MAR 2 5 1987

Advanced Medical Systems, Inc.
ATTN: S. S. Stein, Ph.D.
President
121 North Eagle Street
Geneva, OH 44041

Gentlemen:

SUBJECT: NRC LICENSE NUMBER 34-19089-01

As stated in a letter dated October 23, 1986, the NRC decided not to act upon your request for renewal until resolution of the October 10, 1986 Order suspending your service operations. Instead your request was considered as a timely filed renewal. Based upon NRC letter dated February 2, 1987, relaxing the above Order, it is now appropriate to proceed with the renewal of your license. In order to complete our review of your application for renewal, we need the following information:

1. Training Program

Submit a finalized version of the training program to be used for the training of service engineers, isotope technicians and isotope handlers. The program attached to AMS letter dated January 23, 1987, is stamped "under revision." You also indicate "we have not been able to generate the major revisions that are called out" [by AMS consultant RAD Service, Inc.]. To avoid confusion and conflict between statements and representations, we request a complete resubmission which clearly indicates that it supersedes previously submitted training information.

As discussed with Mr. T. J. Hebert on March 11, 1987, we have reviewed your training revision and request that you address the items listed below in the preparation of your "finalized" training program.

a. Specify the time allotted for each Laboratory Experiment.

b. Revise training summary sheets so they are correlated to your new course syllabus and training program.

c. Describe in greater detail which parts of your program use audio/visual presentations and which parts use live instruction. Include the titles and descriptions of each audio/visual presentation and the length of each presentation. Before final

approval of your program, it will be necessary for NRC representative(s) to review a live presentation of your training program. In your response indicate how you wish to schedule the above presentation, i.e., do you wish to incorporate the NRC presence with actual student instruction or provide a presentation only for the NRC.

d. Provide the names and credentials for each individual used as an instructor. Indicate what segment of training each instructor will be responsible for presenting. Confirm that you will amend your license whenever you wish to change instructors.

e. Submit a copy of the device (e.g., certificate, pocket I.D. card) provided to individuals who have completed your training program. The certificate and/or I.D. card must specify the level of license authorization granted to the individual. For example, the certificate, and/or card for your service engineers should indicate the manufacturer's name and model number for each teletherapy unit and the specific services they are authorized to perform. It should indicate the date of authorization and reference pertinent NRC or Agreement State license number(s).

f. Describe AMS's policy for the presentation of and maintenance of examinations. The NRC expects that answers and copies of examinations are not given to students before testing. If copies of tests are given to the student after examination, confirm that the format and questions are changed before the next test covering the same material. Assure that revised tests will be at least equivalent to previous examinations.

2. Waste Disposal

a. Submit scientific and if necessary actual analytical documentation which demonstrates that cobalt-60 contained in liquid wastes released into the sanitary sewer from your London Road facility is dispersible in water. Section 20.303(a) of Title 10 of the Code of Federal Regulations states that "No licensee shall discharge licensed material into a sanitary system unless, (a) it is readily soluble or dispersible in water." Review of chemistry reference literature indicates that cobalt-60 is not soluble in water.

b. In previous liquid effluent releases from your facility, you used total annual water consumption as a basis for comparing the average concentration of cobalt-60 released with the concentration limit (μCi/ml) specified in Appendix B, Table I, Column 2 of Part 20.

However, your actual quarterly water consumption was not steady throughout the entire year. During quarters when water consumption was low, your released concentration would exceed Part 20 limits if you used quarterly consumption as a basis for calculating releases. Consequently, please modify your procedures for calculating concentrations of cobalt-60 to be released based upon actual quarterly water consumption instead of annual consumption. In addition, please describe a program for monitoring for any suspected concentration of the cobalt-60 downstream from the point of release.

c. Provide detailed information which identifies all current liquid discharge pathways and all liquid waste hold-up tanks. Review of license information and inspection findings indicate modifications have occurred. Confirm also that there will be no future changes to your liquid waste disposal system without prior license amendment approval.

d. Describe sample collection and analysis procedures. Your monitoring program must account for analysis of all liquid waste discharges. Although ISP-12 describes use of a sample batch tan. it is not clear if this system is still utilized as previously described and if it is representative for all liquid wastes generated at and disposed from your facility.

3. Radiation Safety Management Program

a. Describe the administrative procedures and duties to be used in the management of your radiation safety programs, i.e., teletherapy service and radioactive source manufacturing. The program described in Attachment G ATC Medical Group Management Plan to letter dated January 23, 1987, is generally acceptable, however, it should be expanded to cover your sealed source manufacturing operations.

b. Describe your internal and external audit program. The audit program described in Attachment M Audit System For ATC Medical Group to letter dated January 23, 1987 is generally acceptable, however, your description should be modified to include internal and external audits for your London Road manufacturing operation.

c. Submit a copy of your consultant's audit findings as required by the October 23, 1986 Order.

As requested by Mr. Hebert, we are willing to meet with your staff to discuss your response to the above. Please contact me to schedule a date for the meeting.

We request that you respond to the above within 30 days in duplicate and refer to Mail Control No. 82095. Should you have any questions, you may contact me at (312) 790-5625.

Sincerely,

Original Signed By
George M. McCann
Materials Licensing Section

RIII	RIII	NMSS	OGC
McCann/pd 3/ /87	Mallett 3/ /87	Hickey 3/ /87	Lewis 3/ /87

August?

AMS TRAINING PROGRAM

ACADEMIC

TAB 1	General Policy Statements
	Instructors
TAB 2	Basic Radiation Safety Training Manual
TAB 3	Supplemental Radiation Safety Manual

PRACTICAL

TAB 4	Class 2 Service Engineer Program
TAB 5	Class 1 Service Engineer Program
TAB 6	Isotope Technician Program
TAB 7	Isotope Handler Program
TAB 8	Ancillary Personnel Program

MAY 12 1987

May 1987

AMS TRAINING PROGRAM

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	Instructors
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PRACTICAL

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TAB 5	Class 1 Service Engineer Program
TAB 6	Isotope Technician Program
TAB 7	Isotope Handler Program
TAB 8	Ancillary Personnel Program
TAB 9	Annual Refresher Training

Superseded

Revised August 1987

EXAMINATION POLICY

Copies of exmainations, quizzes, and answers will not be distributed to students prior to test.

After the exams are graded, they may be redistributed to the students for review; however, the exams will be collected and all copies retained by AMS for documentation purposes in the individual's C.V. files.

If retesting of a student is required, the format and questions will be altered before the next test. Revised tests will be at least equivalent to previous examinations.

TEXTS

The primary text utilized in the Basic Radiation Safety course is found after TAB 2. This text will be supplemental with the manual found after TAB 3.

AUDIO/VISUAL PRESENTATIONS

AMS intends to videotape all classroom and laboratory presentations, if possible. These videotapes may be edited and utilized for student review and refresher training. They are not intended to be used as primary training sessions.

INSTRUCTORS

The training program outlines, which are part of this manual, refer to instructors by job title or classification. The present qualified individuals who will be utilized as instructors are listed below by job title or classification. The credentials of these individuals follow:

Health Physicist *	Rodney Johnson
Raidation Safety Officer	Howard Irwin
Engineering/Production Manager	Ed Svigel
Isotope Handler	William Turbett
Qualified Service Engineer *	James Cochran
Qualified Service Engineer *	Keith Jordan
Assembly Supervisor	Clyde Hess

* Health Physicists used as instructors must be approved by the USNRC.

Qualified Service Engineers, used as instructors, shall have 6-12 months on-the-job experience and must be evaluated and approved by the RSO and Isotope Committee prior to becoming instructors.

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Isotope Handler	William Turbett
Qualified Service Engineer	James Cochran
Qualified Service Engineer	Keith Jordan
Assembly Supervisor	Clyde Hess

Superseded

RAD
Services Inc.

Rodney C. Johnson

Health Physicist

Experience

12/85-Present

Health Physicist, Licensing and Compliance Group, RAD Services Inc. Responsible for providing consulting services to radioactive material and diagnostic imaging device users. These services include, but are not limited to:

- Licensing Assistance
- Health Physics Program Evaluation
- Radwaste Program Evaluation
- Transportation Program Evaluation
- Radiation Protection Training
- Survey Instrumentation Services
- Leak Testing of Sealed Sources
- X-ray System Inspections
- Procedure Writing
- Incident Investigation/Enforcement Mitigation
- Program Support
- Information Management

5/83-12/85

Assistant Radiation Safety Officer with East Carolina University. Responsibilities included: inspection and monitoring of equipment and associated work areas utilizing radioactive materials and radiation emitting devices; radioactive material inventory and waste management; incinerator operation and ash analysis; bioassay program; incident review and analysis; information management; and training of radiation workers.

4/75 - 8/82

Self-employed outside the radiation protection field.

3/69- 3/75

U.S. Naval Nuclear Power Program. Served on a nuclear powered submarine and a mechanical operator and leading Engineering Laboratory Technician.

Education

College

B.S., Applied Physics (Medical Physics option), East Carolina University.

