in place, what would be the approximate beta fluence rate be if 0.1 cm of lucite were placed between you and the source? The density of lucite is about 0.936 gm / cm^3. What is are the shielded and unshielded beta absorbed dose rates to the skin or eyes?

betas / cm^2 - sec : ________________

unshielded skin/eye dose rate: ______________ mrad/hr

shielded skin/eye dose rate: ______________ mrad/hr

BETA DOSE EVALUATION

As described in the study guide problem on photon shielding, compute the beta skin dose rates at locations A and B in the diagram. What would be the total beta skin dose at each point for a 45 minute exposure time? What effects would you expect from such an exposure?

at point A skin dose rate:____________mrad/hr
total dose :______________mrad
Effect :________________________

at point B skin dose rate:____________mrad/hr
total dose :______________mrad
Effect :________________________

ALPHA PARTICLE RANGE

Compute for the alpha particles in the decay scheme in figure 4 for ^{232}Th only the range in air and tissue. Is there any region of the body where this isotope would be a problem?

TABLE

Isotope Z A	Half-life	Type of decay ([illegible]); % abundance; Mass excess (Δ≡M−A), MeV (C¹²=0); Thermal neutron cross section (σ), barns	Class; Identification; Genetic relationships	Major radiations: approximate energies (MeV) and intensities	Principal means of production
$_{26}Fe^{61}$	6.0 m (StraJ66, RiccE57) others (RiccE55)	ϒ β^- (RiccE55, RiccE57) Δ −59 (MTW)	A chem, genet (RiccE55, RiccE57, StraJ66) parent Co^{61} (RiccE55, RiccE57, StraJ66)	β^- 2.8 max γ 0.33 (I 11), 0.30 (I 48), 1.03 (I 98), 1.20 (I 100) daughter radiations from Co^{61}	Ni^{64}(n, α) (RiccE57) Ni^{64}(d, αp) (RiccE57)
$_{27}Co^{54}$	0.194 s (FreeJ65) others (MartiW52, LeiO56, TyrH54)	ϒ β^+ (MartiW52) Δ −47.99 (MTW)	C excit (MartiW52, FreeJ65)	β^+ [7.23 max] γ [0.511 (200%, γ±)]	Fe^{54}(p, n) (FreeJ65, MartiW52)
Co^{54}	1.5 m (SutD59)	ϒ β^+ (SutD59)	E excit (SutD59, FreeJ65)	β^+ 4.3 max γ 0.41 (100%), 0.511 (200%, γ±) 1.14 (100%), 1.41 (100%)	Fe^{54}(p, n) (FreeJ65)
Co^{55}	18.2 h (DarB37) 17.9 h (RudG52) 18.0 h (LivJ41)	ϒ β^+ 81%, EC 19% (MukA58) β^+ ≈60%, EC ≈40% (calc from DeuM49) Δ −54.61 (MTW)	A chem (DarB37) chem, cross bomb, genet (LivJ41) parent Fe^{55} (LivJ41)	β^+ 1.50 max γ Fe X-rays, 0.480 (12%), 0.511 (160%, γ±), 0.930 (80%), 1.41 (13%)	Fe^{54}(d, n) (DarB37, LivJ41, DeuM49) Fe^{54}(p, γ) (LivJ41) Fe^{56}(p, 2n) (MukA58)
Co^{56}	77.3 d (WriH57) 77 d (BurgW54) others (CookCS42, LivJ41)	ϒ EC 80%, β^+ 20% (CookCS56) Δ −56.03 (MTW)	A chem, excit, cross bomb (LivJ41) daughter Ni^{56} (ShelR52, WorW52)	β^+ 1.49 max γ Fe X-rays, 0.511 (40%, γ±), 0.847 (100%), 1.04 (15%), 1.24 (66%), 1.76 (15%), 2.02 (11%), 2.60 (17%), 3.26 (13%)	Fe^{56}(p, n) (KieP59, GrabZ60a, SakM54) Mn^{55}(α, 3n) (ChenL52a) daughter Ni^{56} (ShelR52, WorW52) Fe^{56}(d, 2n) (LivJ41, JensA41, PleE42, ElliL43a) Ni^{58}(d, α) (LivJ41, CookCS42, ElliL43a)
Co^{57}	270 d (LivJ41) 267 d (CorkJ55)	ϒ EC, no β^+, lim 0.002% (CrasB55) Δ −59.339 (MTW)	A chem, excit, cross bomb (LivJ41) daughter Ni^{57} (FrieG52)	γ Fe X-rays, 0.014 (9%), 0.122 (87%), 0.136 (11%), 0.692 (0.14%) e^- 0.007, 0.013, 0.115, 0.129	Ni^{58}(γ, p) [illegible] Fe^{56}(d, n) (LivJ38a, PerrC38, BarrG39, LivJ41) Fe^{56}(p, γ) (LivJ41) Mn^{55}(α, 2n) (ChenL52a)
Co^{58}	71.3 d (SchumR56) 71.0 d (CorkJ55) 72 d (LivJ41, HoffD52, PreiI60)	ϒ EC 85%, β^+ 15% (GooW46, CookCS56) Δ −59.84 (MTW) σ_c 2500 (GoldmDT64)	A chem, excit, cross bomb (LivJ41)	β^+ 0.474 max γ Fe X-rays, 0.511 (30%, γ±), 0.810 (99%), 0.865 (1.4%), 1.67 (0.6%)	Mn^{55}(α, n) (LivJ38a, LivJ41)
Co^{58m}	9.2 h (ChrisD50) 9.0 h (PreiI60) 8.8 h (StraK50)	ϒ IT, no β^+ (StraK50) Δ −59.81 (LHP, MTW) σ_c 1.4×10^5 (GoldmDT64)	A chem, excit (StraK50)	γ Co X-rays e^- 0.017, 0.024	Mn^{55}(α, n) (StraK50)
<u>Co^{59}</u>		% 100 (MitJ41) Δ −62.233 (MTW) σ_c 19 (to Co^{60}) 18 (to Co^{60m}) (GoldmDT64)			
Co^{60}	5.263 y (GorbS63) 5.24 y (GeiKW57) 5.20 y (LocE56) 5.21 y (KasJ53a) 5.27 y (TobJ55, TobJ51) others (LocE53, LivJ41, BrowG50, SinW51)	ϒ β^- (RisJ37) Δ −61.651 (MTW) σ_c 6 (GoldmDT64)	A n-capt (SamM36) chem, excit, cross bomb (LivJ41)	β^- 1.48 max (0.12%), 0.314 max (99+%) γ 1.173 (100%), 1.332 (100%)	Co^{59}(n, γ) (RisJ37, LivJ38a, LivJ41, SerL47b, YafL51)
Co^{60m}	10.47 m (BarthR53b) 10.3 m (SchmW63) 10.5 m (PreiI60) 10.7 m (LivJ41)	ϒ IT 99+%, β^- 0.25% (SchmW63) IT 99+%, β^- 0.28% (DeuM51) Δ −61.593 (LHP, MTW) σ_c 100 (GoldmDT64)	A n-capt (HeyF37a) chem, excit, cross bomb (LivJ41) daughter Fe^{60} (RoyJ57)	β^- 1.55 max e^- 0.051, 0.058 γ Co X-rays, 0.059 (2.1%), 1.33 (0.25%)	Co^{59}(n, γ) (HeyF37a, LivJ37a, LivJ41, SerL47b)

Isotope Z A	Half-life	Type of decay (Ψ); % abundance; Mass excess (Δ≡M−A), MeV (C^{12}=0); Thermal neutron cross section (σ), barns	Class; Identification; Genetic relationships	Major radiations: approximate energies (MeV) and intensities	Principal means of production
$_{55}Cs^{135}$	3.0×10^6 y sp act (ZelH49) 2.1×10^6 y yield (SugaN49a)	Ψ β^- (SugaN49a) Δ −87.8 (MTW) σ_c 8.7 (GoldmDT64)	A chem, genet (SugaN49a) chem, mass spect (IngM49) daughter Xe^{135} (SugaN49a)	β^- 0.21 max γ no γ	daughter Xe^{135} (SugaN49a) fission (ZelH49)
Cs^{135m}	53 m (WarhH62, HalleI64)	Ψ IT (WarhH62) Δ −86.2 (MTW, LHP)	A chem, sep isotopes, cross bomb, crit abs (WarhH62) chem, mass spect (HalleI64)	γ Cs X-rays, 0.781 (100%), 0.840 (96%) e^- 0.745, 0.775, 0.804	Xe^{134}(d, n) (WarhH62) Xe^{132}(α, p) (WarhH62) Ba^{135}(n, p) (WarhH62) protons on Ba (HalleI64)
Cs^{136}	13.7 d (GleL49) 12.9 d (OlsJ54a) 13.5 d (WilleR60)	Ψ β^- (GleL51ℓ) Δ −86.6 (LHP, MTW)	A chem (GleL46, GleL51ℓ) chem, excit (GleL49) chem, mass spect (OlsJ54a)	β^- 0.057 max (7%), 0.341 max e^- 0.116, 0.126, 0.158, 0.302 γ Ba X-rays, 0.067 (11%), 0.086 (6%), 0.16 (36%, complex), 0.273 (18%), 0.340 (53%), 0.818 (100%), 1.05 (82%), 1.25 (20%) daughter radiations from Ba^{136m} included in above listing	La^{139}(n, α) (CamM44, GleL49, BernsI61) Ba^{138}(d, α) (GizR59, GrabZ60b)
Cs^{137}	30.0 y (weighted average by FlyK65) 29.7 y (GorbS63) 30.4 y mass spect (FarrH61, DieL63) 29.2 y mass spect (RideB63) 30.0 y sp act, mass spect (BrowF55) others (FlyK65, FleD62a, WileDM55a, GlazM61, WileDR53, GleL51j)	Ψ β^- (MelhM41) Δ −86.9 (MTW) σ_c 0.11 (GoldmDT64)	A chem, genet (MelhM41) chem, mass spect (HaydR46a, IngM49) daughter Xe^{137} (TucA51, GleL51k) parent Ba^{137m} (TownJ48)	β^- 1.176 max (7%), 0.514 max (≈13%) e^- 0.624, 0.656 γ Ba X-rays, 0.662 (85%) daughter radiations from Ba^{137m} included in above listing	fission (HaydR48, IngM49, GleL51j, GrumW48, FinB51c)
Cs^{138}	32.2 m (BarthR56) 32.1 m (BunkM56) others (GlasG40, WilleR60, EvaHB51, AteA39, HahO39a, GleL51k, OckD62, LangeL53a)	Ψ β^- (HahO39c) Δ −83.7 (NDS, MTW)	A chem (HahO39c, HeyF39) chem, mass spect (ThuS69) descendant I^{138} (SugaN49) daughter Xe^{138} (HahO39c, HahO40, GlasG40, SeeW43a)	β^- 3.40 max γ 0.463 (23%), 0.55 (8%), 1.01 (23%), 1.426 (73%), 2.21 (18%), 2.63 (9%)	fission (HahO39c, HahO40a, HeyF39, HahO40, BunkM56) Ba^{138}(n, p) (WilleR60, SeeW43a)
Cs^{139}	9.5 m (SugaN50, ZheE63) others (AteA39, HeyF39, OckD62, HahO40)	Ψ β^- (HahO39c) Δ −81.1 (MTW)	A chem, genet (HahO39c, HeyF39) daughter Xe^{139} (HahO39c, HeyF39, HahO40a, HahO40) parent Ba^{139} (HahO39c, HeyF39, HahO40a, HahO40, SugaN50)	γ 0.50, 0.63, 0.80, 1.28 (strong), 1.65 (complex), 1.90, 2.08 daughter radiations from Ba^{139}	fission (HahO39c, HeyF39, HahO40a, AteA39, SugaN50, HahO40a, HahO40, AkaV62, ZheE63, OckD62)
Cs^{140}	66 s (SugaN50) 63 s (ZheE63)	Ψ β^- (HahO40) Δ −77 (MTW)	A chem (HahO40) chem, genet (SugaN50) parent Ba^{140} (SugaN50)	γ 0.59, 0.E8, 1.14, 1.62, 1.85, 2.06, 2.32, 2.72, 3.15	fission (HahO40, SugaN50, ZheE63)
Cs^{141}	24 s (FritK62a) 25 s (WahA62)	Ψ [β^-] (BradE51)	A chem, genet (WahA62, FritK62a) parent Ba^{141} (WahA62, HahO42a) ancestor Ce^{141} (FritK62a)		fission (BradE51, DilC51a, OveR51, WahA62, FritK62a)
Cs^{142}	2.3 s (FritK62a) others (WahA62, HahO42a)	Ψ [β^-] (FritK62a)	B chem, genet (FritK62a) ancestor La^{142} (FritK62a)		fission (FritK62a)
Cs^{143}	2.0 s (FritK62a)	Ψ [β^-] (BradE51)	B genet (BradE51) chem, genet (FritK62a) ancestor La^{143} (FritK62a)		fission (BradE51, DilC51a)
Cs^{144}	short (DilC51, DilC51a)	Ψ [β^-] (DilC51)	F genet (DilC51) [descendant Xe^{144}, ancestor Ce^{144}] (DilC51)		descendant Xe^{144} from fission (DilC51, DilC51a)
$_{56}Ba^{123}$	2.0 m (PreiI62)	Ψ [β^+, EC] (PreiI62)	B chem, cross bomb, genet (PreiI62) parent Cs^{123} (PreiI62)		O^{16} on In, Sn (PreiI62) N^{14} on In (PreiI62) C^{12} on Sn (PreiI62)

TABLE I

Isotope Z A	Half-life	Type of decay (ϒ); % abundance; Mass excess (Δ≡M−A), MeV (C¹²=0); Thermal neutron cross section (σ), barns	Class; Identification; Genetic relationships	Major radiations: approximate energies (MeV) and intensities	Principal means of production
$_{61}Pm^{146}$	4.4 y (PagI63) 1.9 y (FunE60) 1 y (FiecV52) 1-2 y (LongJ52a)	ϒ EC 65%, β^- 35% (FunE6[illegible] EC 69%, β^- 31% (PagI63) Δ −79.52 (MTW)	chem, excit (FiecV52) chem, sep isotopes, genet energy levels (FunE60, FunE62)	β^- 0.78 max γ Nd X-rays, 0.453 (65%), 0.75 (65%, doublet)	$Nd^{146}(p,n)$ (PagI63, FiecV52, LongJ52a) $Nd^{148}(p,3n)$ (FunE60)
Pm^{147}	2.62 y (WherE65) 2.60 y (FlyK65a) 2.64 y (MerW57) 2.66 y (SchumR56) others (MelaE55, IngM50a, SchumR51a)	ϒ β^- (BallN51g) Δ −79.08 (MTW) σ_c 120 (to Pm^{148}) 110 (to Pm^{148m}) (GoldmDT64)	A chem (MarinJ47, MarinJ51a) mass spect (HaydR48) daughter Nd^{147} (MarinJ47, MarinJ51a) parent Sm^{147} (Ras250)	β^- 0.224 max average β^- energy: 0.070 calorimetric (HovV62) γ no γ	$Nd^{146}(n,\gamma)Nd^{147}(\beta^-)$ (MarinJ47, MarinJ51a) fission (BallN51g, SelJ51c, MarinJ51a, GrumW48, IngM50a)
Pm^{148}	5.4 d (ReicC62, EldJ61) others (SchweC62a, ParkG47, KurbJ43, BhaS59)	ϒ β^- (KurbJ43) Δ −76.89 (BabC63a, MTW) σ_c ≈2000 (GoldmDT64)	A chem, n-capt, mass spect (ParkG47) daughter Pm^{148m} (BabC63a)	β^- 2.48 max γ 0.551 (27%), 0.914 (15%), 1.465 (23%)	$Nd^{148}(p,n)$ (LongJ52, FiecV52, KurbJ43, SchweC62a) $Nd^{148}(d,2n)$ (KurbJ42, KurbJ43, BabC63a) $Pm^{147}(n,\gamma)$ (ParkG47, ReicC62)
Pm^{148m}	41.8 d (EldJ61) 40.6 d (ReiC62) 45.5 d (SchweC62a) others (FiecV52, FolR51, LongJ52)	ϒ β^- 93%, IT 7% (BabC63a) others (ReiC62, SchweC62a) Δ −76.35 (LHP, MTW) σ_c 30,000 (GoldmDT64)	A excit, sep isotopes (LongJ52) chem (FolR51) chem, mass spect, genet (BabC63a) parent Pm^{148} (BabC63a)	β^- 0.69 max e^- 0.031, 0.053, 0.091, 0.242, 0.503, 0.583 γ Pm X-rays, Sm X-rays, 0.289 (13%), 0.413 (17%), 0.551 (95%), 0.630 (87%), 0.727 (36%), 0.916 (21%), 1.015 (20%) daughter radiations from Pm^{148}	$Nd^{148}(p,n)$ (LongJ52, FiecV52, SchweC62a) $Nd^{148}(d,2n)$ (BabC63a) $Pm^{147}(n,\gamma)$ (ReiC62)
Pm^{149}	53.1 h (HoffD63, BunnL60) others (ArinA60, FiecV52, IngM47d, RutW52, KondE51c, BotW65a, MarinJ51b)	ϒ β^- (MarinJ47) Δ −76.97 (MTW)	A chem (MarinJ47, MarinJ51b) chem, mass spect (IngM47d) daughter Nd^{149} (KruP52, MarinJ51c)	β^- 1.07 max γ 0.286 (2%), 0.58 (0.1%), 0.85 (0.2%)	$Nd^{148}(n,\gamma)Nd^{149}(\beta^-)$ (KruP52, MarinJ47, SchmL60a, BunnL60)
Pm^{150}	2.68 h (FiecV52) 2.7 h (LongJ52)	ϒ β^- (LongJ52) Δ −73.6 (MTW)	A excit, sep isotopes (LongJ52) chem, excit, sep isotopes (FiecV52)	β^- 3.05 max γ 0.334 (71%), 0.406 (7%), 0.71 (8%), 0.831 (18%), 0.88 (12%), 1.165 (23%), 1.33 (22%), 1.75 (10%), 1.96 (2.5%), 2.06 (1.2%), 2.53 (0.9%)	$Nd^{150}(p,n)$ (LongJ52, FiecV52)
Pm^{151}	27.8 h (HoffD63) 28.4 h (BunnL60) 27.5 h (RutW52)	ϒ β^- (RutW52) Δ −73.40 (MTW)	A genet, atomic level spacing (RutW52) chem (BunnL60) daughter Nd^{151} (RutW52)	β^- 1.19 max e^- 0.003, 0.018, 0.053, 0.058 γ Sm X-rays, 0.07 (5%, complex), 0.10 (7%, doublet), 0.17 (18%, complex), 0.24 (5%, complex), 0.275 (6%), 0.340 (21%), 0.45 (5%, complex), 0.66 (3%, complex), 0.72 (6%, complex), others to 0.96	$Nd^{150}(n,\gamma)Nd^{151}(\beta^-)$ (RutW52, BunnL60)
Pm[illegible]	12.5 h (FolR51, PoolM38a)	ϒ β^- (PoolM38a)	E (PoolM38a) chem (FolR51)		deuterons on Nd (PoolM38a) fission (FolR51)
Pm^{152}	6.5 m (WilleR58, WilleR60)	ϒ β^- (WilleR58) Δ −71 (MTW)	B sep isotopes, excit (WilleR58) genet energy levels (AteA59)	β^- 2.2 max γ [Sm X-rays], 0.122, 0.245	$Sm^{152}(n,p)$ (WilleR58, WilleR60, AteA59)
Pm^{153}	5.5 m (KotK62)	ϒ β^- (KotK62) Δ −70.8 (MTW)	E excit, sep isotopes (KotK62)	β^- 1.65 max γ 0.090 (?), 0.12, 0.18	$Sm^{154}(\gamma,p)$ (KotK62)
Pm^{154}	2.5 m (WilleR58, WilleR60)	ϒ β^- (WilleR60)	C excit, sep isotopes (WilleR58)	β^- 2.5 max	$Sm^{154}(n,p)$ (WilleR58, WilleR60)
$_{62}Sm^{142}$	73 m (GratI59) 72 m (MarsT58)	ϒ EC ≈50%, β^+ ≈50% (DCapG59)	B chem (MarsT58) excit (GratI59) parent Pm^{142} (MarsT58)	γ [illegible]m X-rays, 0.15-0.35 (complex), 0.511 (100%, $\gamma^\pm$) daughter radiations from Pm^{142}	$Nd^{142}(\alpha,4n)$ (GratI59, MarsT58)
Sm^{143}	9.0 m (SIIE56) 8.9 m (AlfWL63a) 8.6 m (GratI59) 8.5 m (WilleR60) 8.3 m (MirM56) 8.8 m (KotK60) others (ButeF50)	ϒ EC 52%, β^+ 48% (DCapG59) EC ≈63%, β^+ ≈37% (GratI59) others (SIIE56, MirM56) Δ −79.6 (MTW)	B chem (ButeF50) excit (SIIE56) chem, sep isotopes (MirM56)	γ Pm X-rays, 0.511 (100%, $\gamma^\pm$)	$Nd^{142}(\alpha,3n)$ (GratI59) $Sm^{144}(n,2n)$ (WilleR60, MirM56, AlfWL63a) $Sm^{144}(\gamma,n)$ (SIIE56, ButeF50, KotK60, DCapG59)

