AlphaTRAC
Meeting the Challenge of the Atmosphere

October 11, 2001

Dear Stakeholder:

The Rocky Flats Cleanup Agreement (RFCA) Stakeholder Focus Group will meet at the Broomfield Municipal Center at One DesCombes Drive on October 17, 2001 from 3:30 to 6:30 p.m.

The agenda for the October 17, 2001 meeting is enclosed (Attachment A). We will discuss the following topics:

- RSALs Task 3 Peer Review and Wind Tunnel Technical Review - update
- Final results from the RSAL Modeling - Resident Rancher Scenario - RESRAD results, key parameters, and comparison to historical results
- Task 3 Report - Briefing and Discussion
- Task 3 Peer Review - Framing the Questions for the Reviewers

The presentations from the October 3, 2001 RFCA Focus Group meeting are enclosed as Attachment B, including:

- 09/27/01 RSALs Working Group notes,
- *Comparison of Permissible Body Burden of Plutonium and Soil Action Levels, Joe Goldfield,* September 20, 2001,
- Presentation by Joe Legare: Approach to Cleanup using RSALs, and
- Presentation by Reed Hodgin: Wind Tunnel Technical Review - Status.

The Rocky Flats Coalition of Local Governments sponsored a meeting on Health Effects of Low-level Radiation on October 1, 2001. The meeting agenda and presentations are enclosed as Attachment C.

If you need additional information to prepare you for the Focus Group discussion on August 22, 2001, please contact Christine Bennett of AlphaTRAC, Inc. at 303 428-5670 (cbennett @alphatrac.com). Christine will help to find the appropriate resource for you.

You may call either Christine or me if you have any questions, comments, or suggestions concerning the RFCA Stakeholder Focus Group or the upcoming meeting.

Sincerely,

C. Reed Hodgin

C. Reed Hodgin, CCM
Facilitator / Process Manager

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AlphaTRAC, Inc. Sheridan Park 8, Suite 120 8670 Wolff Court Westminster, CO 80031-3692 303 428-5670 Fax: 303 428-5930 info@alphatrac.com

RFCA Stakeholder Focus Group
Attachment A

Title:	Agenda for October 17, 2001 Focus Group Meeting
Date:	October 11, 2001
Author:	C. Reed Hodgin AlphaTRAC, Inc.
Phone Number:	(303) 428-5670
Email Address:	cbennett@alphatrac.com

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RFCA Stakeholder Focus Group
Meeting Agenda

When: **October 17, 2001 3:30 - 6:30 p.m.**

Where: **Broomfield Municipal Hall, Bal Swan and Zang's Spur Rooms**

3:30-3:40	Agenda Review, 8/22/01 Meeting Minutes Review, Objectives for this Meeting
3:40-4:00	Task 3 Peer Review and Wind Tunnel Technical Review - update
4:00-4:20	Final results from the RSAL Modeling – Resident Rancher Scenario – RESRAD results, key parameters, and comparison to historical results
4:20–5:00	Task 3 Report – Briefing and Discussion
5:00-5:10	Break
5:10–6:00	Task 3 Report – Briefing and Discussion (cont.)
6:00-6:25	Task 3 Peer Review – Framing the Questions for the Reviewers
6:25-6:30	Review Meeting
6:30	Adjourn

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RFCA Stakeholder Focus Group
Attachment B

Title: October 3, 2001 RFCA Stakeholder Focus Group Meeting Handouts, including:

- 09/27/01 RSALs Working Group notes,
- *Comparison of Permissible Body Burden of Plutonium and Soil Action Levels, Joe Goldfield,* September 20, 2001,
- Presentation by Joe Legare: Approach to Cleanup using RSALs, and
- Presentation by Reed Hodgin: Wind Tunnel Technical Review – Status

Date: October 11, 2001

Phone Number: (303) 428-5670

Email Address: cbennett@alphatrac.com

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NOTES FROM RSALs WORKING GROUP MEETING ON 9/27/01

ITEMS COVERED ON 9/27:

1. Task 3 report.

ACTIONS

Action Item	Who	When	Notes
Go back & include necessary references in Task 3 text, along with an attached reference list.	All Task 3 authors	10/3/01	
Review compiled Task 3 report & have comments ready for 10/4 meeting.	All working group members	10/4/01	
Finalize missing information for Task 3 report: Appendix A (physical parameters); Appendix C; Appendix D; Section VI.	Assignees	10/3/01	
Draft cancer slope factors write-up	Diane N.	after 10/3	
Prepare list of terms from draft Task 3 report that should be in the glossary.	Tricia Powell	after Task 3 report is drafted	

DECISIONS

None

NEXT MEETING: THURSDAY, 10/4/01, 8:30 a.m., at ROCKY FLATS B060

Agenda Items:

1. Review draft Task 3 report (please come with comments ready).
2. Go through action item table.

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COMPARISON OF PERMISSIBLE BODY BURDEN OF PLUTONIUM AND SOIL ACTION LEVELS

Joe Goldfield
Denver, CO.

September 20, 2001

COMPARISON OF PERMISSIBLE BODY BURDEN OF PLUTONIUM AND SOIL ACTION LEVELS

PURPOSE: The purpose of this report is to compare the permissible body burden of plutonium with the concentration of plutonium in soil after clean up to various proposed soil action levels (SAL).

PERMISSIBLE BODY BURDEN OF PLUTONIUM

August 8,1983, Dr Karl Z. Morgan was interviewed concerning work he had done in the development of the atomic bomb for the Manhattan Project. The interview concerned, among other topics, Dr. Morgan's work, qualifications, and his views of the safety hazards of radionuclides in general but of plutonium in particular. That interview was reprinted in a book written by Robert Del Tredici, "At Work in the Fields of the Bomb". (N.Y. Harper and Row, 1987.)

Dr. Morgan is described as the "Father of Health Physics". He was director of Health Physics at the Oak Ridge National Laboratory for twenty-nine years. He has published several hundred articles on nuclear safety. For more than twenty-five years he was an active member of the International Commission on Radiation Protection (ICRP) and of the National Council on Radiation Protection (NCRP). During that time he was chairman of the Dose Committee of both organizations.

In the course of discussing hazards of plutonium, he said, "We set the permissible body burden for plutonium 239 as 0.04 millionths of a curie, that is 0.04 microcuries." Hereinafter given as 0.04 μCi. He said further that "I've published papers in the *Journal of Industrial Hygiene* showing that this level was in fact far too high and should be reduced by a factor of 240."

A body burden of 0.04 μCi of plutonium, undergoes 88,000 dpm (disintegrations per minute)--over 5,000,000 per hour. Each disintegration causes a highly energetic particle, called an alpha particle, to be emitted. Each alpha particle is capable of injuring or destroying a cell in the body of a human being contaminated with the plutonium. Damaging a cell in a particular fashion is what is believed to cause cancers to develop. It is therefore not surprising that Dr. Morgan found evidence that the permissible body burden was too high by a factor of 240. That

would still allow about 400 disintegrations per minute to emit alpha particles and injure human tissue.

It is difficult to find what the permissible body burden means. Does it mean that the exposed individual will suffer no ill effects of any kind after a long life-time of carrying that body burden? Does it mean that the exposed individual will have no greater chance of developing a cancer than is acceptable to the person setting the standard? Because the members of the ICRP and the NCRP are selected by members of that organization only and that the members are in the employment of the Nuclear industry and the DOE, there is a strong suspicion that their standards are set to cause the minimum degree of difficulty for their employers.

The permissible body burden of 0.04 μCi must be multiplied by 15.9 to change it to micrograms (μg). The result is 0.6 μg. Dividing that result by 240 results in a permissible body burden of 0.0025μg which is equivalent to 2.5 ng (nanograms--1000 nanograms are equal to one microgram.)

The permissible body burdens discussed are for a healthy worker in a plant of the nuclear industry. The permissible body burden is not acceptable for the general public--consisting of infants, young children, pregnant women, people with all sorts of health problems and damaged immune systems. It is common practise in the setting of health standards to reduce allowable exposures for the general public by a factor of 10 or 20. (I would find it difficult as a parent to accept any body burden of plutonium for any young child of mine.) Using the factors described, will reduce the permissible body burden from 0.6 μg to 0.06 to 0.03 μg. Multiplying by 1000 changes the body burden to 60 to 30 ng (nanograms).

PROPOSED SOIL ACTION LEVELS

The following table shows four selected, possible soil concentrations considered for several alternative land use scenarios:

Land Use Scenario	25-mrem annual dose
Wildlife Refuge Worker	875
Wildlife Refuge Worker (10^{-4} Risk)	512
Open Space User Adult	8540
Office Worker	2329

The doses in the above table are given as pCi/g (picocuries of plutonium per gram of soil).

The SAL's listed in the above table are concenrations of plutonium that are reduced because of the presence of americium. The concentration of americium associated with plutonium at Rocky Flats is about 18% of that of plutonium. Thus the dose of 25 mrem for the wildlife refuge worker is delivered by 875pCi of plutonium per gram of soil plus 158 pCi of americium per gram of soil. Similarly the SAL of 512 pCi of plutonium is associated with 92 pCi of americium per gram of soil. The open space user is subject to a concentration of 1540 pCi of americium plus 8540 pCi of plutonium per gram of soil. Finally the office worker is exposed to 420 pCi of americium plus 2329 pCi of pltonium.

In discussing permissible body burdens of soil contaminated with multiple contaminants, it is obvious that the additional health effects of all the contaminants must be considered. There may be more elegant methods of dealing with the problem but I chose to use a ratio developed in earlier studies of the problem where the presence of americium caused the allowable concentration of plutonium to be reduced from 1429 piC/g to 651 pCi/g because of the presence of 117 pCi/g of americium. The unstated conclusion is that the health effect of the radionuclides combined is equal to the health effect of 1429 pCi/g of plutonium alone.

Accounting for the presence of americium:

1. 1429/651 x 875 = 1920 pCi/g of plutonium (1.92 nC--nanocuries)

2. 1429/651 x 512 = 1120 pCi/g (1.1 nC)

3. 1429/651 x 8540 = 18700 pCi/g (19 nC)

4. 1429/651 x 2329 = 5100 pCi/g (5 nC)

To make these results comparable to the permissible body burdens which were expressed in nanograms, the above results must be multiplied by 15.9 to convert nCi to ng (nanocuries to nanograms).

The equivalent concentration of plutonium per gram of soil becomes for each of the four scenarios:

1. 1.9 x 15.9 = 30 ng

2. 1.1 x 15.9 = 18 ng

3. 19 x 15.9 = 300 ng

4. 5 x 15.9 = 80 ng

Compare these results with the "permissible" lifetime body burdens calculated in the previous section of 30 to 60 ng. The content of one gram of soil cleaned to the level of the four action levels reviewed will be in the range of or exceed by five to ten times the "permissible" life time body burden of plutonium. How do they compare to the body burdens that Dr. Watson said should be 240 times lower than those compared here? Those body burdens for the general public would be 0.125 to 0.25 ng--many, many times lower than the equivalent concentration of plutonium allowed in each gram of soil for the four SALs reviewed.

Cleanup is not an exact science. Due to the impossibility of testing a sufficient number of samples, after cleanup, hot spots as high as ten times the cleanup objective may be found. Certainly hot spots three times the cleanup goal will be more or less widespread. The ingestion of soils contaminated to those levels by children playing, office workers, or wildlife workers living on that soil is truly frightening to contemplate.

APPROACH TO CLEANUP USING RSALS

- Get the best cleanup possible with a fixed set of resources
- Apply effort where the greatest risk reduction can be achieved
- Increase the likelihood that accelerated actions will meet final standards

RISK-BASED RSAL APPROACH

- More surface removal particularly in areas of diffuse contamination such as the 903 lip area.

- Subsurface remediation is commensurate with risk. Less subsurface removal for similar contaminant levels.

ACTION AND CLEANUP LEVELS

- Establish action levels within the CERCLA risk range and ARARs
- Apply ALARA and Stewardship analysis to evaluate alternatives for soils between Tier I and Tier II.
- Actions are RFCA accelerated actions but approach as if final actions
- Use scenario RSAL matrix to establish conservative land use with tier II as surface soil ALARA goal

ACTION LEVELS
Surface Soil

- Tier I protective of USFWS Worker
- Tier II protective of rural resident
- Apply ALARA and Stewardship analysis to evaluate actions between tier I and tier II (note this is not practically different than the current approach)

ACTION LEVELS
Sub-surface Soil

- Tier I levels similar to surface soil but use as cleanup versus action levels
- As a practical matter, subsurface soil poses extremely low risk unless a pathway to surface water
- Use decision flow chart to trigger actions
- Apply ALARA and Stewardship analysis to soils between tier I and tier II

SUMMARY OF RFCA ATTACHMENT 5 TIERED APPROACH FOR SURFACE AND SUBSURFACE SOIL REMEDIATION				
Subsurface Soil	Organics	Inorganics	Radionuclides	Action
Tier I	100 x MCLs	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem to anticipated future user or 85 mrem to hypothetical future resident	Removal of soil by CERCLA/RFCA accelerated action
Tier II	MCLs	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem/yr to hypothetical future resident	Subsurface soil presenting unacceptable ecological risks [HI> or = 1] identified using the Ecological Risk Assessment Methodology will be evaluated for remediation or management. Implement efficient, cost-effective and feasible remediation or management actions. May be removal, treatment, disposal or in-place stabilization.
Surface Soil				
Tier I	Carcinogenic risk = 10^{-4} or HI = 1	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem to anticipated future user or 85 mrem to hypothetical future resident	Identify, evaluate and implement efficient, cost-effective and feasible remediation or management actions. May include removal, treatment, disposal or in-place stabilization of contaminated surface soils
Tier II	Carcinogenic risk = 10^{-4} or HI = 1	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem/yr to hypothetical future resident	Surface soils will be managed. May include hotspot removal, capping, or institutional controls

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SUBSURFACE SOIL ACTION LEVEL TIERED APPROACH
CURRENT ATTACHMENT 5 VERSUS PROPOSED APPROACH

Subsurface Soil	Organics	Inorganics	Radionuclides	Action
Tier I Current	100 x MCLs	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem to anticipated future user or 85 mrem to hypothetical future resident	Removal of soil by CERCLA/RFCA accelerated action
Proposed	Unchanged	Unchanged	10^{-4} – 10^{-6} to anticipated future land user (USFWS worker) Action triggered by flow chart analysis.	Unchanged
Tier II Current	MCLs	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem/yr to hypothetical future resident	Subsurface soil presenting unacceptable ecological risks [HI> or = 1] identified using the Ecological Risk Assessment Methodology will be evaluated for remediation or management. Implement efficient, cost-effective and feasible remediation or management actions. May be removal, treatment, disposal or in-place stabilization.
Proposed	Unchanged	Unchanged	10^{-4} – 10^{-6} to anticipated future land user (USFWS worker). Action triggered by flow chart analysis.	Apply ALARA and stewardship analysis to determine appropriate management action for soils between Tier I and Tier II. If there is no pathway to groundwater, then risk would only be associated with IC failure and digging.