A.S., Applied Science, Lenoir Community College

U. S. Navy Schools - Basic Engineering School
- Nuclear Power School
- Nuclear Power Training Unit
- Engineering Laboratory Technician School

Honors

Honor Society of Phi Kappa Phi, Elected 1984

Professional Affiliations

Plenary Member of the Health Physics Society
Midwest Chapter Health Physics Society Member
North Carolina Chapter Health Physics Society Member
National Registry of Radiation Protection Technologists

References Provided on request

DATE: January, 1987

CV For Edward L. Svigel
Engineer Manager
Advanced Medical Systems, Inc.
121 North Eagle Street
Geneva, Ohio 44041

I. Primary Function: To manage and supervise Engineering and related departments. Mechanical and electrical design of medical equipment to include R & D, test and evaluation, Quality Control and GMP compliance.

II. Organizational Relationship:

A. Reports to: General Manager

B. Manages: R & D, Manufacturing Department, Quality Control Department and draftsmen

C. Works with Isotope Department, Service Department, Purchasing Department and Materials Control

III. Education:

A. B.M.E. - Gannon College - 1970

B. Communication/Electronics Staff Officers School - 1971

IV. Employment History:

Diamond Shamrock	1963-1965 Drafting
True-Temper - Central Engineering	1970-1976 Research Engineer
U.S. Army Signal Corps	1971-1973 Signal Officer
True-Temper Corporation	1976-1977 Plant Engineer
Gould/Engine Parts Division	1978-1982 Machine Design Engineer
Advanced Medical Systems	1982-Present Engineering Manager

MAY 14 1987

V. Previous Experience:

A. Design and development of fiberglass hammer handles, tennis racquets.

B. Design and development of automatic golf shaft straightening machine.

C. Project engineer for installation of Reverse Osmosis System.

D. Energy Conservation Engineer and Coordinator.

E. Supervisor of plant draftsmen and Quality Control technicians.

F. Supervision of Army Battalion Communications Radio Relay Section.

G. Deputy Chief of Ft. Bliss Education Television Division - US Army.

V. Previous Experience (Continued):

H. Project Engineer for purchase and installation of Carbon Absorption unit.

I. Designed, specified and purchased plating room equipment.

J. Supervised and coordinated rebuilds of elevator plating machines.

K. Designed special tools for use in areas of high radiation.

L. Supervised and coordinated GMP program on medical equipment.

M. Coordinated and managed capital equipment purchases and moves.

N. Supervised the construction of 34 Cobalt units and 2 simulators.

O. Initiated ECO procedure per Title 21 and AMS Q.C./GMP program.

DATE: January, 1987

CV For Howard R. Irwin
Manager of Isotope Operation
Advanced Medical Systems, Inc.
121 North Eagle Street
Geneva, Ohio 44041

I. Primary Function: Manager of Isotope Operation and London Road Facility Radiation Safety Officer.

II. Organization Relationships:

A. Reports to: General Manager

B. Supervises: Isotope Handlers and Isotope Technicians

C. Supports: Regulatory Affairs, Technical Service, Safety Assessment

III. Education:

A. Formal - Carnegie Mellon University, Pittsburgh, PA earning B.S. Chemistry Degree in 1971.

B. Job Related - Harvard School of Public Health "Occupational and Environmental Radiation Protection" - 5 day course - 1986.

Chem Nuclear Systems, Inc. "Radioactive Waste Packaging, Transportation and Disposal Workshop" - 3 day course - 1986.

American Society of Appraisers "Machinery and Equipment Appraisers Seminars" - 3 day - 1984.

American Society of Appraisers "Machinery and Equipment Appraisers Seminars" - 3 day - 1979.

IV. Employment History:

1971 - Present: Seymour S. Stein, Ph.D. P.E. & Associates Consulting Engineers. Project Engineer and Machinery Appraiser.

1984 - Present: Advanced Medical Systems, Inc. Radiation Safety Officer and Manager of Isotope Operations.

V. Previous Experience:

A. Regulatory Affairs - 1979 to present - Review applicable state and federal regulations, specifically pertaining to medical equipment companies, including FDA, NRC, DOT, EPA. Liason between company and various agencies.

V. Previous Experience (Continued):

B. Preparation of license applications and amendments.

C. Preparation of state and local permit applications.

D. Preparation of medical device registrations and transportation package applications and amendments.

E. Submission of annual reports to FDA, NRC, etc.

F. Responsible for radiation safety program (RSO) including major revisions to program content (documents, manuals, procedures, instrumentation).

G. Auditing of records required to be maintained by company.

H. Training of personnel involved with radioactive materials and radiation areas.

I. Managing London Road Isotope operation including scheduling of activities, personnel assignments, requisition and procurement of supplies, etc.

J. Supervision and participation in specific activities related to the Isotope facility including:

1. Packaging and shipment of radioactive waste
2. Hot cell entries
3. Decontamination of equipment and building areas
4. Hot cell window replacement
5. Assay of liquid waste and disposal to sanitary sewer
6. Source fabrication and transfer
7. Use of computer analysis source and survey data

K. Responsible for facility management (330,000 s.f.) including building improvements, modifications - Coordination of top management decisions with plant engineer, maintenance personnel and outside contractors.

L. Capital asset management including procurements and disposal of capital equipment used in manufacturing op rations. Coordination with company financial department and insurance carriers.

M. Project engineer on start up of new product manufacture. Responsible for scheduling entire start up project and managing engineering, facility and capital equipment phases of project.

N. Preparation of appraisal reports for insurance, condemnations, estate, acquisition purposes, courtroom experience as expert witness.

O. Quality Control technician in testing laboratory. Documentation of results for audits by customers.

Statement of Training and Experiences

William Turbett

Personal: Born: September 23, 1950
Social Security Number: 282-46-7871

Education: High School
Lorain County Community College - 1 year
Control Data Institue - 1 year course in electronics theory and instrumentation
Advanced Medical Systems formal training course for Isotope Technician - May 1986
Advanced Medical Systems formal training course for Isotope Handlers - September 1986

Experience: Employed by Advanced Medical Systems at London Road facility since September 1985

Qualifications as an Isotope Technician were submitted to the USNRC in Part 2 of our letter dated July 23, 1986. NRC Approval 10-23-86.

Under the job classifications of Isotope Handler, Mr. Turbett has completed the training and instruction requirements as summarized on the following pages. The instructors as indicated in the initials column are as follows:

DM - Darwin Murray	JC - James Cochran
WE - William Evans	HI - Howrard Irwin
AP - Art Parsons	PT - Paul Tomlin

During the course of this period, Mr. Turbett has:

a) fabricated and processed six sources
b) performed at least 20 source transfers
c) packed and unpacked at least 10 shipping containers
d) packaged solid waste for disposal
e) disposed of liquid waste
f) performed maintenance on hot cell equipment including manipultors, source welders, cell lathe, HEPA filter system, Isotope Shop source transfer equipment.

Mr. Turbett was approved as an Isotope Handler by the USNRC on December 15, 1986, Licensee Amendment 11. Currently, Mr. Turbett has completed the restrictions indicated in this amendment and is qualified to instruct trainees for the Isotope Handling position.

Mr. Turbett completed in April 1987 the enclosed 24 hour academic course (Basic Radiation Safety), an annual refresher academic achievement.

MAY 1 4 1987

DATE: FEBRUARY 4, 1987
CV FOR CLYDE HESS
IN-PLANT MECHANICAL ASSEMBLY
ADVANCED MEDICAL SYSTEMS
121 NORTH EAGLE STREET
GENEVA, OH 44041

I. Primary Function: To build and assemble Cobalt machines, C-4, C-8, C-9, vertical unit and therapy tables of same units. Also to build sub-assemblies that go into the machines.

II. Organization Relationship

A. Reports to Production Manager

III. Education

Riverside High School - Painesville, OH

Night School in 1979 for Diploma
Madison, OH

IV. Employment History

Aug. 1986 - Present	Advanced Medical Systems, Inc. - Geneva, OH In-Plant Mechanical Assembly

V. Previous Experience

1983 - 1984	Advanced Medical Systems, Inc. - Geneva, OH Mechanical Assembly

IRC Fibers - Painesville, OH; Duties as Maintenance Millwright Mechanic included installing of new equipment and to rebuild old equipment.

Statement of Training and Experience

Keith Jordan

Personal:	Born September 18, 1958 Married
Social Security:	279-64-5492
Education:	High School - General Electronics Ohio Institute of Technology, 2 years Graduated 1981 - Major: Electronics Advanced Medical Systems formal training course for field service, July 1985 Advanced Medical Systems formal training course for source exchange, July 1985
Experience:	Employed by AMS since August 1984 Involved in manufacture and service of Therapy Simulators and teletherapy equipment

Radiation Industry Experience:

Mr. Jordan has been involved in the manufacture, test and service of Therapy Simulators since 1984. This work has involved working with x-rays in both test cells and at customer sites. Since early 1985, he has also been involved in service work on teletherapy equipment. This work includes participation in at least 4 machine installations, 4 machine removals, 12 preventive maintenance procedures, 10 unit checkouts, 6 isocenter adjustments, 4 shipping container procedures 4 collimator removal and installations. In June 1985, he was approved as a Service Engineer by the Isotope Committee.

Under the supervision of Darwin Murray, he has performed 4 source exchanges and 3 Five-Year Inspections at customer sites. He is experienced in the packing and unpacking of the source exchange shipping container.

Mr. Jordan has been approved by the USNRC as an 01 Level Service Engineer since January 1986 and is listed on the AMS License.