FIGURE 1

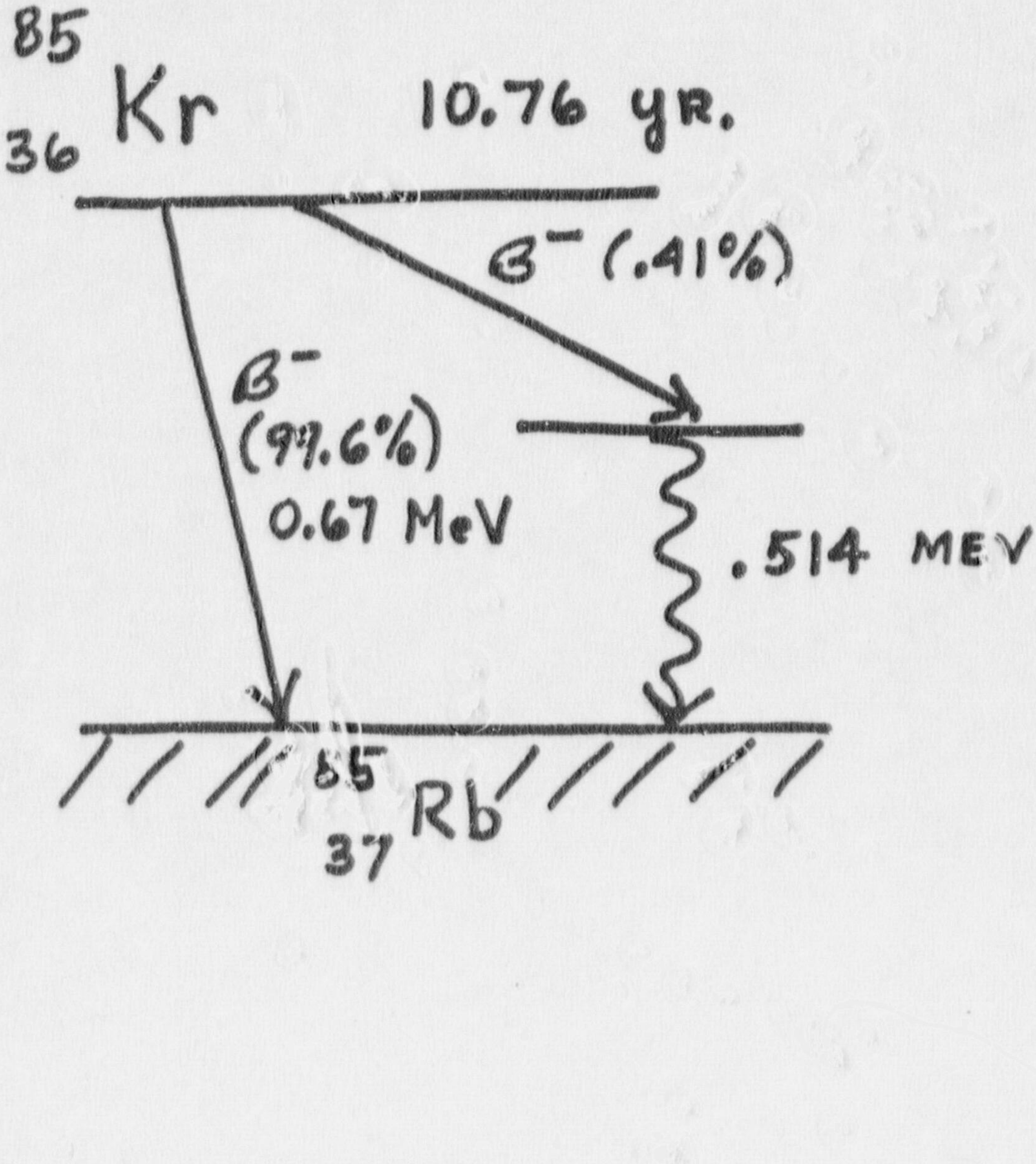
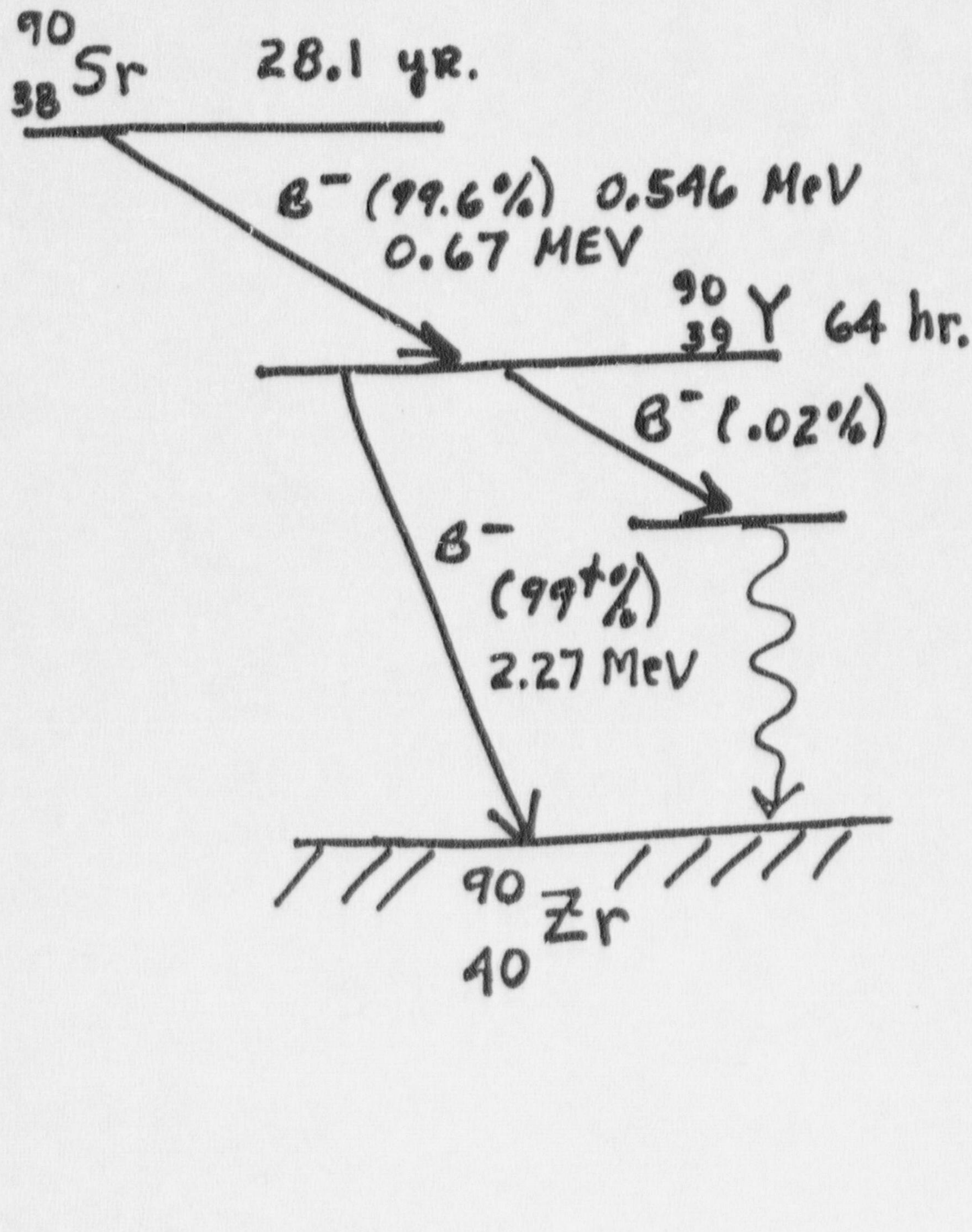
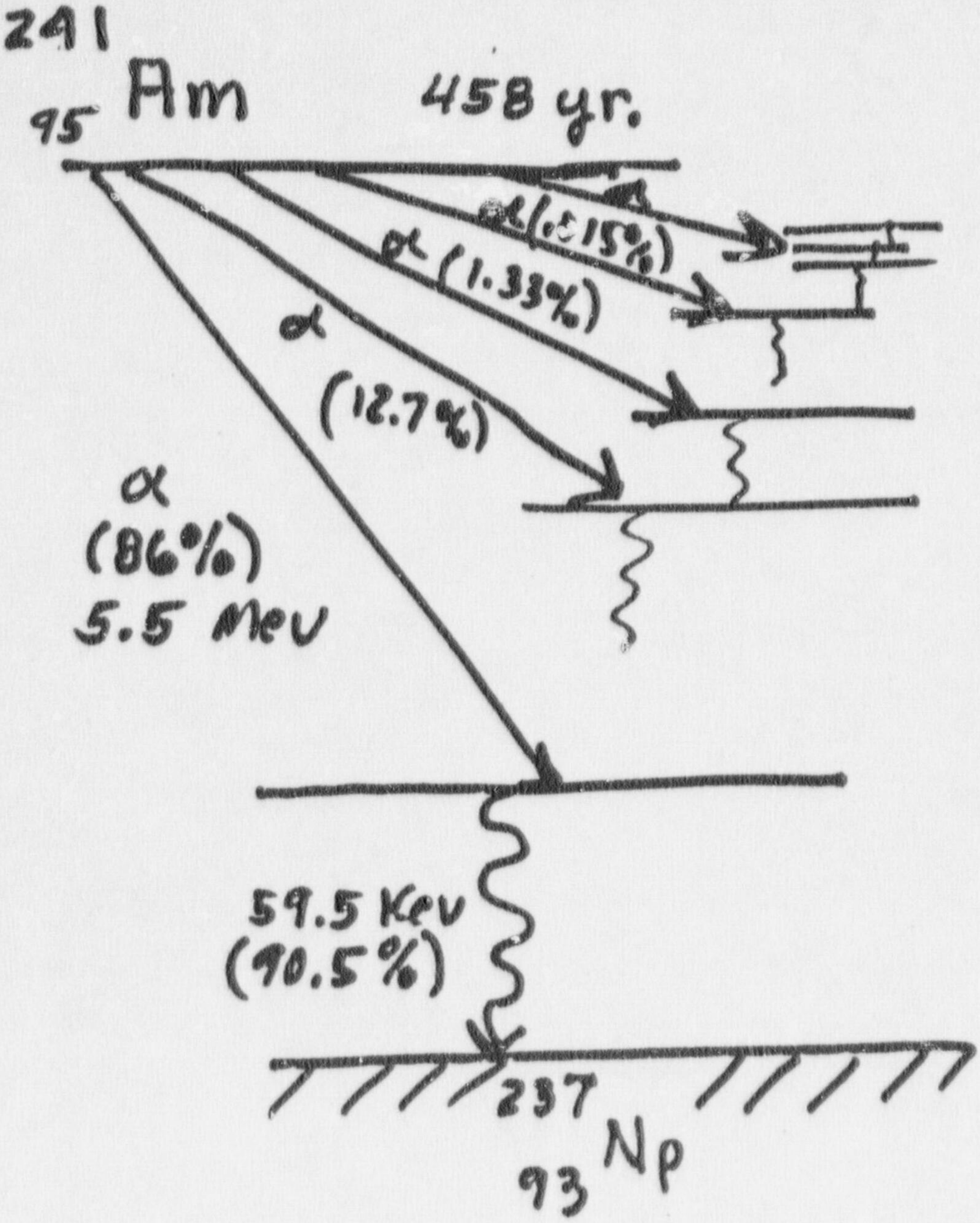


FIGURE 2



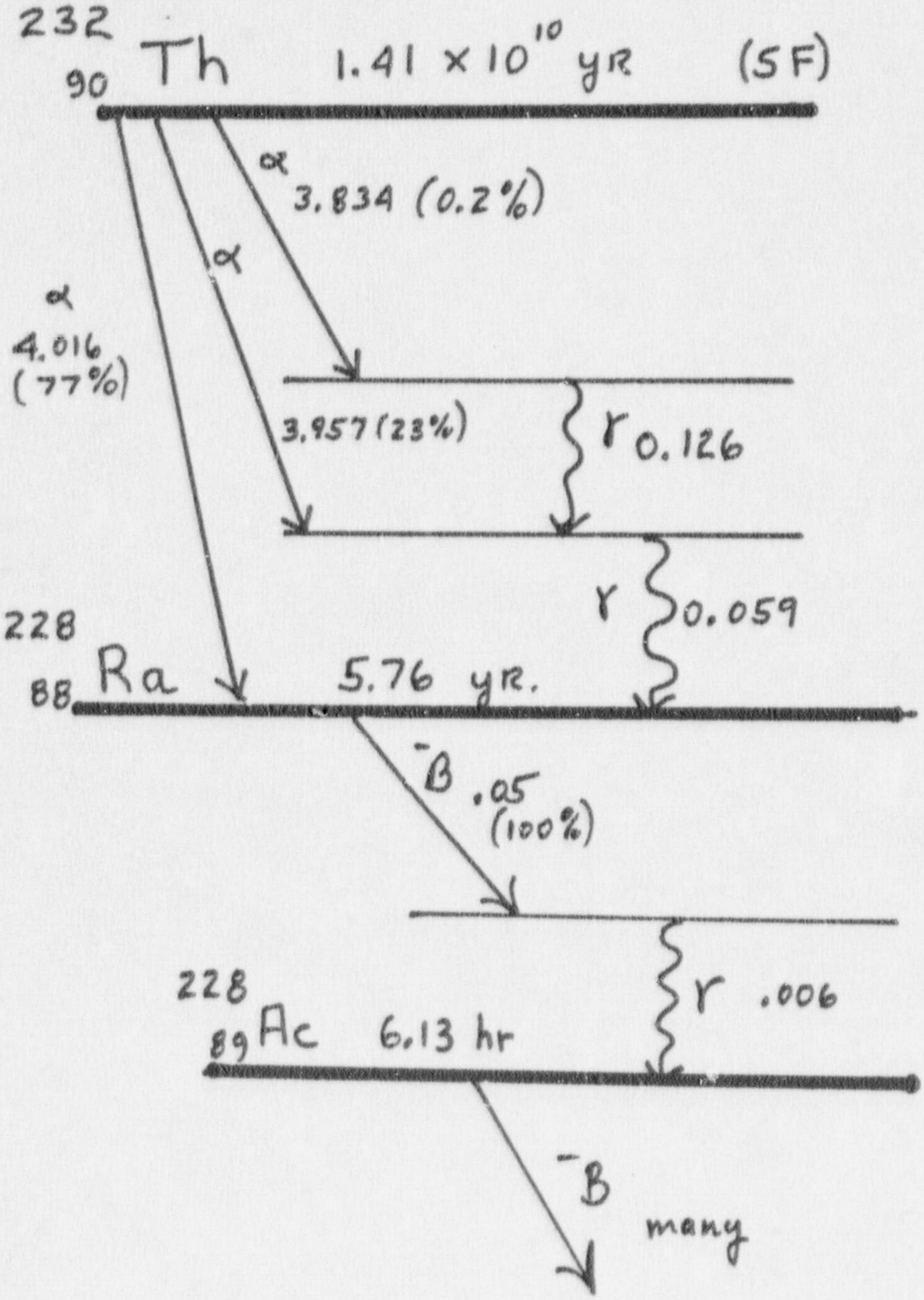
90 38 Sr 28.1 yr.
B⁻ (99.6%) 0.546 MeV
0.67 MEV
90 39 Y 64 hr.
B⁻ (.02%)
B⁻
(99+%)
2.27 MeV
90 40 Zr

FIGURE 3



(α, n) also

FIGURE 4



232
90 Th
1.41 x 10^10 yr
(SF)
α
3.834 (0.2%)
α
α
4.016
(77%)
3.957 (23%)
γ 0.126
γ 0.059
228
88 Ra
5.76 yr.
β⁻ .05
(100%)
228
89 Ac
6.13 hr
γ .006
β⁻
many

FIGURE 4
(cont'd)

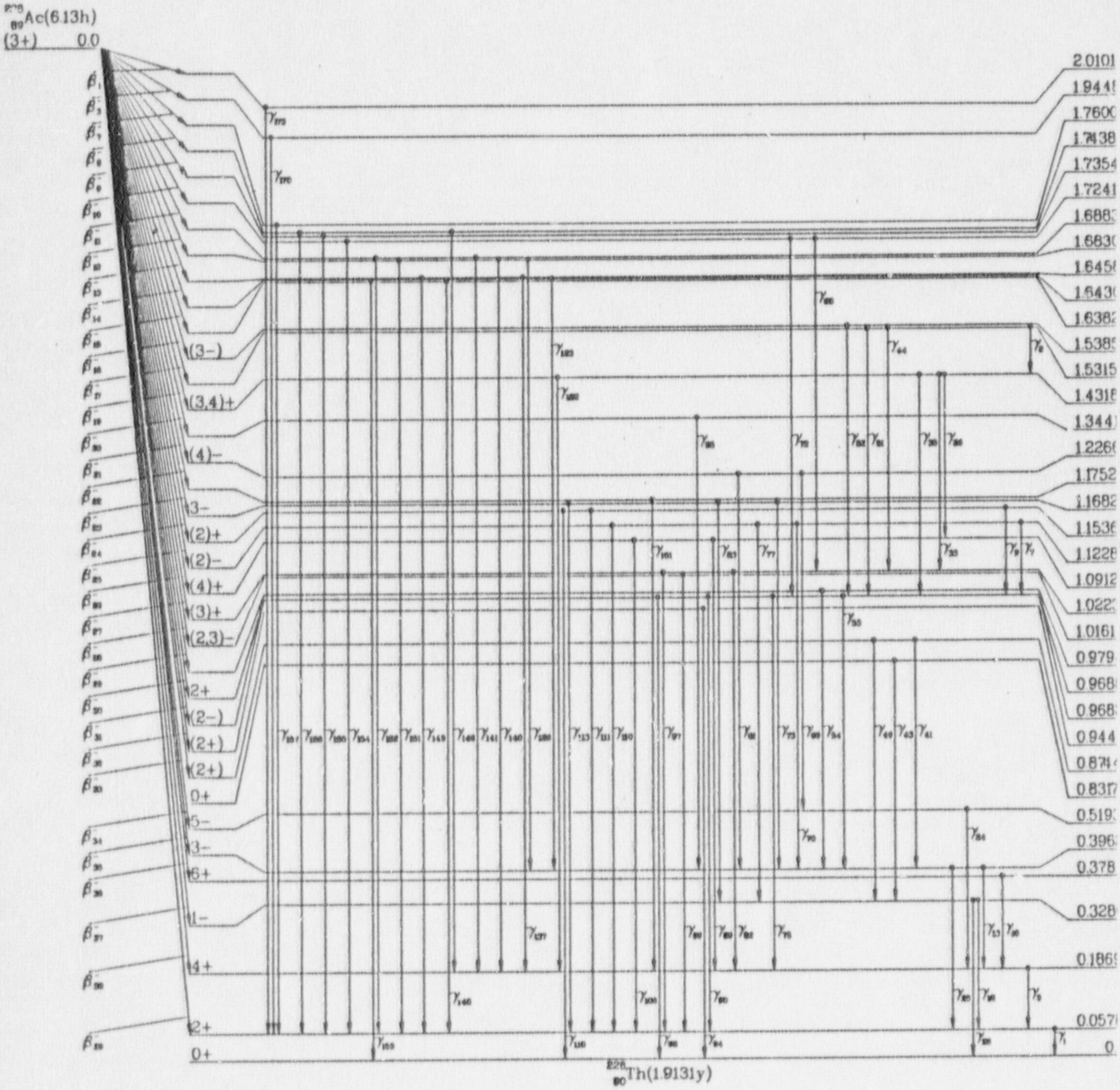


TABLE 2-10

Table 2-10. Thorium series *(2.15)*

Isotope	Symbol	Half-life	Radiation	Energy[a] (MeV)
Thorium-232	^{232}Th	1.41×10^{10} y	α	4.01(76), 3.95(24)
			γ	0.06(24)
Radium-228	^{228}Ra	6.7 y	β	0.05(100)
Actinium-228	^{228}Ac	6.13 h	β	2.18(10), 1.85(9), 1.72(7), 1.13(53), 0.64(8), 0.45(13)
			γ	1.64(13), 1.59(12), 1.10, 1.04, 0.97(18), 0.91(25), 0.46(3), 0.41(2), 0.34(11), 0.23, 0.18(3), 0.13(6), 0.11, 0.10, 0.08
Thorium-228	^{228}Th	1.91 y	α	5.42(72), 5.34(28)
			γ	0.08(2)
Radium-224	^{224}Ra	3.64 d	α	5.68(95), 5.45(5)
			γ	0.24(5)
Radon-220	^{220}Rn	54.5 s	α	6.28(99+)
Polonium-216	^{216}Po	0.158 s	α	6.78(100)
Lead-212	^{212}Pb	10.64 h	β	0.58(14), 0.34(80), 0.16(6)
			γ	0.30(5), 0.24(82), 0.18(1), 0.12(2)
Bismuth-212	^{212}Bi	60.5 min.	α	6.09(10), 6.04(25)
			β	2.25(56), 1.52(4), 0.74(1), 0.63(2)
			γ	0.04(1), with α 2.20(2), 1.81(1), 1.61(3), 1.34(2), 1.04(2), 0.83(8), 0.73(10), with β
Polonium-212[b]	^{212}Po	0.30×10^{-6} s	α	8.78(100)
Thallium-208[c]	^{208}Tl	3.1 min.	β	2.37(2), 1.79(47), 1.52, 1.25
			γ	2.62(100), 0.86(14), 0.76(2), 0.58(83), 0.51(25), 0.28(9), 0.25(2)
Lead-208	^{208}Pb	Stable		

[a]Numbers in parentheses indicate percent abundance.

[b]Divide given percentage yields by 1.5 to obtain yield in terms of thorium-232.

[c]Divide given percentage yields by 3 to obtain yield in terms of thorium-232.

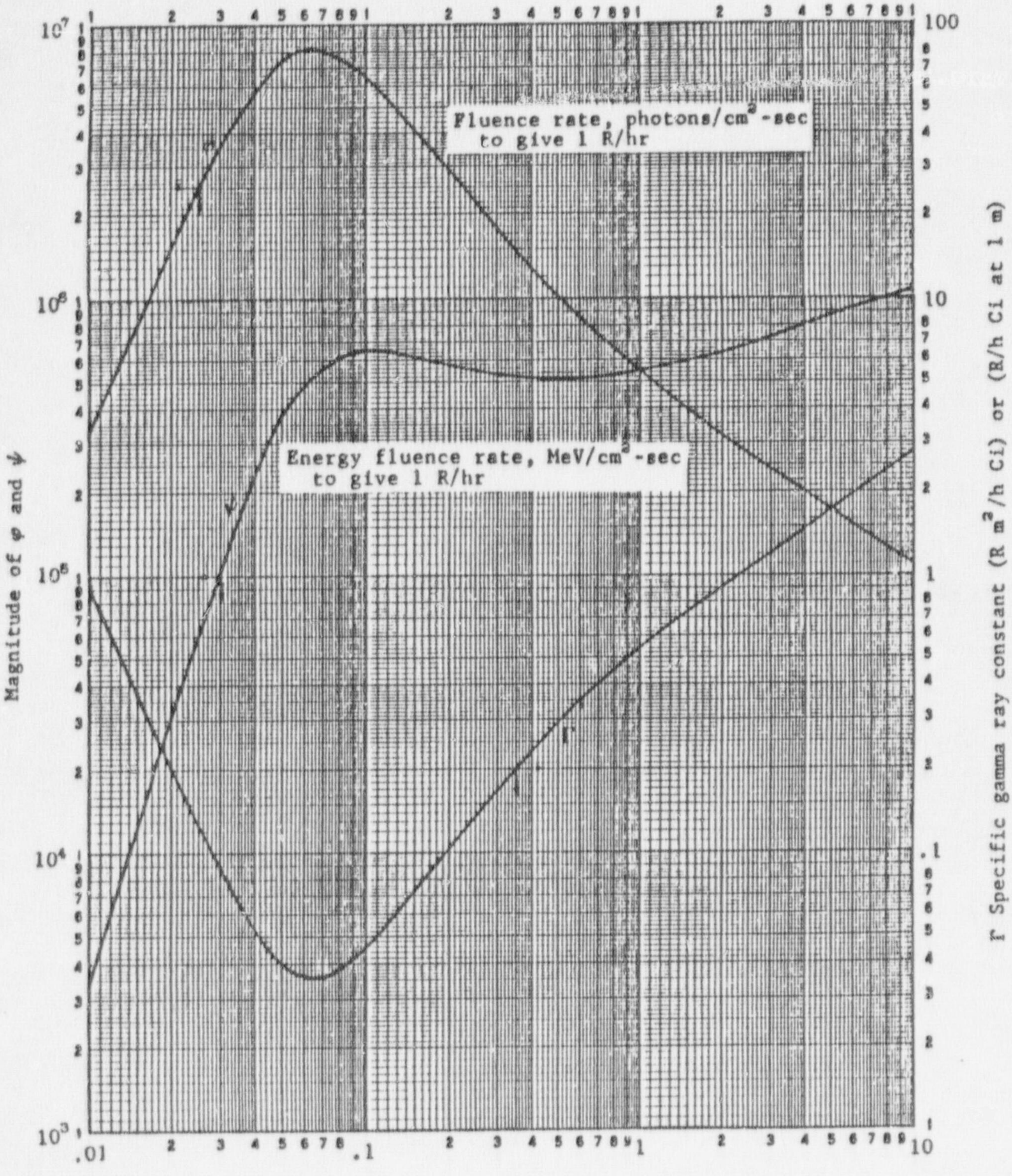


Figure 6.1. Specific Gamma Ray Constants (R m²/hCi) or (R at 1m/hCi) (From Radiological Health Handbook, 1970)

Table 5.1. Mass Attenuation Coefficients*

Photon Energy	H	Be	B	C	N	O	Na	Mg	Al	Si	P	S
keV												
10	0.383	0.593	1.16	2.28	3.73	5.78	15.5	20.8	26.3	34.2	40.8	51.0
15	.376	.300	0.463	0.787	1.18	1.74	4.58	6.23	7.93	10.3	12.4	15.6
20	.369	.227	.295	.429	0.596	0.826	2.01	2.72	3.41	4.39	5.31	6.66
30	.357	.183	.206	.251	.304	.372	0.705	0.918	1.12	1.41	1.66	[illegible]
40	.346	.165	.180	.206	.229	.257	.395	.485	0.567	0.696	0.797	0.958
50	.335	.156	.167	.187	.198	.213	.281	.329	.369	.437	.489	.579
60	.326	.150	.159	.176	.182	.191	.228	.258	.280	.322	.350	.404
80	.309	.140	.147	.161	.164	.168	.181	.196	.203	.224	.234	.259
100	.294	.133	.139	.152	.153	.156	.159	.169	.171	.184	.187	.202
150	.265	.119	.126	.135	.135	.136	.134	.140	.138	.145	.146	.151
200	.243	.109	.114	.123	.123	.124	.120	.125	.122	.128	.125	.130
300	.211	.0945	.0984	.107	.107	.107	.103	.106	.104	.108	.106	.109
400	.189	.0847	.0883	.0957	.0954	.0957	.0918	.0949	.0927	.0962	.0936	.0965
500	.173	.0773	.0806	.0872	.0871	.0873	.0836	.0864	.0844	.0875	.0850	.0878
600	.160	.0715	.0745	.0807	.0805	.0808	.0774	.0797	.0780	.0808	.0784	.0810
800	.140	.0629	.0655	.0709	.0708	.0708	.0678	.0701	.0684	.0707	.0688	.0709
MeV												
1.0	.126	.0565	.0589	.0637	.0636	.0637	.0609	.0628	.0613	.0635	.0617	.0630
1.5	.103	.0460	.0479	.0519	.0518	.0518	.0497	.0512	.0500	.0518	.0503	.0510
2.0	.0875	.0394	.0411	.0445	.0445	.0446	.0428	.0442	.0432	.0448	.0436	.0449
3.0	.0691	.0314	.0328	.0357	.0358	.0360	.0349	.0361	.0354	.0368	.0359	.0371
4	.0581	.0266	.0280	.0305	.0307	.0310	.0304	.0316	.0311	.0324	.0317	.0329
5	.0505	.0235	.0248	.0271	.0274	.0278	.0276	.0287	.0284	.0297	.0292	.0304
6	.0450	.0212	.0225	.0247	.0251	.0255	.0256	.0268	.0265	.0279	.0275	.0287
8	.0375	.0182	.0195	.0216	.0221	.0226	.0232	.0244	.0244	.0257	.0255	.0268
10	.0325	.0163	.0175	.0196	.0202	.0209	.0218	.0231	.0231	.0246	.0245	.0258
15	.0254	.0136	.0149	.0170	.0178	.0186	.0202	.0216	.0219	.0234	.0236	.0251
20	.0215	.0122	.0137	.0158	.0167	.0177	.0196	.0212	.0216	.0233	.0235	.0252
30	.0174	.0110	.0125	.0147	.0158	.0170	.0196	.0213	.0219	.0238	.0242	.0261
40	.0154	.0104	.0121	.0144	.0156	.0169	.0199	.0217	.0224	.0245	.0250	.0270
50	.0141	.0102	.0119	.0142	.0156	.0170	.0202	.0222	.0230	.0252	.0257	.0278
60	.0133	.0100	.0118	.0143	.0157	.0172	.0206	.0227	.0235	.0257	.0264	.0286
80	.0124	.00991	.0118	.0144	.0160	.0175	.0213	.0235	.0244	.0267	.0274	.0298
100	.0119	.00992	.0119	.0146	.0163	.0179	.0218	.0241	.0251	.0275	.0283	.0307
150	.0113	.0100	.0122	.0150	.0168	.0186	.0228	.0253	.0263	.0289	.0298	.0324
200	.0112	.0102	.0124	.0153	.0172	.0191	.0235	.0260	.0271	.0299	.0307	.0334
300	.0111	.0104	.0128	.0159	.0178	.0198	.0244	.0270	.0282	.0310	.0319	.0348
400	.0112	.0106	.0130	.0162	.0182	.0202	.0249	.0276	.0288	.0317	.0327	.0356
500	.0113	.0108	.0132	.0164	.0185	.0205	.0252	.0280	.0292	.0322	.0332	.0361
600	.0113	.0109	.0134	.0166	.0187	.0207	.0255	.0283	.0295	.0325	.0335	.0365
800	.0115	.0111	.0136	.0169	.0190	.0210	.0259	.0287	.0300	.0330	.0340	.0370
GeV												
1	.0116	.0112	.0137	.0171	.0192	.0212	.0261	.0290	.0302	.0333	.0344	.0374
1.5	.0117	.0114	.0140	.0173	.0195	.0216	.0265	.0293	.0307	.0338	.0348	.0380
2	.0118	.0115	.0141	.0175	.0196	.0218	.0267	.0296	.0309	.0341	.0351	.0383
3	.0120	.0116	.0143	.0177	.0199	.0220	.0269	.0298	.0312	.0344	.0354	.0386
4	.0120	.0117	.0144	.0178	.0200	.0221	.0270	.0300	.0313	.0345	.0356	.0388
5	.0121	.0118	.0144	.0179	.0200	.0222	.0271	.0301	.0314	.0346	.0357	.0389
6	.0121	.0118	.0145	.0179	.0201	.0222	.0272	.0302	.0315	.0347	.0358	.0390
8	.0122	.0119	.0145	.0180	.0202	.0223	.0272	.0302	.0316	.0348	.0359	.0391
10	.0122	.0119	.0146	.0180	.0202	.0223	.0273	.0303	.0316	.0348	.0359	.0391
15	.0122	.0119	.0146	.0181	.0203	.0224	.0274	.0303	.0317	.0349	.0360	.0392
20	.0123	.0120	.0147	.0181	.0203	.0224	.0274	.0304	.0317	.0350	.0361	.0393
30	.0123	.0120	.0147	.0182	.0203	.0225	.0274	.0304	.0318	.0350	.0361	.0393
40	.0123	.0120	.0147	.0182	.0203	.0225	.0275	.0305	.0318	.0351	.0361	.0394
50	.0123	.0120	.0147	.0182	.0204	.0225	.0275	.0305	.0318	.0351	.0362	.0394
60	.0123	.0120	.0147	.0182	.0204	.0225	.0275	.0305	.0318	.0351	.0362	.0394
80	.0123	.0120	.0147	.0182	.0204	.0225	.0275	.0305	.0318	.0351	.0362	.0394
100	.0123	.0120	.0147	.0182	.0204	.0225	.0275	.0305	.0319	.0351	.0362	.0394

* Coefficients are "Total with Coherent." Unit is cm^2/g .