SURFACE SOIL ACTION LEVEL APPROACH CURRENT ATTACHMENT 5 VERSUS PROPOSED APPROACH				
Tier I Current	Carcinogenic risk = 10^{-4} or HI = 1	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem to anticipated future user or 85 mrem to hypothetical future resident	Identify, evaluate and implement efficient, cost-effective and feasible remediation or management actions. May include removal, treatment, disposal or in-place stabilization of contaminated surface soils.
Proposed	Unchanged	Unchanged	10^{-4} – 10^{-6} to anticipated future land user (USFWS worker)	Unchanged
Tier II Current	Carcinogenic risk = 10^{-4} or HI = 1	Carcinogenic risk = 10^{-4} or HI = 1	15 mrem/yr to hypothetical future resident	Surface soils will be managed. May include hotspot removal, capping, or institutional controls.
Proposed	Unchanged	Unchanged	10^{-4} – 10^{-6} to rural resident	Apply ALARA and stewardship analysis to determine appropriate management action for soils between Tier I and Tier II.

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WIND TUNNEL TECHNICAL REVIEW -

STATUS

Reed Hodgin

October 3, 2001

RFCA Stakeholder Focus Group

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Objectives for the Wind Tunnel Technical Review

- Evaluate the appropriateness of the wind tunnel technology used in studies at Rocky Flats for developing wind resuspension values for use in establishing Radioactive Soil Action Levels at Rocky Flats.

Objectives for the Wind Tunnel Technical Review

- Evaluate if the wind tunnel results are being properly used in developing input values for use in the selected dose (RESRAD) and risk (RAGS) models for establishing Radioactive Soil Action Levels at Rocky Flats.

NOT Just Another Peer Review

- Will involve examining the technical basis for the wind tunnel methodology and its application

- Thus a technical review of a methodology rather than a peer review of a report

Approach

- Reviewers will use documents and information provided by Rocky Flats Cleanup Agreement (RFCA) agencies
- Reviewers will use additional information they may have or obtain
- Reviewers will apply this information along with their professional judgment in conducting the evaluations

Deliverable

- Each reviewer will develop and submit a written report containing his evaluation and justification

Level of Effort and Schedule

- An "expert opinion" analysis rather than original research
- Expected level of effort = around 3 days (24 person-hours) per reviewer
- Schedule = 5 weeks, might be shortened to four weeks

Status

- 3 primary reviewers and 3 alternates identified by subgroup of Focus Group
- Budget has been established and funding provided
- 3 primary reviewers have agreed to perform evaluations

Status (Cont.)

- Most of materials are compiled
- Materials and contract information will go out this week
- Review period will formally begin 10/8/01

RFCA Stakeholder Focus Group
Attachment C

Title:	October 1, 2001 Health Effects of Low-level Radiation meeting materials
Date:	October 11, 2001
Phone Number:	(303) 412-1200
Email Address:	coalition@rfclog.org

HEALTH EFFECTS OF LOW-LEVEL RADIATION

Agenda

(October 1, 2001)

Rocky Flats Coalition of Local Governments

MORNING SESSION

9:00 – 9:15 A.M. Introduction/Welcome

9:15 – 10:00 A.M. Overview of Radiation and Risk

This portion of the meeting will provide the Coalition with a background on the current body of knowledge on radiation. We will discuss the different sources and types of radiation, and how each contributes to risk. We will also look at the radioactive material at Rocky Flats in terms of this background information.

- What is Radiation
  - definition of low-level radiation
  - types (ionizing, non-ionizing; alpha, beta, gamma, x-ray)
  - sources (natural, anthropogenic)
  - what types of radioactive material exist (and subsequently, what type of radiation is emitted) at Rocky Flats

- What Contributes to Risk
  - exposure
  - dose (depends on route and duration of exposure, type of radiation emitted, shielding, bioavailability and half-life of radioactive material, etc…)
  - how risk is defined
  - relative contributions of natural and anthropogenic sources to dose and risk
  - average background dose and dose limits for the United States – comparison of predicted doses at Rocky Flats to limits

10:00 – 10:15 A.M. Break

10:15 – 11:30 A.M. Health Impacts of Low-Level Radiation

This portion of the meeting will look at the health effects of exposure to low-level radiation. We will focus on contaminants at Rocky Flats, in particular.

- Health Impacts of Low-Level Ionizing Radiation
  - possible outcomes of cellular exposure to radiation (pass through, damage, kill)
  - distribution in the body (specific targets versus whole-body dose)
  - possible health endpoints of radiation exposure in general (cancer, embryonic effects) and of exposure to Rocky Flats contaminants

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- what studies have shown about the health impacts of low-level radiation (what we know and don't know)
- relative dangers of exposure to plutonium (versus other radionuclides)
- impacts of taking in one larger mass of plutonium versus several smaller masses

11:30 – 12:15 P.M. Lunch Break

12:15 – 1:45 P.M. Uncertainties of Low-Level Radiation Health Effects

This portion of the meeting will focus on the uncertainties associated with health effects of exposure to low-level radiation. We will explore the sources of uncertainty and the different schools of thought for assessing health effects at low doses.

- Sources of Uncertainty
  - epidemiology versus toxicology
  - confounding factors

- Different Scientific Schools of Thought (Dose-Response Models)
  - linear no-threshold
  - supralinear
  - sublinear
  - threshold
  - hormesis

1:45 – 2:00 P.M. Break

AFTERNOON SESSION

2:00 – 4:00 P.M. Differences between ICRP 30 and ICRP 72

This portion of the meeting will educate the Coalition on the changes between the ICRP 30 and ICRP 72 reports, why changes were made, and how these changes affect the magnitude of the dose conversion factors and cancer risk slope factors that are based on these reports. We will also discuss how uncertainty is addressed in exposure models.

- ICRP 30: Biokinetic Models and Assumptions
  - Inhalation Pathway
  - Ingestion Pathway
  - External Exposure

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- ICRP 72: Biokinetic Models and Assumptions
  - Inhalation Pathway
  - Ingestion Pathway
  - External Exposure

4:00 – 4:15 P.M. Closure

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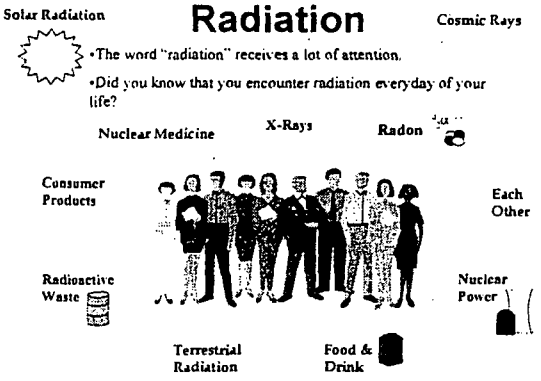
Radiation and Risk

Presented to the Rocky Flats Coalition of Local Governments

October 1, 2001

Jim Durham
Department of Radiological Health Sciences
Colorado State University

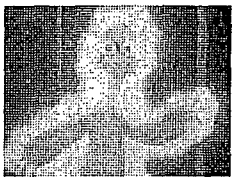
Radiation



Radiation Quiz

Q. Which of the following statements is true?

- Even small quantities of radiation are very dangerous.
- All materials give off some radiation.
- Most of the radiation to which people are exposed comes from the nuclear industry.
- Very little is known about the risks from radiation.



Basic Radiation Physics

- History of Radiation
  - 1895: William Konrad Roentgen showed that x-rays he discovered could penetrate through matter and darken film
  - 1896: Henri Becquerel discovered that minerals that contained Uranium gave off rays that were capable of
    - penetrating black paper and blackening a photographic plate
    - producing fluorescence in certain substances
    - inducing electrical conductivity in air
    - passing through plates of metal

Basic Radiation Physics

- History of Radiation
  - 1896: Elihu Thomson deliberately exposed his little finger to x-rays and discovered biological damage
  - 1898: Marie Curie and her husband worked with Uranium Ore (Pitchblend) and discovered Polonium and extracted Radium, a radionuclide that was more than 1,000,000 times more active than uranium
  - Characterization of the radiation emitted led to the discovery of alpha rays, beta rays, and gamma rays

Basic Radiation Physics

- History of Radiation
  - 1900: X-rays were known to cause biological damage if exposure was too long or too intense
  - 1910: The atom was thought to consist of a "plum pudding" of positive and negative charges
  - 1911: Rutherford showed that alpha particles would scatter from gold nuclei and that the nucleus of the atom was very small compared to the size of the atom

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Basic Radiation Physics

- History of Radiation
  - 1932: Chadwick discovered the neutron
  - 1939: Hahn and Strassman demonstrated nuclear fission
  - 1941: Plutonium made from Uranium by neutron bombardment in a laboratory setting
  - December 2, 1942: First man-made reactor went critical at the University of Chicago (Enrico Fermi)
  - 1943: Construction started on first reactors for the production of plutonium at Hanford, Washington

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Basic Radiation Physics

- History of Radiation
  - July 16, 1945: First test of an atomic bomb completed at the Trinity site at Alamagordo, New Mexico
  - August 6 and August 9, 1945: Atomic bombs dropped on Hiroshima and Nagasaki
  - 1951: Construction of Rocky Flats site initiated to produce "triggers" for nuclear weapons

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Basic Radiation Physics

- History of Radiation
  - 1952: Production at Rocky Flats begins
  - 1990: Rocky Flats production ceases

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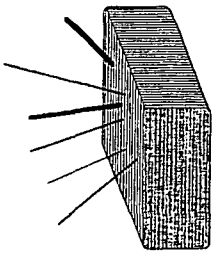
Basic Radiation Physics

- What is Radiation?
  - Elementary particle
  - Sufficient kinetic energy to interact with and transfer energy to objects



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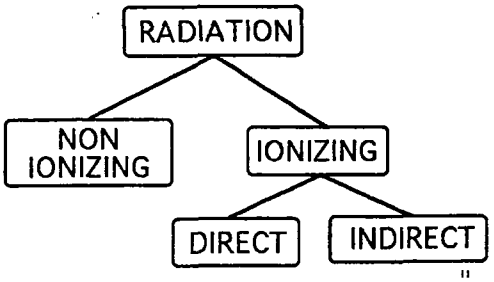
Basic Radiation Physics

- Classes of Radiation



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Basic Radiation Physics

- Non-ionizing Radiation
  - Radiation that does not have enough energy to create ions in matter
  - Includes microwaves, laser light, and ultraviolet radiation
  - Causes damage to tissue through different mechanisms than ionizing radiation

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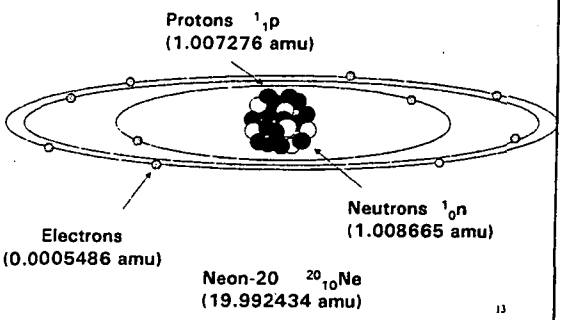
Atomic Structure



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Atomic Structure

- Nucleus (analogous to our Sun)
  - Protons (positive electrical charge)
  - Neutrons (no electrical charge)
  - Protons and neutrons have roughly the same mass, but are about 1800 times more massive than electrons
- Electrons (analogous to our planets)
  - Negative electrical charge

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Atomic Structure (cont'd)

- So how small is an atom?
  - If the nucleus were as big as a baseball, the closest electron would be about 1 mile away!
  - There's a lot of space between electrons and the nucleus!
- Knowledge of the structure of an atom is important because this is where radiation originates.

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Radioactivity

- Radioactivity: The process by which energetic atoms spontaneously transform into different atoms and in the process emit radiation.
- This is a two step process
  - There is a transformation inside the nucleus.
  - Simultaneously, radiation is emitted in one or several forms.
    - Alpha particles
    - Beta particles
    - Neutrons
    - Gamma rays
- When an atom undergoes this transformation, we say that it decays, or disintegrates.

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Measures of Radioactivity

- Activity: The quantity of radioactive material present at a given time:
  - Curie (Ci) : 3.7×10^{10} disintegration per second (dps)
  - milliCurie (mCi): 3.7×10^{7} dps
  - microCurie (μCi): 3.7×10^{4} dps
  - picoCuries (pCi): 0.037 dps
  - Becquerel (Bq): 1 dps
  - megaBecquerel (MBq): 1×10^{6} dps
- Specific Activity: The amount of radioactivity in a given mass or volume, e.g. pCi/l or Ci/gm

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Radioactive Decay

- Half-life: The time required for 1/2 of a sample to decay from its original activity.
  - Example:
    - If we have a sample of 1000 atoms, and its half-life is 10 days, then after 10 days have passed, about 500 atoms will remain.
- Remember, half-life tells us how long a substance may last and activity (Ci or Bq) tells us how active the material is.

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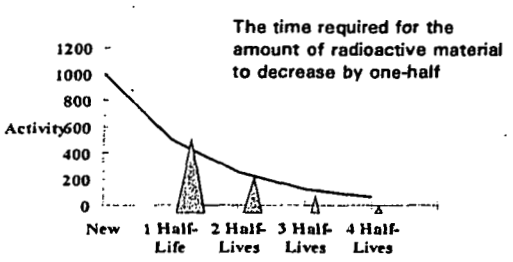
Half-Life



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Types of Radiation

- Alpha Particles
  - Composed of 2 protons, 2 neutrons and has no electrons.
  - Has a positive 2 electrical charge.
  - Travels only an inch or two in air.
  - Easily shielded with paper or the dead layer of your skin.

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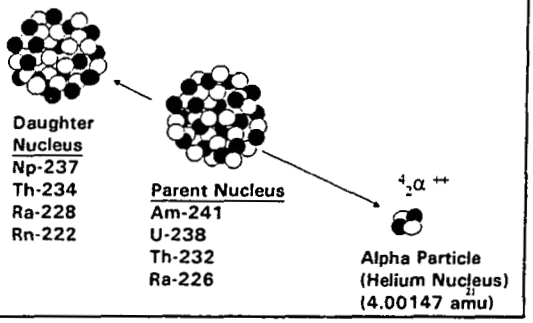
Alpha Decay



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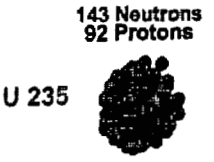
Alpha Disentegration



Types of Radiation (cont'd)

- Beta Particles
  - Identical to an electron and has a negative one electrical charge.
  - 7200 times less massive than an alpha particle.
  - Travels several feet in air.
  - Easily shielded by clothing, a few sheets of cardboard, or Plexiglas.

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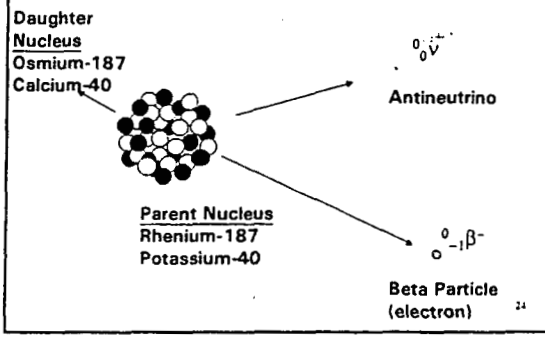
Beta (Negatron) Decay



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Beta- Disentegration

17 Neutrons
15 Protons

$^{32}_{15}P$

Types of Radiation (cont'd)

- Gamma Rays
  - Have no electrical charge and no mass.
  - Travels at the speed of light no matter what its energy.
  - Average travel distance in air is approximately 12 miles.
  - Shielded by dense materials such as lead or tungsten.