Statement of Training and Experience

James Cochran

Personal:	Born February 28, 1957 Married, children
Social Security:	233-94-3094
Education:	High School Advanced Medical Systems formal training course for field service, October 1982 Advanced Medical Systems formal training course for source exchanges, January 1986
Experience:	Employed by AMS since March 1982 Involved in the manufacture, packaging and shipping of AMS teletherapy equipment since 1982

Radiation Industry Experience:

Mr. Cochran was qualified as a Service Engineer by the Isotope Committee in April 1984. Since that time, he has performed at least 5 machine installations, 15-20 machine removals, 12 collimator removal and installations, 30 preventive maintenance procedures, isocenter adjustments and unit checkouts, 20 shipping container procedures.

Under the supervision of Glenn Sibert or Darwin Murray, he has performed 4 source exchanges and five-year inspections at customer sites. He is experienced in the preparation of the source exchange shipping container.

At the London Road Isotope facility, Mr. Cochran has been involved in such activities and waste processing, hot cell entry, receiving and shipping radioactive material.

Mr. Cochran was approved by the USNRC at the 01 Service Engineer Level since March 1986 and is listed on the AMS License.

BASIC RADIATION THEORY
AND
SAFETY PROCEDURES

COURSE SYLLABUS
(Broad)

Topic	Time (Hours)
Mathematics Review	1
Basic Radiation Physics	6
Radiation Detection and Measurements	4
Biological Effects of Radiation	2
Radiation Protection Standards	2
Protection Against External Exposures	3
Protection Against Internal Exposures	3
Shipping and Receiving Radioactive Material	1
Emergency Procedures and Response	.5
Quizzes/Examinations	2-3

LABORATORY EXERCISES

Survey Meter Use and Care	1.5
Calibration of Survey Meters including Demonstration of Shielding and Distance	1.5
Radiation Measurements and Contamination Monitoring	1
Packaging, Shipping, and Receiving Radioactive Material	[illegible]

33.5

TRAINING RECORD

STUDENT NAME: ____________________

UNIT #	COURSE IDENTIFICATION	NO. HOURS	STUDY AIDE	LOCATION & DATE ATTENDED	TESTING RESULTS	STUDENT SIGNATURE	INSTRUCTOR SIGNATURE
LAB 1	Survey Meter Use & Care						
LAB 2	Calibration of Survey						
	Meters, Shielding &						
	Distance						
LAB 3	Radiation Measurements &						
	Contamination Monitoring						
LAB 4	Packaging, Shipping, &						
	Receiving Radioactive						
	Material						

Isotope Committee Review Date: ____________

Comment: ______________________________

____

Member Officer Signature: ____________________

RADIATION SAFETY TRAINING

FOR

ADVANCED MEDICAL SYSTEMS PERSONNEL

I. Basic Radiation Physics

Atomic and Nuclear Structure
Ionization - Isotopes
Radioactivity

Decay Process
Types of Emissions
Half-Life
Curie
Decay Formula - Use of Decay Tables

Properties of Alpha, Beta Particles, Gamma Rays, X-rays, and Neutrons
Interaction of Radiation with Matter
Radiation Dosimetry

Definition of Terms (Roentgen, RAD, REM)
Exposure Rate - Dose Rate
Specific Gamma-Ray Constant
Inverse Square Law
Calculations

Background Radiation
Characteristics of Co-60 and Cs-137 Sealed Sources

II. Biological Effects of Radiation

Cells and Radiosensitivity
Somatic Effects

Acute Exposures
Chronic Exposures

Genetic Effects
Factors Affecting Biological Damage
Case Histories

III. Radiation Detection

Principles

Ionization Method
Scintillation Method
Thermoluminescence
Photographic Film Dosimetry

Instrumentation

GM Survey Meters
Pocket Dosimeters
TLDs/Film Badges
Detectors Used at AMS

Instrument Calibration
GM Saturation

IV. Radiation Protection Standards

History
Regulatory Agencies
NRC License
10 CFR Parts 19, 20, and 30
Regulatory Guides
ANSI Standards
Exposure Guides
Bioassay Program

V. Radiation Protection

Principles of Radiation Safety

ALARA Principle
Time, Distance, Shielding
Personnel Monitoring
Radiation Measurements
Instrument Calibrations
Required Postings

- Receiving, Handling, Storage of Sealed Sources
- Source Installation
- Routine Use of Source in Device
- Leak Testing Sealed Sources
- Source Exchange
- Source Inventory/Accountability
- Packaging and Shipping Sources
- Emergency Procedures
- Stay Time Calculation
- Shielding Calculation
- Activity Calculations

VI. Hands on Activities

Each of the following procedures will be demonstrated by the instructor. In turn, each participant will be required to demonstrate their ability to perform the procedure properly:

- Leak Testing Sealed Sources
- Packaging Sealed Sources for Shipment
- Use of a Survey Meter Including Care and Calibration
- Air Monitoring
- Contamination Monitoring

RELATIVE STRENGTHS OF

FORCES IN NATURE

Nuclear Force	1
Electromagnetic Force	10^{-2}
*Weak Force	10^{-13}
Gravitational	10^{-39}

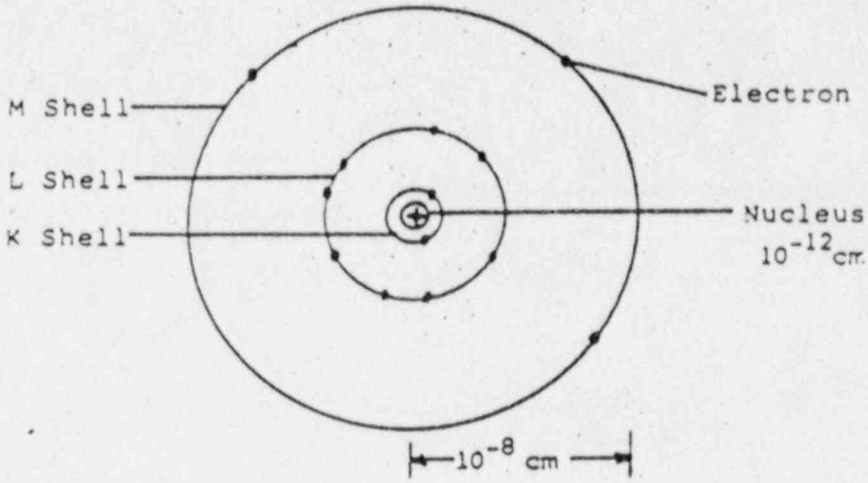
*weak force - an interactive force between the constituents of beta decay

Force = mass x acceleration

Work or Energy "ability to do work" = force x distance

An electron in orbit around the nucleus has potential energy due to being immersed in an electric field (the positive protons in the nucleus and the negative electrons in the electron orbits). It also has Kinetic energy because it is moving (has velocity). The total energy which holds the electron in orbit is the binding energy. To remove an electron from an atom, you must give it enough energy (work) to overcome its binding energy.

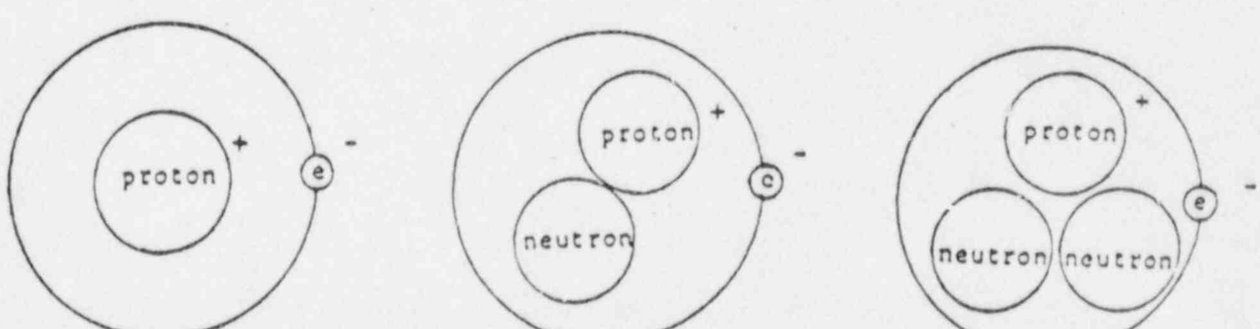
BOHR'S ATOMIC MODEL



1 inch = 2.54 cm

10^{-8} cm = .00000001 cm

$= \frac{1}{250,000,000}$ inch



HYDROGEN ATOM (H)   DEUTERIUM (D)   TRITIUM (T)

CURRENT CONVENTION

FOR

ELEMENTAL NOTATION

$$^{A}_{Z}X$$

Where: X = chemical symbol

Ex: Co - Cobalt
Cs - Cesium

Z = atomic number

= number of protons and
number of electrons for
neutral atoms (net charge = 0)