Source: Photon Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients From 10 keV to 100 GeV (NSRDS-NBS 29), 1969.

Table 5.1. Mass Attenuation Coefficients (Continued)

Photon Energy	Ar	K	Ca	Fe	Cu	Mo	Sn	I	W	Pb	U	H_2O
keV												
10	64.5	80.9	96.5	173.	224.	86.2	141.	161.	95.5+	133.+	178.	5.18
15	19.9	25.0	30.1	56.4	74.2	28.2	47.0	55.2	142.	115.+	63.9+	1.58
20	8.53	10.8	13.0	25.5	33.5	81.7*	21.3*	26.0	67.0	85.7+	71.0+	0.775
30	2.62	3.30	3.99	8.13	10.9	28.8	41.3	8.67*	23.0	29.7	41.0+	.370
40	1.20	1.49	1.78	3.62	4.89	13.3	19.4	22.7	10.7	14.0	19.7	.267
50	0.687	0.843	0.998	1.94	2.62	7.20	10.7	12.6	5.91	7.81	11.1	.227
60	.460	.560	.648	1.20	1.62	4.41	6.53	7.78	3.65*	4.87	6.96	.206
80	.275	.324	.365	0.595	0.772	2.02	3.02	3.65	7.89	2.33*	3.35	.184
100	.204	.233	.256	.370	.461	1.11	1.68	2.00	4.43	5.40	1.91*	.171
150	.143	.158	.168	.196	.223	0.428	0.614	0.714	1.57	1.97	2.56	.151
200	.121	.132	.138	.146	.157	.245	.328	.377	0.777	0.991	1.28	.137
300	.0994	.108	.112	.110	.112	.139	.164	.178	.320	.404	0.509	.119
400	.0878	.0949	.0979	.0940	.0941	.105	.116	.122	.190	.231	.286	.106
500	.0795	.0859	.0885	.0840	.0836	.0883	.0946	.0976	.136	.161	.193	.0968
600	.0733	.0792	.0814	.0769	.0762	.0788	.0816	.0835	.108	.125	.146	.0896
800	.0641	.0692	.0712	.0669	.0660	.0661	.0669	.0676	.0799	.0885	.0997	.0786
MeV												
1.0	.0576	.0621	.0639	.0599	.0589	.0583	.0578	.0581	.0654	.0708	.0776	.0707
1.5	.0470	.0506	.0520	.0488	.0480	.0470	.0463	.0464	.0497	.0517	.0548	.0575
2.0	.0407	.0439	.0453	.0425	.0420	.0415	.0410	.0411	.0437	.0455	.0475	.0494
3.0	.0338	.0366	.0378	.0362	.0360	.0366	.0367	.0370	.0402	.0418	.0438	.0397
4	.0302	.0328	.0340	.0331	.0332	.0349	.0355	.0359	.0400	.0416	.0435	.0340
5	.0280	.0306	.0317	.0314	.0318	.0344	.0354	.0359	.0407	.0424	.0445	.0303
6	.0267	.0291	.0303	.0305	.0310	.0343	.0357	.0364	.0416	.0435	.0455	.0277
8	.0251	.0276	.0289	.0298	.0306	.0350	.0369	.0378	.0439	.0459	.0480	.0243
10	.0244	.0270	.0283	.0298	.0308	.0362	.0385	.0395	.0464	.0484	.0506	.0222
15	.0244	.0268	.0283	.0307	.0323	.0393	.0425	.0438	.0524	.0548	.0573	.0194
20	.0244	.0273	.0289	.0321	.0339	.0470	.0461	.0476	.0577	.0606	.0636	.0181
30	.0255	.0286	.0305	.0345	.0368	.0470	.0517	.0536	.0659	.0696	.0733	.0171
40	.0266	.0299	.0319	.0365	.0391	.0505	.0557	.0578	.0716	.0757	.0799	.0167
50	.0275	.0310	.0331	.0382	.0410	.0532	.0588	.0611	.0760	.0804	.0850	.0167
60	.0284	.0319	.0342	.0395	.0425	.0553	.0613	.0637	.0794	.0841	.0889	.0167
80	.0296	.0334	.0358	.0416	.0448	.0586	.0651	.0676	.0845	.0896	.0948	.0170
100	.0306	.0345	.0370	.0432	.0465	.0609	.0677	.0704	.0881	.0934	.0984	.0172
150	.0325	.0368	.0394	.0458	.0494	.0648	.0721	.0750	.0939	.0996	.106	.0178
200	.0334	.0377	.0405	.0475	.0511	.0672	.0748	.0778	.0976	.103	.110	.0182
300	.0348	.0393	.0422	.0494	.0532	.0700	.0780	.0811	.102	.108	.115	.0188
400	.0356	.0402	.0432	.0506	.0544	.0716	.0798	.0830	.104	.111	.117	.0192
500	.0361	.0408	.0438	.0514	.0552	.0727	.0810	.0842	.106	.112	.119	.0195
600	.0365	.0412	.0443	.0519	.0558	.0735	.0819	.0851	.107	.113	.121	.0197
800	.0371	.0419	.0450	.0527	.0566	.0745	.0831	.0864	.108	.115	.122	.0200
GeV												
1	.0375	.0423	.0455	.0532	.0572	.0753	.0838	.0871	.109	.116	.123	.0202
1.5	.0380	.0429	.0461	.0539	.0579	.0762	.0849	.0884	.111	.118	.125	.0205
2	.0382	.0432	.0464	.0543	.0583	.0767	.0856	.0890	.111	.118	.126	.0206
3	.0386	.0436	.0468	.0548	.0538	.0773	.0862	.0896	.112	.119	.127	.0208
4	.0387	.0438	.0470	.0550	.0590	.0777	.0865	.0900	.113	.120	.127	.0210
5	.0389	.0439	.0472	.0551	.0591	.0779	.0867	.0902	.113	.120	.128	.021
6	.0389	.0440	.0473	.0552	.0593	.0780	.0868	.0904	.113	.120	.128	.0211
8	.0391	.0441	.0474	.0554	.0594	.0781	.0870	.0905	.113	.120	.128	.0211
10	.0391	.0442	.0475	.0555	.0595	.0783	.0871	.0906	.114	.121	.128	.0212
15	.0392	.0443	.0476	.0556	.0596	.0785	.0873	.0908	.114	.121	.129	.0213
20	.0393	.0443	.0477	.0556	.0596	.0785	.0874	.0910	.114	.121	.129	.0213
30	.0393	.0444	.0477	.0557	.0598	.0786	.0875	.0911	.114	.121	.129	.0213
40	.0393	.0445	.0477	.0557	.0598	.0786	.0876	.0911	.114	.121	.129	.0213
50	.0393	.0445	.0478	.0558	.0598	.0786	.0877	.0911	.114	.121	.129	.0213
60	.0394	.0445	.0478	.0558	.0598	.0787	.0877	.0912	.114	.121	.129	.0214
80	.0394	.0445	.0478	.0558	.0598	.0788	.0877	.0912	.114	.121	.129	.0214
100	.0394	.0445	.0478	.0555	.0598	.0788	.0877	.0912	.114	.121	.129	.0214

* K edge, + L edge-- Mo 20keV 12.6, 81.7; Sn 29.2keV 7.54, 44.3; I 33.2keV 6.62, 36.4; W 10.2keV 90.7, 235.; 11.5keV 170., 235.; 12.1keV 206., 248.; 69.5keV 2.49, 11.3; Pb 13.0keV 67.8, 166.; 15.2keV 112., 146.; 15.9keV 130., 157.; 88.0keV 1.83, 7.45; U 17.2keV 45.8, 106.; 20.9keV 62.7, 88.0; 21.8keV 79.8, 91.8; 116keV 1.34, 4.86.

Table 5.1. Mass Attenuation Coefficients (Continued)

Photon Energy	SiO_2	NaI	Air	Concrete	0.8N H_2SO_4	Bone	Muscle	Polystyrene	Lucite	Polyethylene	Bakelite	Pyrex Glass
keV												
10	19.0	139.	4.99	26.9	5.76	20.3	5.27	2.13	3.25	2.01	2.76	17.1
15	5.73	47.4	1.55	8.24	1.76	6.32	1.63	0.755	1.06	0.728	0.923	5.14
20	2.49	22.3	0.752	3.59	0.849	2.73	0.793	.424	0.551	.420	.492	2.25
30	0.859	7.45*	.349	1.19	.391	0.962	.373	.259	.298	.266	.277	0.786
40	.463	19.3	.248	0.605	.276	.512	.268	.217	.234	.226	.223	.431
50	.318	10.7	.208	.392	.231	.349	.227	.199	.208	.209	.200	.302
60	.252	6.62	.188	.295	.208	.274	.205	.188	.193	.198	.187	.242
80	.194	3.12	.167	.213	.185	.209	.183	.173	.176	.183	.171	.190
100	.169	1.72	.154	.179	.171	.180	.170	.163	.164	.172	.161	.166
150	.140	0.625	.136	.144	.150	.149	.149	.145	.146	.154	.143	.139
200	.126	.334	.123	.127	.137	.133	.136	.132	.133	.140	.130	.125
300	.108	.167	.107	.108	.118	.114	.118	.115	.115	.122	.113	.107
400	.0959	.117	.0954	.0963	.106	.102	.105	.103	.103	.109	.101	.0954
500	.0874	.0955	.0870	.0877	.0965	.0927	.0960	.0938	.0941	.0995	.0921	.0870
600	.0808	.0826	.0805	.0810	.0893	.0857	.0888	.0868	.0871	.0921	.0852	.0804
800	.0707	.0676	.0707	.0709	.0783	.0752	.0779	.0763	.0765	.0809	.0749	.0704
MeV												
1.0	.0636	.0586	.0636	.0637	.0704	.0676	.0700	.0685	.0687	.0727	.0673	.0633
1.5	.0518	.0469	.0518	.0519	.0573	.0550	.0570	.0558	.0559	.0592	.0548	.0516
2.0	.0447	.0413	.0445	.0448	.0492	.0473	.0489	.0478	.0480	.0507	.0470	.0444
3.0	.0363	.0366	.0358	.0365	.0396	.0383	.0393	.0383	.0385	.0405	.0377	.0361
4	.0317	.0351	.0308	.0319	.0340	.0331	.0337	.0327	.0329	.0345	.0322	.0314
5	.0287	.0346	.0275	.0290	.0303	.0297	.0300	.0290	.0292	.0305	.0286	.0282
6	.0266	.0347	.0252	.0270	.0277	.0274	.0274	.0263	.0266	.0277	.0260	.0263
8	.0241	.0355	.0223	.0245	.0243	.0244	.0240	.0228	.0232	.0239	.0227	.0237
10	.0226	.0368	.0204	.0231	.0222	.0226	.0219	.0206	.0211	.0215	.0206	.0222
15	.0209	.0402	.0181	.0215	.0194	.0204	.0192	.0176	.0182	.0182	.0178	.0204
20	.0203	.0433	.0170	.0220	.0182	.0194	.0179	.0162	.0168	.0166	.0164	.0198
30	.0202	.0484	.0162	.0210	.0172	.0189	.0168	.0149	.0157	.0151	.0153	.0195
40	.0204	.0520	.0161	.0213	.0169	.0189	.0165	.0144	.0153	.0145	.0148	.0198
50	.0208	.0548	.0161	.0218	.0168	.0190	.0164	.0142	.0151	.0142	.0147	.0201
60	.0212	.0571	.0162	.0222	.0169	.0193	.0165	.0142	.0151	.0141	.0147	.0204
80	.0218	.0605	.0165	.0229	.0171	.0197	.0167	.0142	.0152	.0141	.0148	.0210
100	.0224	.0629	.0168	.0235	.0174	.0201	.0170	.0144	.0154	.0142	.0150	.0215
150	.0234	.0670	.0174	.0247	.0180	.0210	.0175	.0147	.0159	.0145	.0154	.0225
200	.0241	.0695	.0179	.0254	.0184	.0215	.0179	.0150	.0162	.0147	.0157	.0232
300	.0250	.0724	.0185	.0264	.0190	.0223	.0185	.0155	.0167	.0152	.0162	.0240
400	.0256	.0741	.0189	.0269	.0194	.0228	.0189	.0158	.0171	.0155	.0166	.0245
500	.0260	.0752	.0192	.0273	.0197	.0231	.0192	.0160	.0173	.0157	.0168	.0249
600	.0262	.0760	.0194	.0276	.0199	.0233	.0194	.0162	.0175	.0159	.0170	.0252
800	.0266	.0771	.0197	.0281	.0202	.0237	.0197	.0165	.0178	.0161	.0173	.0256
GeV												
1	.0269	.0778	.0199	.0283	.0204	.0239	.0199	.0166	.0180	.0163	.0174	.0258
1.5	.0273	.0789	.0202	.0287	.0207	.0243	.0202	.0169	.0182	.0165	.0177	.0262
2	.0275	.0794	.0204	.0290	.0209	.0245	.0203	.0171	.0184	.0167	.0179	.0264
3	.0278	.0800	.0206	.0292	.0211	.0247	.0205	.0173	.0186	.0169	.0181	.0267
4	.0279	.0803	.0207	.0294	.0212	.0249	.0206	.0174	.0187	.0170	.0182	.0268
5	.0280	.0805	.0208	.0295	.0213	.0249	.0207	.0174	.0188	.0170	.0183	.0269
6	.0281	.0807	.0208	.0295	.0213	.0250	.0208	.0175	.0188	.0171	.0183	.0269
8	.0281	.0808	.0209	.0296	.0214	.0251	.0208	.0175	.0189	.0172	.0184	.0270
10	.0282	.0809	.0209	.0297	.0214	.0251	.0209	.0176	.0189	.0172	.0184	.0271
15	.0283	.0811	.0210	.0298	.0215	.0252	.0209	.0176	.0190	.0173	.0185	.0271
20	.0283	.0812	.0210	.0298	.0215	.0252	.0210	.0177	.0190	.0173	.0185	.0272
30	.0283	.0813	.0211	.0298	.0216	.0253	.0210	.0177	.0191	.0173	.0185	.0272
40	.0284	.0813	.0211	.0299	.0216	.0253	.0210	.0177	.0191	.0173	.0186	.0272
50	.0284	.0814	.0211	.0299	.0216	.0253	.0210	.0177	.0191	.0173	.0186	.0272
60	.0284	.0814	.0211	.0299	.0216	.0253	.0210	.0177	.0191	.0174	.0186	.0273
80	.0284	.0815	.0211	.0299	.0216	.0253	.0210	.0178	.0191	.0174	.0186	.0273
100	.0284	.0815	.0211	.0299	.0216	.0253	.0211	.0178	.0191	.0174	.0186	.0273

* K edge of Iodine--33.2keV 5.69, 30.9.

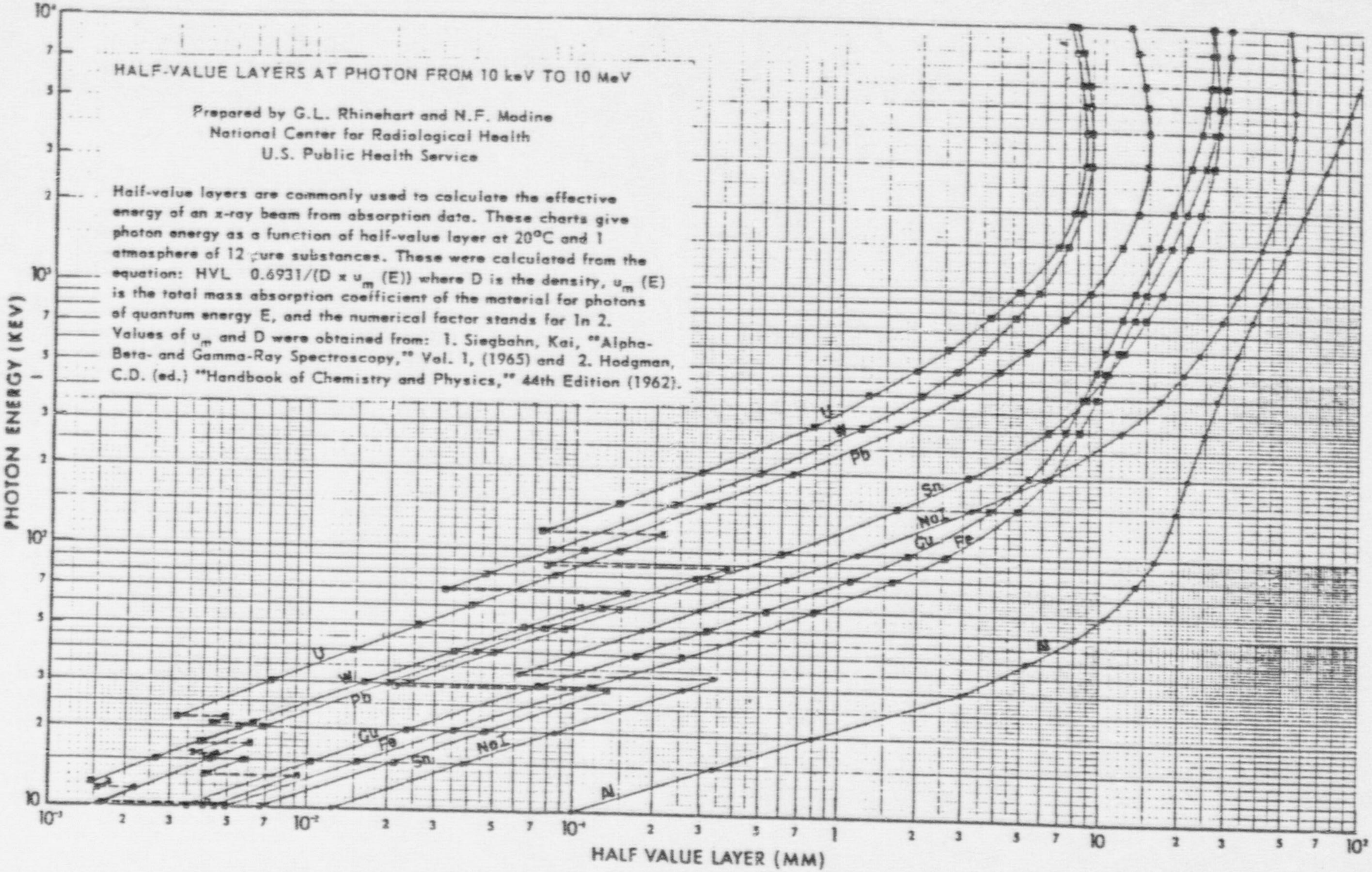

HALF-VALUE LAYERS AT PHOTON FROM 10 keV TO 10 MeV
Prepared by G.L. Rhinehart and N.F. Modine
National Center for Radiological Health
U.S. Public Health Service
Half-value layers are commonly used to calculate the effective energy of an x-ray beam from absorption data. These charts give photon energy as a function of half-value layer at 20°C and 1 atmosphere of 12 pure substances. These were calculated from the equation: HVL 0.6931/(D x u_m (E)) where D is the density, u_m (E) is the total mass absorption coefficient of the material for photons of quantum energy E, and the numerical factor stands for ln 2.
Values of u_m and D were obtained from: 1. Siegbahn, Kai, "Alpha- Beta- and Gamma-Ray Spectroscopy," Vol. 1, (1965) and 2. Hodgman, C.D. (ed.) "Handbook of Chemistry and Physics," 44th Edition (1962).
PHOTON ENERGY (KEV)
HALF VALUE LAYER (MM)
U
W
Pb
Sn
NaI
Cu
Fe
Al

FIGURE 5

Table 6.1. Gamma Radiation Levels for One ~~Curie~~ mCi of Some Radionuclides[a,b]

$\Gamma : \frac{R-cm^2}{HR-mCi}$

Nuclide	Γ	Nuclide	Γ	Nuclide	Γ
Actinium-227	~ 2.2	Gold-198	2.3	Potassium-43	5.6
Antimony-122	2.4	Gold-199	~ 0.9	Radium-226	8.25
Antimony-124	9.8	Hafnium-175	~ 2.1	Radium-228	~ 5.1
Antimony-125	~ 2.7	Hafnium-181	~ 3.1	Rhenium-186	~ 0.2
Arsenic-72	10.1	Indium-114m	~ 0.2	Rubidium-86	0.5
Arsenic-74	4.4	Iodine-124	7.2	Ruthenium-106	1.7
Arsenic-76	2.4	Iodine-125	~ 0.7	Scandium-46	10.9
Barium-131	~ 3.0	Iodine-126	2.5	Scandium-47	0.56
Barium-133	~ 2.4	Iodine-130	12.2	Selenium-75	2.0
Barium-140	12.4	Iodine-131	2.2	Silver-110m	14.3
Beryllium-7	~ 0.3	Iodine-132	11.8	Silver-111	~ 0.2
Bromine-82	14.6	Iridium-192	4.8	Sodium-22	12.0
Cadmium-115m	~ 0.2	Iridum-194	1.5	Sodium-24	18.4
Calcium-47	5.7	Iron-59	6.4	Strontium-85	3.0
Carbon-11***	5.9	Krypton-85	~ 0.04	Tantalum-182	6.8
Cerium-141	0.35	Lanthanum-140	11	Tellurium-121***	3.3
Cerium-144	~ 0.4	Lutecium-177	[illegible]	Tellurium-132	2.2
Cesium-134	8.7	Magnesium-28	15..	Thulium-170	0.025
Cesium-137	3.3	Manganese-52	18.6	Tin-113	~ 1.7
Chlorine-38*	8.8	Manganese-54	4.7	Tungsten-185	~ 0.5
Chromium-51	0.16	Manganese-56	8.3	Tungsten-187	3.0
Cobalt-56	17.6	Mercury-197	~ 0.4	Uranium-234	~ 0.1
Cobalt-57	0.9	Mercury-203	1.3	Vanadium-48	15.6
Cobalt-58	5.5	Molybdenum-99	1.8	Xenon-133	0.1
Cobalt-60	13.2	Neodymium-147	0.8	Ytterbium-175	0.4
Copper-64	1.2	Nickel-65	~ 3.1	Yttrium-88	14.1
Europium-152	5.8	Niobium-95	4.2	Yttrium-91	0.01
Europium-154	~ 6.2	Osmium-191	~ 0.6	Zinc-65	2.7
Europium-155	~ 0.3	Palladium-109	0.03	Zirconium-95	4.1

$$R/HR = \frac{\Gamma * mCi}{(Distance, cm)^2}$$

$$\Gamma = \frac{R-cm^2}{HR-mCi}$$

PENETRATION ABILITY OF BETA RADIATION

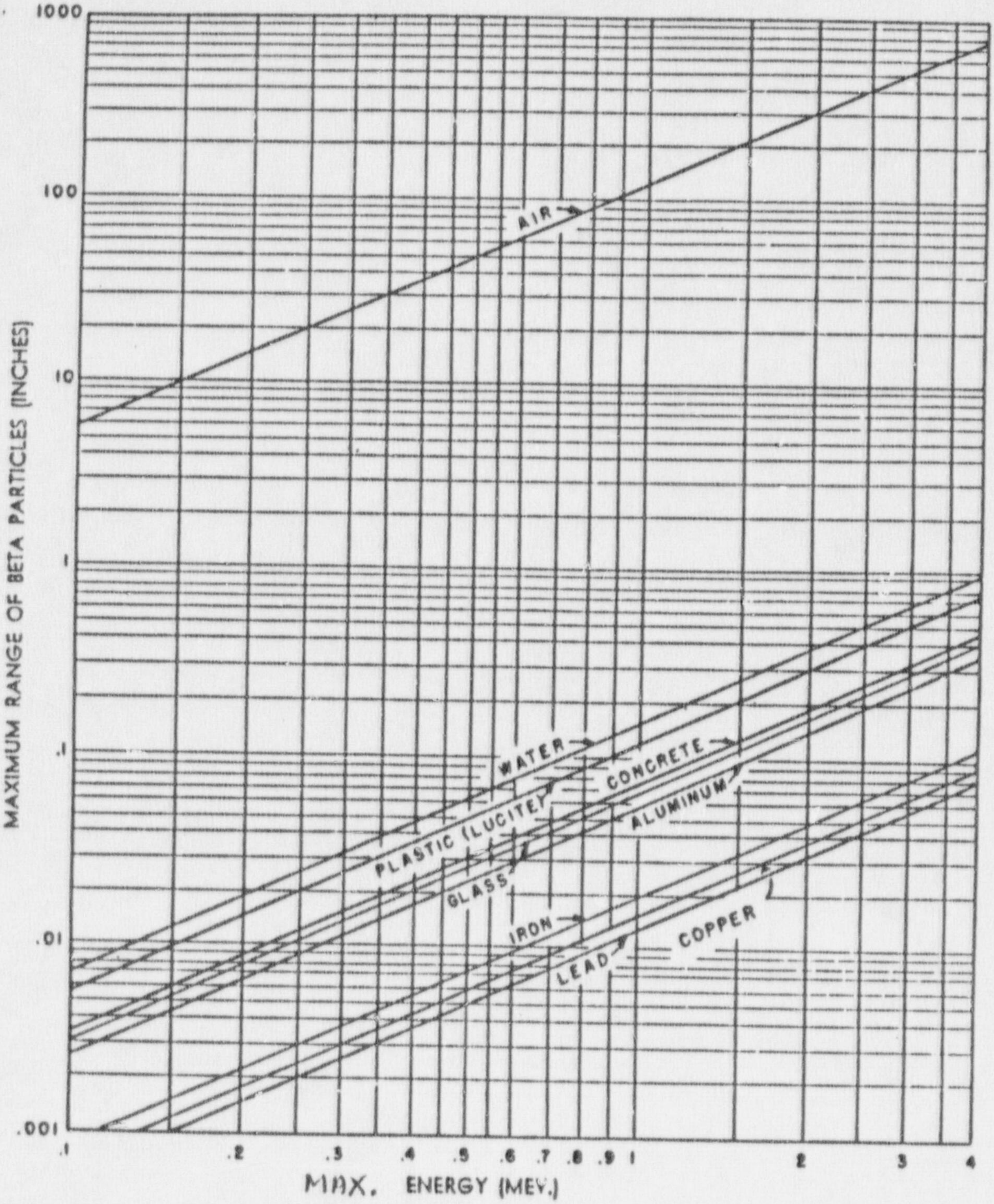


Figure 6.11 The maximum range of beta particles as a function of energy in the various materials indicated. (From SRI Report No. 361, "The Industrial Uses of Radioactive Fission Products.") (With Permission)