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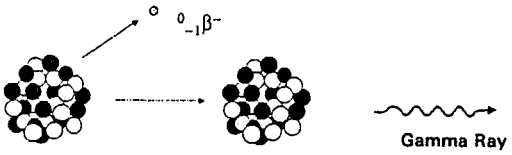
Gamma-Ray Emission



Parent Nucleus
Cesium-137
Molybdenum-99

Daughter Nucleus
Barium-137m
Technetium-99m

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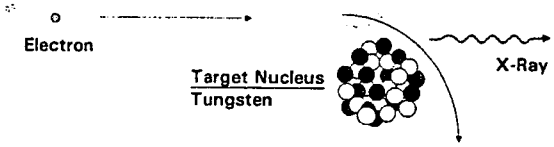
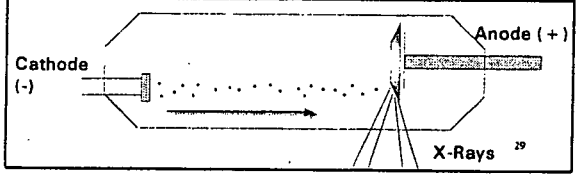
Gamma Radiation

33 Neutrons
27 Protons

Co 60
High Energy

X-Ray Production (Bremsstrahlung)





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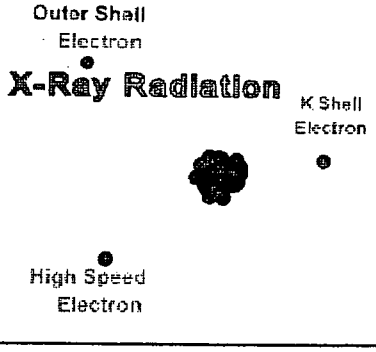
X-Ray Radiation



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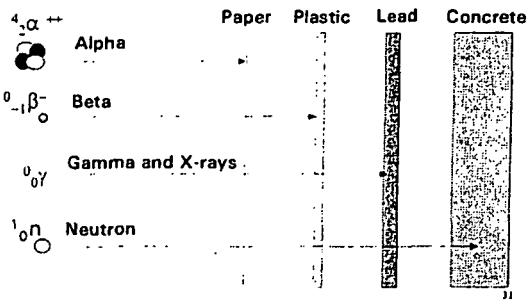
Types of Radiation



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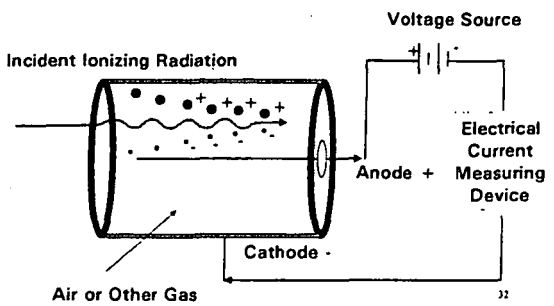
Radiation Detection
Gas Filled Detectors and Demo



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Ionization

- A process by which an electron is ejected from its orbit around the nucleus of an atom. The ejected electron and the resulting positively charged atom form an ion pair.
- Alpha and beta particles directly ionize atoms.
  - Alpha particles cause dense ionization along a straight, short path.
  - Beta particles cause less dense ionizations and follow a random path.
- Gamma Rays/X-Rays indirectly ionize atoms.
  - Can scatter or be absorbed in material, lose energy, and transfer it to electrons, which cause ionizations.

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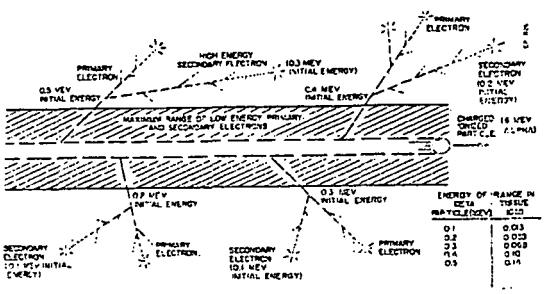
Examples of Ionization



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External Exposure to Radiation

- Review:
  - What are alpha particles stopped by?
    - No external hazard is expected since ionizing dead skin cells is not harmful to us.
  - What are beta particles stopped by?
    - Can penetrate about 1 cm into skin and cause minimal damage to cells by ionization.
  - What are gamma rays/x-rays stopped by?
    - Can penetrate deep into tissue and may or may not cause damage to cells since they have no mass and no electrical charge.

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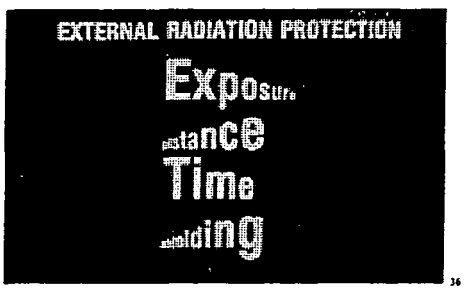
Minimizing Exposure to Radiation



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Internal Exposure to Radiation

- Alpha particles can cause dense ionizations in a straight, short path. Inside the body these ionizations may cause damage to surrounding cells.
- Beta particles, which cause less dense ionizations, can penetrate into soft tissue (inside the body) and cause damage to cells.
- Gamma Rays/X-Rays may or may not interact to cause damage to cells since they have no mass and no electrical charge.

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Radiation Dose

- The amount of energy deposited per mass of material.
- If the material is live tissue, then the deposited energy might cause physical and chemical changes, which could possibly result in biological effects.
- How much energy is deposited and how much risk this causes is what we need to know.
- A measurement of this risk is called Dose Equivalent and is expressed in units of rem.

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Radioactivity, Radiation and Contamination

- What's the difference?
  - First let's picture a pile of dirt that smells bad.
    - Radioactivity describes how active a material is.
    - Radiation describes the "emanations" (the smell) from this pile of dirt. The closer you get to the pile, the stronger the smell, or the the more radiation you are exposed to.
    - Contamination is when you step onto this dirt pile. So contamination is radioactive material where you don't want it.

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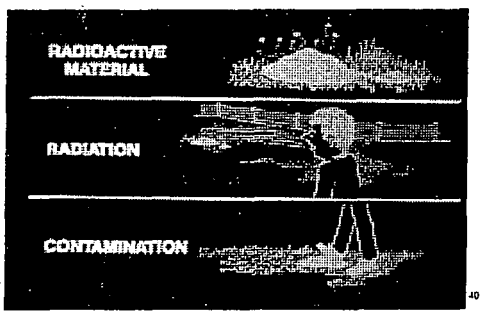
Radioactivity, Radiation, and Contamination



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Biological Effects

- High Doses in a short period of time (acute dose)
  - A short period of time is considered to be less than 1 week.
  - 25 rem: Decrease in RBC's and increase in WBC's
  - 50 - 100 rem: Nausea, vomiting, diarrhea
  - 100 - 250 rem:Lethargic, infection, fever, erythema, edema
  - 250 - 450 rem:GI Disorder, internal bleeding, death to 50% of population in 60 days with no medical treatment.
  - >600 rem:CNS Disorder, temporary feeling of well-being, death to most people within two weeks, with no medical treatment.
- *Reference: The numbers used here are from "The Cancer Risk from Low-Level Radiation." Bernard L. Cohen. Health Physics, Vol. 39, No.4, Oct., 1980.*

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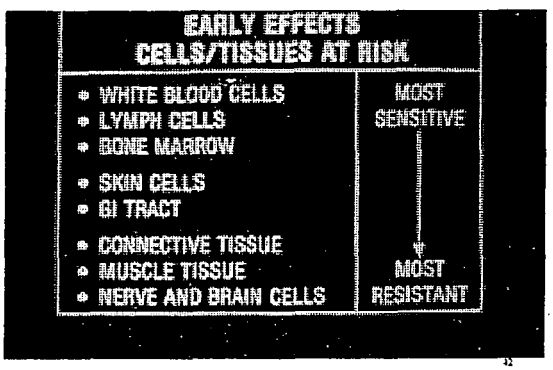

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Biological Effects

- Each year 1,000,000 cancers are diagnosed in the U.S.
- Cancer is the second leading cause of death in the U.S. Approximately 1 in 6 will die of cancer.
- Radiation exposure does not cause unique forms of cancer.
- The risk of cancer from radiation exposure is assumed to be linear with dose (ICRP 60)
- It is estimated that if 1,000,000 people were each exposed to 1 rem, there will be:
  - 100 additional leukemia cases
  - 700 additional other cancers (BEIR V)

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LATE EFFECTS CELLS/TISSUES AT RISK

Gonads	Bone
Lung	Thyroid
Breast	Skin
Eye Lens	Other

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FACTORS WHICH DETERMINE THE BIOLOGICAL EFFECTS OF RADIATION EXPOSURE

- Amount of exposure
- Exposure rate
- Portion of body exposed
- Radiation characteristics
- Biological Variability

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Radiation and Cancer

- Radium watch/clock painters
  - 48 out 1700 women died of bone cancer (17,000 Rem to bones)
- U.S. miners and lung cancer
  - 135 out of 4100 workers died of lung cancer (4700 Rem to lungs)
- Hiroshima/Nagasaki (Atomic Bomb)
  - 120 out of 24,000 died of cancer (130 Rem)

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Radiation Risk

- 10,000 persons exposed to 1 Rem results in 1 excess cancer death
- Natural incidence of cancer for the same 10,000 people results in 1667 deaths due to cancer.

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Two Theories of Risk

- Linear No-Threshold Theory
- Hormesis

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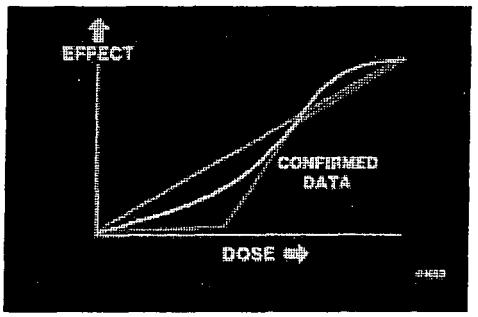
Two Theories of Risk



Late Effects - Low Dose Estimations

- The linear extrapolation curve is used for radiation protection purposes.
  - The curve, in general, is true for low LET radiation (gamma, beta).
  - May underestimate the risk associated with high LET radiation (alpha, neutron)
- The use of quality factors for high LET radiation takes into account this uncertainty.

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Late Effects - Low Dose Estimations

- The S-shaped curve is closer to reality than the linear extrapolation model.
- At very high doses, more cells die from exposure and do not have time to become cancerous, thus a plateau is present.
- At low doses, there is disagreement on whether the effect is linear, quadratic, or otherwise curved.
- The linear curve, at low doses, overestimates the risk

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Late Effects - Low Dose Estimations

- The third curve shows that the effect goes to zero with a non-zero dose.
- This means that the body can tolerate a dose of radiation below this threshold with no ill effects.
- This assumption is made for almost every other carcinogen known to man (and ones for which we have less data).

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Basic Health Physics

- Background Radiation
  - Background radiation comes from 4 sources
    - Cosmic radiation (sources in outer space)
      - increases with altitude because of loss of shielding provided by the atmosphere
      - national average is 30 mrem/yr
    - Terrestrial radiation (sources in the earth)
      - increases with proximity to uranium-bearing rocks and sands
      - national average is 30 mrem/yr

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Basic Health Physics

- Background Radiation
  - Background radiation comes from 4 sources
    - Internal radiation (sources in the human body)
      - Potassium-40 and Carbon-14 are naturally-existing radionuclides
      - relatively constant
      - national average is 40 mrem/yr
    - Radon from decay of Uranium progeny
      - radon is an inert gas that can seep into houses from the soil
      - can give lung doses of up to 2400 mrem/yr
        - equivalent to whole body dose of 200 mrem

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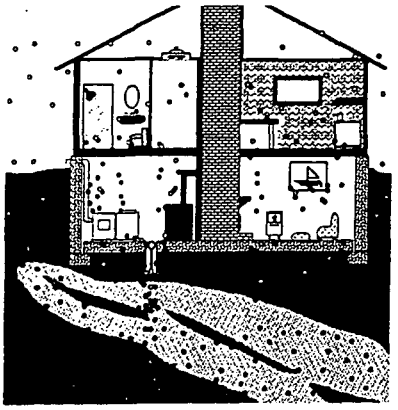

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Basic Health Physics

- Man-Made Radiation
  - Medical radiation sources
    - typical chest x-ray gives dose of 10 mrem
    - average dose is 55 mrem/yr
  - Atmospheric testing of nuclear weapons
    - dose is less than 1 mrem/yr
  - Consumer products
    - TVs, smoke detectors, older luminous watches
    - dose is about 10 mrem/yr

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Basic Health Physics

- Background Radiation
  - Background radiation levels in the United States are typically 300 mrem per year
    - 200 mrem from radon
    - 60 mrem from cosmic and terrestrial
    - 40 mrem from internal radiation
  - In front range cities, background radiation levels are typically 500 mrem/y
    - 340 mrem from radon
      - Radon levels can be much higher
    - 120 mrem from cosmic and terrestrial
    - 40 from internal radiation

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Basic Radiation Physics

- Background Radiation

Table 1. Background Radiation

	USA	Colorado
External		
Cosmic	30 mrem	60 mrem
Terrestrial	30 mrem	60 mrem
Internal		
Body Tissue	40 mrem	40 mrem
Radon	200 mrem	350 mrem
Total	300 mrem	500 mrem

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Sources of Radiation

- Consumer Products
  - Luminous Dial Watches (Pm-147, H-3, Ra-226)
  - Lantern Mantles (Ce-144, Th-230)
  - Fiesta Ware Pottery (U-238)
  - Smoke Detectors (Am-241)
- Food Products
  - Brazil Nuts (Rb-87)
  - Bananas (K-40)
  - Milk (K-40)

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Sources of Radiation

- Air (Rn-222, Sr-90, H-3, C-14)
- Soil (U-238, Th-230, Ra-226, Rn-222)
- Water (Ra-226, Rn-222)

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Medical Sources of Radiation

- Chest X-Rays (140 mrem to skin of chest)
- Dental X-Rays (400 mrem to skin of face)
- I-131 to treat hyperthyroidism (20 to 300 rem to thyroid)
- Radiotherapy for polycythemia (excess RBC's) About 600 rem to bone marrow using P-32.
- Nuclear Power Plants (0.3 mrem per year)

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Medical Uses of Radioactive Material

- Therapeutic purposes - Radiation and radioisotopes can be used to damage or destroy abnormal or diseased cells. Therapeutic uses include treatment of cancer and other diseases with ionizing radiation.
- Diagnostic purposes - Radioisotopes can be used to provide an image of an internal structure in the human body, or they can allow doctors to visualize various stages in the function of an organ. Radiation from X-rays also fall into the diagnostic category.

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Risk Vs. Benefit

- The risk of exposure to radiation must be weighed against the benefit
  - Benefit of medical exposures is greater than the risk of cancer from radiation
- The risk of exposure to radiation must be weighed against the cost of reducing the exposure
  - Incremental cost of cleanup must balance reduction of dose to public

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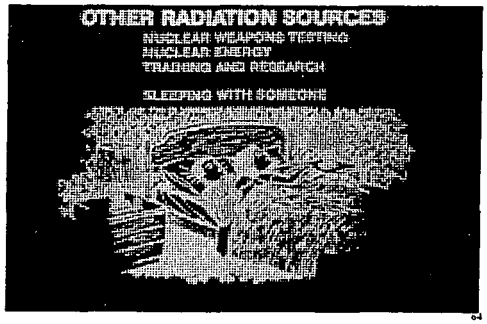
Other Sources of Radiation



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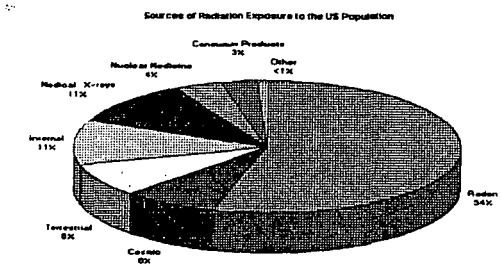
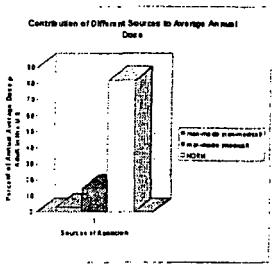
Sources of Radiation Exposure to the U.S. Population



Sources of Radiation Exposure to the U.S. Population

- 82% of the annual dose to the U.S. population comes from naturally occurring radiation.
- Of the remaining 18%, less than 1% is a result of nuclear power and fallout.