Ex: $^{60}_{27}Co$

27 protons and 27 electrons

A = atomic mass

= number of protons and neutrons (nucleons)
in the nucleus

Accordingly,

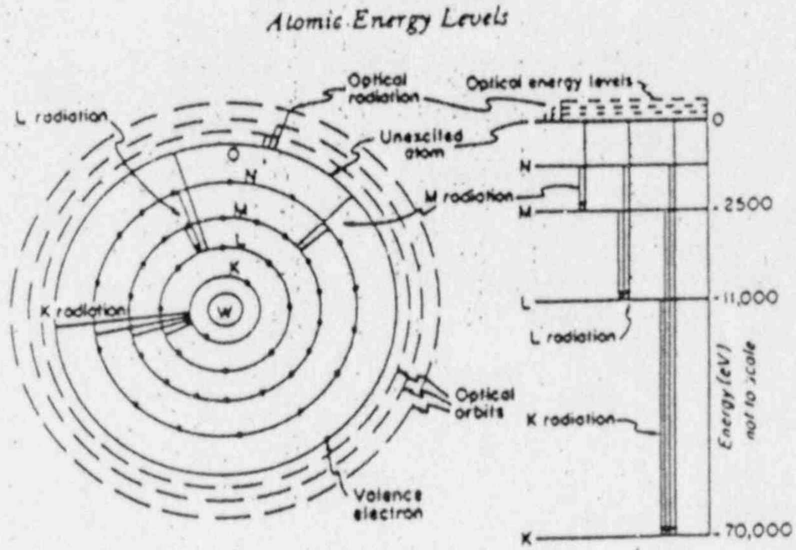
A - Z = number of neutrons in the nucleus

Ex: $^{60}_{27}Co$

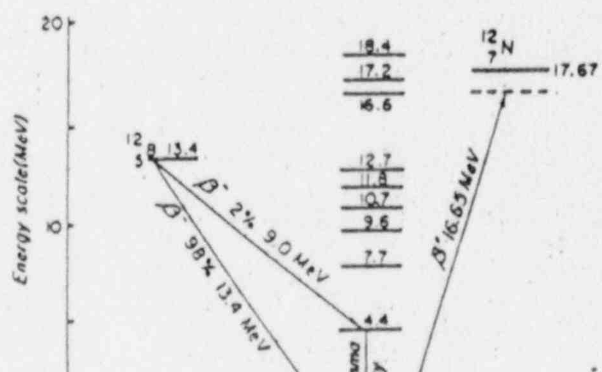
60 nucleons (neutrons and protons)

A - Z = 60 - 27 = 33 neutrons

ATOMIC ENERGY LEVELS

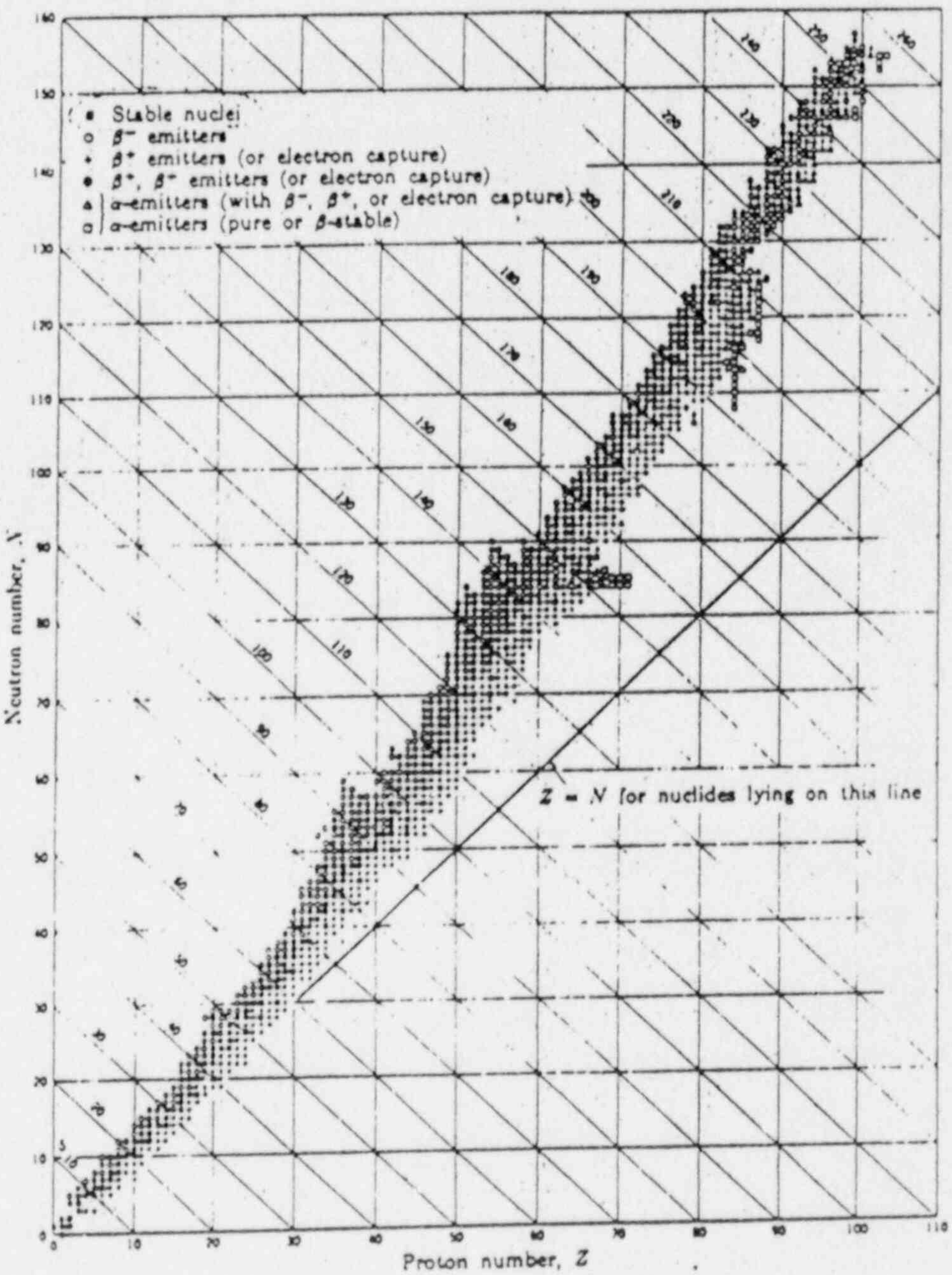


NUCLEAR ENERGY LEVELS



Energy level diagram for carbon 12.

CHART OF NUCLIDES



A plot of neutron number N versus proton Z for all all known nuclei, stable and unstable. A curve through the stable nuclei starts with N/Z = 1 for low-A nuclei and reaches a value of N/Z - 1.6 for high-A nuclei.

REF 1

RADIOACTIVITY

The <u>Curie</u> - A measure of radioactivity equivalent to 37 billion disintegrations per second. (Ci)

1 millicurie (mCi) = one thousandth of a curie

1 microcurie (uCi) = one millionth of a curie

The <u>Becquerel</u> - A measure of radioactivity equivalent to 1 disintegration per second. (Bq)

<u>Unit Conversions</u>

ACTIVITY			
1 terabecquerel	= 1 TBq	= 27 curies	
1 gigabecquerel	= 1 GBq	= 27 millicuries	
1 megabecquerel	= 1 MBq	= 27 microcuries	
1 kilobecquerel	= 1 kBq	= 27 nanocuries	
1 becquerel	= 1 Bq	= 27 picocuries	

ACTIVITY			
1 kilocurie	= 1 kCi	= 37 terabecquerels	
1 curie	= 1 Ci	= 37 gigabecquerels	
1 millicurie	= 1 mCi	= 37 megabecquerels	
1 microcurie	= 1 μCi	= 37 kilobecquerels	
1 nanocurie	= 1 nCi	= 37 becquerels	

Factor	Prefix	Symbol
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	<u>giga</u>	G
10^{6}	<u>mega</u>	M
10^{3}	<u>kilo</u>	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	<u>centi</u>	c
10^{-3}	<u>milli</u>	m
10^{-6}	<u>micro</u>	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

Advanced Medical Systems

Device Nominal Activity: ______ Ci

______ Bq

RADIOACTIVE DECAY

$A_{final} = A_{initial} \times e^{-(\lambda \times t)}$

A = activity

$\lambda = \dfrac{.693}{\text{half-life}}$

t = decay period

e = base for natural log

$= 2.71828 \ldots$

$\log_e x = y$

$e^y = x$

for ^{60}Co, the half-life ($t_{1/2}$) = 5.3 years

Example: What is the activity of a 5000 curie (Ci.) ^{60}Co sealed source after 15.9 years?

$A_{final} = 5000\text{Ci.} \times e^{-(.693/5.3 \text{ years} \times 15.3 \text{ years})}$

$= 5000\text{Ci.} \times e^{-2.079}$

$= 5000\text{Ci.} \times .125$

$= 625 \text{ Ci.}$

UNIVERSAL DECAY TABLE (REF 5)

The accompanying table can be used to determine the fraction of activity remaining of any radionuclide, from 0.001 half-life to 1.00 half-life. To use the table complete the following:

1. Divide elapsed time by the known physical half-life of the radionuclide under consideration ($t - T_{1/2}$).
   NOTE: the same time unit must be used in each instance.

2. Use this answer (to three significant figures) in locating the percent of original activity remaining. The first two significant figures are listed on the vertical column at the left of the table; the third significant figure is listed on the horizontal across the tope of the table.

3. Multiply original activity by this percentage figure to obtain amount remaining.

Example: What is the strength of a 10 mCi ^{131}I source after 2 days?