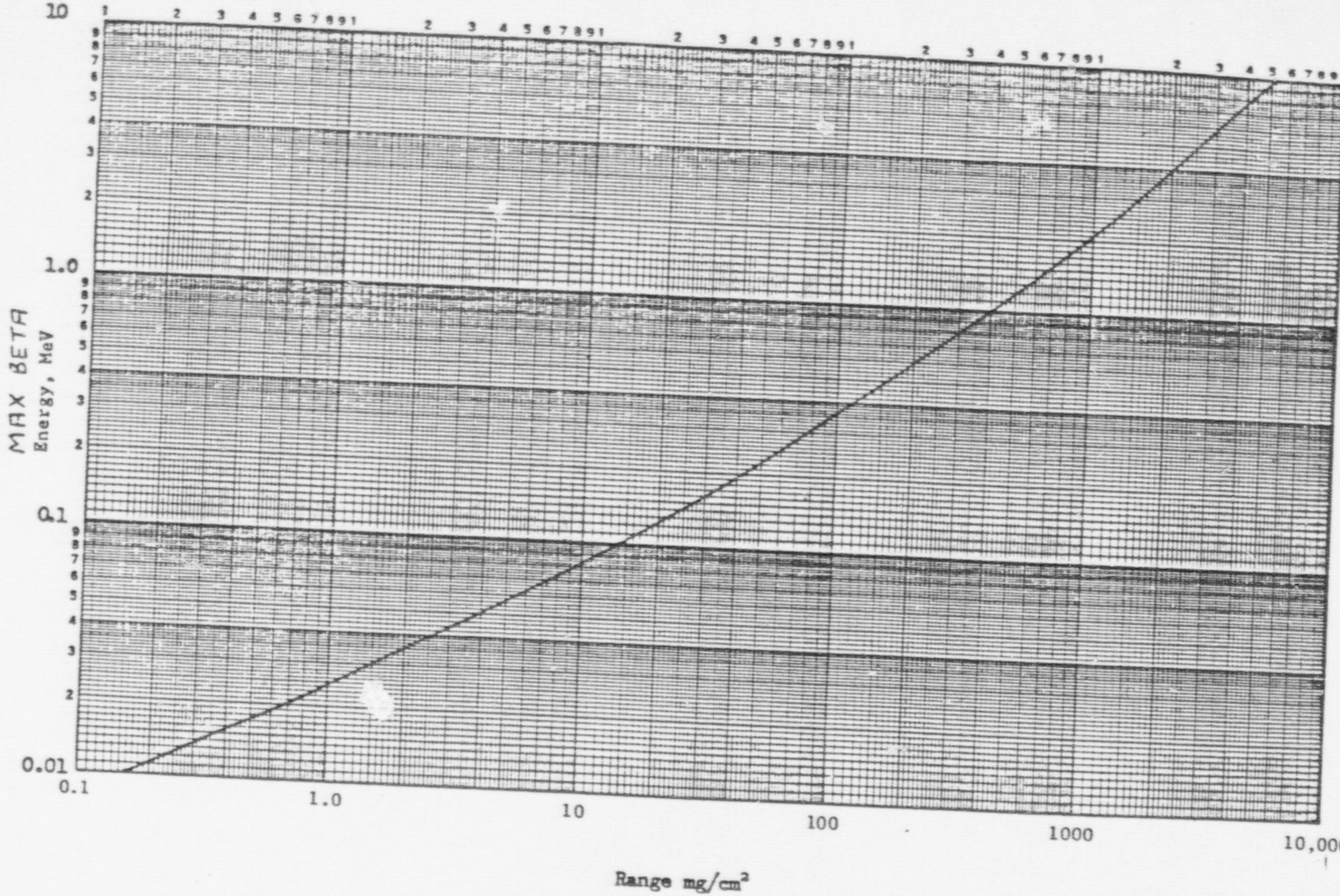
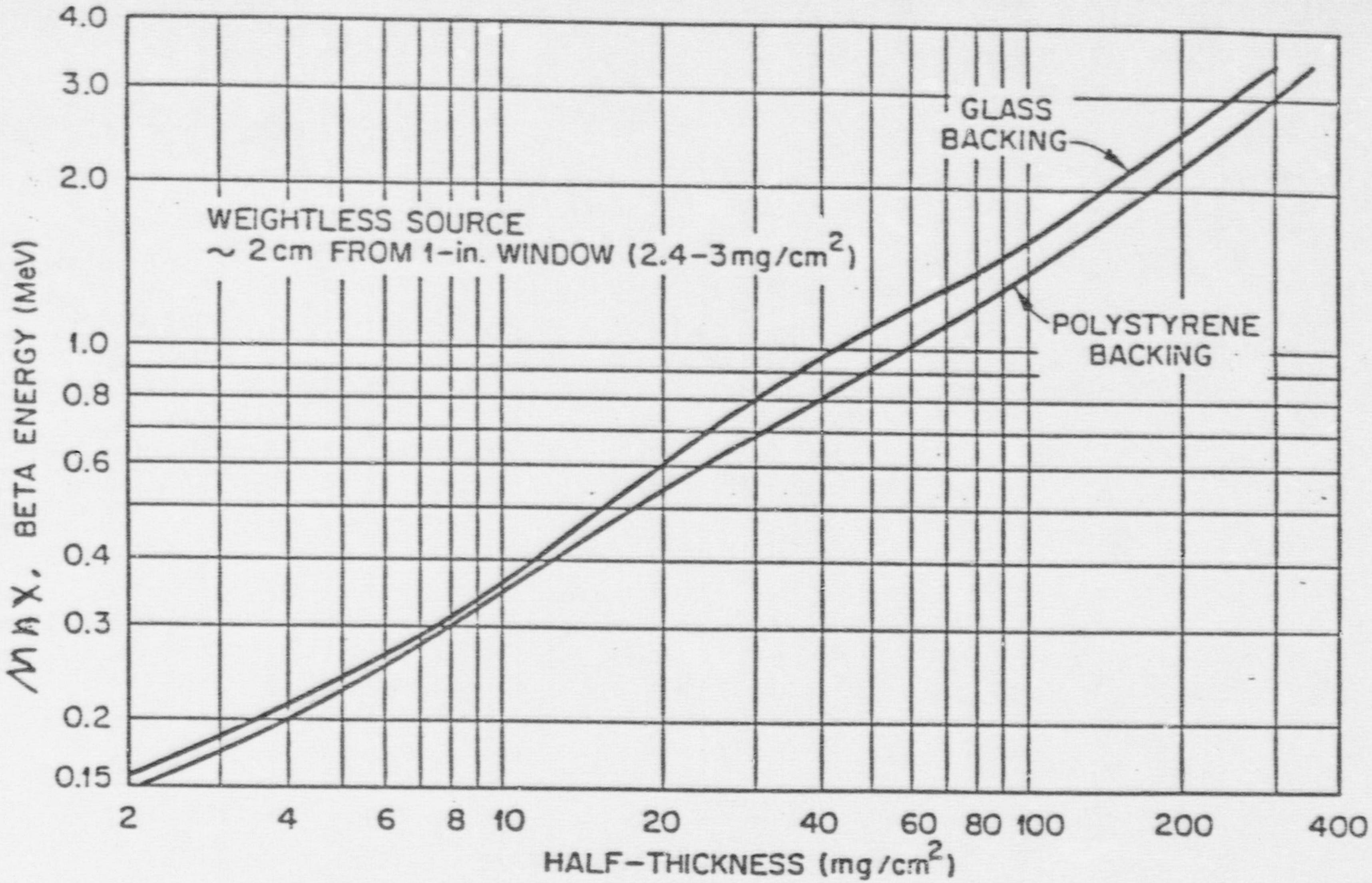
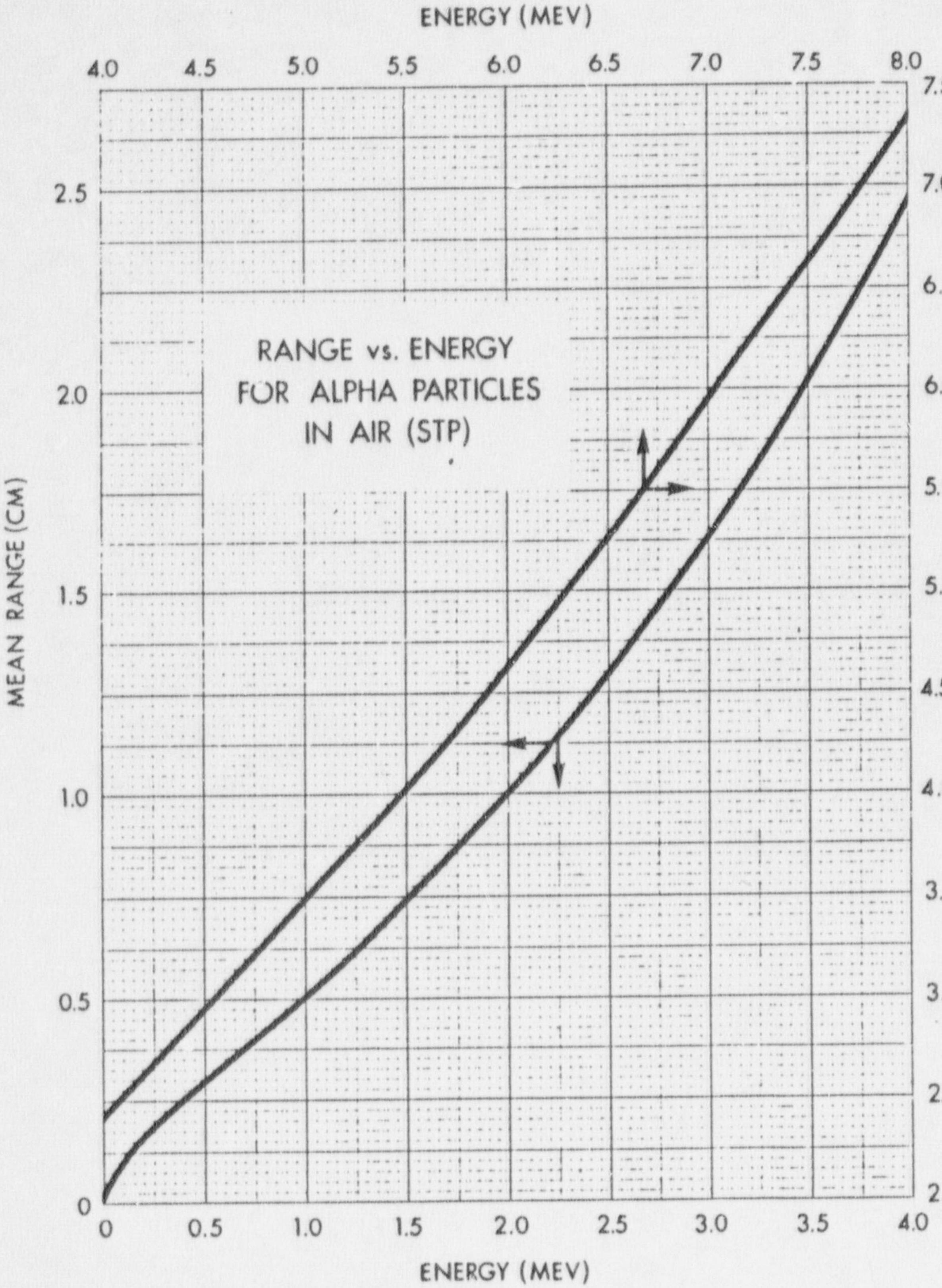


Figure 6.12 Beta Particle Range Energy Curve
(From Radiological Health Handbook, 1970).



Beta Radiation Initial Half-Thickness in Aluminum vs. Maximum Energy

FIGURE 6.13



7.5 Mev α to penetrate skin 7 mg/cm²

Figure 6.13 Range vs. energy for alpha particles in air (STP)
(From Radiological Health Handbook, 1970)

VALUES AND LOGARITHMS OF EXPONENTIAL FUNCTIONS

Note: If $0 < x < .01$ the value for e^{-x} can be found by the use of $(1-x)$ or the value for e^x can be found by the use of $(1 + x)$.

x	e^x		e^{-x}	x	e^x		e^{-x}
	Value	Log_{10}	Value		Value	Log_{10}	Value
0.00	1.0000	.00000	1.00000	0.50	1.6487	.21715	.60653
0.01	1.0101	.00434	.99005	0.51	1.6653	.22149	.60050
0.02	1.0202	.00869	.98020	0.52	1.6820	.22583	.59452
0.03	1.0305	.01303	.97045	0.53	1.6989	.23018	.58860
0.04	1.0408	.01737	.96079	0.54	1.7160	.23452	.58275
0.05	1.0513	.02171	.95123	0.55	1.7333	.23886	.57695
0.06	1.0618	.02606	.94176	0.56	1.7507	.24320	.57121
0.07	1.0725	.03040	.93239	0.57	1.7683	.24755	.56553
0.08	1.0833	.03474	.92312	0.58	1.7860	.25189	.55990
0.09	1.0942	.03909	.91393	0.59	1.8040	.25623	.55433
0.10	1.1052	.04343	.90484	0.60	1.8221	.26058	.54881
0.11	1.1163	.04777	.89583	0.61	1.8404	.26492	.54335
0.12	1.1275	.05212	.88692	0.62	1.8589	.26926	.53794
0.13	1.1388	.05646	.87809	0.63	1.8776	.27361	.53259
0.14	1.1503	.06080	.86936	0.64	1.8965	.27795	.52729
0.15	1.1618	.06514	.86071	0.65	1.9155	.28229	.52205
0.16	1.1735	.06949	.85214	0.66	1.9348	.28664	.51685
0.17	1.1853	.07383	.84366	0.67	1.9542	.29098	.51171
0.18	1.1972	.07817	.83527	0.68	1.9739	.29532	.50662
0.19	1.2092	.08252	.82696	0.69	1.9937	.29966	.50158
0.20	1.2214	.08686	.81873	0.70	2.0138	.30401	.49659
0.21	1.2337	.09120	.81058	0.71	2.0340	.30835	.49164
0.22	1.2461	.09554	.80252	0.72	2.0544	.31269	.48675
0.23	1.2586	.09989	.79453	0.73	2.0751	.31703	.48191
0.24	1.2712	.10423	.78663	0.74	2.0959	.32138	.47711
0.25	1.2840	.10857	.77880	0.75	2.1170	.32572	.47237
0.26	1.2969	.11292	.77105	0.76	2.1383	.33006	.46767
0.27	1.3100	.11726	.76338	0.77	2.1598	.33441	.46301
0.28	1.3231	.12160	.75578	0.78	2.1815	.33875	.45841
0.29	1.3364	.12595	.74826	0.79	2.2034	.34309	.45384
0.30	1.3499	.13029	.74082	0.80	2.2255	.34744	.44933
0.31	1.3634	.13463	.73345	0.81	2.2479	.35178	.44486
0.32	1.3771	.13897	.72615	0.82	2.2705	.35612	.44043
0.33	1.3910	.14332	.71892	0.83	2.2933	.36046	.43605
0.34	1.4049	.14766	.71177	0.84	2.3164	.36481	.43171
0.35	1.4191	.15200	.70469	0.85	2.3396	.36915	.42741
0.36	1.4333	.15635	.69768	0.86	2.3632	.37349	.42316
0.37	1.4477	.16069	.69073	0.87	2.3869	.37784	.41895
0.38	1.4623	.16503	.68386	0.88	2.4109	.38218	.41478
0.39	1.4770	.16937	.67706	0.89	2.4351	.38652	.41066
0.40	1.4918	.17372	.67032	0.90	2.4596	.39087	.40657
0.41	1.5068	.17806	.66365	0.91	2.4843	.39521	.40252
0.42	1.5220	.18240	.65705	0.92	2.5093	.39955	.39852
0.43	1.5373	.18675	.65051	0.93	2.5345	.40389	.39455
0.44	1.5527	.19109	.64404	0.94	2.5600	.40824	.39063
0.45	1.5683	.19543	.63763	0.95	2.5857	.41258	.38674
0.46	1.5841	.19978	.63128	0.96	2.6117	.41692	.38289
0.47	1.6000	.20412	.62500	0.97	2.6379	.42127	.37908
0.48	1.6161	.20846	.61878	0.98	2.6645	.42561	.37531
0.49	1.6323	.21280	.61263	0.99	2.6912	.42995	.37158
0.50	1.6487	.21715	.60653	1.00	2.7183	.43429	.36788

x	e^x Value	e^x $\log_{10}$	e^{-x} Value	x	e^x Value	e^x $\log_{10}$	e^{-x} Value
1.00	2.7183	.43429	.36788	1.50	4.4817	.65144	.22313
1.01	2.7456	.43864	.36422	1.51	4.5267	.65578	.22091
1.02	2.7732	.44298	.36060	1.52	4.5722	.66013	.21871
1.03	2.8011	.44732	.35701	1.53	4.6182	.66447	.21654
1.04	2.8292	.45167	.35345	1.54	4.6646	.66881	.21438
1.05	2.8577	.45601	.34994	1.55	4.7115	.67316	.21225
1.06	2.8864	.46035	.34646	1.56	4.7588	.67750	.21014
1.07	2.9154	.46470	.34301	1.57	4.8066	.68184	.20805
1.08	2.9447	.46904	.33960	1.58	4.8550	.68619	.20598
1.09	2.9743	.47338	.33622	1.59	4.9037	.69053	.20393
1.10	3.0042	.47772	.33287	1.60	4.9530	.69487	.20190
1.11	3.0344	.48207	.32956	1.61	5.0028	.69921	.19989
1.12	3.0649	.48641	.32628	1.62	5.0531	.70356	.19790
1.13	3.0957	.49075	.32303	1.63	5.1039	.70790	.19593
1.14	3.1268	.49510	.31982	1.64	5.1552	.71224	.19398
1.15	3.1582	.49944	.31664	1.65	5.2070	.71659	.19205
1.16	3.1899	.50378	.31349	1.66	5.2593	.72093	.19014
1.17	3.2220	.50812	.31037	1.67	5.3122	.72527	.18825
1.18	3.2544	.51247	.30728	1.68	5.3656	.72961	.18637
1.19	3.2871	.51681	.30422	1.69	5.4195	.73396	.18452
1.20	3.3201	.52115	.30119	1.70	5.4739	.73830	.18268
1.21	3.3535	.52550	.29820	1.71	5.5290	.74264	.18087
1.22	3.3872	.52984	.29523	1.72	5.5845	.74699	.17907
1.23	3.4212	.53418	.29229	1.73	5.6407	.75133	.17728
1.24	3.4556	.53853	.28938	1.74	5.6973	.75567	.17552
1.25	3.4903	.54287	.28650	1.75	5.7546	.76002	.17377
1.26	3.5254	.54721	.28365	1.76	5.8124	.76436	.17204
1.27	3.5609	.55155	.28083	1.77	5.8709	.76870	.17033
1.28	3.5966	.55590	.27804	1.78	5.9299	.77304	.16864
1.29	3.6328	.56024	.27527	1.79	5.9895	.77739	.16696
1.30	3.6693	.56458	.27253	1.80	6.0496	.78173	.16530
1.31	3.7062	.56893	.26982	1.81	6.1104	.78607	.16365
1.32	3.7434	.57327	.26714	1.82	6.1719	.79042	.16203
1.33	3.7810	.57761	.26448	1.83	6.2339	.79476	.16041
1.34	3.8190	.58195	.26185	1.84	6.2965	.79910	.15882
1.35	3.8574	.58630	.25924	1.85	6.3598	.80344	.15724
1.36	3.8962	.59064	.25666	1.86	6.4237	.80779	.15567
1.37	3.9354	.59498	.25411	1.87	6.4883	.81213	.15412
1.38	3.9749	.59933	.25158	1.88	6.5535	.81647	.15259
1.39	4.0149	.60367	.24908	1.89	6.6194	.82082	.15107
1.40	4.0552	.60801	.24660	1.90	6.6859	.82516	.14957
1.41	4.0960	.61236	.24414	1.91	6.7531	.82950	.14808
1.42	4.1371	.61670	.24171	1.92	6.8210	.83385	.14661
1.43	4.1787	.62104	.23931	1.93	6.8895	.83819	.14515
1.44	4.2207	.62538	.23693	1.94	6.9588	.84253	.14370
1.45	4.2631	.62973	.23457	1.95	7.0287	.84687	.14227
1.46	4.3060	.63407	.23224	1.96	7.0993	.85122	.14086
1.47	4.3492	.63841	.22993	1.97	7.1707	.85556	.13946
1.48	4.3929	.64276	.22764	1.98	7.2427	.85990	.13807
1.49	4.4371	.64710	.22537	1.99	7.3155	.86425	.13670
1.50	4.4817	.65144	.22313	2.00	7.3891	.86859	.13534

x	e^x		e^{-x}	x	e^x		e^{-x}
	Value	$\log_{10}$	Value		Value	$\log_{10}$	Value
2.00	7.3891	.86859	.13534	2.50	12.182	1.08574	.08208
2.01	7.4633	.87293	.13399	2.51	12.305	1.09008	.08127
2.02	7.5383	.87727	.13266	2.52	12.429	1.09442	.08046
2.03	7.6141	.88162	.13134	2.53	12.554	1.09877	.07966
2.04	7.6906	.88596	.13003	2.54	12.680	1.10311	.07887
2.05	7.7679	.89030	.12873	2.55	12.807	1.10745	.07808
2.06	7.8460	.89465	.12745	2.56	12.936	1.11179	.07730
2.07	7.9248	.89899	.12619	2.57	13.066	1.11614	.07654
2.08	8.0045	.90333	.12493	2.58	13.197	1.12048	.07577
2.09	8.0849	.90768	.12369	2.59	13.330	1.12482	.07502
2.10	8.1662	.91202	.12246	2.60	13.464	1.12917	.07427
2.11	8.2482	.91636	.12124	2.61	13.599	1.13351	.07353
2.12	8.3311	.92070	.12003	2.62	13.736	1.13785	.07280
2.13	8.4149	.92505	.11884	2.63	13.874	1.14219	.07208
2.14	8.4994	.92939	.11765	2.64	14.013	1.14654	.07136
2.15	8.5849	.93373	.11648	2.65	14.154	1.15088	.07065
2.16	8.6711	.93808	.11533	2.66	14.296	1.15522	.06995
2.17	8.7583	.94242	.11418	2.67	14.440	1.15957	.06925
2.18	8.8463	.94676	.11304	2.68	14.585	1.16391	.06856
2.19	8.9352	.95110	.11192	2.69	14.732	1.16825	.06788
2.20	9.0250	.95545	.11080	2.70	14.880	1.17260	.06721
2.21	9.1157	.95979	.10970	2.71	15.029	1.17694	.06654
2.22	9.2073	.96413	.10861	2.72	15.180	1.18128	.06587
2.23	9.2999	.96848	.10753	2.73	15.333	1.18562	.06522
2.24	9.3933	.97282	.10646	2.74	15.487	1.18997	.06457
2.25	9.4877	.97716	.10540	2.75	15.643	1.19431	.06393
2.26	9.5831	.98151	.10435	2.76	15.800	1.19865	.06329
2.27	9.6794	.98585	.10331	2.77	15.959	1.20300	.06266
2.28	9.7767	.99019	.10228	2.78	16.119	1.20734	.06204
2.29	9.8749	.99453	.10127	2.79	16.281	1.21168	.06142
2.30	9.9742	.99888	.10026	2.80	16.445	1.21602	.06081
2.31	10.074	1.00322	.09926	2.81	16.610	1.22037	.06020
2.32	10.176	1.00756	.09827	2.82	16.777	1.22471	.05961
2.33	10.278	1.01191	.09730	2.83	16.945	1.22905	.05901
2.34	10.381	1.01625	.09633	2.84	17.116	1.23340	.05843
2.35	10.486	1.02059	.09537	2.85	17.288	1.23774	.05784
2.36	10.591	1.02493	.09442	2.86	17.462	1.24208	.05727
2.37	10.697	1.02928	.09348	2.87	17.637	1.24643	.05670
2.38	10.805	1.03362	.09255	2.88	17.814	1.25077	.05613
2.39	10.913	1.03796	.09163	2.89	17.993	1.25511	.05558
2.40	11.023	1.04231	.09072	2.90	18.174	1.25945	.05502
2.41	11.134	1.04665	.08982	2.91	18.357	1.26380	.05448
2.42	11.246	1.05099	.08892	2.92	18.541	1.26814	.05393
2.43	11.359	1.05534	.08804	2.93	18.723	1.27248	.05340
2.44	11.473	1.05968	.08716	2.94	18.916	1.27683	.05287
2.45	11.588	1.06402	.08629	2.95	19.106	1.28117	.05234
2.46	11.705	1.06836	.08543	2.96	19.298	1.28551	.05182
2.47	11.822	1.07271	.08458	2.97	19.492	1.28985	.05130
2.48	11.941	1.07705	.08374	2.98	19.688	1.29420	.05079
2.49	12.061	1.08139	.08291	2.99	19.886	1.29854	.05029
2.50	12.182	1.08574	.08208	3.00	20.086	1.30288	.04979

x	e^x		e^{-x}
	Value	Log_{10}	Value
3.00	20.086	1.30288	.04979
3.05	21.115	1.32460	.04736
3.10	22.198	1.34631	.04505
3.15	23.336	1.36803	.04285
3.20	24.533	1.38974	.04076
3.25	25.790	1.41146	.03877
3.30	27.113	1.43317	.03688
3.35	28.503	1.45489	.03508
3.40	29.964	1.47660	.03337
3.45	31.500	1.49832	.03175
3.50	33.115	1.52003	.03020
3.55	34.813	1.54175	.02872
3.60	36.598	1.56346	.02732
3.65	38.475	1.58517	.02599
3.70	40.447	1.60689	.02472
3.75	42.521	1.62860	.02352
3.80	44.701	1.65032	.02237
3.85	46.993	1.67203	.02128
3.90	49.402	1.69375	.02024
3.95	51.935	1.71546	.01925
4.00	54.598	1.73718	.01832
4.10	60.340	1.78061	.01657
4.20	66.686	1.82404	.01500
4.30	73.700	1.86747	.01357
4.40	81.451	1.91090	.01227
4.50	90.017	1.95433	.01111
4.60	99.484	1.99775	.01005
4.70	109.95	2.04118	.00910
4.80	121.51	2.08461	.00823
4.90	134.29	2.12804	.00745
5.00	148.41	2.17147	.00674
5.10	164.02	2.21490	.00610
5.20	181.27	2.25833	.00552
5.30	200.34	2.30176	.00499
5.40	221.41	2.34519	.00452
5.50	244.69	2.38862	.00409
5.60	270.43	2.43205	.00370
5.70	298.87	2.47548	.00335
5.80	330.30	2.51891	.00303
5.90	365.04	2.56234	.00274
6.00	403.43	2.60577	.00248
6.25	518.01	2.71434	.00193
6.50	665.14	2.82291	.00150
6.75	854.06	2.93149	.00117
7.00	1096.6	3.04006	.00091
7.50	1808.0	3.25721	.00055
8.00	2981.0	3.47436	.00034
8.50	4914.8	3.69150	.00020
9.00	8103.1	3.90865	.00012
9.50	13360.	4.12580	.00007
10.00	22026.	4.34294	.00005

0062p

INTERNAL DOSIMETRY

I. Differences between internal and external exposures

A. The material is deposited inside of the individual.

II. Contamination and external dose concepts.

A. Exposure from a sealed source or x-ray machine

B. Exposure from an unsealed source or radioactive compound.

III. Radiation protection from external sources

A. Time

B. Distance

C. Shielding

IV. Protection mechanisms from internal exposures

A. Cannot use time, distance, or shielding

B. Sometimes elimination may be increased by chemicals.

C. Prevention is best internal dose reduction technique

V . Route of intake for internal exposures

A. Inhalation

B. Ingestion

C. Puncture

D. Absorption through skin

VI Metabolic pathways for radioactive material uptake to body.