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"Normal" Cancer Occurrence due to Natural Daily Exposures

- Taking an average of 200 mrem per year for 70 years, this results in an average lifetime dose of 14 rem. .
- Taking our same group of 10,000 people, this results in a *potential* of 14 cancer deaths.
- This means that of the 1667 cancer deaths, 14 of them might be attributed to our daily exposure to radiation. Or 0.47% of them.

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Radiation and Risk: Activities which increase risk by 1 in a Million

Smoking 1.4 Cigarettes	Cancer, heart disease
Drinking 0.5 liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black lung disease
Spending 3 hours in a coal mine	Accident
Living two days in Boston or New York	Air Pollution
Traveling 10 miles by bicycle	Accident
Traveling 150 miles by car	Accident
Flying 1000 miles by jet	Accident
Flying 6000 miles by jet	Cancer caused by cosmic radiation
Living two months in Denver	Cancer caused by cosmic radiation
Living two months in brick building	Cancer caused by natural radiation
One chest x-ray	Cancer caused by radiation
Eating 40 Tablespoons of peanut butter	Liver cancer caused by aflatoxin B
Living 5 years at site boundary of a nuclear plant	Cancer caused by radiation
Eating 100 charcoal -broiled steaks	Cancer from benzopyrene
Living within 5 miles of a nuclear reactor for 50 years	Cancer caused by accidental radiation release

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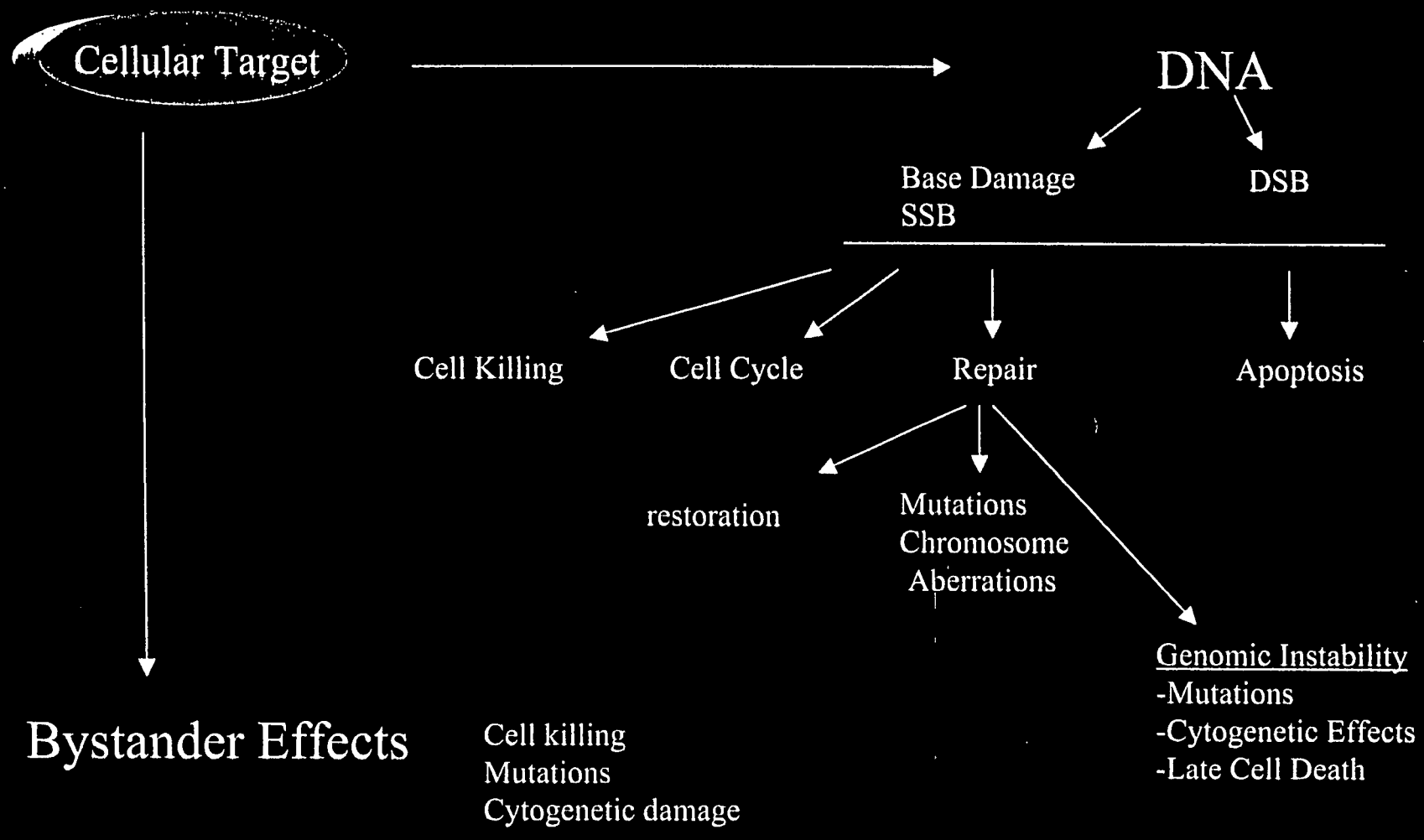
Biology of Relevance to Low Dose Risk

- Damage
  - Unique?
  - Accurately repairable?
- Damage Processing
  - Mechanisms of repair-high versus low dose
  - Role of damage response pathways in propagation or elimination of damaged cells
  - Bystander effects;adaptive response;genomic instability
- Cell and Molecular Mechanisms
- Modifiers of Expression
  - Tissue effects
- Quantitative Data –Experimental
  - Cytogenetic;Mutagenic;Carcinogenic
- Quantitative Data-Human Populations

Mechanisms of Radiation Damage



Repair of Radiation-Induced DNA Damage

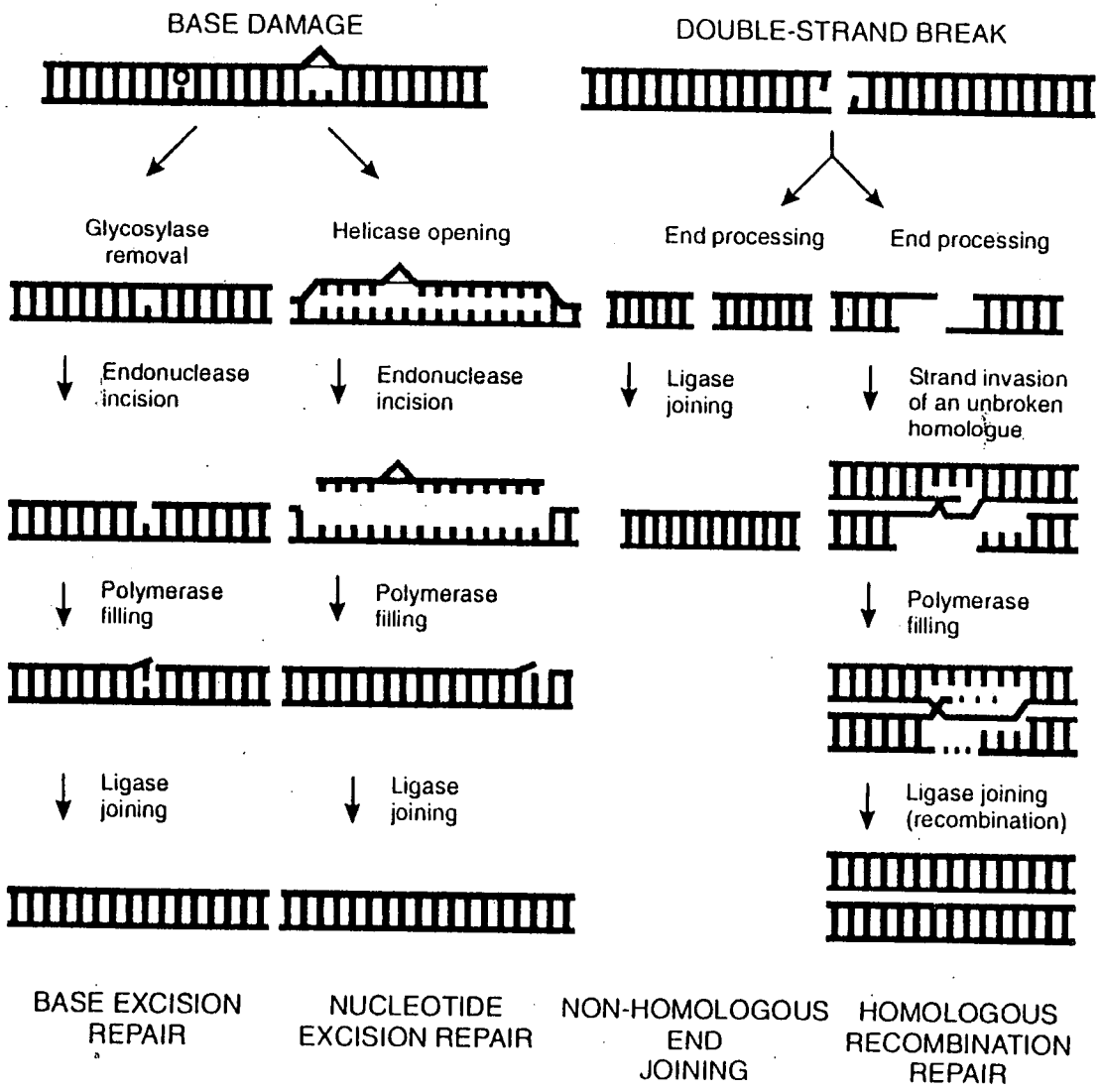


Figure Ia. Figure Ib. Figure Ic. Figure Id.

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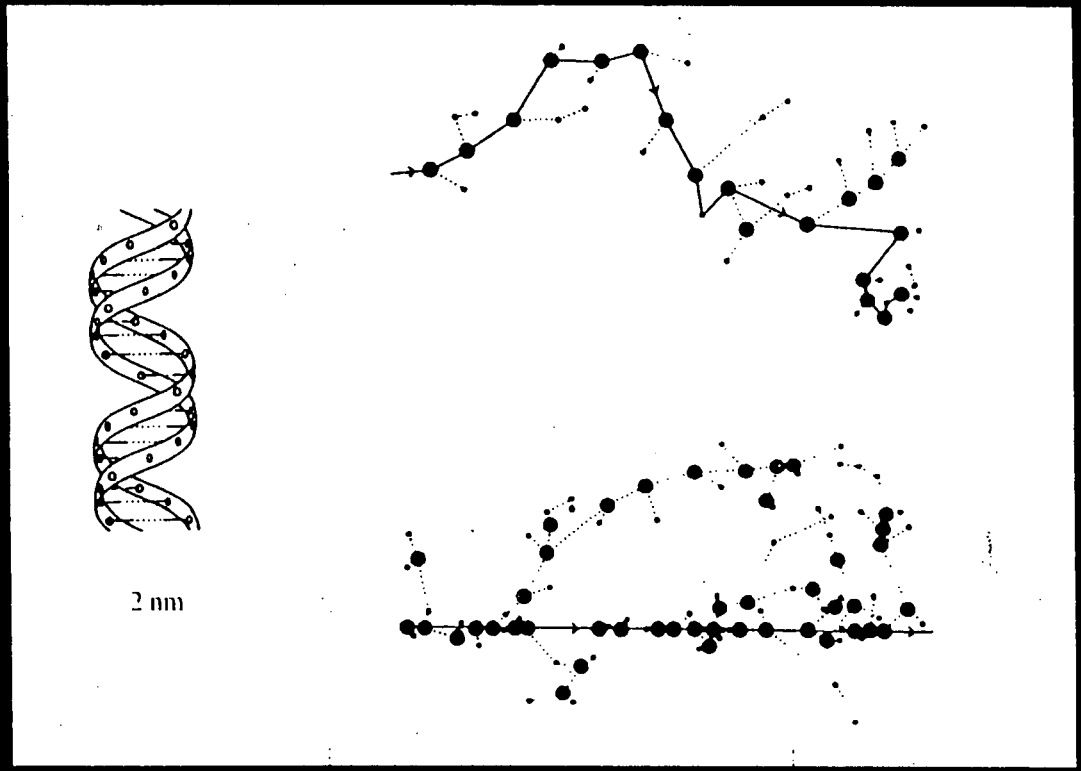
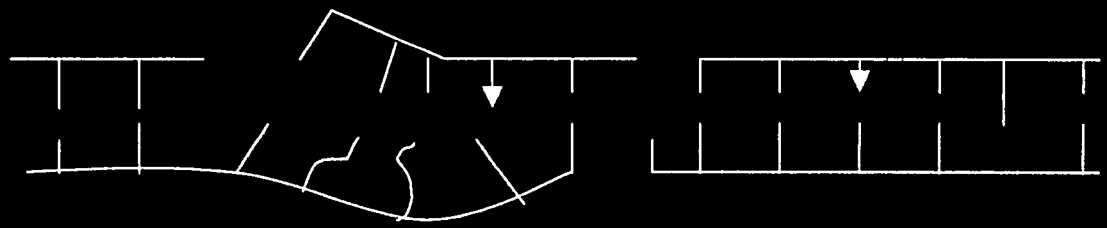
Radiation Results in Unique Clustered Forms of DNA Damage

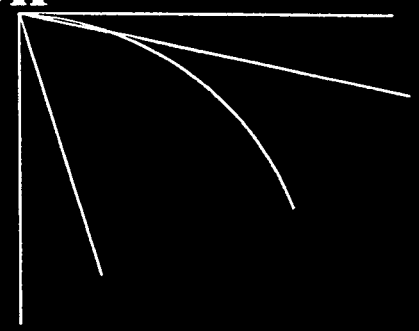




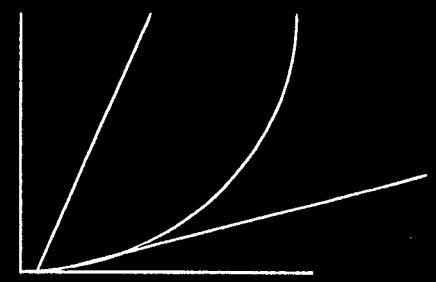
Cellular Effects of Ionizing Radiation

Dose, Dose Rate, Radiation Quality

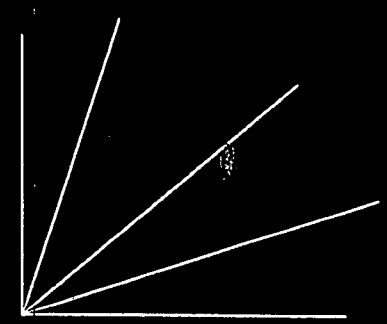
Cell Killing



Chromosome Aberrations
- dicentrics
- translocations
- inversions
- complex



Mutations
- Single Alpha Particle ↑
- 20% of Cells ↑

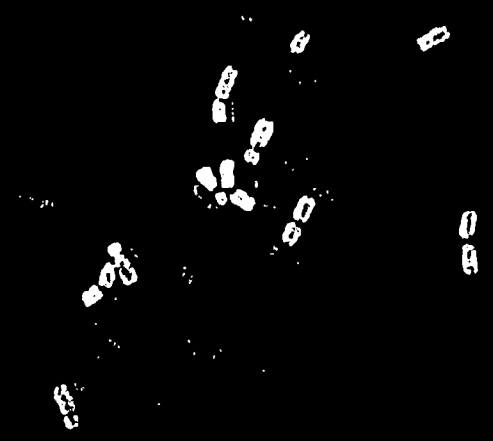


High-LET Radiation

- At low Doses Not all Cells Are "Hit"
  - Increasing Dose Increases Number of Hit Cells
- Those "Hit" Receive Relatively High "Dose"
  - Dose Meaning Energy Deposition
- Less RBE in Cells That Have Repair Defects
  - Suggesting That Damage From Low-LET Radiation Is More Repairable