1. $t \div T_{1/2} = 2 \div 8.1 = 0.247$

2. Fraction remaining from decay table = 0.84265

3. 10 mCi × 0.84265 = 8.43 mCi

	Activity remaining for $t \div T_{1/2}$ from 0 to 1.00									
	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
	1.00000	.99931	.99861	.99792	.99723	.99654	.99585	.99516	.99447	.99378
.01	.99309	.99240	.99172	.99103	.99034	.98966	.98897	.98829	.98760	.98692
.02	.98623	.98555	.98487	.98418	.98350	.98282	.98214	.98146	.98078	.98010
.03	.97942	.97874	.97806	.97739	.97671	.97603	.97536	.97468	.97400	.97333
.04	.97265	.97198	.97131	.97063	.96996	.96929	.96862	.967[illegible]	.96728	.96661
.05	.96594	.96527	.96460	.96393	.96326	.96259	.96193	.96126	.96059	.95993
.06	.95926	.95860	.95794	.95727	.95661	.95595	.95528	.95462	.95396	.95330
.07	.95264	.95198	.95132	.95066	.95000	.94934	.94868	.94803	.94737	.94671
.08	.94606	.94540	.94475	.94409	.94344	.94278	.94213	.94148	.94083	.94017
.09	.93952	.93887	.93822	.93757	.93692	.93627	.93562	.93498	.93433	.93368
.10	.93303	.93239	.93174	.93109	.93045	.92980	.92916	.92852	.92787	.92723
.11	.92659	.92595	.92530	.92466	.92402	.92338	.92274	.92210	.92146	.92083
.12	.92019	.91955	.91891	.91828	.91764	.91700	.91637	.91573	.91510	.91447
.13	.91383	.91320	.91257	.91193	.91130	.91067	.91004	.90941	.90878	.90815
.14	.90752	.90689	.90626	.90563	.90501	.90438	.90375	.90313	.90250	.90188
.15	.90125	.90063	.90000	.89938	.89876	.89813	.89751	.89689	.89627	.89565
.16	.89503	.89440	.89379	.89317	.89255	.89193	.89131	.89069	.89008	.88946
.17	.88884	.88823	.88761	.88700	.88638	.88577	.88515	.88454	.88393	.88332
.18	.88270	.88209	.88148	.88087	.88026	.87965	.87904	.87843	.87782	.87721
.19	.87661	.87600	.87539	.87478	.87418	.87357	.87297	.87236	.87176	.87115
.20	.87055	.86995	.86934	.86874	.86814	.86754	.86694	.86634	.86574	.86514
.21	.86454	.86394	.86334	.86274	.86214	.86155	.86095	.86035	.85976	.85916
.22	.85857	.85797	.85738	.85678	.85619	.85559	.85500	.85441	.85382	.85323
.23	.85263	.85204	.85145	.85086	.85027	.84968	.84910	.84851	.84792	.84733
.24	.84675	.84616	.84557	.84499	.84440	.84382	.84323	.84265	.84206	.84148
.25	.84090	.84031	.83973	.83915	.83857	.83799	.83741	.83683	.83625	.83567
.26	.83509	.83451	.83393	.83335	.83278	.83220	.83162	.83105	.83047	.82989
.27	.82932	.82874	.82817	.82760	.82702	.82645	.82588	.82531	.82473	.82416
.28	.82359	.82302	.82245	.82188	.82131	.82074	.82017	.81960	.81904	.81847
.29	.81790	.81734	.81677	.81620	.81564	.81507	.81451	.81394	.81338	.81282
.30	.81225	.81169	.81113	.81057	.81000	.80944	.80888	.80832	.80776	.80720
.31	.80664	.80608	.80552	.80497	.80441	.80385	.80329	.80274	.80218	.80163
.32	.80107	.80051	.79996	.79941	.79885	.79830	.79775	.79719	.79664	.79609
.33	.79554	.79499	.79443	.79388	.79333	.79278	.79223	.79169	.79114	.79059
.34	.79004	.78949	.78895	.78840	.78785	.78731	.78676	.78622	.78567	.78513
.35	.78458	.78404	.78350	.78295	.78241	.78187	.78133	.78079	.78025	.77970
.36	.77916	.77862	.77809	.77755	.77701	.77647	.77593	.77539	.77486	.77432
.37	.77378	.77325	.77271	.77218	.77164	.77111	.77057	.77004	.76950	.76897
.38	.76844	.76791	.76737	.76684	.76631	.76578	.76525	.76472	.76419	.76366
.39	.76313	.76260	.76207	.76154	.76102	.76049	.75996	.75944	.75891	.75838
.40	.75786	.75733	.75681	.75628	.75576	.75524	.75471	.75419	.75367	.75315
.41	.75262	.75210	.75158	.75106	.75054	.75002	.74950	.74898	.74846	.74794

Activity remaining for $t \div T_{1/2}$ from 0 to 1.00

	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.42	.74742	.74691	.74639	.74587	.74536	.74484	.74432	.74381	.74329	.74278
.43	.74226	.74175	.74123	.74072	.74021	.73969	.73918	.73867	.73816	.73765
.44	.73713	.73662	.73611	.73560	.73509	.73458	.73408	.73357	.73306	.73255
.45	.73204	.73154	.73103	.73052	.73002	.72951	.72900	.72850	.72799	.72749
.46	.72699	.72648	.72598	.72548	.72497	.72447	.72397	.72347	.72297	.72247
.47	.72196	.72146	.72096	.72047	.71997	.71947	.71897	.71847	.71797	.71747
.48	.71698	.71648	.71598	.71549	.71499	.71450	.71400	.71351	.71301	.71252
.49	.71203	.71153	.71104	.71055	.71005	.70956	.70907	.70858	.70809	.70760
.50	.70711	.70662	.70613	.70564	.70515	.70466	.70417	.70368	.70320	.70271
.51	.70222	.70174	.70125	.70076	.70028	.69979	.69931	.69882	.69834	.69786
.52	.69737	.69689	.69641	.69592	.69544	.69496	.69448	.69400	.69352	.69304
.53	.69255	.69208	.69160	.69112	.69064	.69016	.68968	.68920	.68873	.68825
.54	.68777	.68729	.68682	.68634	.68587	.68539	.68492	.68444	.68397	.68349
.55	.68302	.68255	.68207	.68160	.68113	.58066	.68019	.67971	.67924	.67877
.56	.67830	.67783	.67736	.67689	.67642	.67596	.67549	.67502	.67455	.67408
.57	.67362	.67315	.67268	.67222	.67175	.67129	.67082	.67036	.66989	.66943
.58	.66896	.66850	.66804	.66757	.66711	.66665	.66619	.66573	.66526	.66480
.59	.66434	.66388	.66342	.66296	.66250	.66204	.66159	.66113	.66067	.66021
.60	.65975	.65930	.65884	.65838	.65793	.65747	.65702	.65656	.65611	.65565
.61	.65520	.65474	.65429	.65384	.65338	.65293	.65248	.65203	.65157	.65112
.62	.65067	.65022	.64977	.64932	.64887	.64842	.64797	.64752	.64707	.64662
.63	.64618	.64573	.64528	.64483	.64439	.64394	.64349	.64305	.64260	.64216
.64	.64171	.64127	.64082	.64038	.63994	.63949	.63905	.63861	.63816	.63772
.65	.63728	.63684	.63640	.63596	.63552	.63508	.63464	.63420	.63376	.63332
.66	.63288	.63244	.63200	.63156	.63113	.53069	.63025	.62982	.62938	.62894
.67	.62851	.62807	.62764	.62720	.62677	.62633	.62590	.62546	.62503	.62460
.68	.62417	.62373	.62330	.62287	.62244	.62201	.62157	.62114	.62071	.62028
.69	.61985	.61942	.61900	.61857	.61814	.61771	.61728	.61685	.61643	.61600
.70	.61557	.61515	.61472	.61429	.61387	.61344	.61302	.61259	.61217	.61174
.71	.61132	.61090	.61047	.61005	.60963	.60921	.60878	.60836	.60794	.60752
.72	.60710	.60668	.60626	.60584	.60542	.60500	.60458	.60416	.60374	.60332
.73	.60290	.60249	.60207	.60165	.60123	.60082	.60040	.59999	.59957	.59915
.74	.59874	.59832	.59791	.59750	.59708	.59667	.59625	.59584	.59543	.59502
.75	.59460	.59419	.59378	.59337	.59296	.59255	.59214	.59173	.59132	.59091
.76	.59050	.59009	.58968	.58927	.58886	.58845	.58805	.58764	.58723	.58682
.77	.58642	.58601	.58561	.58520	.58479	.58439	.58398	.58358	.58317	.58277
.78	.58237	.58196	.58156	.58116	.58075	.58035	.57995	.57955	.57915	.57875
.79	.57834	.57794	.57754	.57714	.57674	.57634	.57594	.57554	.57515	.57475
.80	.57435	.57395	.57355	.57316	.57276	.57236	.57197	.57157	.57117	.57078
.81	.57038	.56999	.56959	.56920	.56880	.56841	.56801	.56762	.56723	.56683
.82	.56644	.56605	.56566	.56527	.56487	.56448	.56409	.56370	.56331	.56292
.83	.56253	.56214	.56175	.56136	.56097	.56058	.56019	.55981	.55942	.55903
.84	.55864	.55826	.55787	.55748	.55710	.55671	.55632	.55594	.55555	.55517
.85	.55478	.55440	.55402	.55363	.55325	.55287	.55248	.55210	.55172	.55133
.86	.55095	.55057	.55019	.54981	.54943	.54905	.54867	.54829	.54791	.54753
.87	.54715	.54677	.54639	.54601	.54563	.54525	.54488	.54450	.54412	.54374
.88	.54337	.54299	.54261	.54224	.54186	.54149	.54111	.54074	.54036	.53999
.89	.53961	.53924	.53887	.53849	.53812	.53775	.53737	.53700	.53663	.53626
.90	.53589	.53552	.53514	.53477	.53440	.53403	.53366	.53329	.53292	.53255
.91	.53218	.53182	.53145	.53108	.53071	.53034	.52998	.52961	.52924	.52888
.92	.52851	.52814	.52778	.52741	.52705	.52668	.52632	.52595	.52559	.52522
.93	.52486	.52449	.52413	.52377	.52340	.52304	.52268	.52232	.52196	.52159
.94	.52123	.52087	.52051	.52015	.51979	.51943	.51907	.51871	.51835	.51799
.95	.51763	.51727	.51692	.51656	.51620	.51584	.51548	.51513	.51477	.51441
.96	.51406	.51370	.51334	.51299	.51263	.51228	.51192	.51157	.51121	.51086
.97	.51051	.51015	.50980	.50945	.50909	.50874	.50839	.50803	.50768	.50733
.98	.50698	.50663	.50628	.50593	.50558	.50523	.50488	.50453	.50418	.50383
.99	.50348	.50313	.50278	.50243	.50208	.50174	.50139	.50104	.50069	.50035
1.00	.50000									