A. Explain difference between intake and uptake.

VII. Metabolics of a Puncture

A. Skin contamination may lead to similar consequences.

VIII Inhalation metabolics

STUDY GUIDE PROBLEM

IX. Define the body burden

A. The amount of radioactive material in the body at any time

B. Body burdens may be measured directly.

1. Radiation must be penetrating enough to exit body.

2. If radiation is not penetrating, then samples of body fluids may be required.

3. Urine anlysis, sweat, blood, breath, fecal

X. Maximum permissible body burden

A. Define and explain the concept.

B. q is based on
0.1 REM/WEEK for gonads
0.6 REM/WEEK for skin and thyroid
0.3 REM/WEEK for soft tissues

BONE SEEKERS A SPECIAL CASE

XI. Dose commitment

A. Explain the dose commitment as it relates to the MPBB.

B. Explain using plot of activity versus time in the body and acute and chronic intakes.

XII. Factors which determine the organ dose

A. The mass of the organ, m

B. f_1, the fraction from the GI to blood

C. f_2, fraction from the blood to the organ

D. T_{eff}, the effective half life,

$$T_{eff} = T_{rad} * T_{bio} / T_{eff} + T_{rad}$$

E. $\mathcal{E}$ the effective energy absorbed per disintegration, MeV/disintegration

F. f_a, fraction taken in by breath reaching organ

G. f_w, fraction taken in by ingestion which reaches the organ.

mass -

T_e = effective half-life, hours.

STUDY GUIDE PROBLEM

.II. Basic Physics of Internal Exposures

A. Explain fraction retained. Handout tables 1 and 8, with appendix A.

1. Man breaths at 20 liters/min, 20000 cm^3 / min

f_a = fraction of inhaled isotope reaching the organ

PROBLEM: man breaths air at 5 uC/cm^3 for 20 minutes of I^{131}. Where does isotope deposite and how much deposited?

From table 1, $f_a = .23$

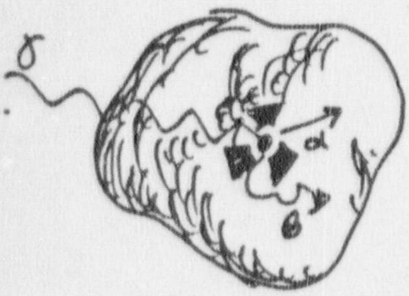
$$q = 5 \frac{uC}{cm^3} * 20000 \ cm^3/min * 20 \ min * .23 = 4.6 \times 10^5 \ uCi$$

IN THYROID GLAND

STUDY GUIDE PROBLEM.

IV. RAD ORGAN DOSES.

ORGAN



A. 1 RAD = 100 ergs / gm.

$$\frac{RAD}{HR} = \left(\frac{MEV}{DIS}\right)_{ABS.} * \frac{(dps)}{MASS, gm} \ 5.76 \times 10^{-5}$$

$$RAD_{\infty} = \left(\frac{RAD}{hr}\right) * \frac{T_E}{.693}$$

B. α's, Beta's, gammas absorbed to varying degrees.

TABLE 1 $\left(\frac{MEV}{DIS}\right)_{ABS}$ = Mev of energy given off as Radiation which is absorbed in the organ. = E

dps = dps in organ.

MASS = mass of organ, grams.

T_e = effective half-life, hours.

STUDY GUIDE PROBLEM

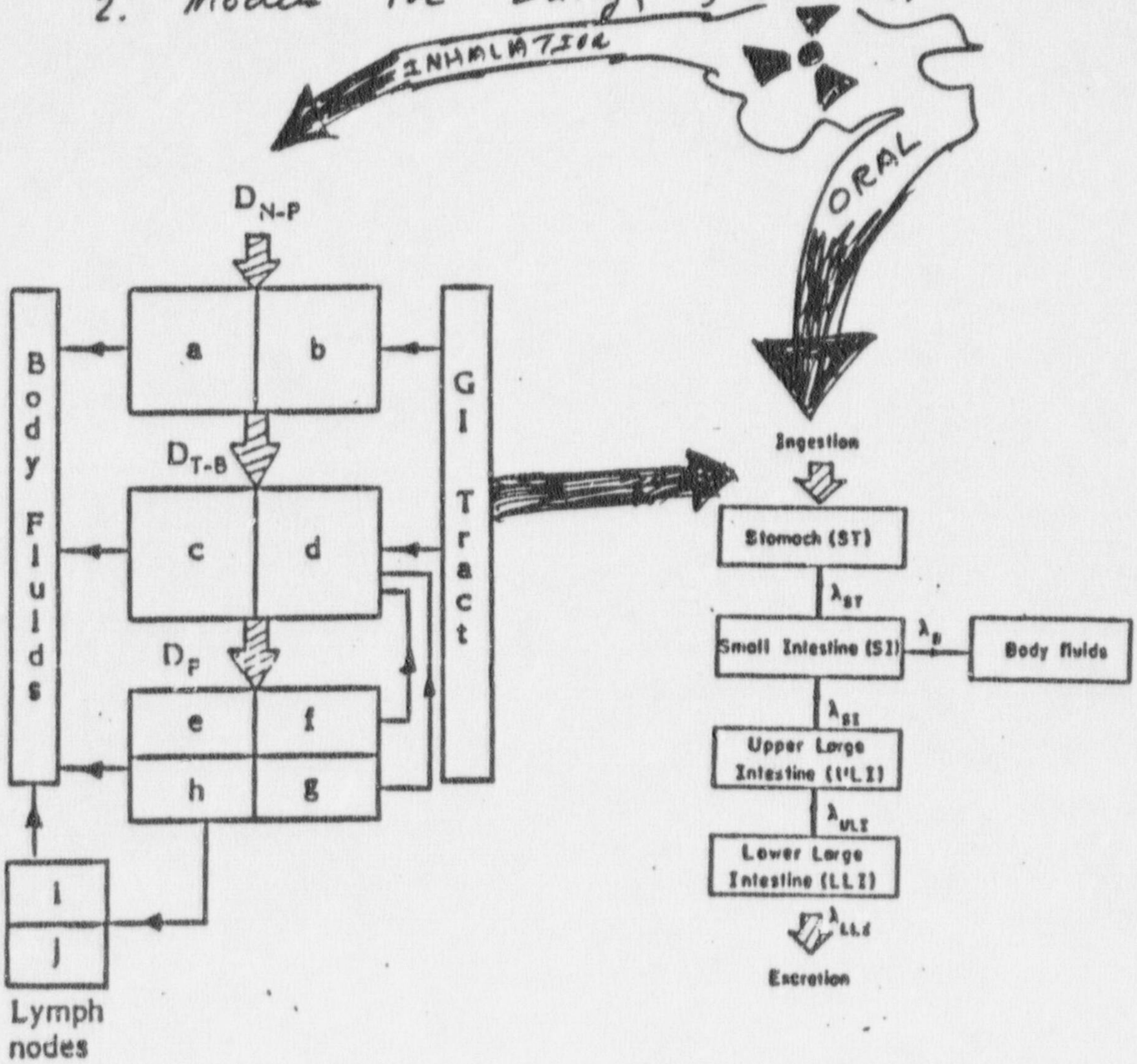
V. ICRP 30 COMMITTED DOSE SYSTEM.

A. Explain concept

1. Grays, Sieverts

   1 Sievert = 100 REM

2. Models For Lung, Stomach.



3. Airborne materials classed as DAY, WEEK, YEAR lung clearance.

   CLASS Y: THORIUM OXIDES
   HYDROXIDES

   CLASS W: ALL OTHERS

XVI. RISK AND WEIGHTING FACTORS

A. Lifetime cancer risk mortality

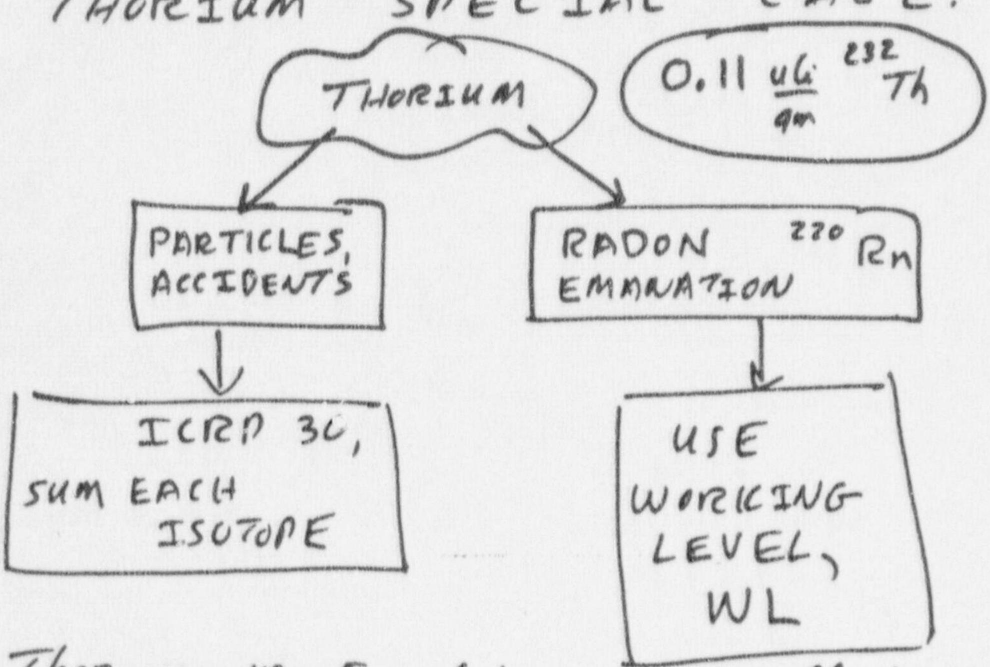
$$1 \times 10^{-4} \text{ PER REM}$$

< 5 REM / year Limit

B. ORGAN WEIGHTS

ORGAN	W_T WEIGHTING
GONADS	0.25
BREAST	0.15
RED BONE MARROW	0.12
LUNG	0.12
THYROID	0.03
BONE SURFACES	0.03
REMAINDER	0.30

C. THORIUM SPECIAL CASE - DOSE ASSESSMENT



D. Thorium in Equilibrium — all daughters are equal in activity.

II. WORKING LEVEL

A. Based on ^{222}Rn (Uranium Series)

$$1 \text{ WL} = 1.3 \times 10^5 \frac{\text{Mev alpha}}{\text{Liter of air}}$$

B. Dose factor 2 WLM/yr = 4×10^{-4} annual CA risk

14 REM / WLM Lung

C. WL for 40 hrs/week, 4 weeks/month.

D. Air samples required to determine WL.

$$\# \text{WLM} = \left(\frac{\text{Hours exp. per month}}{160 \text{ hours/mo.}}\right) * f_{WL}$$

1 WLM = 40 hrs/wk for 1 month at 1 WL

USA average indoor = 0.2 WLM/yr → 3 Rem/yr.

STUDY GUIDE PROBLEM

XVIII. CHART OF DOSE FACTORS FOR Thorium Daughters.

A. Explain seperation of daughters From parent.

1. Fire, heat
2. Grinding

B STUDY GUIDE PROBLEM.

APPENDIXES

APPENDIX A

TABULATION OF METABOLIC INFORMATION FROM ICRP PUBLICATION 2 (REVISED ACCORDING TO PUBLICATION 6)

In Table I (p. 25) the column headings have the meanings:

Organ: that leading to the smallest value of q given in Table I

ϵ	$\Sigma EF\,(RBE)n$, (E in MeV), for the appropriate organ
T_r	radioactive half-life (days)
T_b	biological half-life (days) for critical organ, and for whole body in parentheses when different from that of critical organ
T_{eff}	effective half-life (days)
f_1	fraction from gastrointestinal tract to blood
f_2	fraction in organ of reference of that in total body
— f_2'	fraction from blood to organ of reference —
f_w	fraction of that taken into the body by ingestion that is retained in the critical organ
f_a	fraction of that taken into the body by inhalation that is retained in the critical organ
q	maximum permissible body burden (μCi)
MPC_w	maximum permissible concentration in drinking water for radiation workers for 40-hr week (μCi/ml)
MPC_a	maximum permissible concentration in inhaled air for radiation workers for 40-hr week (μCi/cc)
*	The critical organs for C–14, S–35, Te–132, Au–198, and Po–210 given in Table I are different from those used in Appendix C. In each case the reasons for the change are given in the section of Appendix C dealing with that nuclide.

MEV / dis

TABLE I. METABOLIC INFORMATION FROM ICRP PUBLICATIONS 2 AND 6

Table Radio-nuclide	1 Organ	5 ε	12 DAYS T_r	12 DAYS T_b	12 DAYS T_{eff}	12 f_1	12 f_2	12 f_2'	12 f_w	12 f_a	1 q	1 MPC_w	1 MPC_a
1 H-3 (oxide)	Body tissue	0·010	$4\cdot5 \times 10^3$	12	12	1·0	1·0	1·0	1·0	1·0	1×10^3	0·1	5×10^{-6}
*6 C-14 (CO_2)	Fat	0·27	$2\cdot0 \times 10^6$	40 (10)	40	1·0	0.1	0·025	0·025	0·02	400	0·04	6×10^{-6}
11 Na-22	Total body	1·6	950	11	11	1·0	1·0	1·0	1·0	0·75	10	1×10^{-3}	2×10^{-7}
15 P-32	Bone	3·5	14·3	1155 (257)	14·1	0·75	0.5	0·5	0·375	0·32	6	5×10^{-4}	7×10^{-8}
*16 S-35	Testis	0·056	87·1	90	44·3	1·0	1·0	1·0	1·0	0·75	400	7×10^{-3}	1×10^{-6}
17 Cl-36	Total body	0·26	$1\cdot2 \times 10^{8}$	29	29	1·0	1·0	1·0	1·0	0·75	80	2×10^{-3}	4×10^{-7}
20 Ca-45	Bone	0·43	164	$1\cdot8 \times 10^4$ ($1\cdot64 \times 10^4$)	162	0·6	0·9	0·9	0·54	0·5	30	3×10^{-4}	3×10^{-8}
26 Fe-59	Spleen	0·94	45·1	600 (800)	41·9	0·1	0·02	0·02	$2\cdot0 \times 10^{-3}$	6×10^{-3}	20	4×10^{-3}	1×10^{-7}
27 Co-60	Total body	1·5	$1\cdot9 \times 10^3$	9·5	9·5	0·3	1·0	1·0	0·3	0·4	10	4×10^{-4}	4×10^{-7}
30 Zn-65	Total body	0·32	245	933	194	0·1	1·0	1·0	0·1	0·3	60	3×10^{-4}	1×10^{-7}
37 Rb-86	Total body	0·70	18·6	45	13·2	1·0	1·0	1·0	1·0	0·75	30	2×10^{-3}	3×10^{-7}
38 Sr-85	Total body	0·33	65	$1\cdot3 \times 10^4$	64·7	0·3	1·0	1·0	0·3	0·4	60	3×10^{-3}	2×10^{-7}
38 Sr-89	Bone	2·8	50·5	$1\cdot8 \times 10^4$ ($1\cdot3 \times 10^4$)	50·4	0·3	0·99	0·7	0·21	0·28	4	3×10^{-4}	3×10^{-8}
38 Sr-90	Bone	5·5	$1\cdot0 \times 10^4$	$1\cdot8 \times 10^4$ ($1\cdot3 \times 10^4$)	$6\cdot4 \times 10^3$	0·3	0·99	0·3	0·09	0·12	2	1×10^{-6}	1×10^{-8}
*52 Te-132	Kidney	0·96	3·2	30 (15)	2·9	0·25	0·07	0·07	0·02	0·03	3	5×10^{-3}	4×10^{-7}
53 I-131	Thyroid	0·23	8	138	7·6	1·0	0·2	0·3	0·3	0·23	0·7	6×10^{-4}	9×10^{-8}
53 I-132	Thyroid	0·65	0·097	138	0·097	1·0	0·2	0·3	0·3	0·23	0·3	2×10^{-3}	2×10^{-7}
55 Cs-137	Total body	0·59	$1\cdot1 \times 10^4$	70	70	1·0	1·0	1·0	1·0	0·75	30	4×10^{-4}	6×10^{-8}
56 Ba-140	Bone	4·2	12·8	65	10·7	0·05	0·7	0·7	0·035	0·19	[illegible]	6×10^{-3}	1×10^{-7}
58 Ce-144	Bone	6·3	290	1500 (563)	243	$<10^{-4}$	0·38	0·3	$3\cdot0 \times 10^{-5}$	0·0?3	5	0·2	1×10^{-8}
*79 Au-198	Kidney	0·41	2·7	280 (120)	2·7	0·1	0·03	0·03	$3\cdot0 \times 10^{-3}$	9×10^{-3}	20	0·07	3×10^{-8}
*84 Po-210	Spleen	55	138·4	60 (30)	42	0·06	0·07	0·04	$2\cdot0 \times 10^{-2}$	0·01	0·03	2×10^{-5}	5×10^{-10}
88 Ra-226	Bone	110	$5\cdot9 \times 10^5$	$1\cdot64 \times 10^4$ (900)	$1\cdot6 \times 10^4$	0·3	0·99	0·1	0·03	0·04	0·1	4×10^{-7}	3×10^{-11}
90 Th nat	Bone	270	?	$7\cdot3 \times 10^4$ ($5\cdot7 \times 10^4$)	$7\cdot3 \times 10^4$	$<10^{-4}$	0·9	0·7	$7\cdot0 \times 10^{-4}$	0·18	0·01	3×10^{-5}	2×10^{-12}
92 U nat & U 238	Kidney	43	?	15 (100)	15	$<10^{-4}$	0·065	0·11	$1\cdot1 \times 10^{-3}$	0·028	5×10^{-3}	2×10^{-4}	7×10^{-11}
92 U-233	Bone	250	$5\cdot9 \times 10^7$	300 (100)	300	$<10^{-4}$	0·85	0·11	$1\cdot1 \times 10^{-3}$	0·028	0·05	1×10^{-4}	5×10^{-10}
92 U-234	Bone	240	$9\cdot1 \times 10^7$	300 (100)	300	$<10^{-4}$	0·85	0·11	$1\cdot1 \times 10^{-3}$	0·028	0·05	1×10^{-4}	5×10^{-10}
92 U-235	Kidney	46	$2\cdot6 \times 10^{11}$	15 (100)	15	$<10^{-4}$	0·065	0·11	$1\cdot1 \times 10^{-3}$	0·028	0·03	1×10^{-4}	5×10^{-10}
93 Np-239	Bone	0·98	2·33	$7\cdot3 \times 10^4$ ($3\cdot9 \times 10^4$)	2·33	$<10^{-4}$	0·45	0·45	$4\cdot5 \times 10^{-5}$	0·11	30	100	4×10^{-6}
94 Pu-239	Bone	270	$8\cdot9 \times 10^6$	$7\cdot3 \times 10^4$ ($6\cdot5 \times 10^4$)	$7\cdot2 \times 10^4$	3×10^{-5}	0·9	0·8	$2\cdot4 \times 10^{-5}$	0·2	0·04	1×10^{-4}	2×10^{-12}
94 Pu-241	Bone	14	$4\cdot8 \times 10^3$	$7\cdot3 \times 10^4$ ($6\cdot5 \times 10^4$)	$4\cdot5 \times 10^3$	3×10^{-5}	0·81	0·8	$2\cdot4 \times 10^{-5}$	0·2	0·9	7×10^{-5}	9×10^{-11}

Table 8. Organs of standard man

Mass and effective radius of organs of the adult human body

	Mass, *m* (g)	Per cent of total body*	Effective radius, *X* (cm)
Total body*	70,000	100	30
Muscle	30,000	43	30
Skin and subcutaneous tissue†	6100	8.7	0.1
Fat	10,000	14	20
Skeleton			
Without bone marrow	7000	10	5
Red marrow	1500	2.1	
Yellow marrow	1500	2.1	
Blood	5400	7.7	
Gastrointestinal tract*	2000	2.9	30
Contents of GI tract			
Lower large intestine	150		5
Stomach	250		10
Small intestine	1100		30
Upper large intestine	135		5
Liver	1700	2.4	10
Brain	1500	2.1	15
Lungs (2)	1000	1.4	10
Lymphoid tissue	700	1.0	
Kidneys (2)	300	0.43	7
Heart	300	0.43	7
Spleen	150	0.21	7
Urinary bladder	150	0.21	
Pancreas	70	0.10	5
Salivary glands (6)	50	0.071	
Testes (2)	40	0.057	3
Spinal Cord	30	0.043	1
Eyes (2)	30	0.043	0.25
Thyroid gland	20	0.029	3
Teeth	20	0.029	
Prostate gland	20	0.029	3
Adrenal glands or suprarenal (2)	20	0.029	3
Thymus	10	0.014	
Ovaries (2)	8	0.011	3
Hypophysis (Pituitary)	0.6	8.6×10^{-4}	0.5
Pineal Gland	0.2	2.9×10^{-4}	0.04
Parathyroids (4)	0.15	2.1×10^{-4}	0.06
Miscellaneous (blood vessels, cartilage, nerves, etc.)	390	0.56	

* Does not include contents of the gastrointestinal tract.

† The mass of the skin alone is taken to be 2000 grams.

COMMITTED DOSE EQUIVALENT FACTORS
THORIUM AND DAUGHTERS (ICRP#30)

MREM / UCI OF INTAKE

ISOTOPE	ORAL Bone Surfaces	INHALATION	Lung	Bone Surfaces
^{232}Th	7.03×10^4	D	----	----
		W	----	4.07×10^7
		Y	3.5×10^6	1.85×10^7
^{228}Ra	2.15×10^4	D	----	-----
		W	2.66×10^4	2.41×10^4
		Y	-----	----
^{228}Ac	1.11×10^1	D	------	5.18×10^3
		W	1.29×10^2	1.29×10^3
		Y	9.25×10^2	------
^{228}Th	8.88×10^3	D	-----	-----
		W	3.52×10^5	5.18×10^6
		Y	2.55×10^6	-----
^{224}Ra	5.92×10^3	D	----	----
		W	2.44×10^4	-----
		Y	-----	-----
^{220}Rn	----		-----	-----
^{216}Po	-----		-----	-----
^{212}Pb	6.29×10^2	D	7.4×10^2	1.37×10^3
		W	-----	------
		Y	----	-----
^{212}Bi	5.92×10^0 (Stomach Wall)	D	1.26×10^2	9.99×10^1 (Kidneys)
		W	1.44×10^2	-----
		Y	----	-----
^{208}Tl	----		----	---
^{212}Po	----		----	---

STUDY GUIDE PROBLEMS

Internal Exposure Evaluation

A total of 1 uCi of ^{86}Rb is known to be in an individuals body. What is the effective half life of this isotope and how much activity will be present in the body 20 days from now?

A worker accidently disperses 1 mCi of ^{45}Ca into a room of volume 1000 liters(L). He breaths the air for 3 hours. What is his intake? What is the uptake to bone?

A worker breaths air for 20 minutes containing a concentration of ^{59}Fe equal to 0.01 uC/L. What is the initial dose rate to the spleen? What is the total dose to the spleen?

What would be the dose to the lung of an individual exposed to 0.05 WL for 10 hours per week in a months time? What would be the dose per year?

1 WL = 40 HRS week   1 WLM = 4 wks / month.

WLM = $\left(\frac{10}{40}\right)$ each wk.   WLM = 0.05 * 1/4 = 0.0125 WLM

1 month = (0.0125) * 14 Rem/WLM = 0.175 Rem

Dose / yr = 12 * .175 = 2.1 REM

USA Average indoor 0.2 WLM/yr → 3 Rem/yr.