Aberrations and Mutations

Chromosome Aberrations



Mutations

	N.T	Chemical	Radiation
Point Mutations (Single Bases)	90	100	20
Large Changes (Deletions/Rearrangements	10	0	80

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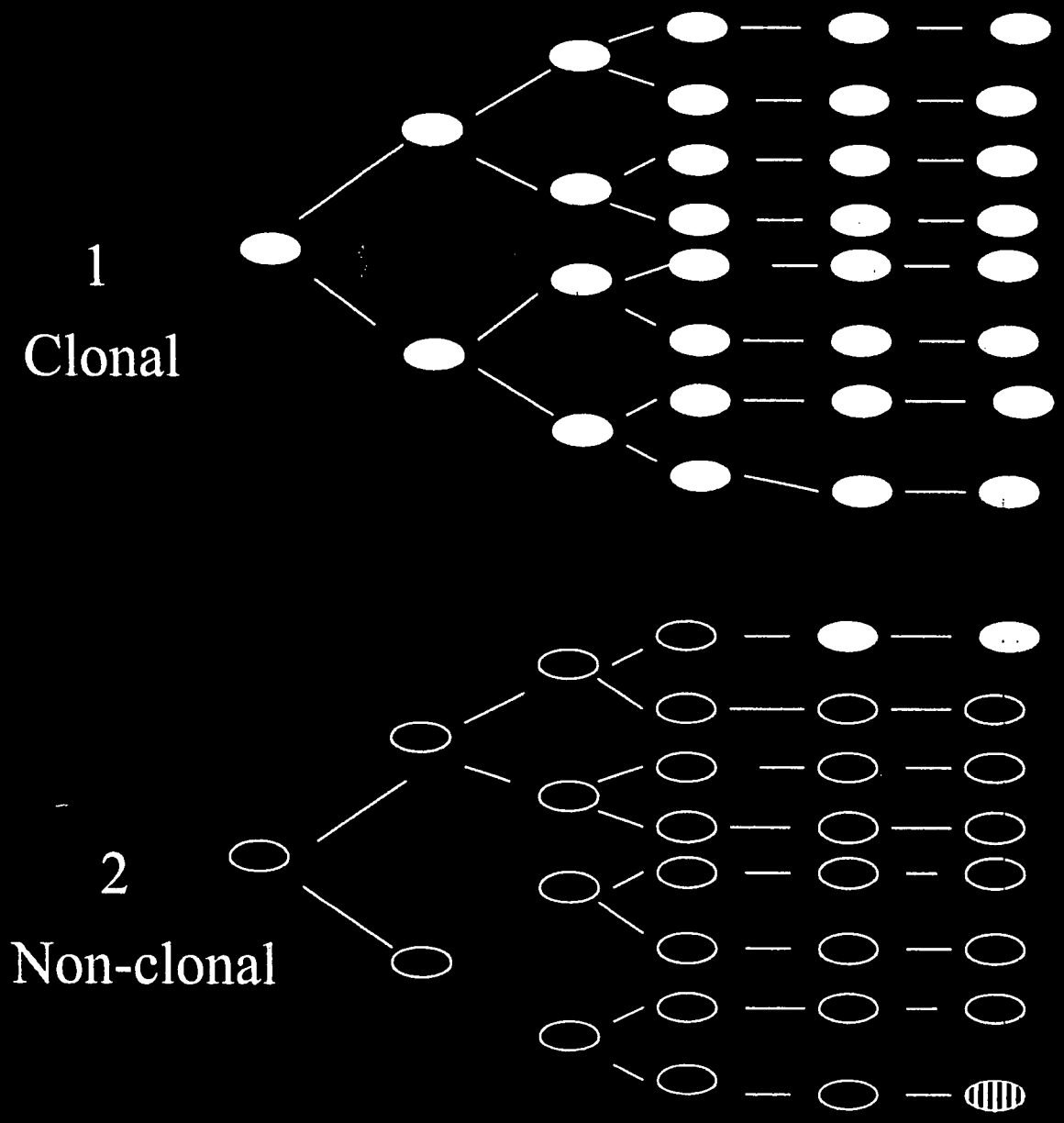

Genomic Instability

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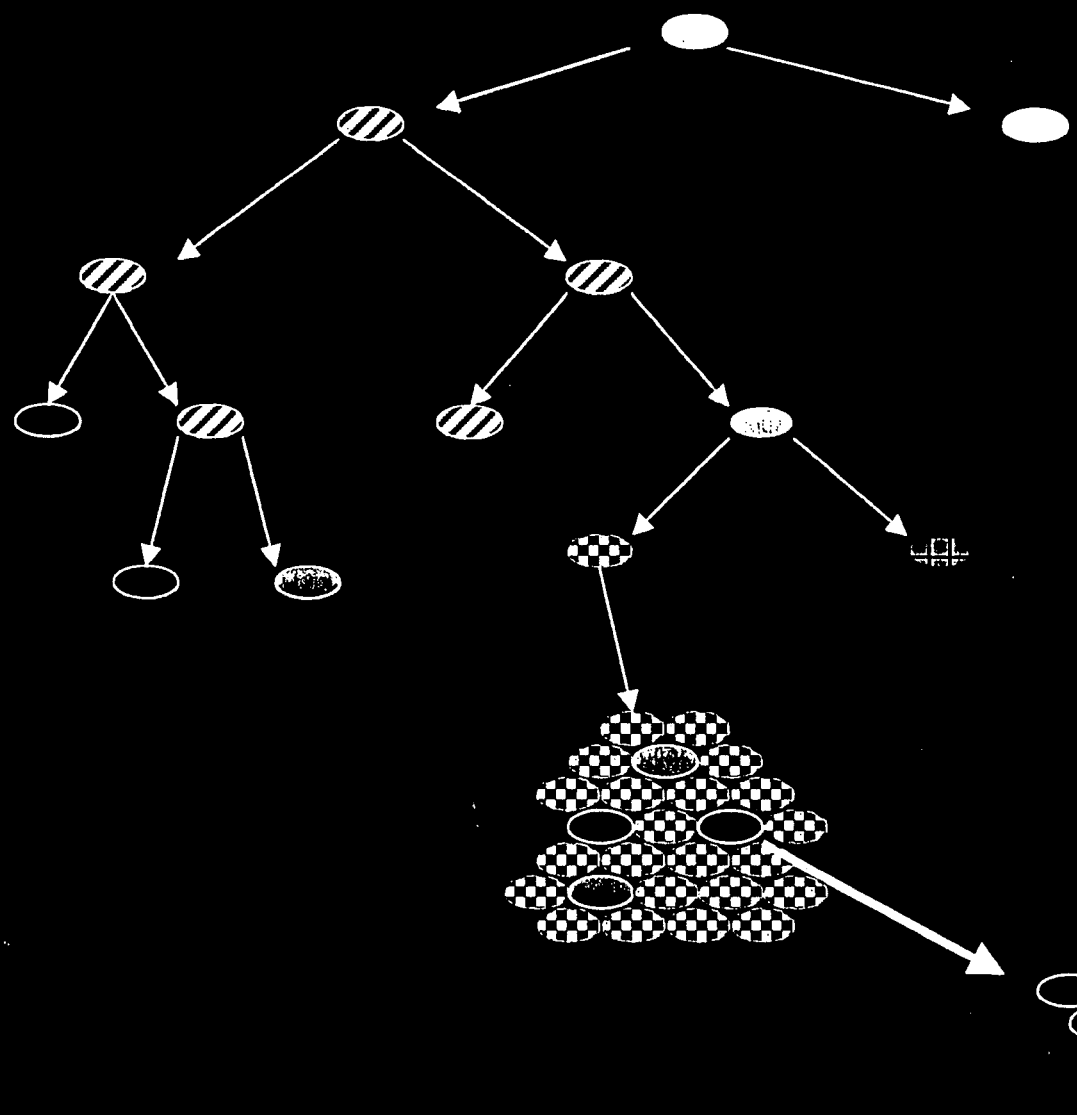
Radiation-Induced Instability And Cancer



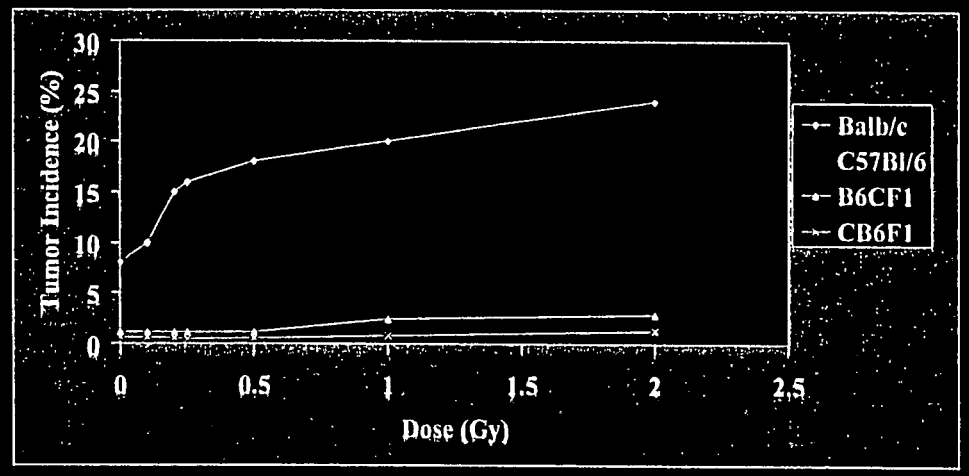
Instability

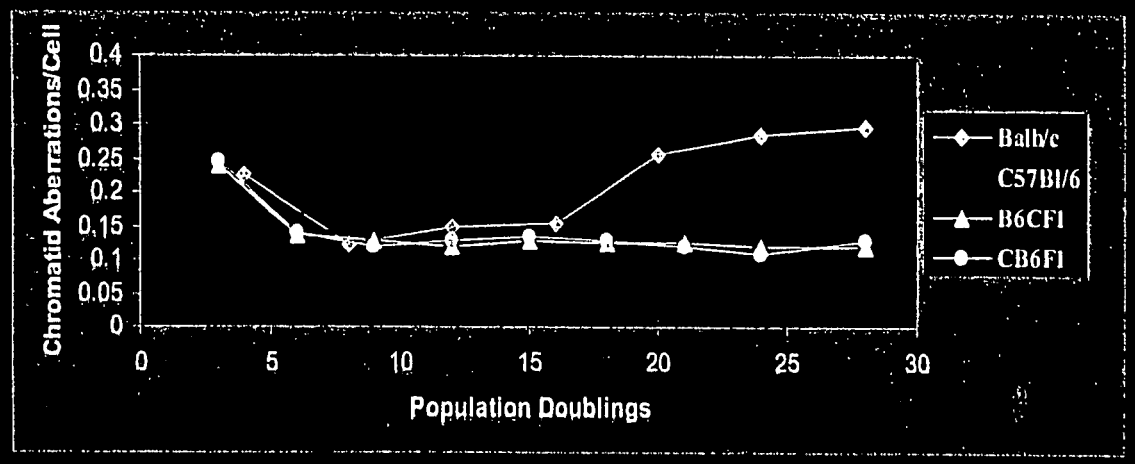
Critical Mutations

- → **persistence**
- → **amplification**
- → **growth advantage**

Progression

Radiation-Induced Mammary Cancer and Instability as a Function of Genetic Background





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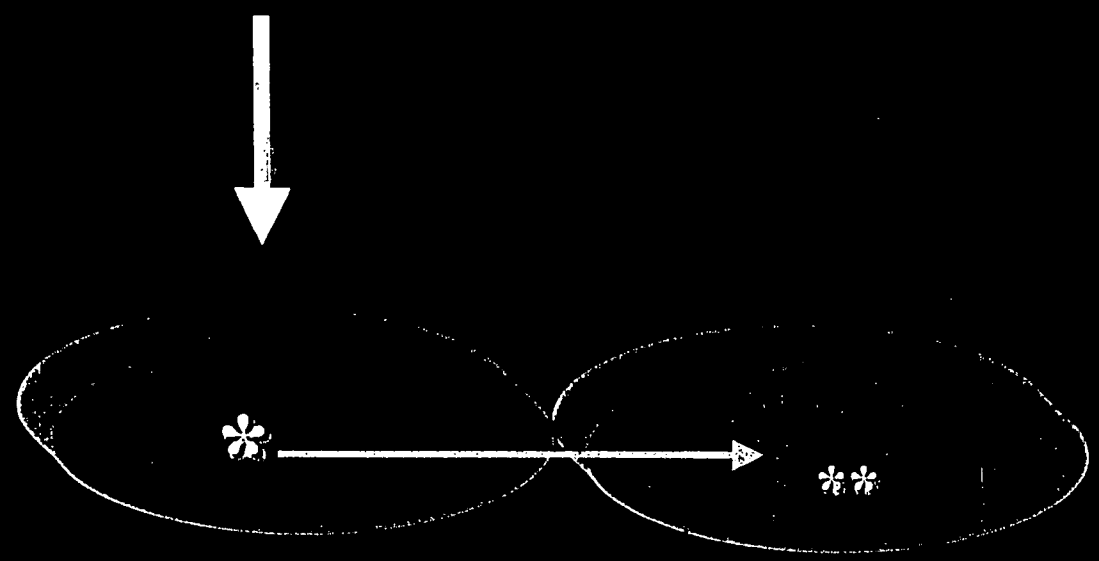
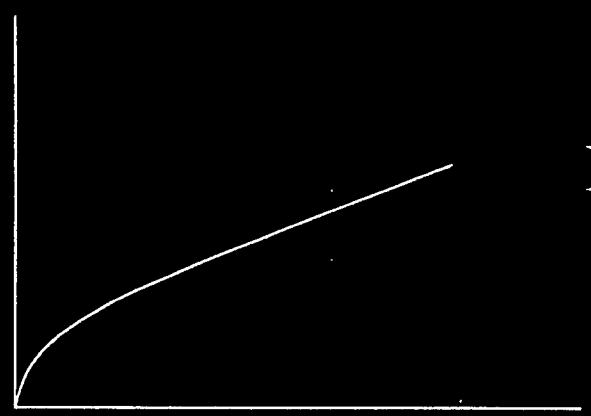
Bystander Effects





Radiation-Induced Mutations
(α irradiation)