RADIOACTIVE DECAY MODES

<u>ALPHA DECAY</u> - approximately 160 known radionuclides

- occurs primarily in heavier elements
- the disintegrating nucleus emits an alpha particle (α) which essentially is a helium nucleus

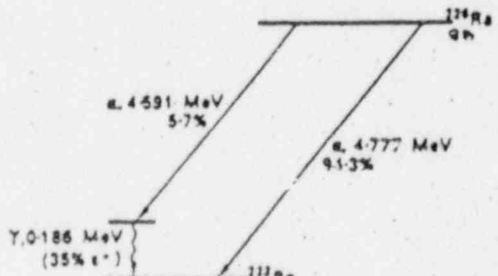
$$^{4}_{2}He^{2+}$$

Symbolically noted as:

$$^{A}_{Z}X \longrightarrow \, ^{A-4}_{Z-2}Y + \, ^{4}_{2}He^{2+} + \text{Kinetic Energy of } \alpha \text{ particle}$$

Example:

$$^{228}_{90}Th \longrightarrow \, ^{224}_{88}Ra + \, ^{4}_{2}He^{++} + \text{Kinetic Energy}$$



Radium-226 transformation (decay) scheme.

BETA DECAY - approximately 1000 artificially produced

- lie above (B^-) and below (B^+ or E.C.) stability curve
- the disintegrating nucleus seeks nuclear stability by emitting a beta particle or capturing an orbital electron
- 3 types

  Negatron Emission - B^-
  Positron Emission - B^+
  Electron Capture - E.C.

Negatron Decay

Negatron (B^-) decay occurs when an electron is created in and emitted from the nucleus

Symbolically noted as:

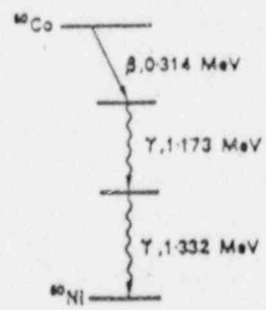
$$^{A}_{Z}X \longrightarrow \, ^{A}_{Z+1}Y + \, ^{0}_{-1}e \; (B^-) + \bar{\nu} \quad \text{(antineutrino)}$$

caused by:

$$n \longrightarrow p + B^- + \bar{\nu} \; *$$

*the neutrino was discovered when observed beta energies were continuous and not discreet

Example:

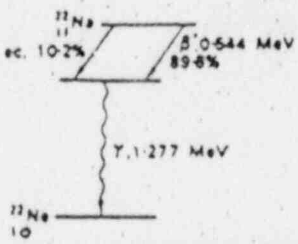


Positron (B^+) Decay

Positron decay occurs when a positron is created and emitted from the nucleus

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e(B^+) + \checkmark \quad \text{(neutrino)} $$

Example:



Sodium-22 transformation (decay) scheme.

A positron is a unique creature in that it annihilates with an electron to form two .51 MeV photons.

Electron Capture or K-Capture

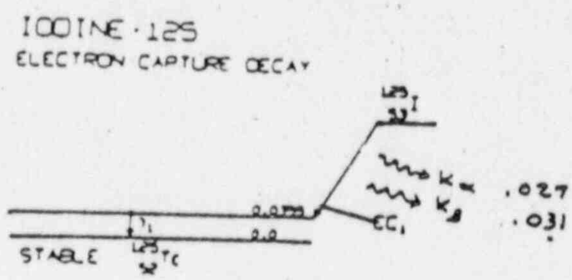
- the disintegrating nucleus seeks nuclear stability by capturing an orbital electron

- $p + {}^{0}_{-1}e \longrightarrow n$

Symbolically noted as:

$${}^{A}_{Z}X + {}^{0}_{-1}e \longrightarrow {}^{A}_{Z-1}Y + K_{x\text{-ray}}$$

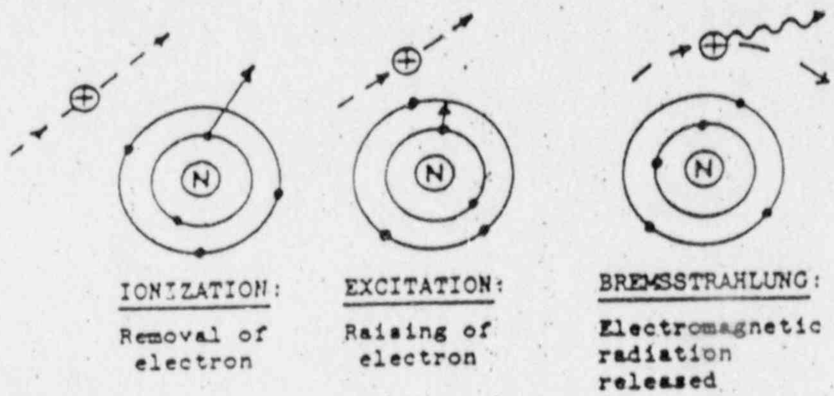
Example:



RADIATION INTERACTIONS

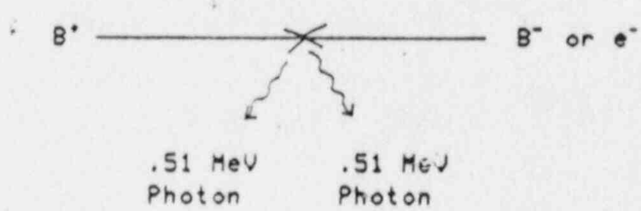
WITH MATTER

Charged Particle



Energy Loss Mechanism

B^+ (Positron-Electron Annihilation)



Rules of Thumb

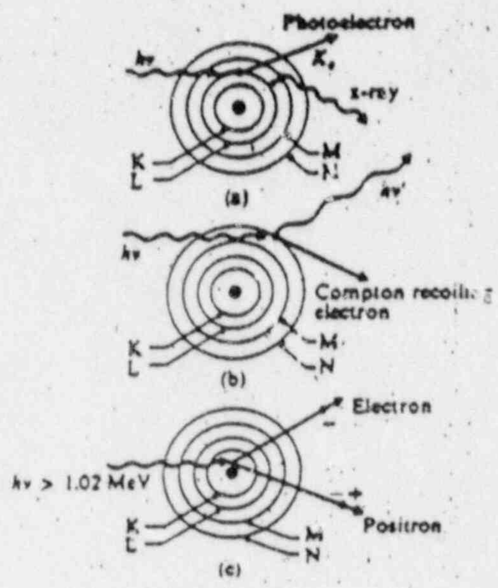
1. Alpha particles up to 7.5 MeV are stopped in the dead layer of normal skin.

2. Beta particles will penetrate about 4 meters in air per MeV of energy.

3. Beta particles will penetrate about 0.5 cm in soft tissue per MeV of energy.

4. Beta particles up to 70 keV are stopped in the dead layer of normal skin.

Photon - An electromagnetic wave with no charge and no mass (x-rays and gamma rays).



The three processes by which x and gamma rays most often interact with matter.

(a) Photoelectric process: the incident photon is absorbed by one of the inner electrons. The resulting photoelectron leaves its orbital. The vacancy created is filled by an outer electron jumping in, with simultaneous emission of x-ray.

(b) Compton process: the incident gamma ray interacts with one of the outer electrons and transfers a part of its energy to this electron.

(c) Pair production: the incident photon converts into an electron-positron pair in the coulombic field of the nucleus. THe positron annihilates with an electron.

[illegible] ility of a particular type of [illegible] is related to the photon energy [illegible] atomic number (density) of the target [illegible].

MAY 12 1987.