A metal alloy fire occurrs and thorium is seperated from its daughters. Assume all daughters are in equilibrium and are released to the air. A total of 3 grams of alloy which has a 3% ^{232}Th content are released into 10000 L of air. A worker is present for 10 minutes. What is the committed dose to the lung and bone surfaces?

3 grams × 0.03 = 0.09 gm ^{232}Th ^{232}Th ≈ .11 uCi/gm

Q_m = 9.9 × 10^{-3} uCi = Q daughters.

Fire releases all but Th.

χ = 9.9 × 10^{-7} uCi/L   at 20 L/min   INTAKE ≈ 1.98 × 10^{-4} uCi EACH DAUGHTER

	Lung (mrem)	Bone
^{228}Ra	5.27	4.77
^{228}Ac	0.18	1.02
^{224}Ra	4.83	—
^{212}Pb	0.15	0.27
^{212}Bi	0.03	-

Σ = 10.5 mrem   Σ = 6.06 mrem

\+   ≈ ~~[illegible]~~ .2 mrem GASES → ~~[illegible]~~ 10.7 mrem Total Lung

---

assume GAS IN EQUILIBRIUM WITH DAUGHTERS:

100 pCi/l = 1 WL   χ = 9.9 × 10^{-7} uCi/l = 1 pCi/l.

Exposure f_{WL} ≈ .01 WL ~~: [illegible] 102 min / week = 0.0042 [illegible] = [illegible] WL~~

~~Lung Dose = ∫ 0.017 WLM * 14 Rem/WLM = [illegible] mRem~~

~~[illegible] Exposure Σ (.01)(.017) = 1.7 × 10^{-4} Total~~

$$\left[\frac{\text{(Hours exposed / month)}}{\text{160 Hours / month}}\right] * f_{WL} = \text{\# WLM}$$

$$\left[\frac{.17}{160}\right] .01 = 1.1 \times 10^{-5} \text{ WLM} \rightarrow 0.15 \text{ mrem.}$$

HOMEWORK PROBLEM

Internal Exposures

A worker is grinding a metal part for a total of 20 minutes. Assume the thorium alloy is 3% of the total weight. If one gram of the metal is released into 100 liters of air space, what would be the total committed lung and bone surface dose if the individual breathed this concentration?

OUTLINE

DETECTION AND MEASUREMENT OF NUCLEAR RADIATION

I. Types of Radiations

II. Interaction of Radiation with Matter

   A. Particulate Radiation

   B. Electromagnetic Radiation
      1. Photoelectric Effect
      2. Compton Scattering
      3. Pair Production

III. Detection Systems

IV. Pulse Height Analyzers

OUTLINE

BASIC PRINCIPLES OF RADIATION DETECTION INSTRUMENTS

I. Introductions

II. Gas Ionizations

A. Regions of Response

1. Recombination Region
2. Proportional Region
3. Region of Limited Proportionality
4. Geiger-Mueller Region
5. Continuous Discharge Region

B. Operational and Practical Considerations

III. Photographie Emulsions

IV Scintillation Media

V. Semiconductors

A. Diffused p-n junction

B. Surface barrier Detectors

C. Lithium Drifted Detectors

VI. Thermoluminescence

VII. Summary

VIII. References

SURVEY INSTRUMENTS

I. Introduction

II. Ionization Chambers

A. Theory

B. Physical Description

C. Operation

D. Calibration

E. Use

III. Geiger-Mueller Instruments

A. Theory

B. Physical Description
1. G-M Tube
2. Electronics

C. Operation

D. Calibration

E. Use

IV. Proportional Survey Instruments

A. Theory

B. Physical Description
1. Probe
2. Electronics

C. Operation

D. Calibration

E. Use

V. Scintillation Survey Instruments

A. Theory

B. Physical Description
   1. Scintillation Phosphors
   2. Photpmultiplier Tube
   3. Electronics

C. Operations

D. Calibration

E. Use

VI. Energy Dependence of Instruments

A. Electronic Equilibrium

B. Bragg-Gray Principle

C. Gas-Filled Detectors

D. Pocket Dosimeters

E. G-M Tubes

F. Scintillation Detectors

OUTLINE

PERSONNEL INSTRUMENTS

I. Introduction

II. Film Dosimetry

  A. Emulsions

  B. Theory of Latent Image Formation

  C. Limitations
    1. Energy Dependence
    2. Angular Dependence
    3. Rate of Exposure
    4. Developing Techniques
    5. Material of Holder

  D. Dosimeters and Pocket Chambers
    1. Dosimeters
    2. Pocket Chambers
    3. Characteristics

III. Summary

IV. References

OUTLINE

RADIATION PROTECTION PROGRAM

1. Definitions

   Radioactive
   Radioactive Contamination
   Curie
   Airborne Activity
   Decontamination
   Half-life

2. External Exposure

   Protection Techniques

   Time
   Distance
   Shielding

   Internal Exposure

   Pathways into Body

   Inhalation
   Ingestion
   Absorption
   Puncture

   Protective Techniques

   Protective Clothing
   Contamination Control
   Eating, Drinking, Smoking

   Pathways out of Body

   Urine
   Feces
   Exhalation
   Perspiration

3. Natural Background Radiation

   Cosmic
   Terrestrial
   Internal
   Man-made

4. Radiation Protection Organization

   International
   National
   Governmental

5. Provisions of Radiation Control Regulations

Registration and/or Licensing
Limitation of Exposure
Fixation of Responsibility
Recordkeeping
Reporting
Penalties

6. Dose Limit Recommendations

7. Evaluation of Personal Exposures

. Required Records

Regulations

10 CFR Part 19
10 CFR Part 20
10 CFR Part 40, Domestic Licensing of Source Material

1. Part 40.3 License Requirements
   Part 40.4 Definition of Source Material

2. Part 40.7 Employee Protection
   Protected Activities

3. Part 40.13 Unimportant Quantities of Source Material
   Exemptions
   Magnesium-Thorium Alloys
   Finished Aircraft Engine Parts

4. Part 40.20 Types of Licenses
   General
   Special

5. General Licenses
   Small quantities of source material
      15 lbs. at any one time
      150 lbs./year limit

6. Part 40.31 Application for Specific License
   General Requirements for issuance of Specific License
   Terms and Conditions of Licenses
   Amendments
   Renewals

7. Part 40.61 Records

8. Inspections

9. Enforcement
   Part 40.81 Violations

RSO FINAL EXAM

NAME:_______________________________________ DATE:____________________

(1) The Federal Agency which controls the licensing and use of byproduct Radioactive material in the United States is:

(a) AEC, Atomic Energy Commission.

(b) DOE, Department of Energy.

(c) NRC, Nuclear Regulatory Commission.

(d) IRS, Internal Revenue Service.

(2) The current philosophy on the Biological effects of low doses of Radiation is:

(a) There is a threshold dose below which no effects occur.

(b) Any Radiation exposure poses a risk of future effect.

(c) The damage produced depends on your physical condition at the time of exposure.

(d) Radiation is harmless and causes no damage.

(3) Which of the following is the largest amoung of radioactivity?

(a) 50 uCi

(b) 10 mCi

(c) 1 uCi

(d) 1 Ci

(4) The radioactive half life of a radioactive substance is:

(a) time required for the material to completely decay.

(b) time which a particular substance is useful for experimentation.

(c) related to the chemical form and is not used in activity determinations.

(d) time required for one half of the activity to decay.

(5) Radioactive contamination is:

(a) Radioactive material on a surface which when rubbed with a piece of filter paper deposits on the paper.

(b) A measurable dose Rate emanating from a radioactive package.

(c) A virus labeled with a radioactive isotope.

(d) A laboratory surface which has not been properly disinfected.

(6) The unit of Radiation exposure which indicates electrical charge produced in air:

(a) Rad

(b) REM

(c) Roentgen

(d) REP

(7) The unit of Radiation energy absorption is the:

(a) RAD

(b) REM

(c) Roentgen

(d) REP

(8) The unit of Radiation dose which indicates the risk of a radiation exposure with the damaging ability of the radiation factored in:

(a) RAD

(b) REM

(c) Roentgen

(d) REP

(9) The maximum yearly whole body dose permitted by law to an occupationally exposed radiation worker is:

(a) 500 MREM

(b) 10 RAD

(c) 5 REM

(d) Not specified in federal guidelines.

(10) The effects of very large doses of radiation:

(a) are not well known as no human exposure data are available.

(b) are not known but require years for symptoms to appear.

(c) are of no concern as the body's immune system repairs the damage.

(d) are well documented, predictable, and occur within hours to days depending on the dose.

(11) The major concern in exposing human populations to low doses of radiation is:

(a) induced abortion in pregnant females.

(b) induction of leukemia and other forms of cancer later on in life.

(c) defense against viral infection is reduced.

(d) production of brain tumors.

(12) An external whole body exposure to radiation occurs:

(a) when you accidentally swallow some radioactive material.

(b) during your entire life.

(c) only when you get a dental x-ray.

(d) only if you are an occupationally exposed radiation worker.

(13) When a radioactive material enters your body:

(a) it is excreted immediately and hence no radiation dose results.

(b) it creates a high fever with chills.

(c) it distributes throughout your body and is eliminated at a rate which is determined by a combination of the radiological half life of the element and the biological half life of the element in your body.

(d) a large and massive radiation dose occurs, leading to radiation sickness and death.

(14) Urine samples are collected from individuals using radioactive compounds in order to:

(a) determine glucose level.

(b) determine amount of radioactive material an individual has ingested.

(c) determine if individual is pregnant.

(d) flush the body of all radioactive material.

(15) The most prudent immediate action to take if you suspect you have generated a radioactive gas or aerosol is:

(a) take a smear and count it in a liquid scintillation counter.

(b) try to contain the release of radioactive material by using absorbent matting.

(c) hold breath and leave area, restrict access.

(d) take no action as the material diffuses rapidly in air to insignificant concentrations.

(16) If an occupationally exposed worker receives the maximum yearly allowed dose each year during his working lifetime,

(a) he is most likely to die of cancer as a result of the exposure.

(b) he should be monitored by a physician and extensive blood work performed.

(c) he would have no greater health risk than a typical "safe" occupation, such as a clerk typist.

(d) this is impossible, as radiation sickness would result within the first two years and the person would die.

(17) The naturally occurring throium decay series is best described as

(a) two radioactive isotopes

(b) thorium and several of its radioactive daughters, including the stable end product of lead-208.

(c) a competition between two major league isobars to see which will become an isotone.

(d) several radioactive nuclides of thorium, radioactive magnesium, and other daughter elements.

(18) Select any of the below for a correct answer.

(a) 3.148×10^{38}

(b) 0.0

(c) none of the above

(19) The difference between a radioactive atom and a non-radioactive atom is:

(a) the radioactive atom has an excess number of electrons in the nucleus.

(b) the outer electron shell of the radioactive atom is deficient in electrons.

(c) the radioactive atom must have tritium in its nucleus.

(d) the number of neutrons and protons in the nucleus is such that an excess amount of energy exists.

(20) Generally speaking, as the energy of a beta particle or gamma ray increases the amount of shielding required for adequate protection:

(a) must be reduced.

(b) should not be altered.

(c) should be halved.

(d) should be increased.

(21) An external whole body occupational radiation exposure is usually determined using:

(a) a film badge.

(b) a liquid scintillation counter.

(c) an estimate of the quantity of radioactive material used.

(d) changes in white blood cell counts.

(22) The basic factors in reducing radiation exposure from external sources of radiation are:

(a) plenty of rest, fluids, and aspirin.

(b) time, distance, and shielding.

(c) personality, charm, and perseverance.

(d) wearing a film badge and changing it routinely.

(23) In designing an experiment with radioactive material, the potential radiation dose you receive should be of concern. In the experimental design,

(a) you are permitted to receive the maximum yearly dose as prescribed by federal law.

(b) you are permitted to receive 1/10th of the maximum yearly dose as prescribed by federal law.

(c) you are not permitted any exposure.

(d) your exposure should be kept as low as is practicable in completion of your experiment, and much less than the allowed limits.

(24) If a radioactive compound is accidentally splashed or dropped on your skin, you should:

(a) apply ice for 24 hours, followed by hot packs.

(b) begin flushing the area immediately scrubbing lightly with soap and water

(c) cover the contaminated area of skin to prevent further contamination.

(d) not be concerned as very little material will enter your body.

(25) In case of an emergency list whom you would contact for radiation safety advice and action.

1. ________________________________ Phone: ____________________

(26) An isotope has a half-life of 10 days. If you initially had 8 mCi of this isotope, how much would be left 20 days later?

(a) 7 mCi

(b) 6 mCi

(c) 4 mCi

(d) 2 mCi

(27) The most appropriate shield for a beta source is:

(a) no shield is required as betas are easily absorbed

(b) Lead

(c) lucite or plastic

(d) glass

(28) The natural background radiation dose rate increases as you increase in altitude because:

(a) there are fewer nuclear power plants at these altitudes.

(b) there is less atmosphere to absorb the radiation coming from outer space.

(c) radioactive waste in the atmosphere tends to concentrate at higher altitudes.

(d) the radioactive half-life of this radiation is very short.

0042p

RADIATION SAFETY OFFICER FINAL EXAM

In completing the following please show your work in a step by step manner as credit is given for proper technique even though a calculational error may be made. Good luck!

1. Convert the following

5 mCi = ______________ dps   3 Ci = ________________dps

5 uCi = ______________ dps 1×10^4 dps = __________ mCi

1.7×10^8 dps = ______________ Ci   1700 dps= __________________uCi

2. A radioactive material decays by the emission of beta particles followed by gamma radiation. Beta particles of 1.0 MeV maximum energy are emitted in 10 % of the disintegrations and gamma rays are emitted with 0.5 MeV energy 50 % and .35 MeV 40 % of the disintegrations. Compute for 5 mCi of this radioactive material(this test is easy!)

Total gammas/second emitted = ____________________

Total betas/second emitted = ____________________

3. If the radioactive material in the problem 2 has a radiological half life of 10 days, what would be the activity 30 days from now? What would have been the gamma emission rate 20 days before in gammas/sec?(a piece of cake!)

Activity 30 days from now = ______________________

Gammas/sec 20 days before = ______________________

4. A radioactive material has the following radioactive decay characteristics:

1.2 Mev max. beta	30 %
0.3 Mev max. beta	20 %
.3 Mev gamma	100 %
1.0 Mev gamma	100 %

Compute the gamma ray exposure rate and the approximate beta absorbed dose rate to the skin at 10 cm from a point source containing 1 mCi. (when the going gets tough, the tough get going!)

gamma exposure rate = __________mr/hr beta dose rate =__________mrad/hr

5. Using the information obtained in problem 4, compute the exposure rate and beta absorbed dose rate to the skin if the source is encapsulated in an aluminum container which is 0.1 cm thick. Assume the density of aluminum is 2.7 gm/cm^3 and the density of air is 0.001293 gm/cm^3(no problem!).

gamma exposure rate = __________mr/hr beta dose rate = ________mrad/hr

6. An individual is working with 4 mCi of ^{32}P in a room measuring 300 cm by 300 cm by 250 cm high. An accident occurrs and this material is released into the room. The worker breaths the air for a period of 8 minutes. What is the intake of ^{32}P? What is the critical organ and what is the uptake to the critical organ? What will be the activity in the critical organ 30 days from now?(being foolish yesterday makes it easier to be wiser today)

intake of ^{32}P = _____________ uCi critical organ = ____________

uptake to organ = _____________ uCi activity in 30 days =_______uCi

7. A metal chip fire occurrs in a storage area measuring 200cm by 200 cm by 200 cm high. It is estimated that the maximum temperature reached was 2200°C. A total of 7000 grams of alloy is involved with a 3% by weight thorium content. What would be the maximum potential internal exposure for an individual who breathed this air for 5 minutes trying to extinguish the fire? (You thought the worst was over, didn't you?)

Appendix C

BUTKIN PRECISION MANUFACTURING CORPORATION

EMPLOYEE RADIATION SAFETY TRAINING

OUTLINE

1. Definitions

    Radioactive
    Radioactive Contamination
    Curie
    Airborne Activity
    Decontamination
    Half-life

2. External Exposure

    Protection Techniques

        Time
        Distance
        Shielding

    Internal Exposure

    Pathways into Body

        Inhalation
        Ingestion
        Absorption
        Puncture

    Protective Techniques

        Protective Clothing
        Contamination Control
        Eating, Drinking, Smoking

    Pathways out of Body

        Urine
        Feces
        Exhalation
        Perspiration

3. Biological Effects of Radiation

4. Natural Background Radiation

    Cosmic
    Terrestrial
    Internal
    Man-made

5. Radiation Protection Organization

   International
   National
   Governmental

6. Provisions of Radiation Control Regulations

   Registration and/or Licensing
   Limitation of Exposure
   Fixation of Responsiblity
   Recordkeeping
   Reporting
   Penalties
   10 CFR Part 19
   10 CFR Part 20

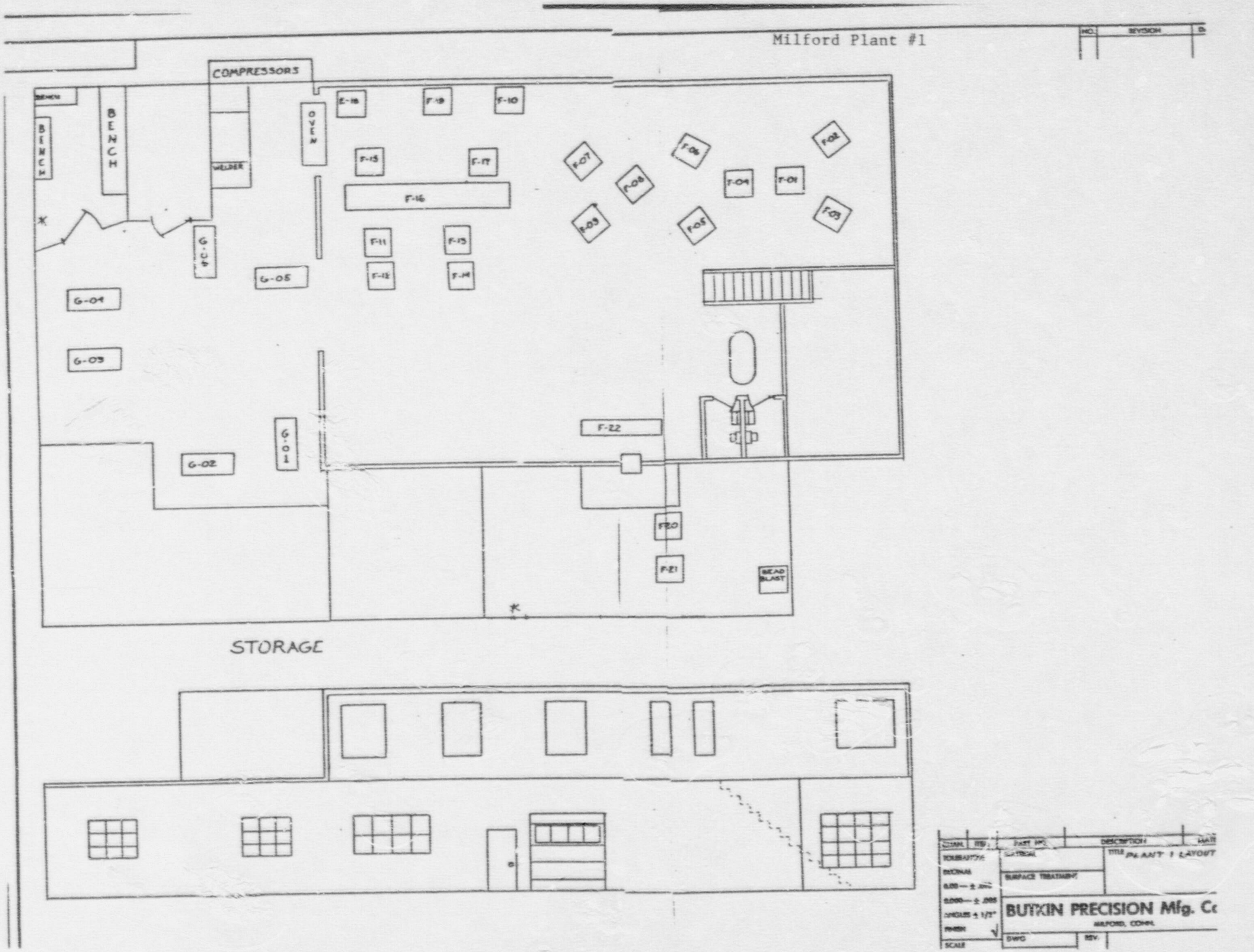
7. Dose Limit Recommendations

8. Evaluation of Personal Exposures

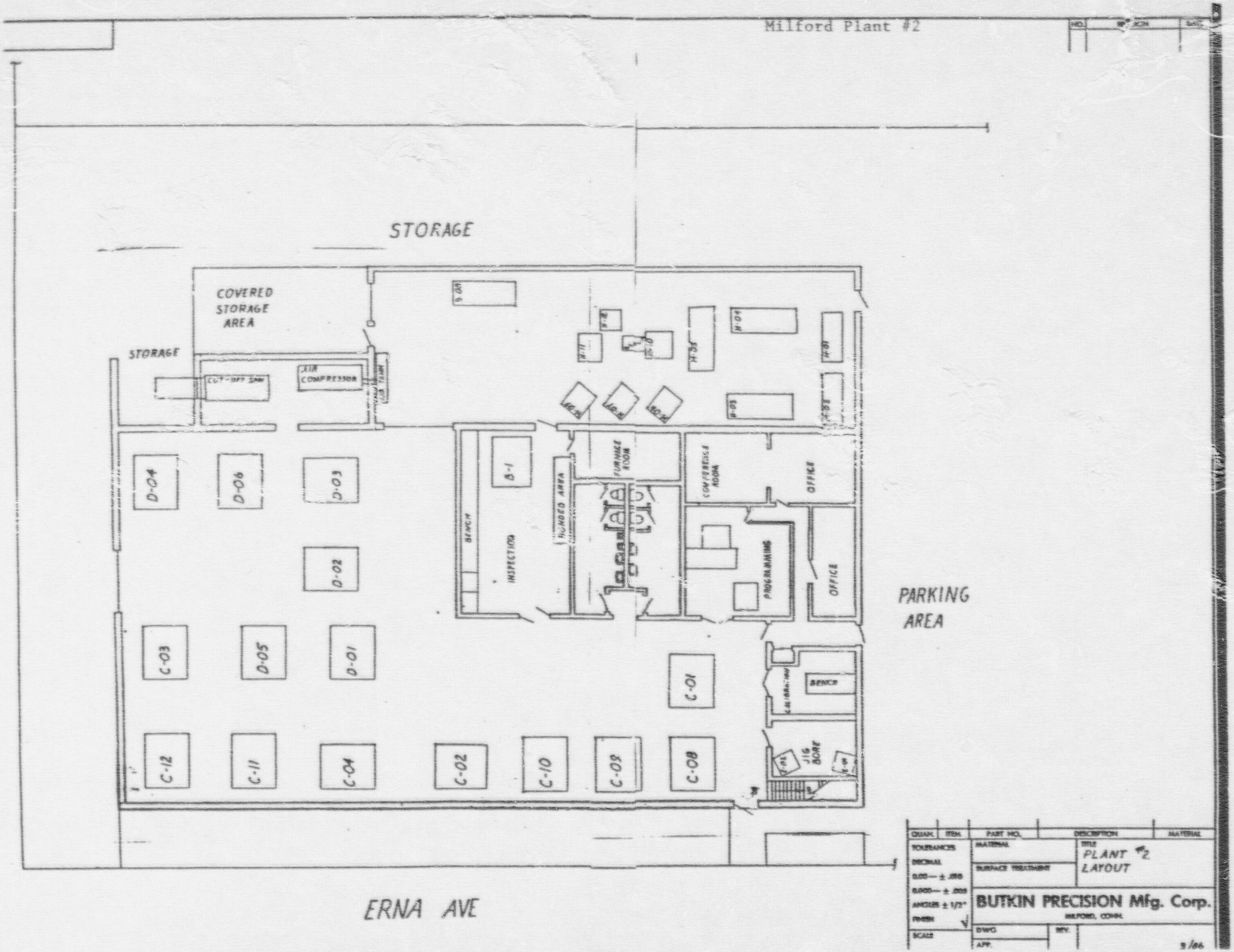
9. Required Records

APPENDIX D

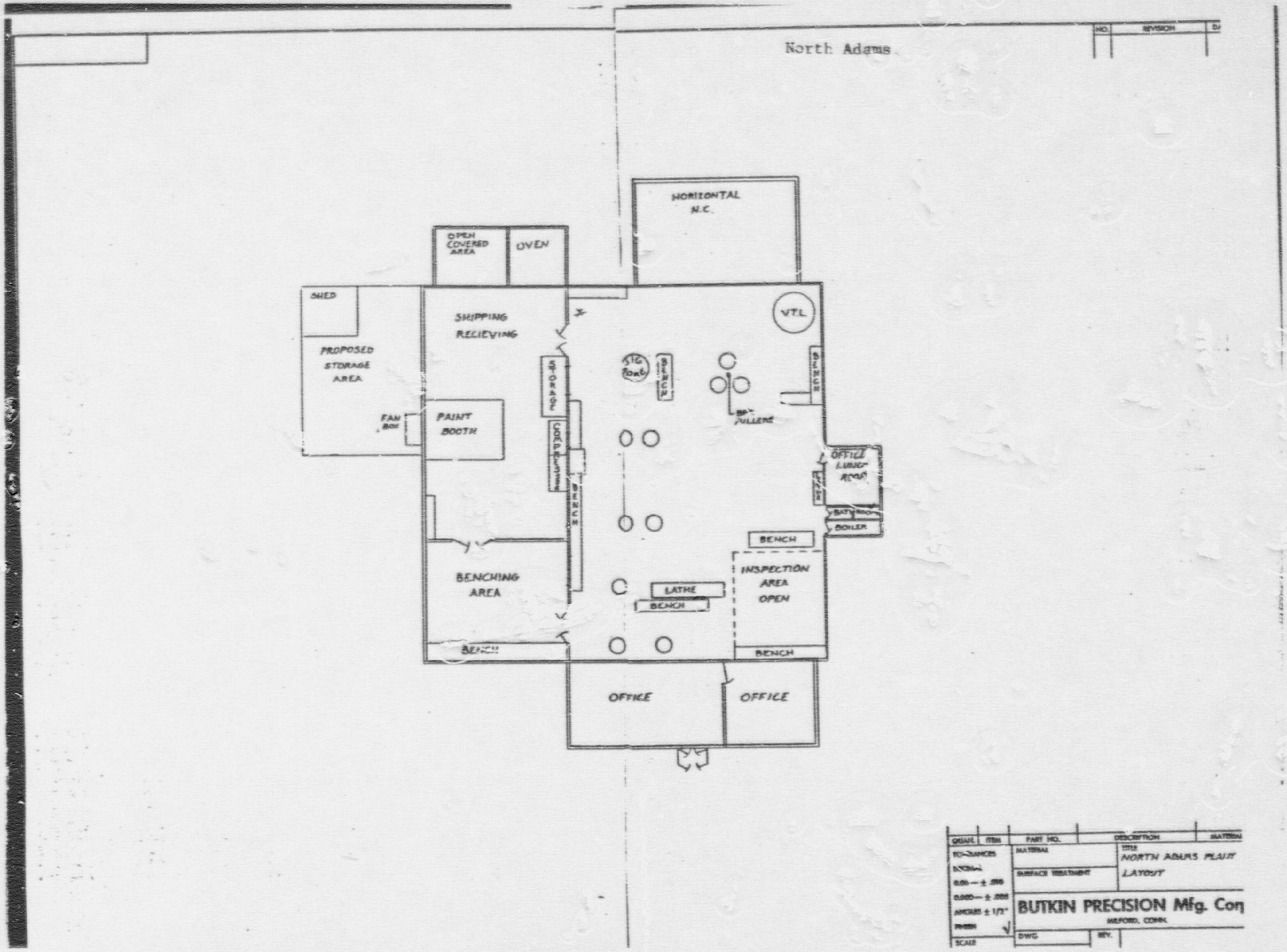
FACILITIES AND EQUIPMENT



Milford Plant #1
NO.
REVISION
COMPRESSORS
BENCH
BENCH
BENCH
WELDER
OVEN
F-18
F-19
F-10
F-15
F-17
F-16
F-11
F-13
F-12
F-14
F-07
F-08
F-09
F-06
F-05
F-04
F-01
F-02
F-03
G-04
G-05
G-04
G-03
G-01
G-02
F-22
F20
F-21
BEAD BLAST
STORAGE
PLANT 1 LAYOUT
BUTKIN PRECISION Mfg. Co
MILFORD, CONN.
DWG
REV.
SCALE
FINISH
SURFACE TREATMENT
MATERIAL
DESCRIPTION
TOLERANCES
DECIMAL
ANGLES ± 1/2°