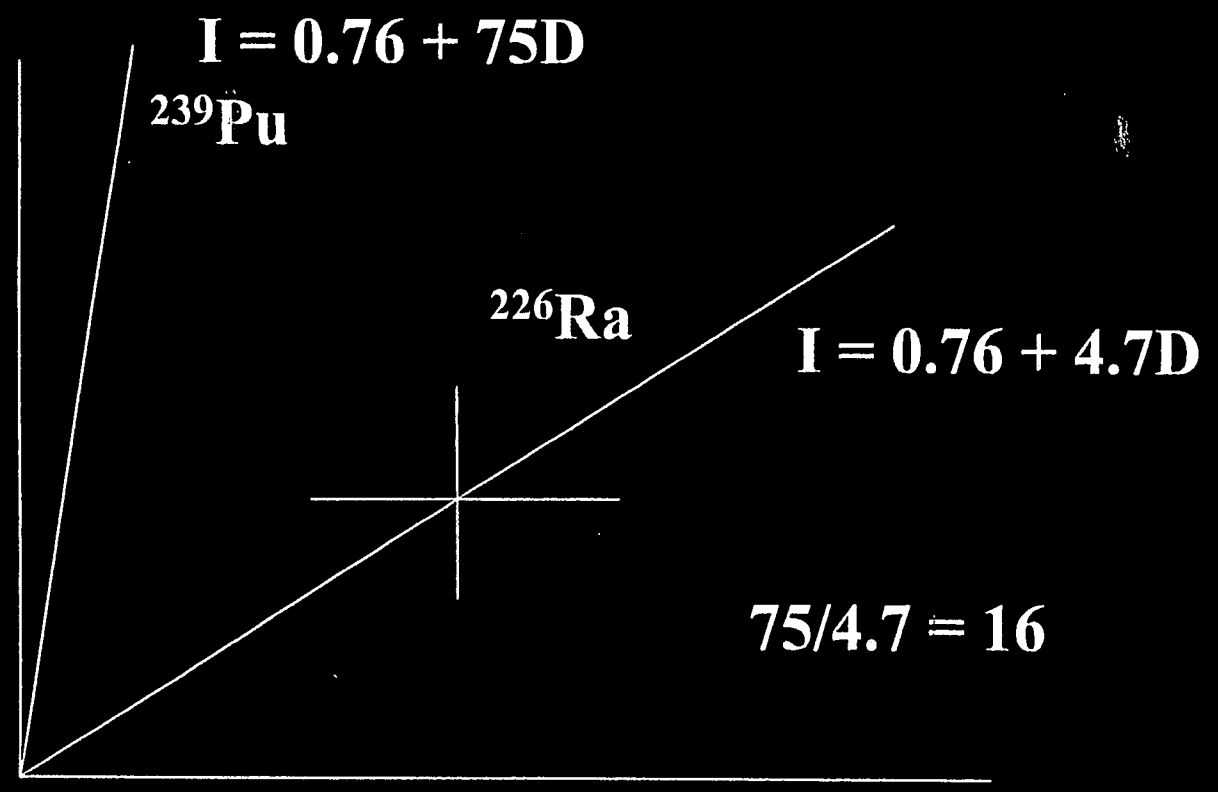
Radiation-Induced Lung Cancer

$$I = \alpha D + \beta D^2$$

$$I = \alpha D$$

8/

Bone Cancer Incidence in Beagle Dogs



Average Skeletal Dose at 1 Year Before Death

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Excess Leukemia In A-Bomb Survivors

Dose (Sv)	Number of People	Observed	Expected	Excess
0	36,459	73	64	9
0.005-0.1	32,849	59	62	-3
0.1-0.2	5467	11	11	0
0.2-0.5	6308	27	12	15
0.5-1.0	3202	23	7	16
1.0-2.0	1608	26	4	22
>2.0	679	30	2	28
Total	86,572	249	162	87

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Radiation-Induced Leukemia in A-Bomb Survivors

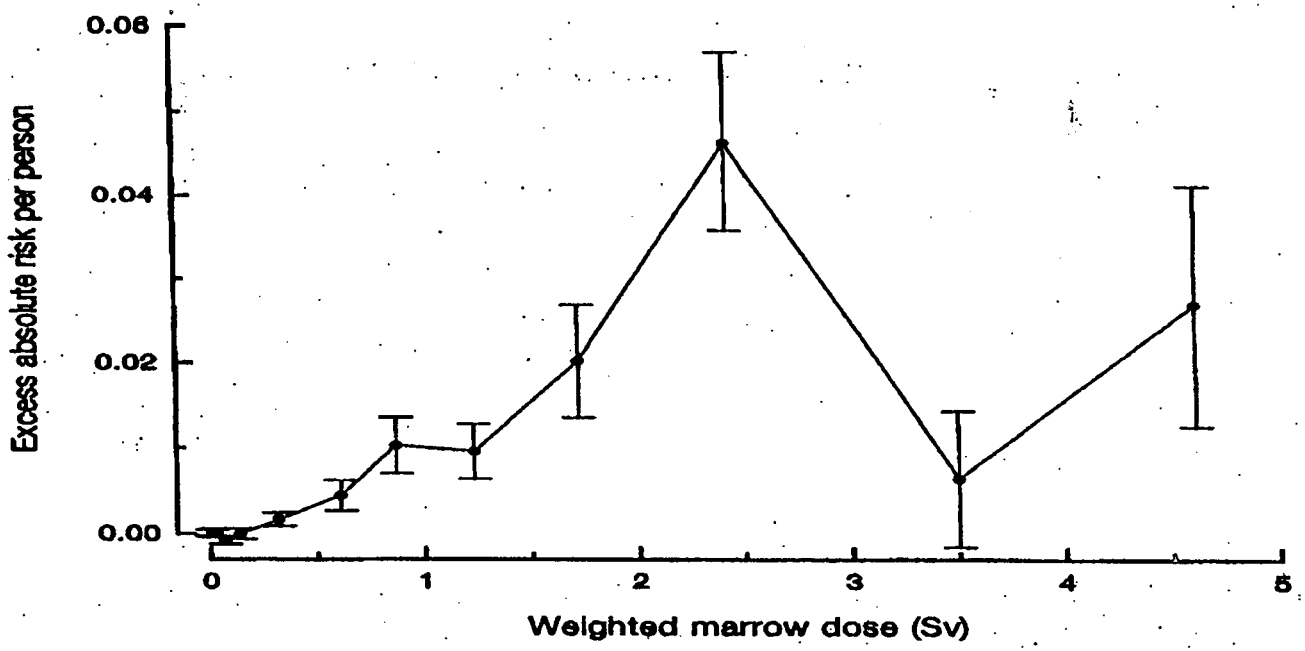

FIG. 6. Shape of the leukemia dose response, shown in terms of the total risk per person over the follow-up. On this scale there are no statistically significant differences with sex or age at exposure. There is a statistically significant upward curvature in the weighted marrow dose range 0–3 Sv, and a statistically significant departure from this in the higher dose range. The slightly negative risk for the second dose category is not statistically significant.

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Excess Solid Cancers In A-Bomb Survivors

Dose (Sv)	Number of People	Cancers	Expected Cancer	Excess Cancers
0	36,459	3013	3055	-42
0.005-0.1	32,849	2795	2710	85
0.1-0.2	5467	504	486	18
0.2-0.5	6308	632	555	77
0.5-1.0	3202	336	263	73
1.0-2.0	1608	215	131	84
>2.0	679	83	44	39
Total	86,572	7578	7244	334

85

Radiation-Induced Solid Cancer in A-Bomb survivors

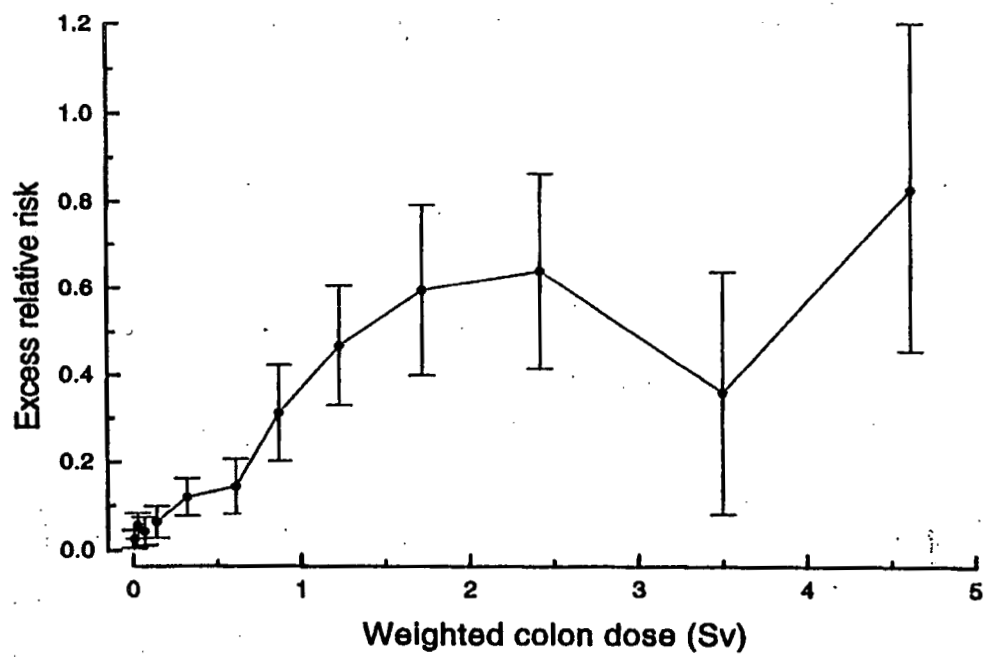

FIG. 5. Shape of the dose response for solid cancer, shown in terms of the ERR, adjusted to males of age 30 at exposure. Fitted using all the data, under a model assuming that the shape of the weighted colon dose response is the same for both sexes and all ages at exposure. There is no statistically significant nonlinearity in the range 0–3 Sv, but the leveling off in the higher dose range is marginally significant.

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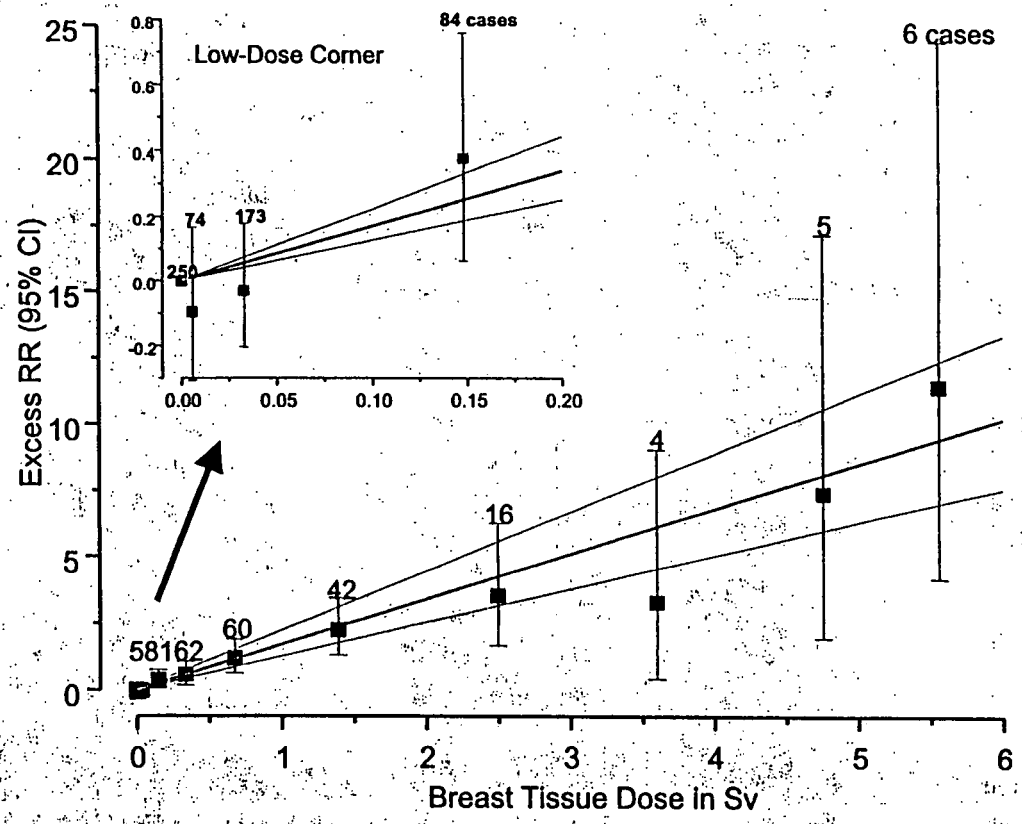
Breast Cancer Incidence, 1950-1990: Dose Response, All Ages ATB



Uncertainty and Radiation Risk

- Dosimetric Uncertainty
- Statistical Uncertainty
- Bias and Confounding Factors
- Data Uncertainty
- Transfer of Risk between Populations
- Modifying Factors
- Mechanistic Uncertainty

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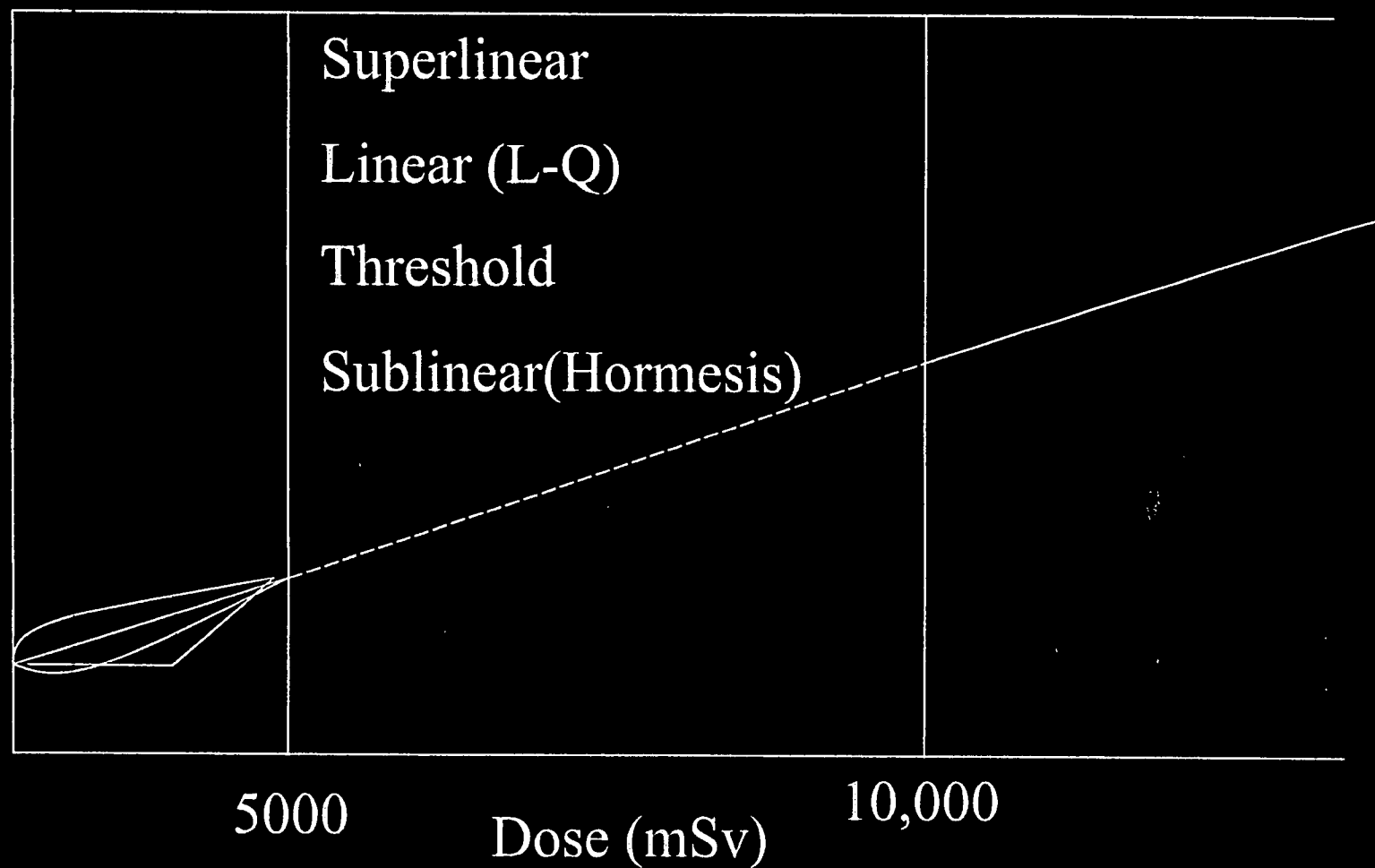
Bias and Confounding Factors