Figure 3-5. Cloud chamber photograph of alpha, beta, and gamma ray tracks (J.B. Hoag *Electron and Nuclear Physics*, courtesy D. Van Nostrand Co.) (H4)

RADIATION DOSIMETRY UNITS

Roentgen (R) (exposure) - A measure of electrical charge distribution in air

- 2.58×10^{-4} Coulombs/$Kg_{(air)}$

RAD (dose) - A measure of energy deposition in a medium by exposure to radiation.

- 100 ergs/$gm_{(medium)}$

- .877 $Rads_{(air)}$ = 1.0 $Roentgen_{(air)}$

- .877 $Rads_{(air)}$ = .95 $Rads_{(soft\ tissue)}$

REM - A unit of radiation dose related to radiation protection.

- rem = Rad x Quality Factor

- The Quality Factor is related to the L.E.T. (Linear Energy Transfer) and the R.B.E. (Relative Biological Effectiveness).

Type of Radiation	Q.F.
X, B, gamma	1
thermal neutrons	2.3
fast neutrons	10
alpha particles	20

For X, B, and gamma: 1 R = 1 RAD ≈ 1 rem for radiation protection purposes

RADIATION DOSIMETRY

FOR ^{60}CO AND ^{137}CS SOURCES

- Nominal Activity ^{60}Co Device 5000 Ci

- Gamma Constant

^{60}Co - 1.32 $\frac{R}{Ci\text{-}hr}$ at 1m ______ $\frac{R}{Ci\text{-}hr}$ at 1cm

^{137}Cs - 0.33 $\frac{R}{Ci\text{-}hr}$ at 1 m

Example: What is dose rate at 1 meter from a 4700 Ci ^{60}Co point source?

$$1.32 \frac{R}{Ci\text{-}hr} \times 4700\ Ci = 6204\ R/hr$$

If distance is decreased to 1/2 meter, what would the dose rate be?

6204 R/hr @ 1 m. (initial)

? @ 1/2 m. (final)

use:

$DR_{final} = DR_{initial}\ (r_i/r_f)^2$ where r is the distance from the source

$DR_{final} = 6204\ R/hr \times (1/.5)^2$

$= 6204\ R/hr \times (4)$

$= 24816\ R/hr$

SUMMARY OF AVERAGE ANNUAL PER CAPITA

DOSES TO WHOLE U.S. POPULATION

Source	Average per capita Dose (mrem/year)	
Natural background		
Cosmic	31	
Terrestrial	68	
Tech. Inhanced	4	
Sub-total		103
Man-made		
Medical		
X-ray	77	
Nuc. Med.	14	
Sub-total		91
Nuclear weapons	4-5	
Nuclear power	<1	
Consumer products	0.5-1.5	
Sub-total		~8
Total		~200

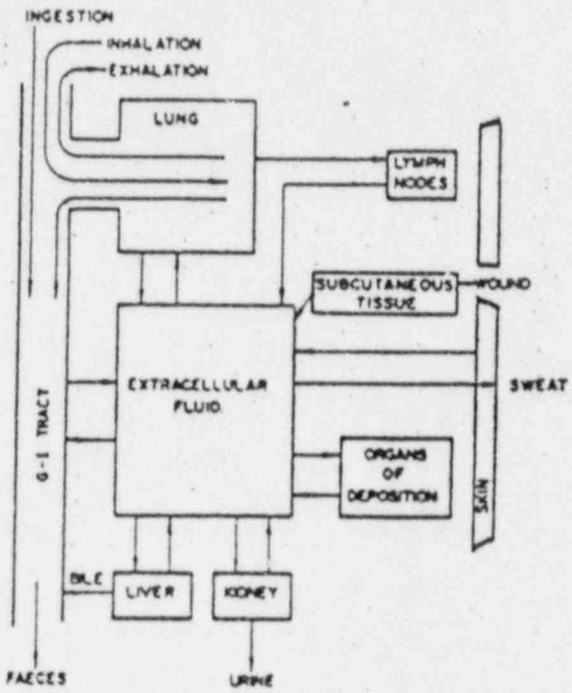
REF 3

U.S. AVERAGE ANNUAL DOSES

FROM RADIOACTIVE PRODUCTS

1. Radium wrist watch .... 3 mrem
2. Tritium wrist watch .... 0.6 mrem
3. Radium dial alarm clocks .... 7 to 9 mrem
4. Cigarettes, 1 1/2 pack per day, to lung ..... 8,000 mrem
5. Building materials, masonry .... 7 mrem
6. Road construction materials .... 4 mrem
7. Coal fired power plant, to lung .... 1 to 4 mrem
8. Cooking with natural gas stove .... 6 to 9 mrem
9. Residential ionization smoke detector .... 1 mrem
10. Dental porcelain in false teeth, to gum ..... 60,000 mrem
11. Thorium rose tinted eyeglasses, to eye ...... 4,000 mrem
12. Phonograph record static eliminator .... 0.001 mrem
13. Reading a book, 3 hrs/day .... 0.5 mrem
14. Aircraft luminous instrument dial .... 1,000 to 5,000 mrem
15. Radium pocket watch, GSD .... 6 mrem
16. Radioactive lightning rods .... 0.05 mrem
17. Uranium glaze in dinnerware, to skin .... 2,400 mrem
18. Farmer using phosphate fertilizer, GSD ...... 2 mrem
19. Worker in fertilizer plant, to lung .... 5,000 mrem
20. Gas lantern mantles for camping .... 0.1 to 0.4 mrem

REF 3



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

BIOLOGICAL EFFECTS OF

EXPOSURE TO IONIZING RADIATION

Observed effects fall into two categories:

Stochastic Effects

1. occurs by chance
2. probability of effect is proportional to dose
3. no threshold, every increment of dose has a corresponding risk
4. Example: cancer or genetic effects

Non-Stochastic Effects

1. a minimum dose must be exceeded-threshold
2. magnitude of effect is proportional to dose
3. Example: LD 50/30 = 600-800 RADS

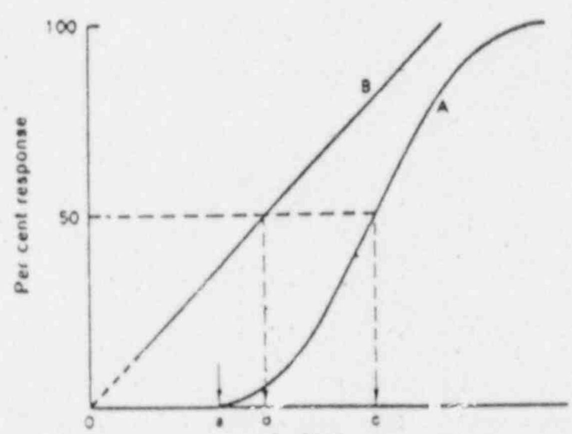


FIG. 7.1. Dose-response curves. Curve *A* is the characteristic shape for a biological effect that exhibits a threshold dose—point *a*. The spread of the curve, from the threshold at *a* until the 100% response is thought to be due to "biological variability" around the mean dose, point *c*, which is called the 50% dose. Curve *B* represents a zero-threshold, or linear response: point *b* represents the 50% dose for the zero-threshold biological effect.

CELL RADIOSENSITIVITY

Law of Bergonie and Tribondean (1906)

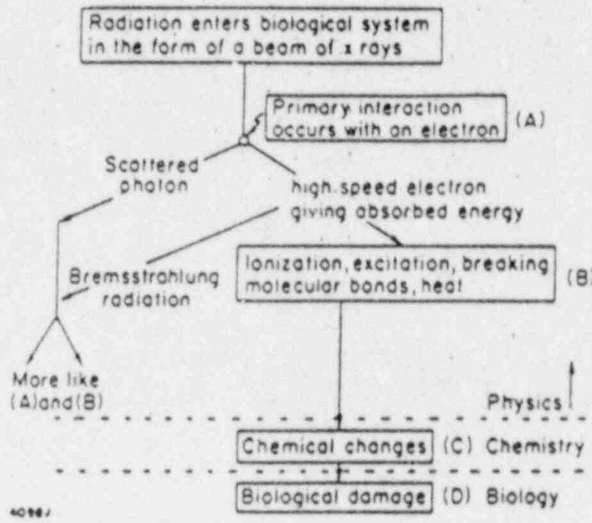
Cells that are most radiosensitive tend to have:

- a high division rate
- a long dividing future
- the capability to "specialize" at some future time into an "adult" cell type

"The generalization of the Law of Bergonie and Tribondeau is that tissues which are young and rapidly growing are most likely radiosensitive. A very practical application of the Law is given by NRC Regulatory Guide 8.13 which is titled "Instruction Concerning Prenatal Radiation Exposure". This Guide requires that women of reproductive age be informed of the increased risk of injury of the human fetus from radiation exposure because such a tissue meets all the criteria of the Law of Bergonie and Tribondeau. The human fetus is particularly sensitive in the first weeks of pregnancy when organs are forming. This is also a time period when the women may not be aware of her pregnancy. Most radiation protection standards recommend that the dose to a developing embryo and fetus be kept below 0.5 rem during the entire 9 months of gestation." (REF 3)

See also NCRP Report No. 54

Schematic Diagram Illustrating The Absorption Of Energy From Radiation Resulting In Biological Damage



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Effects of overexposure

Direct action

- direct insult on a molecule by ionization or excitation and subsequent dissociation

  Example: dissociation of an atom on a DNA molecule

Indirect action (by dissociation of atoms in water molecules)

$$H_2O \longrightarrow H^+ + OH^-$$

can recombine a number of ways

$H + H \longrightarrow H_2$ (gas)

$H + OH \longrightarrow H_2O$ (water)

$OH + OH \longrightarrow H_2O_2$ (H peroxide)

Peroxides are highly toxic (chemically) to cells.