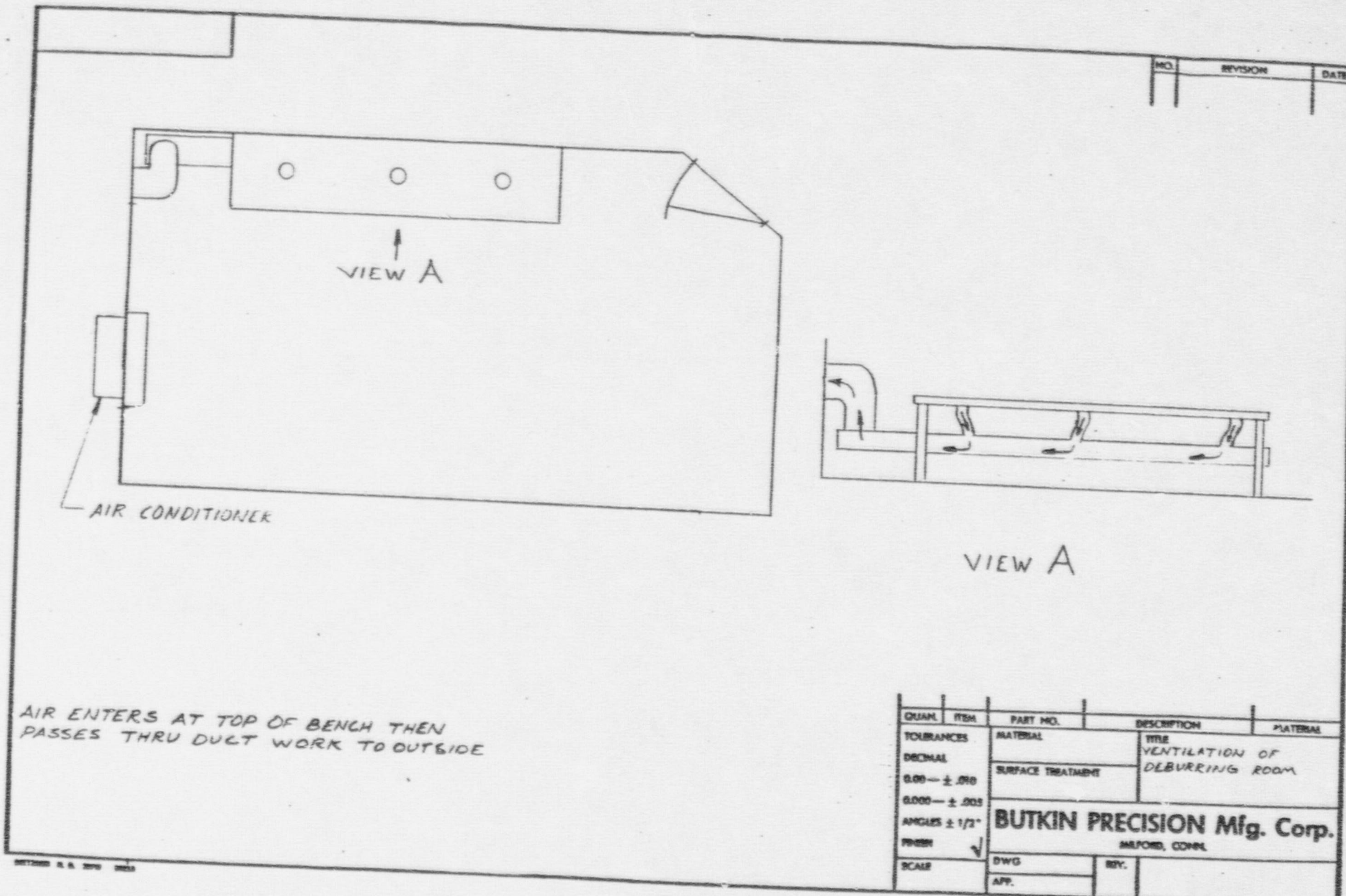


Milford Plant #2
STORAGE
COVERED STORAGE AREA
STORAGE
CUT-OFF SAW
AIR COMPRESSOR
D-04
D-06
D-03
D-02
C-03
D-05
D-01
C-12
C-11
C-04
C-02
C-10
C-09
C-08
C-01
B-1
BENCH
INSPECTION
BONDED AREA
FURNACE ROOM
CONFERENCE ROOM
OFFICE
PROGRAMMING
OFFICE
BENCH
JIG BORE
PARKING AREA
ERNA AVE
PLANT #2 LAYOUT
BUTKIN PRECISION Mfg. Corp.
MILFORD, CONN.



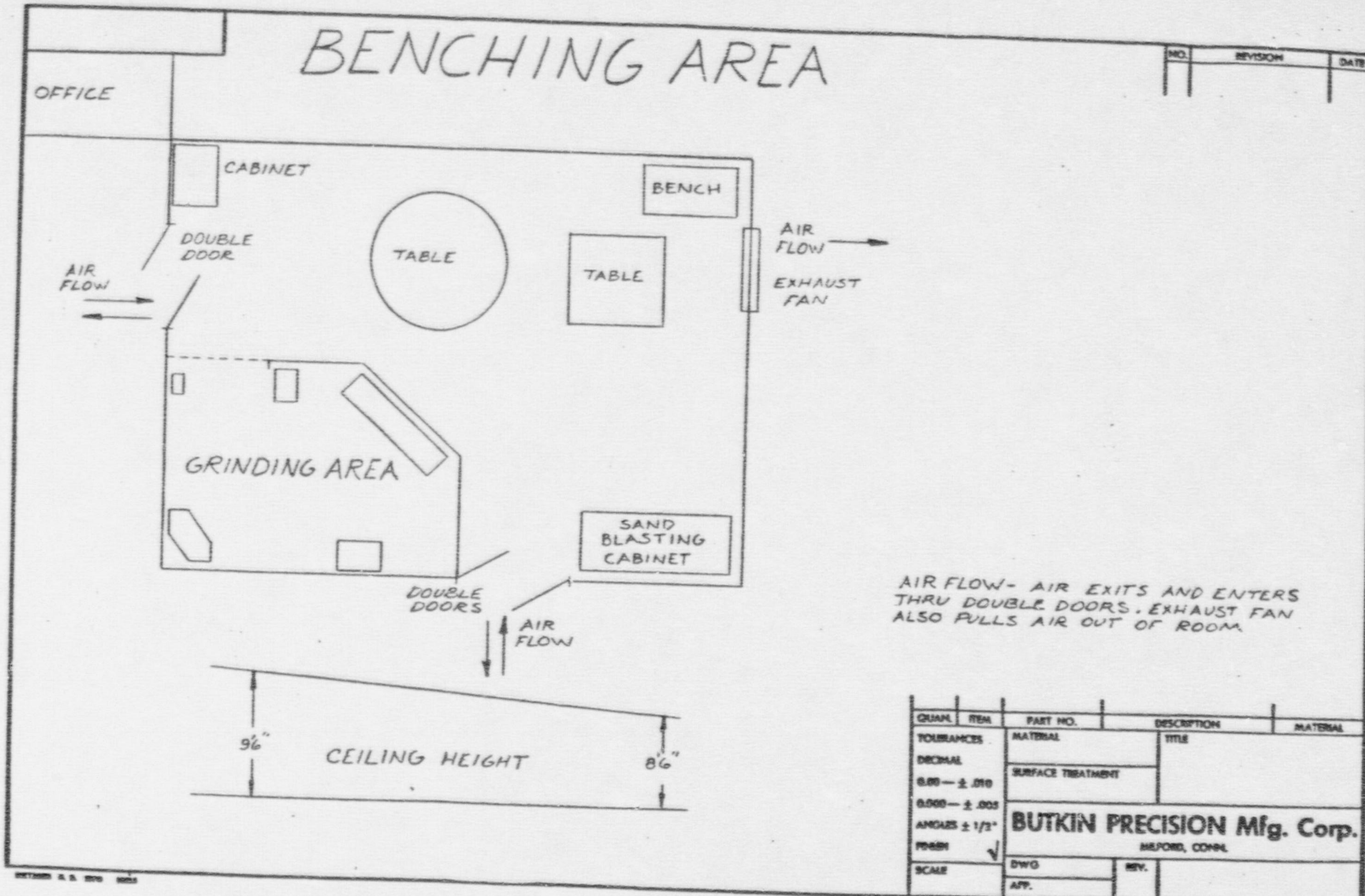
North Adams
NO.
REVISION
HORIZONTAL N.C.
OPEN COVERED AREA
OVEN
SHED
PROPOSED STORAGE AREA
FAN BOX
SHIPPING RECIEVING
PAINT BOOTH
STORAGE
BENCH
BENCHING AREA
V.T.L.
BENCH
LATHE
BENCH
OFFICE LUNCH ROOM
BOILER
INSPECTION AREA OPEN
BENCH
OFFICE
OFFICE
QUAN.
ITEM
PART NO.
DESCRIPTION
MATERIAL
TOLERANCES
MATERIAL
SURFACE TREATMENT
TITLE
NORTH ADAMS PLANT LAYOUT
BUTKIN PRECISION Mfg. Co
MILFORD, CONN.
ANGLES ± 1/2°
FINISH
SCALE
DWG
REV.

Milford

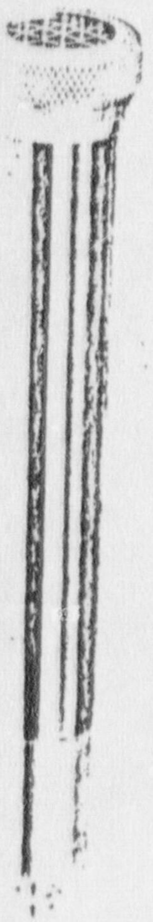


NO.
REVISION
DATE
VIEW A
AIR CONDITIONER
VIEW A
AIR ENTERS AT TOP OF BENCH THEN
PASSES THRU DUCT WORK TO OUTSIDE
QUAN.
ITEM
PART NO.
DESCRIPTION
MATERIAL
TOLERANCES
DECIMAL
0.00 — ± .010
0.000 — ± .005
ANGLES ± 1/2°
FINISH
SCALE
MATERIAL
SURFACE TREATMENT
TITLE
VENTILATION OF
DEBURRING ROOM
BUTKIN PRECISION Mfg. Corp.
MILFORD, CONN.
DWG
APP.
REV.

North Adams


BENCHING AREA
OFFICE
CABINET
DOUBLE DOOR
AIR FLOW
TABLE
TABLE
BENCH
AIR FLOW
EXHAUST FAN
GRINDING AREA
SAND BLASTING CABINET
DOUBLE DOORS
AIR FLOW
9'6"
CEILING HEIGHT
8'6"
AIR FLOW- AIR EXITS AND ENTERS THRU DOUBLE DOORS. EXHAUST FAN ALSO PULLS AIR OUT OF ROOM
NO.
REVISION
DATE
QUAN.
ITEM
PART NO.
DESCRIPTION
MATERIAL
TOLERANCES
DECIMAL
0.00 — ± .010
0.000 — ± .005
ANGLES ± 1/2°
FINISH √
SCALE
MATERIAL
SURFACE TREATMENT
TITLE
BUTKIN PRECISION Mfg. Corp.
MILFORD, CONN.
DWG
APP.
REV.

Hand Probe
Model HP-230A

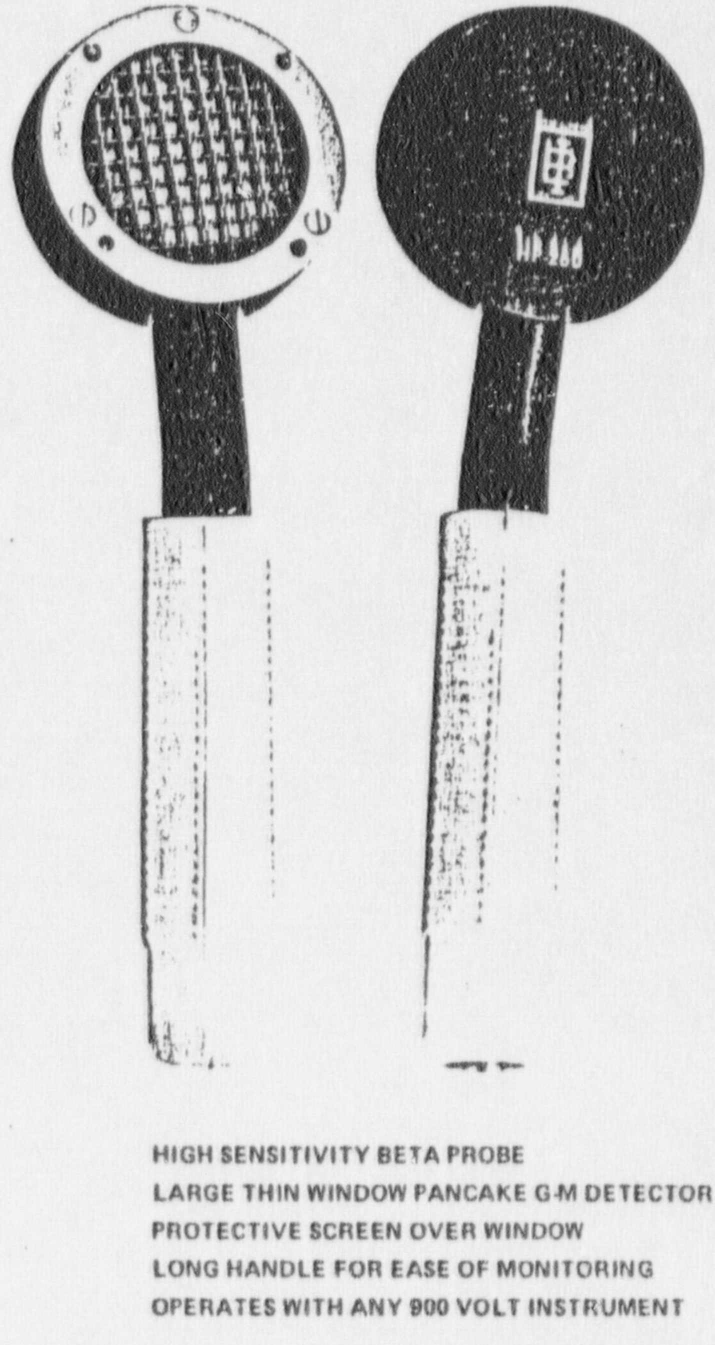


HIN MICA END WINDOW
LIM LIGHTWEIGHT
LPHA-BETA-GAMMA CAPABILITIES
JPPLIED WITH PROTECTIVE SCREEN CAP

eberline

HP-230A

Hand Probe
Model HP-260

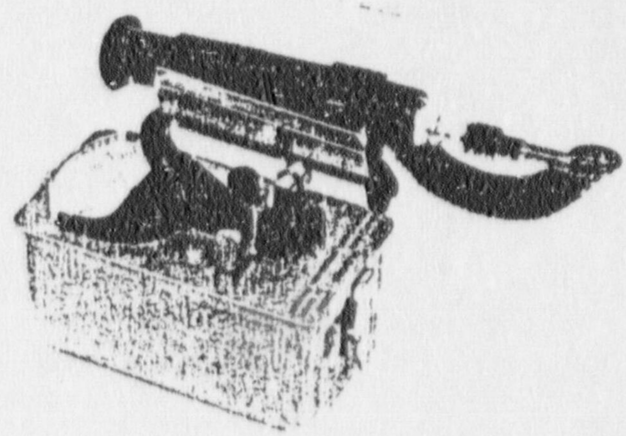


HIGH SENSITIVITY BETA PROBE
LARGE THIN WINDOW PANCAKE G-M DETECTOR
PROTECTIVE SCREEN OVER WINDOW
LONG HANDLE FOR EASE OF MONITORING
OPERATES WITH ANY 900 VOLT INSTRUMENT

eberline

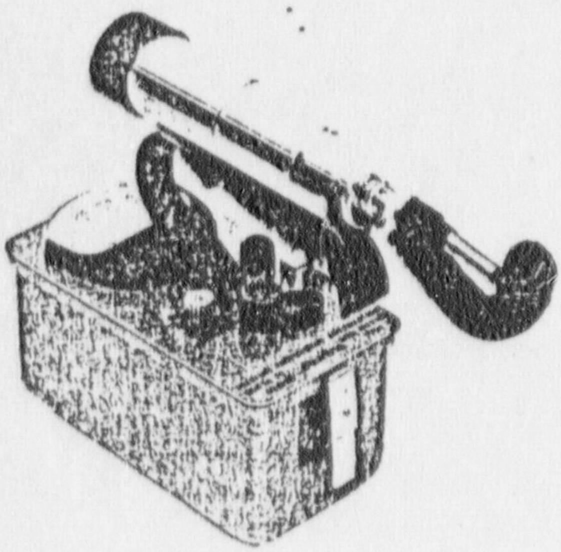
HP-260

Portable Beta-Gamma Geiger Counter Models E-120 and E-120E



E-120 – GAMMA DOSE RATE MONITOR WITH HP-270 ENERGY COMPENSATED HAND PROBE

mR/hr and CPM Scales



E-120E – CONTAMINATION MONITOR WITH HP-190 END WINDOW HAND PROBE

CPM Scale

- UTILIZES INTEGRATED CIRCUITS
- SMALL SIZE – LIGHTWEIGHT
- LONG BATTERY LIFE WITH TWO D-CELLS
- STABLE OVER WIDE TEMPERATURES
- EXCELLENT LINEARITY AND STABILITY
- VARIABLE METER RESPONSE TIME
- BATTERY CONDITION CHECK

eberline

Model E-120/E-120E

Portable Beta-Gamma Geiger Counter
Models E-120 and E-120E

GENERAL DESCRIPTION

The Model E-120 Portable Geiger Counter is furnished with an energy compensated Hand Probe Model HP-270 which is designed to monitor gamma and x-ray radiaiton of energies above 40 KeV. A window is provided for the detection of beta radiation. Both mR/hr and counts per minute (cpm) meter scales are provided on the E-120.

The Model E-120E Portable Geiger Counter is furnished with a thin mica end window G-M tube Model HP-190 which is designed to monitor low-energy beta contamination or x-ray radiation. A cpm meter scale is provided on the E-120E.

Both instruments combine the proven reliability of geiger detectors with electronic circuits to provide an instrument with outstanding operational characteristics in a small, lightweight package at an economical price. The large taut band meter provides exceptional readability and linearity with contiuously variable response time. Calibration stability results from temperature compensation and battery voltage regulation. High efficiency circuits extend the lifetime of the two D-cell batteries. A rotary switch combines the functions of power switch, battery check and selection of one of three sensitivity ranges. The amplifier driven output may be used with headset, speaker assembly or external pulse counter.

The instrument is furnished complete with probe, CZn batteries and technical manual. Available accessories include headset (BA-201), speaker assembly (SK-1), ^{137}Cs gamma check source (CS-7A), and ^{99}Tc beta check source (CS-13).

SPECIFICATIONS

Ranges: 3 linear ranges, switch controlled: E-120 – 0.5, 5, 50 mR/hr full scale (600, 6k, 60k cpm). E-120E – 500, 5k and 50k cpm full scale.

Scale Length: 2.37 inches (6 cm).

Linearity: Within ±5% of full scale, ±2% typical.

Response Time: Variable by panel control from 10 seconds to 2 seconds to 90% of final value.

Phone: One pulse for each event counted. Negative pulse approximately 2.5 V amplitude.

Voltage Coefficient: Reading changes less than 10% with battery voltage from 3 to 2 V (new batteries to end point).

Batteries: Two D-cells held by internal captive holders.

Voltage Requirement: 1.6 maximum to 1.0 minimum volts per cell.

Life: Variable depending on cell type, age, temperature, etc. Nominal life with new cells at room temperature is: CZn – 300 hours; alkaline – 500 hours; mercury – 700 hours; NiCd (single charge) – 200 hours.

Detector and Cable:

E-120: Model HP-270 Energy Compensated Beta-Gamma Hand Probe consisting of a halogen filled G-M tube, 30 mg/cm^2, with beta discriminating shield (see page HP-270). Cable is Model CA-10.

E-120E: Model HP-190, thin window, 1.4 to 2.0 mg/cm^2 with approximately 9 cm^2 (1-1/8 inch dia.) area (see page HP-190). Cable is Model CA-10.

Dimensions: Approximately 6-3/4 inches long x 3-3/8 inches wide x 3-1/8 inches high + 3-1/4 inches handle (17.1 x 8.6 x 7.9 +8.3 cm).

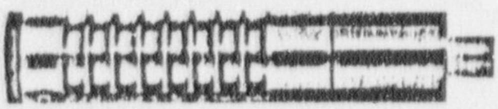
Weight: 3 pounds (1.36 kg) with CZn batteries and hand probe.

Temperature: Typical temperature coefficient of reading is −0.15% per °F from −40° to +140°F (−0.27% per °C from −40° to +60°C). Maximum is −0.25% per °F (−0.45% per °C).

eberline P.O. Box 2108, Santa Fe, New Mexico 87501 (505) 471-3232 TWX:910-985-0678

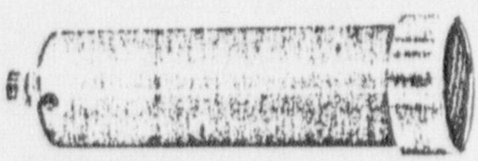
November 1979

Ludlum BETA-GAMMA DETECTORS



MODEL 44-6
THIN WALL GEIGER-MUELLER PROBE

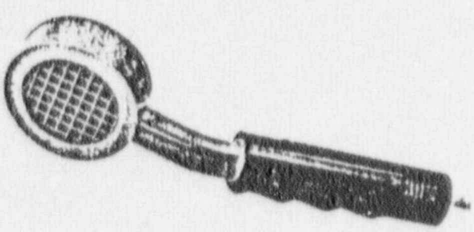
The Detector holder features a rotary beta shield with 1,000 mg/cm² stainless steel wall thickness.
OPERATING POINT: 900 volts.
DIMENSIONS: 1-3/16" diameter by 6½" long.
WEIGHT: 12 ozs.
WALL THICKNESS: 30 mg/cm² stainless steel.
EFFICIENCY FOR RADIUM 226: 1,700 counts per min. per MR/Hr.
QUENCH: Halogen.



MODEL 44-7
END WINDOW GEIGER-MUELLER PROBE

WINDOW: 1.4 to 2.0 mg/cm² mica.
WINDOW DIAMETER: 1-3/32" diameter.
WALL: 0.046 inches stainless steel, plus 0.062 aluminum holder.
MOUNTING: Aluminum holder.
DIMENSIONS: 1⅜" diameter by 5½" long.
WEIGHT: 10 oz.

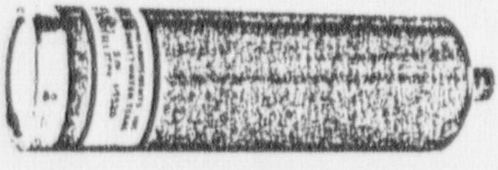
Replaceable GM tube
Removable protective wire screen.



MODEL 44-9
PANCAKE GEIGER-MUELLER PROBE

WINDOW: 1.5 to 2 mg/cm² mica
WINDOW DIAMETER: 1.75"
MOUNTING: Aluminum holder, handle and window protector.
DIMENSIONS: 2¾" wide, 11" long 1.050" dia. Handle.
WEIGHT: 12 oz.