Exposure Types

Acute - high dose in a short time

Chronic - lose doses over a long time
(effects may take years to show up)

Clinical Effects

Acute Radiation Syndrome from acute whole body exposure.

1. Hemopoietic syndrome > 200 RADS
2. Gastrointestinal syndrome ≥ 1000 RADS
3. Central nervous system syndrome > 2000 RADS

Common to each are:

a. nausea and vomiting

b. malaise and fatigue

c. increased body temperature

* d. blood changes

*the most significant biological indicator of overexposure

Delayed Radiation Effects

- caused by acute large exposure <u>or</u> by a continuous low level exposure (internally or externally)
- effect occurs 5-20 years after exposure
- examples: Cancer (hemopoietic system, thyroid, bone and skin are the most common)

  Leukemia

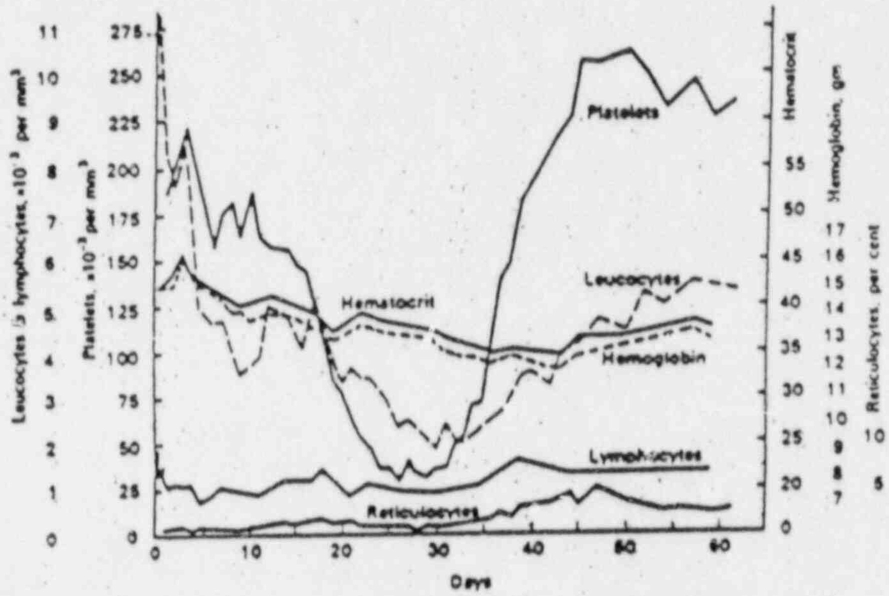
  Lung cancer

  Genetic effects

RADIOBIOLOGY

RANGE	Subclinical Range 0 to 100 rem	Therapeutic Range 100 to 1,000 rem			Lethal Range Over 1,000 rem	
		100 to 200 rem	200 to 600 rem	600 to 1,000 rem	1,000 to 5,000 rem	Over 5,000 rem
INCIDENCE OF VOMITING	None	100 rem: 5% 200 rem: 50%	300 rem: 100%	100%	100%	
DELAY TIME	- - -	3 hr	2 hr	1 hr	30 min	
LEADING ORGAN	None	Bone Marrow			Gastrointestinal Tract	Central Nervous System
CHARACTERISTIC SIGNS	None	Moderate leukopenia	Severe leukopenia, hemorrhage, infection, purpura, epilation above 300 rem		Diarrhea, fever, electrolyte loss	Convulsions, tremor, ataxia
THERAPY	Reassurance	Blood surveillance	Blood transfusion Antibiotics	Possible marrow transplant	Maintain electrolytes	Sedatives
PROGNOSIS	Excellent	Excellent	Good	Guarded	Hopeless	
INCIDENCE OF DEATH	None	None	0 to 80%	80 to 90%	90 to 100%	

REF 3



Hematologic effect of radiation overexposure. Average values for five patients who were exposed to 236–365 rad (estimated) during a criticality accident at the Y-12 plant in Oak Ridge on 16 June 1958. (G. H. Andrews, B. W. Sitterson, A. L. Kretchman and M. Brucer, Criticality accident at the Y-12 plant, *Diagnosis and Treatment of Acute Radiation Injury*, pp. 27–48, World Health Organization, Geneva, 1961.)

MECHANISMS FOR DETECTION

OF RADIATION

1. <u>IONIZATION</u> - Release of ion pairs by the incoming radiation.

2. <u>BIOLOGICAL</u> - Changes produced in a living system exposed to radiation.

3. <u>CHEMICAL</u> - Changes caused in a chemical solution due to free radical release.

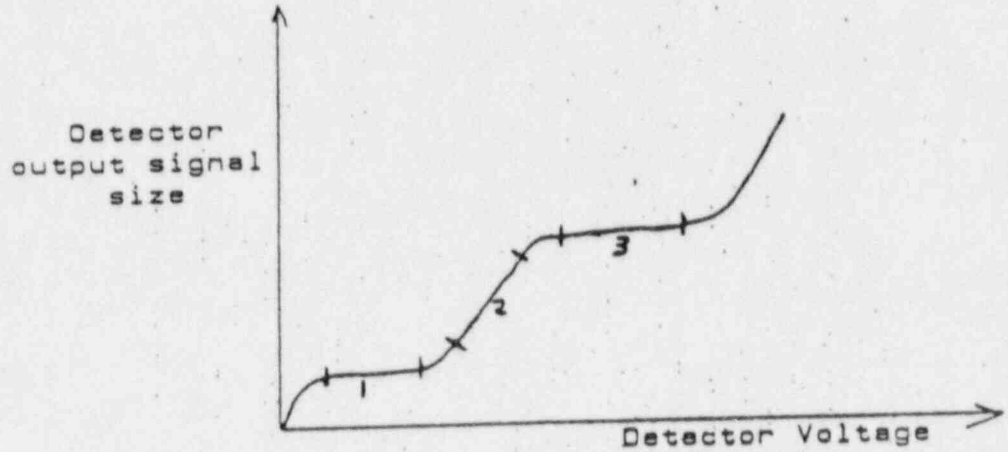
4. <u>HEAT</u> - Energy deposited by the radiation causes a temperature rise in absorber.

5. <u>SCINTILLATION</u> - Production of a flash of visible light in certain phosphors.

6. <u>THERMOLUMINESCENCE</u> - The release of visible light after heating an irradiated sample.

GAS-FILLED DETECTOR

CHARACTERISTIC CURVE



Region 1

- Ion chamber region
- 100% collection of primary ionizations only
- no gas amplification
- can measure only cumulative effects

Region 2

- proportional counter region
- gas amplification produces secondary and tertiary ionizations
- output signal is proportional to incident radiation
- can measure individual events

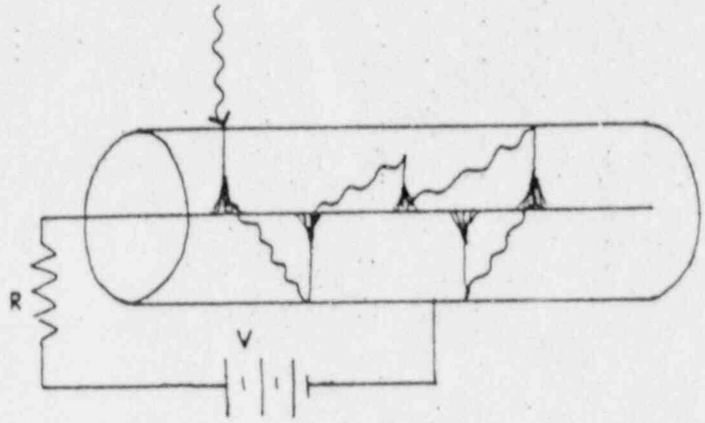
Region 3

- Geiger-Mueller region (G.M.)
- initial ion formation produces total avalanche of gas (complete discharge)
- output signal is the same for any energy of input radiation*

*may overrespond for low energy gamma rays

GM DETECTORS

SPECIAL CONSIDERATIONS



Tube saturation occurs when the tube is exposed to a very high exposure rate in a radiation field.

A conventional instrument will show a momentary upswing of the meter needle followed by a return of the needle to a point near zero, even though the instrument is still in the high field. In such a high field, the ionizing events are interacting with the counter tube with an average separation in time much closer together than the counter dead time. Most of these rays will be missed since the tube is "dead". The problem occurs near the end of the dead time while the last ions are being cleared. If a new event is detected then, the tube still has not fully recovered so the gas multiplication factor will still be depressed. This produces a must smaller pulse than normal. In fact, the pulses formed under these conditions are usually so small as to be at the same level as the background electronic noise. Since the noise pulses are discriminated against by the electronic circuit, this read count will be missed along with all the following counts that continue to trigger the tube before it can recover. Thus the instrument reads "background" while in fact the operator is in an extremely hazardous radiation field. This problem can be eliminated by using only the "non-saturating" type of geiger counters now commercially available. If in doubt, check the instrument specifications to make sure it will not saturate in fields w'ich might be possible at your facility, even under worst case acciden conditions.

REF 3