E120



MODEL 44-1
BETA SCINTILLATOR

The beta scintillator is similar in performance to a 1.5 mg/cm² end window G. M. detector with the added advantage of lower gamma background and the ability to utilize discrimination. Carbon 14 detection is possible with reasonable gamma rejection.
DETECTOR: NE/102 plastic crystal, 0.01 thick. (thinner crystals on request)
WINDOW: 1 mg/cm² aluminized mylar.
EFFICIENCY: Function of discrimination setting.
DIMENSIONS: 6½" long by 2" diameter.
WEIGHT: 12 oz.

LUDLUM MEASUREMENTS, INC.

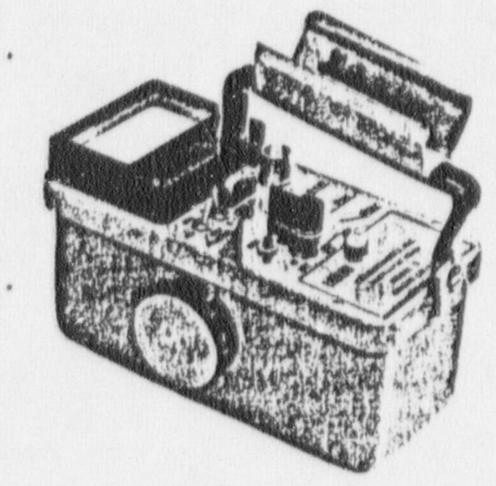
501 Oak Street • Sweetwater, Texas 79556 • Telephone (915) 235-5494

Printed in U.S.A. 12-1-80

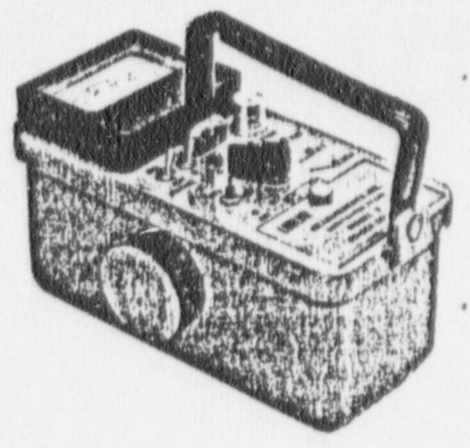
Ludlum SURVEY METERS

GEIGER-MUELLER OR SCINTILLATION

SPECIFICATIONS ON REVERSE SIDE



MODEL 2



MODEL 3

REPRESENTED BY: John Anderson
ATLANTIC NUCLEAR
6 VILLAGE GATE ROAD
CANTON, MASS. 02021
617-828-9118

LUDLUM MODEL 2 AND MODEL 3 SURVEY METERS

COMBINE THE MODEL 2 OR MODEL 3 WITH ANY LUDLUM GEIGER MUELLER OR SCINTILLATION PROBE TO ACCOMPLISH YOUR ALPHA-BETA-GAMMA-NEUTRON-OR X-RAY COUNTING NEED.

DETECTOR SPECIFICATIONS ON DETECTOR SHEET

APPENDIX E

BUTKIN PRECISE MANUFACTURING CORPORATION
RADIATION SAFETY PROGRAM

BUTKIN PRECISION MANUFACTURING CORPORATION

RADIATION SAFETY PROGRAM

Purpose

The purpose of the Butkin Precision Manufacturing Corporation's radiation safety program is to protect the health of workers, minimize danger to life and property, and make every reasonable effort to maintain radiation exposures and releases of radioactive material in effluents to unrestricted areas as low as is reasonably achievable.

Scope

This program is applicable to the possession, use, storage, and transfer or disposal of all United States Nuclear Regulatory Commission (NRC) licensed materials.

References

1. 10 CFR Parts 19, 20, 40, and 71
2. National Council on Radiation Protection and Measurements (NCRP) Reports
3. International Council on Radiation Protection (ICRP) Reports
4. United States Nuclear Regulatory Commission (USNRC) Regulatory Guides

Responsiblities

1. Management has the overall responsiblity for the radiation safety of all individuals who work in or frequent areas under its control. In addition, management is responsible for compliance with applicable NRC regulations and the terms of the NRC license.

2. Radiation safety officers (or supervisors assigned radiation safety responsibilities) are responsible for the conduct of day-to-day radiation safety operations or program tasks set forth below, including the review and approval of standard operating and emergency procedures.

3. Supervisors are responsible for developing and implementing standard operating and emergency procedures applicable to operations under their supervisory control. This includes day-to-day radiation safety supervision and reporting to management unsafe acts or conditions that they cannot correct.

4. Individual workers are responsible for performing their jobs in a safe manner and in accordance with approved standard operating and emergency procedures. In addition, workers must be alert to and immediately report to their supervisor all unsafe acts or conditions noted in work areas.

Program

The following are primary elements of the radiation safety program:

1. Training is provided on a routine basis for personnel who work with radioactive material.

2. Current procedures for routine and emergency operations involving NRC licensed materials are attached to this plan and may be revised as operations dictate.

3. Personnel monitoring devices are not required but may be provided for employee relations purposes. Records are maintained by the radiation safety officer.

4. Contamination is controlled by routine use of fixed and portable survey meters together with routine surveys of the work areas. Records of the survey results are maintained by the radiation safety officer. See attached Wipe Test Analysis Procedure.

5. Area and effluent monitoring are conducted periodically. Area monitoring is conducted routinely by the radiation safety officer. In addition, effluent releases are evaluated semi-annually by the Certified Health Physicists who are consultants.

6. Inventory control of licensed materials is maintained.

7. All accidents or incidents involving radioactive material are investigated by the radiation safety officer and necessary reports issued.

8. Annual audits and evaluations of the effectiveness of the radiation safety program are to be conducted. Reports are to be issued to both management and employees of the results of the audits.

Footnote

Minor revisions and changes may be made to this program and plan without specific Nuclear Regulatory Commission approval as long as the safety intent or effect is comparable.

Standard Operating Procedure - MagTh Parts

PURPOSE

The contained standard operating procedure is reflective of the equipment, work environment, safety procedures and manufacturer's processing of the stated part numbers:

2-063-010-18 Frame
2-063-010-19 Frame
2-103-180-05 Compressor.

SCOPE

The contained standard operating procedure is all inclusive to the manufacturing operation required to complete required Butkin Precision manufacture. This standard operating procedure, however, is limited to the assigned part numbers only:

2-063-010-18 Frame
2-063-010-19 Frame
2-103-180-05 Compressor.

RESPONSIBILITY

It is the responsibility of the plant foreman to oversee the proper safe manufacture of the assigned part numbers:

2-063-010-18 Frame
2-063-010-19 Frame
2-103-180-05 Compressor.

Delegation of such authority can be directed to department heads at the discretion of the plant manager.

MANUFACTURING AND SAFETY ANALYSIS

1. Equipment used in manufacture operations

    a. Vertical Turning Lathe
    b. Bridgeport miller
    c. Jig bore
    d. Deburring tools

2. Publications applicable to manufacture process

    a. included but are not limited to Butkin operation and process sheets which may include customer, Butkin Precision, and/or part changes

3. Qualification and training of personnel

    a. must meet minimal skill level as outlined by plant manager

    b. must receive initial training concerned with safe use of magnesium-thorium

4. Servicing instructions

    a. as required by equipment manufacturer

    b. additional cleaning of metal chip build-up on a daily basis

    c. additional changes of thorium contaminated lubricants

5. Requirements for general safety equipment monitoring, clothing

    a. see standard operating procedure on use of magnesium-thorium

6. Requirements for ventilation control

    a. existing ventilation

    b. additional portable exhaust units as required

7. Step by step instructions for performing operations in deburring or other manufacturing areas with corresponding hazard analysis

    a. see operation sheets for manufacturer's instruction

8. Handling of waste

    a. all scrap is returned to customer

9. Emergency procedures

    a. Magnesium Fires Emergency Procedures

    b. Lacerations Emergency Procedures

    (See attached)

BUTKIN PRECISION MANUFACTURING CORPORATION

MAGNESIUM FIRES

EMERGENCY PROCEDURES

The following steps should be taken in the event of a magnesium fire:

1. Call Fire Department (Phone #'s in Milford and North Adams).

2. Put on emergency respirator found in Thorium manufacturing area.

3. Operator of affected machine should cover area with designated black powder.

3. Clear area of all other employees.

4. Any employees overcome by smoke should be quickly scanned for possible contamination and transported to emergency facility.

5. If fire cannot be controlled by plant personnel, all personnel should leave area.

6. After fire has been extinguished, monitor air in general area for possible contamination. Report any high concentrations to Milford, Ct. immediately.

BUTKIN PRECISION MANUFACTURING CORPORATION

LACERATIONS

EMERGENCY PROCEDURES

THE FOLLOWING STEPS SHOULD BE TAKEN IN THE EVENT OF A SERIOUS LACERATION:

1. Injured area should be scanned for possible contamination.

2. Injured should be transported to emergency facility.

   * This procedure does not pertain to small cuts or slivers. These conditions should be treated as any other injury, i.e., remove metal chips, apply disinfectant, etc.

3. Report any high levels of contamination concentration to Milford, Ct. immediately.

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BUTKIN PRECISION MANUFACTURING CORPORATION

Wipe Test Analysis

All wipe tests will be analyzed by the Butkin Precision Manufacturing Corporation radiation safety officer. The following equipment and supplies will be used in the anaysis:

a. Ludlum Model 2 survey meter with 2" pancake probe with 1.4 to 2.0 mg/cm^2 window.

b. Calibrated Am-241 and Sr-90-y-90 planchet sources will be obtained from Dupont-New England Nuclear Corporation.

Source	Activity	Catalog No.	Description
^{241}Am	50 nCi	NES-302-S	The active area, 10 mm in diameter, is plated on a plantinum disc. Alpha emission calibrated to +/- 3%. Total activity calibrated to +/- 5%.
^{90}Sr-Y	.02 uCi	NES-267 multi	The active material is mounted on a scatterless backing with 1 mg/cm^2 mylar backing. Activity calibrated to +/- 3-5%.

c. Filter papers approximately 30 mm in diameter will be used for actual wipe tests.

BUTKIN PRECISION MANUFACTURING CORPORATION
67 Erna Avenue, Milford, Connecticut 06460 • (203) 878-2416

MAGNESIUM THORIUM

Since you will be working with Thoria Dispersion Strengthened Magnesium, it is important that you understand what you are working with, how it should be handled, any health problems involved with its use and the procedures that must be followed to comply with Government Regulations as well as to insure your safety.

DEFINITION

Natural Thorium is a radioactive element which emits a very low level of Alpha radiation.

These Alpha rays are not the penetrating variety which is used in the X-Ray process. ALPHA RADIATION IS NOT ABSORBED THROUGH THE SKIN .

POSSIBLE HEALTH HAZARDS

When dealing with Mag/Thorium, the radioactive source is contained within the material and direct contact during normal handling and machining operations offer virtually no possibility of hazardous exposure.

Only ingesting (eating) the source material or prolonged inhalation of smoke would offer the chance of overexposure.

PERSONAL HYGIENE

Good personal hygiene must be strictly practiced by all who work with Mag/Thorium.

1) No smoking, eating or drinking is permitted in a work area where Mag/Thorium is being used.

2) Employees must wash their hands and face before eating.

3) Work clothes must be kept clean and frequently changed.

(See Safety Bulletin # 002)

PERSONAL PROTECTION

The same procedures which are followed in handling ordinary metals must be followed when working with Mag/Thorium.

1) Safety glasses must be worn at all times.

2) Suitable work gloves should be worn when not operating rotating machinery.

3) Any injury, no matter how slight must be immediately reported to the proper authority.

SCRAP

All trimmings, punchings, turnings and other scrap containing Mag/Thorium must be identified, collected, segregated from other metals and stored in the special containers provided.

EMPLOYEE INFORMATION

In accordance with the U.S. N.R.C. the following documents are available for your examination upon request:

Part 19 CFR Standards and Reports to Workers.

Part 20 CFR Standards for Protection Against Radiation.

EXTERNAL RADIATION

Direct radiation from handling alloys is not important. The permissible exposure to external radiation is 1500 mr/week for the hands and 300 mr/week for the whole body. HK31A (2000 lb. of sheet) containing 3.5% thorium was measured and found to produce a maximum of 4.2 mr/hour at its surface and 1.8 mr/hour one foot away. Assuming hand contact and the body one foot from the alloy for 40 hours weekly, exposures would be 168 mr/week to the hands and 72 mr/week to the whole body. These are well within the permissible limits and represent maximum values which probably would not be approached in actual practice. Film badge measurements on workmen engaged in typical foundry operations showed a maximum of 30 mr/week on two out of 23 men involved. The other badges measured less than 10 mr/week.

COMMON RADIATION EXPOSURES

The exposure of persons to limited radiation such as from the magnesium -- 3% thorium alloys can be easily measured and is recorded in terms of milliroentgens per hour. Common radiation exposures listed here are compared with an HK31A measurement.

Type of Radiation	Total mr	Normal Exposure Time
HK31A (2000 lbs.) at 4 ft.	20 (0.5 per hr.)	40 hours
Wrist watch- radium dial	1 to 5	1 hour (continuously
Chest X-ray	300	2-3 seconds
Hand-arm X-ray	250-1000	8-9 seconds
Dental X-ray	1500-15000	1-3 seconds
Shoe fitting X-ray	10,000-15,000	5 seconds

WELLMAN DYNAMICS CORPORATION

November 26, 1985

Butkin Precision
67 Erna Street
Milford, CT 06460

Attention: Ms. Halide J. Caine

Subject: Technical Data Mag Thorium Castings

Reference: P/N 2-063-001-10 Frame
P/N 1-060-101-02 Housing

Dear Ms. Caine:

In reply to the technical data questions:

1. The type and quantity of source material in each part

   Thorium 232 — Content 1.4% to 2.2% by weight

2. The chemical and physical form of the source material

   Fused metals — Solid, silvery color

3. The method of retaining source material in product during normal and abnormal conditions of use

   See attached

4. The maximum external radiation level of 5 and 25 centimeters from surface of the product

5 centimeters	0.35 MR/HR
25 centimeters	0.08 MR/HR

I am enclosing a copy of U.S. Department of Labor "Material Safety Data Sheet" and a copy of Dow Chemical's magnesium-thorium alloys entitled "Industrial Health Experience in Fabrication and Production".

If you need further information, please contact me.

Regards,

WELLMAN DYNAMICS CORPORATION

R. C. Fischer
Sales Administrator

RCF:tjb

Enclosures

Castings

OCCUPATIONAL SAFETY AND HEALTH

ADMINISTRATION (OSHA)

HAZARD COMMUNICATION STANDARD

MATERIAL SAFETY DATA SHEET (MSDS)

MATERIAL SAFETY DATA SHEETS (MSDS)

NO. 1 REVISION 0 DATE 11-25-85

WELLMAN DYNAMICS CORPORATION
U.S. ROUTE 34, P.O. BOX 147
CRESTON, IOWA 50801-0147

EMERGENCY PHONE: (515)782-8521 (24 Hours)
CHEMTREC ASSIST: (800)424-9300
ATTENTION: James A. Lauer

I. IDENTIFICATION

TRADE NAME: Aluminum/Magnesium Casting
CHEMICAL NAME: Mixture
FORMULA: See attached Casting Ingredients (by alloy series).
DOT IDENTIFICATION: (Casting containing Thorium ONLY) RADIOACTIVE MATERIAL

NFPA HAZARD CLASS: HEALTH 1, FIRE 1, REACTIVITY 1, OTHER (TH Only)

CAUTION!! WELDING, CUTTING OR GRINDING ON CASTING MAY GENERATE POTENTIALLY TOXIC DUST OR FUMES. DUST AND CHIPS MAY BURN WITH A HOT FLAME.

II. HAZARDOUS INGREDIENTS

REFER TO ATTACHED LIST OF CASTING INGREDIENTS FOR EACH ALLOY SERIES.

CAS NUMBER	COMPONENT	PERCENT RANGE	OSHA PEL	ACGIH TLV	NPT/IARC LISTED
7429-90-5	Aluminum (Al)	0-99.0	N/A	10 mg/m^3	N/A
7440-41-7	Beryllium (Be)	0-0.3	0.002 mg/m^3	0.002 mg/m^3	YES
7440-47-3	Chromium (Cr)	0-0.25	1.0 mg/m^3	0.5 mg/m^3	YES
7440-50-8	Copper (Cu)	0-5.0	1 mg/m^3	1 mg/m^3	N/A
7429-95-4	Magnesium	0-99.0	15 mg/m^3	10 mg/m^3	N/A
7439-96-5	Manganese (Mn)	0-2.4	5 mg/m^3(c)	5 mg/m^3(c)	N/A
7440-21-3	Silicon (Si)	0-8.6	N/A	30 mppcf	N/A
7440-22-4	Silver (Ag)	0-3.0	0.01 mg/m^3	0.01 mg/m^3	N/A
7440-29-1	Thorium (Th)	0-4.0	N/A	N/A	YES
7440-66-6	Zinc (Zn)	0-6.2	5 mg/m^3	30 mppcf	N/A
7440-67-7	Zirconium (Zr)	0-1.0	5 mg/m^3	5 mg/m^3	N/A

III. PHYSICAL DATA

BOILING POINT: 4220F (for aluminum) - 2030F (for magnesium)
MELTING POINT: 1150F (for aluminum) - 1202F (for magnesium)
SPECIFIC GRAVITY: 2.708 (for aluminum - 1.74 (for magnesium)
SOLUBILITY IN WATER: N/A
APPEARANCE AND ODOR: Silver Solid - No Odor
VAPOR PRESSURE, VAPOR DENSITY, EVAPORATION RATE: N/A

IV. FIRE AND EXPLOSION DATA

ALUMINUM CASTINGS IN SOLID FORM WILL NOT BURN OR EXPLODE.
MAGNESIUM CASTINGS ARE NOT EASILY IGNITED BUT, THEY WILL BURN IF EXPOSED TO FIRE OF SUFFICIENT INTENSITY.
FLAMMABLE/EXPLOSIVE LIMITS: LEL 45,000 mg/m^3 (aluminum dust)
EXTINGUISHING MEDIA: Use a class "D" extinguishing agent (Met-l-x, G-1 powder, dry sand, graphite, etc.) and isolate the fire.

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ATTENTION: James A. Lauer

UNUSUAL FIRE AND EXPLOSION HAZARDS: As with all combustible solids, dust from this product may form explosive mixtures in air. Explosive dust concentrations are usually very thick dust clouds, not often found in working areas but may occur in process vessels, dust collectors or bulk handling operations.

SPECIAL FIREFIGHTING PROCEDURES: Do not use water, CO_2 or foam extinguishing agents.

V. REACTIVITY

STABILITY: Stable under normal conditions of use, storage and transportation.

INCOMPATIBILITY: Fine dust or chips from the casting may react violently with halogens (ie: chlorine, bromine), halogenated hydrocarbons and oxidants. The casting may react with acids or caustics producing explosive hydrogen gas. Magnesium contained in the casting may slowly react with water or water soluble cutting oils for form hydrogen gas. Avoid contact with water.

HAZARDOUS DECOMPOSITION PRODUCTS: Hydrogen gas
HAZARDOUS POLYMERIZATION: Will not occur

VI. ENVIRONMENTAL AND DISPOSAL INFORMATION

ACTION TO TAKE FOR SPILLS/LEAKS: Dust and chips should be swept up promptly.

DISPOSAL METHOD: Damaged castings and chips may be sent to a scrap reclaimer. Collected dust and chips from machining, welding, etc. may be classified as a hazardous waste depending on circumstances. Castings, chips and dust from thorium bearing castings may be classified as radioactive material and should be disposed of in accordance with State/Federal regulations. Consult local authorities regarding disposal.

VII. HEALTH HAZARD DATA

EYES: May cause irritation.
SKIN: May cause irritation.
INGESTION: Moderately toxic if ingested. Magnesium LD50 (dogs)=230-280 mg/kg.
INHALATION: Breathing excessive amounts of dust may cause nose and throat irritation. Fumes of metals, such as copper, magnesium or zinc or their oxides, may result in nose, throat and upper respiratory tract irritation, nausea and metal fume fever. Symptons of metal fume fever may appear four to twelve hours after exposure and consist of fever and shaking chills. Inhalation of finely divided aluminum powder has been reported as a cause of pulmonary fibrosis. Breathing dust or fumes of beryllium may result in berylliosis, a serious lung disorder, possibly resulting in weakness, tiredness, weight loss, cough and shortness of breath. Death may result in severe cases. Beryllium is a suspect human carcinogen. Certain forms of chromium are classified as human carcinogens. Some forms, including chromium metal

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INHALATION (Continued): and chromium (VI) oxide, are currently believed to be non-carcinogens. Avoid exposure to dust or fumes of chromium as the form chromium may be released is unknown. Inhalation of copper dust in animals has resulted in adverse changes of the red blood cells, liver pancreas and lung cells. Chronic magnesium poisoning may result from the inhalation of fumes or dust from magnesium. Exposure to manganese dust or fumes may result in upper respiratory infections, pneumonia and chronic poisoning. Silver compounds may be irritating to the skin and mucous membranes. Thorium is a suspect human carcinogen due to it's radioactivity. Avoid inhalation of thorium dust or fumes. Pulmonary granulona in zirconium workers has been reported.
SYSTEMATIC AND OTHER EFFECTS: Machining and grinding castings is noisy. If noise is at or above 85 dBA, a hearing conservation program in accordance with OSHA regulation should be implemented. Castings containing thorium should be handled as a radioactive material in accordance with State/Federal regulations.

VIII. FIRST AID

EYES: Irrigation of the eye immediately with water. Metal particles should be removed by a trained individual (ie: physician, nurse).
SKIN: If irritation develops, seek medical attention.
INGESTION: N/A
INHALATION: Move to fresh air if breathing difficulty is caused by inhalation of metal dust or fumes. Seek prompt medical attention.

IX. HANDLING PRECAUTIONS

VENTILATION: Machining, grinding, flame cutting or welding on the casting may put contaminants in the air. Provide general ventilation and/or local exhaust if necessary to maintain concentrations below the TLV/PEL. If material becomes wet, provide adequate ventilation to disperse any hydrogen gas formed.

RESPIRATORY PROTECTION: If concentrations exceed the TLV/PEL, wear a NIOSH approved respirator for the specific dust or fumes being exceeded.
EYE PROTECTION: Use safety glasses with side shields and/or faceshield for exposure to particles (ie: grinding). Use welding goggles or helmet for welding.
PROTECTIVE CLOTHING: Use general work gloves while handling castings. Wear a protective apron and gauntlets if arc-air gouging, cutting, or welding on castings. If noise is at or above 90 dBA (9 hour Time Weighted Average), wear ear muffs or ear plugs with sufficient attenuation to reduce noise exposure below this level.

X. ADDITIONAL INFORMATION

SPECIAL PRECAUTIONS TO BE TAKEN IN HANDLING & STORAGE: Practice reasonable care in handling to avoid product damage and/or personal injury. Store product in a dry location. See National Fire Association bulletin NFPA-48, "Standard for the Storage, Handling and Processing of Magnesium" and bulletin NFPA65, "Standard for the Processing and Finishing of Aluminum" for detailed information.

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NOTICE

The information and recommendations contained in this Material Safety Data Sheet are supplied pursuant to 29 CFR 1910.1200 of the Occupational Safety and Health Standard Hazard Communications Rule. The information and recommendations set forth herein (hereinafter "information") are presented in good faith and believed to be correct as of the date hereof. Wellman Dynamics Corporation ("Wellman"), however, makes no representations as to the completeness or accuracy thereof, and information is supplied upon the express condition that the persons receiving the same will be required to make their own determination as to its suitability for their purposes prior to use. In no event will Wellman be responsible for any damages of any nature whatsoever resulting from the use of, reliance upon, or the misuse of this information. NO REPRESENTATIONS OR WARRANTIES, EITHER EXPRESSED OR IMPLIED, OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR OF ANY OTHER NATURE, ARE MADE HEREUNDER WITH RESPECT TO INFORMATION OR THE PRODUCT TO WHICH INFORMATION REFERS. The information as supplied herein is simply to be informative and intended solely to alert the user of the substance which is the subject matter of this MSDS. The ultimate compliance with Federal, State or local regulations concerning the use of this mixture, or compliance with respect to products liability, rests solely upon the purchaser thereof. No statements made herein shall be construed or interpreted as an admission or statement of any kind by Wellman that the product or products which are the subject of this MSDS are in any way hazardous, defective or in breach of any warranty, express or implied.

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CASTING INGREDIENTS (BY ALLOY SERIES)
GREATER THAN OR EQUAL TO 1%
(0.1% for Beryllium, Chromium and Thorium)

I. ALUMINUM CASTINGS

356	A356	TENS-50	A-357	355	C355	A206	A201	535
Al	Al	Al	Al	Al	Al	Al	Al	Al
Si	Si	Be	Be	Cr	Cu	Cu	Cu	Mg
		Cr	Si	Cu	Si		Ag	
		Si		Si				

II. MAGNESIUM CASTINGS

AZ91C	AZ91E	AZ92	EZ33A	ZE41A	HZ32A	ZH62A	K1A	HK31A	QE22
Al	Al	Al	Mg	Mg	Mg	Mg	Mg	Mg	Mg
Mg	Mg	Mg	Zn	Zn	Th	Th		Th	Ag
Zn	Zn	Zn	Zr	Zr	Zn	Zn		Zr	Zr
					Zr	Zr			

QH21	EQ21
Mg	Mg
Mn	Ag
Ag	Zr
Th	
Zr	

1C6C54

8704008936

BETWEEN: William O. Miller, Chief
License Fee Management Branch
Office of Administration

John E. Glenn, Chief
Nuclear Materials Section B
Division of Engineering and
Technical Programs

LICENSE FEE TRANSMITTAL

A. REGION

1. APPLICATION ATTACHED

Applicant/Licensee: Butkin Precision Manufacturing Corp

Application Dated: 11/26/86

Control No.: 106654

License No.: NEW

2. FEE ATTACHED

Amount: $350.00

Check No.: 4716

Glenda, 3. COMMENTS

possibly a continuation of control 104289 ? No--New Submittal. SK

Signed Brenda Pilotikek

Date 1/20/87

B. LICENSE FEE MANAGEMENT BRANCH

1. Fee Category and Amount: 2G $350

2. Correct Fee Paid. Application may be processed for:

Per Doug - this is the proper fee category.

Amendment ______

Renewal ______

License ✓

Signed S. Kimberley

Date 1/28/87

REGION I FORM 213
(MARCH 1983)