- Type of Study
  - Case control;cohort;environmental
- Control Population
  - Matched or General Population
- Number of Comparisons
  - Increased chance of spurious result (1/20 = 5%)
- Relationship between Disease and Radiation Exposure
  - Confounding by indication

Low Dose Risk



THE EVOLUTION OF ICRP BIOKINETIC AND DOSIMETRY MODELS

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Los Alamos National Laboratory

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SCOPE OF INFORMATION NEEDED FOR HUMAN HEALTH RISK ASSESSMENTS

SOURCE CHARACTERIZATION

(TRANSPORT MODELS)

EXPOSURE ENVIRONMENT

(EXPOSURE-DOSE MODELS)

DOSE TO CRITICAL TISSUES

(DOSE-RESPONSE MODELS)

HEALTH RISKS

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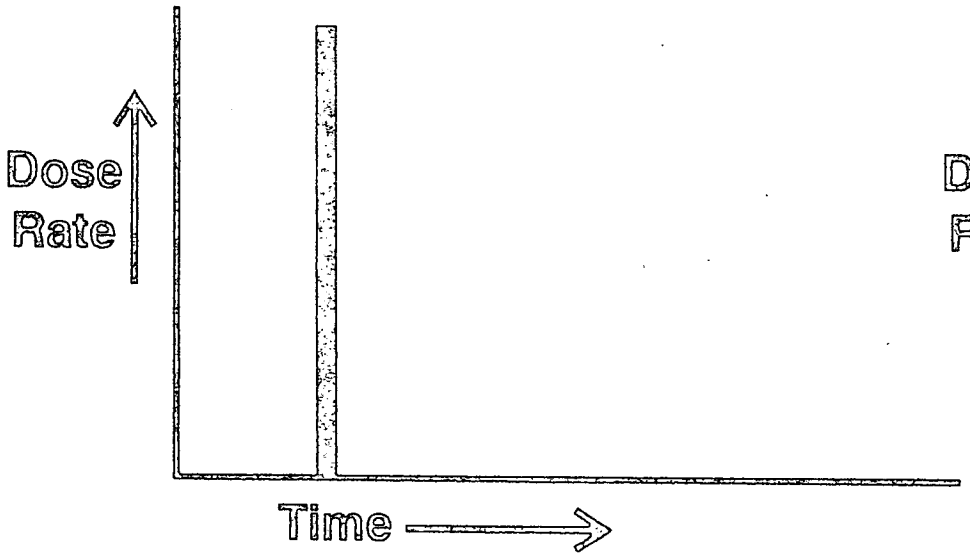
COMPARISON OF DOSIMETRY BETWEEN EXTERNAL IRRADIATION AND INTERNAL RADIONUCLIDES

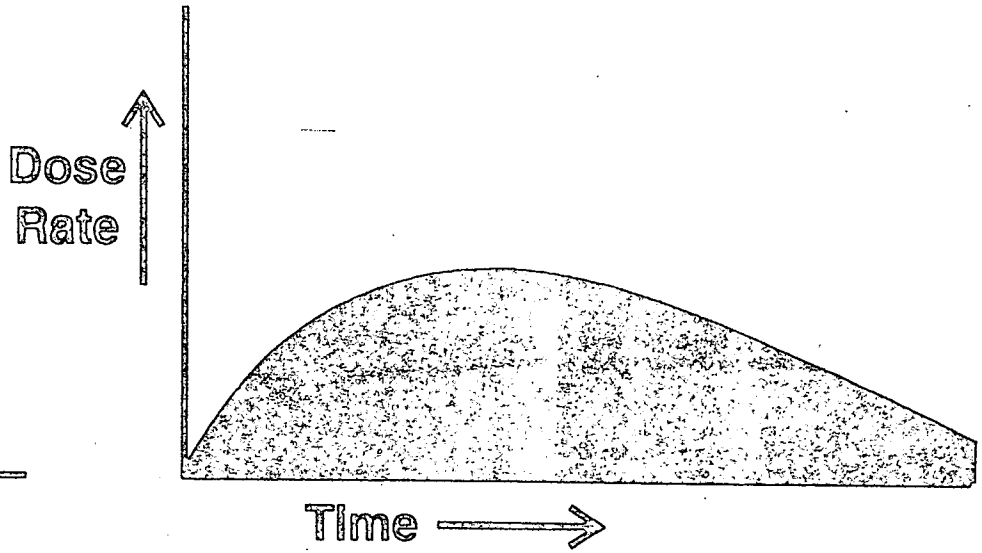
EXTERNAL IRRADIATION

- Exposure and dose occur at same time
- Dose - Relatively uniform over all organs



INTERNAL RADIONUCLIDES

- Dose accumulated over time
- Dose - Nonuniform among organs



3489-2

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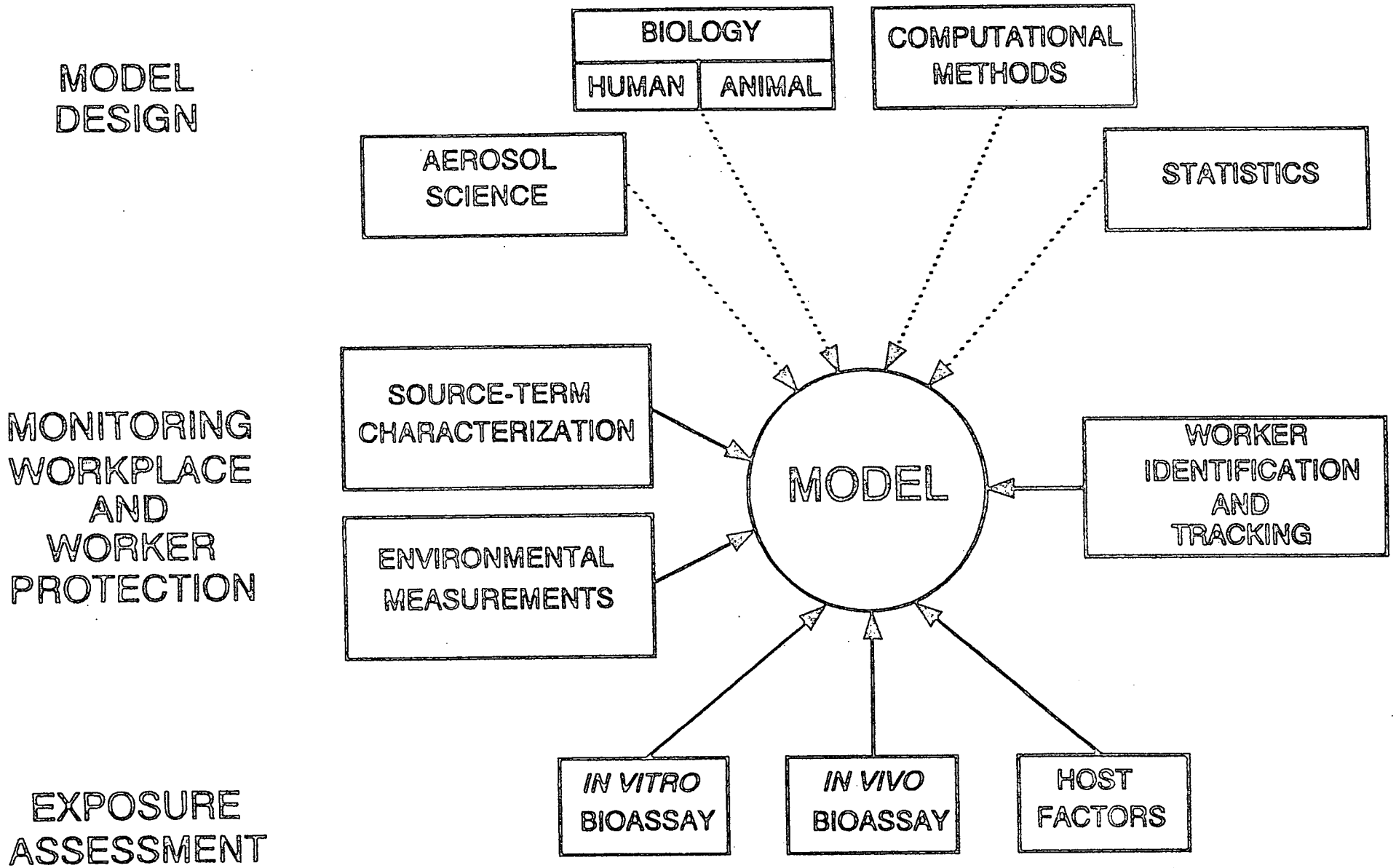
INTERNAL DOSIMETRY IS NEEDED FOR

- Establishing exposure limits
- Interpreting bioassay data
- Assessing intakes
- Calculating radiation doses

PROBLEMS

- Exposure materials vary
- People vary
- Bioassay data fragmentary
- Knowledge of biokinetics limited
- Dose-modifying factors inadequately characterized

INPUT TO DOSIMETRY MODELS



LUNG MODELING TRENDS

- INCREASING COMPLEXITY REFLECTING INCREASING KNOWLEDGE
- GREATER DETAIL ON INFLUENCING FACTORS
- BROADER RANGE OF APPLICABILITY
  - OCCUPATIONAL OR ENVIRONMENTAL EXPOSURES
  - PROSPECTIVE (TYPICAL VALUES) OR RETROSPECTIVE (INDIVIDUAL VALUES)
- SOFTWARE FACILITATING "WHAT-IF" QUESTIONS
- GREATER DEMANDS FOR INPUT DATA

EVOLUTION OF DOSIMETRY MODELS

INHALATION

- ICRP 2 (1959) - simple model
- ICRP 30 (1979) - TGLD 66
- ICRP 66 (1994)

INGESTION

- ICRP 2 - f_1 defined
- ICRP 20 - Eve (1966)
- ICRP xx - HAT model (human alimentary tract; in development)

SYSTEMIC

- ICRP 2 - power function
- ICRP 30, 54 - non-recycling
- ICRP 56, 67, 69, 71 - recycling, age-dependent

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COMPARATIVE LUNG MODEL STATISTICS

	ICRP (1959)	TGLD[a] (1966)	ICRP (1993)
PREPARATION TIME	?	2 y	9 y
STAFFING (COMMITTEE AND OTHERS)	?	12	28
REPORT			
PAGES	1	34	~600
REFERENCES	?	252	~1200

[a] TASK GROUP ON LUNG DYNAMICS REPORT (1966) WAS THE BASIS FOR THE ICRP 30 MODEL (1979).

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INFLUENCING FACTORS IN 1993 ICRP MODEL

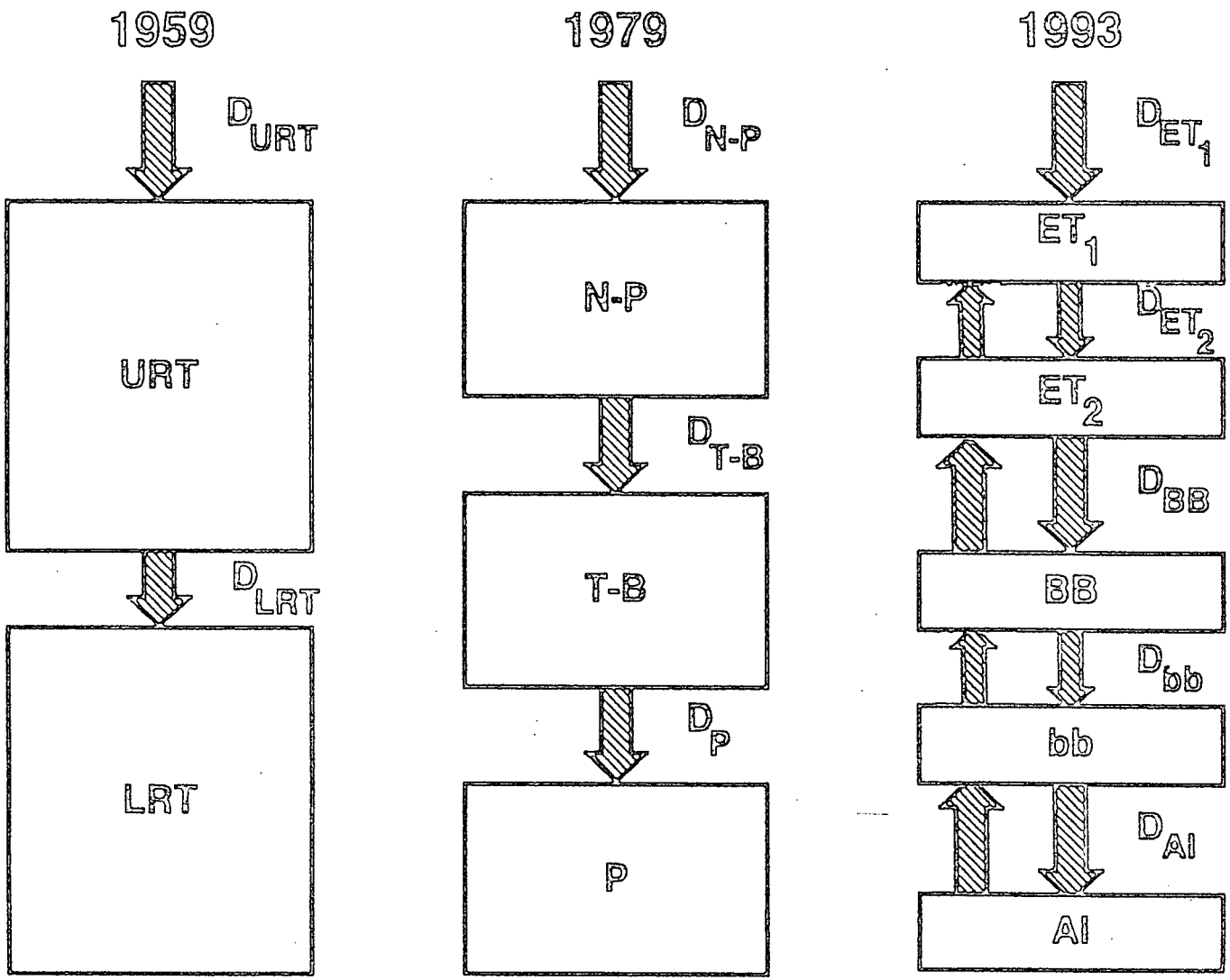
MANY ARE CONSIDERED SUCH AS:

- AGE
- ETHNIC GROUPS
- RESPIRATORY TRACT DISEASES
- SMOKING AND OTHER AIR POLLUTANTS

CONCERNS WITH ICRP 30 LUNG DOSIMETRY MODEL

- Neglect of nasopharyngeal dose
- Treatment of lung as a composite organ
  - Conducting airways
  - Pulmonary parenchyma
  - Lymph nodes
- Particle size range limited to 0.2 - 10 μm AMAD
- Use of AMAD to predict deposition
  - Multimodal aerosols
  - Thermodynamic size range
- Solubility classifications - suspect compartment values
- Effective clearance - combination of mechanical and dissolution/absorption mechanisms
- Heterogeneous populations
  - Age
  - Health status

STRUCTURE OF ICRP DEPOSITION MODELS



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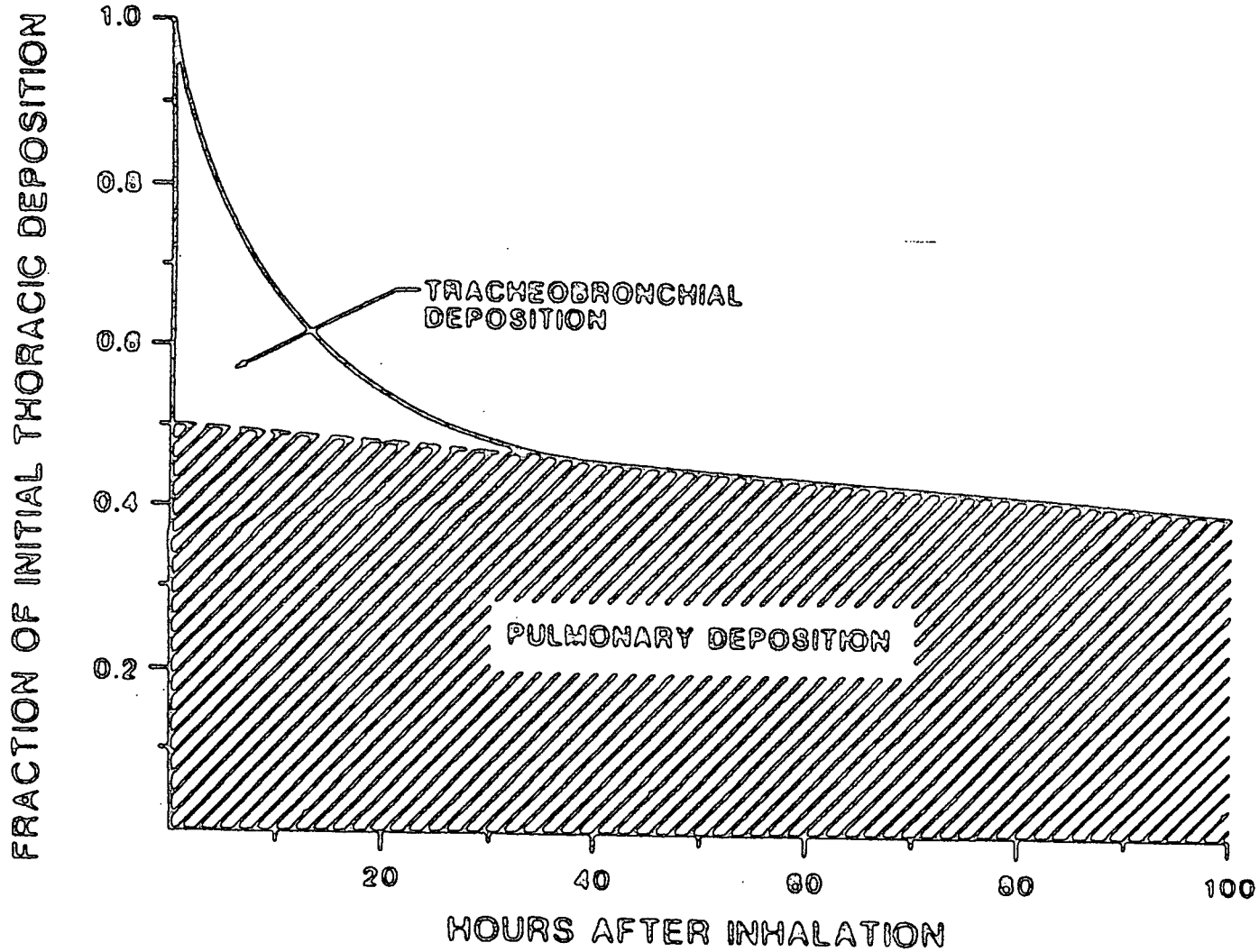
STRATEGY FOR DETERMINING TRACHEOBRONCHIAL AND PULMONARY DEPOSITION BY ANALYZING RETENTION CURVES



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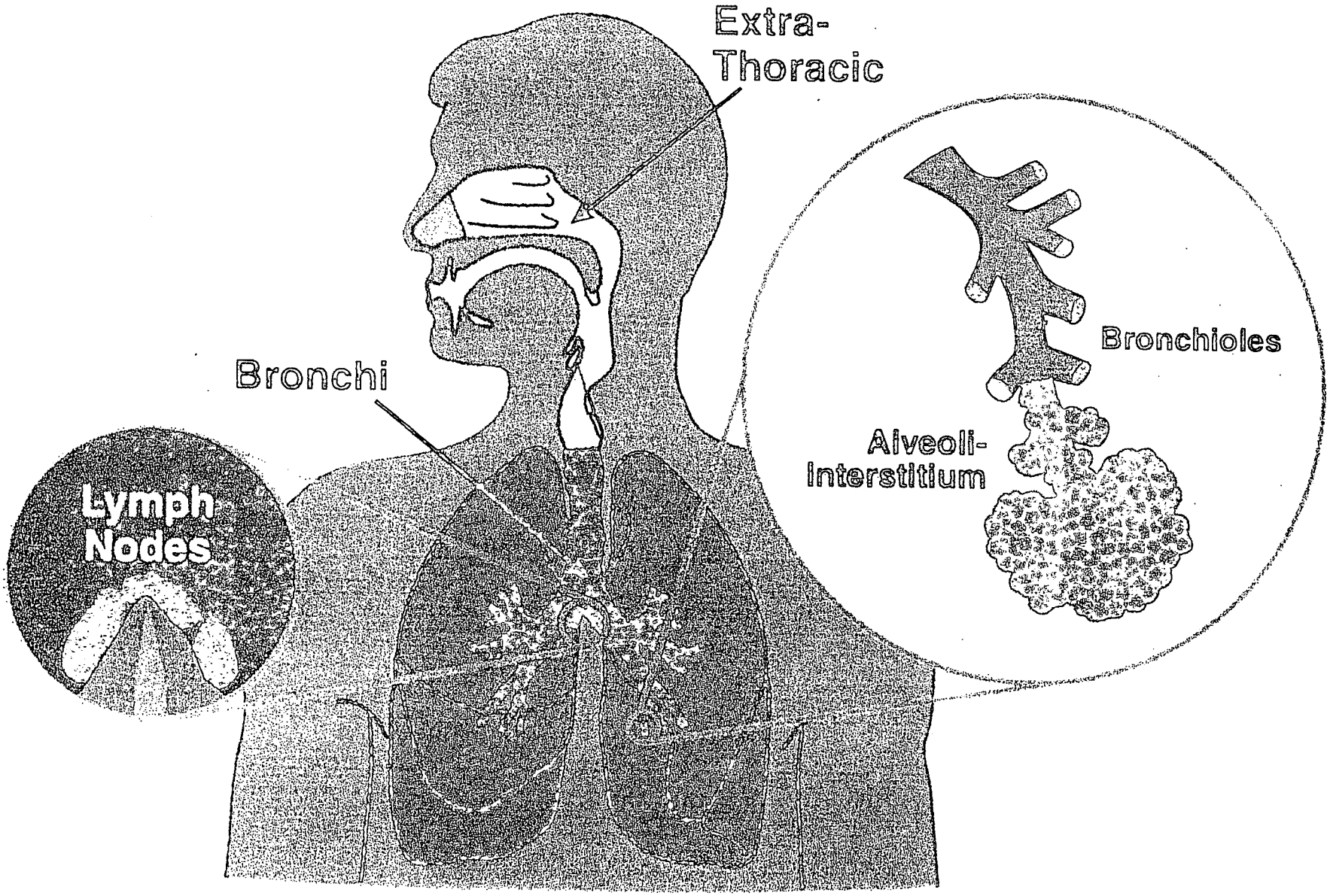
ANATOMICAL COMPARTMENTS OF THE RESPIRATORY TRACT



3489-1

DEFAULT DEPOSITION VALUES FOR ICRP RESPIRATORY TRACT MODELS

	1959 (NO SIZE SPECIFIED)		1979 (1.0 μm)[a]		1993 (5.0 μm)[a]	1993 (1.0 μm)[b]
URT	50	N-P	30	ET_1	34	14
				ET_2	40	18
		T-B	8	BB	1.8	1.1
				bb	1.1	2.1
LRT	25	P	25	AI	5.3	12
TOTAL	75		63		82	47

[a]Occupational Exposure
[b]Environmental Exposure

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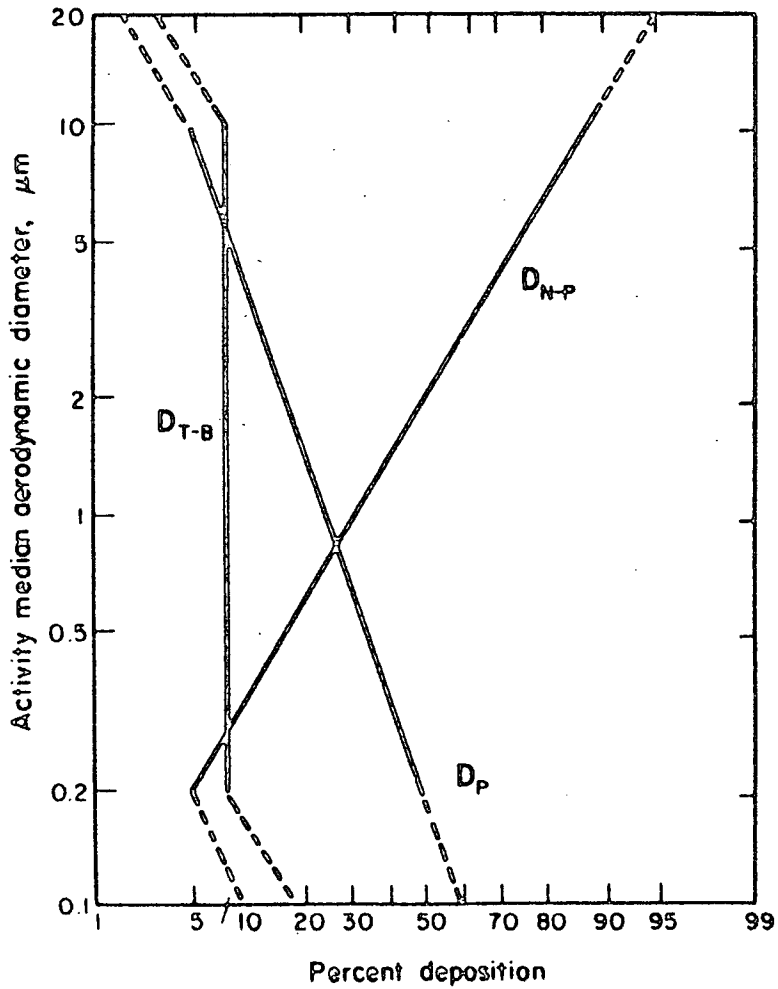
ICRP 30 FORMULATION FOR DEPOSITION OF DUST IN THE RESPIRATORY TRACT



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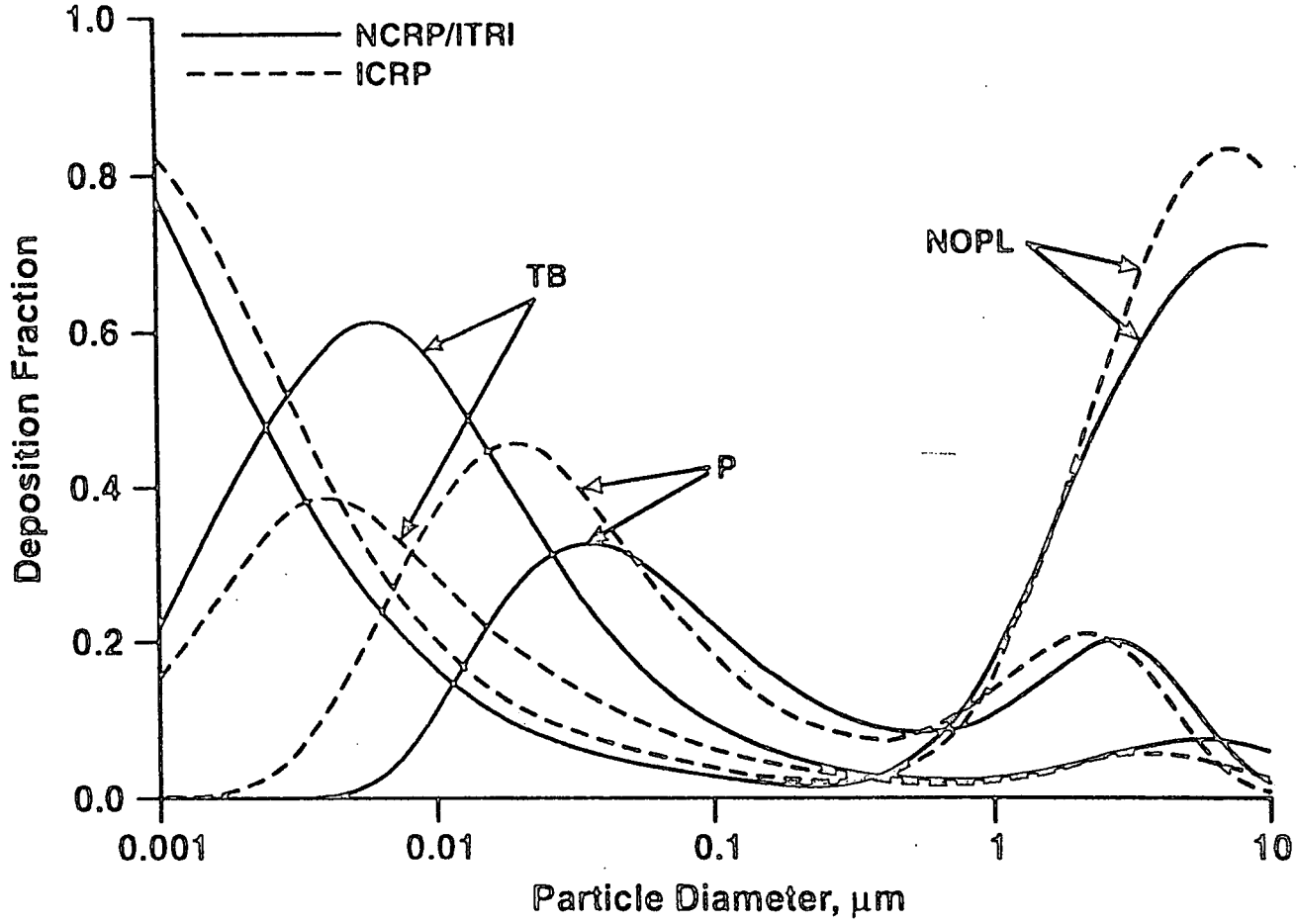
PREDICTED DEPOSITION EFFICIENCIES FORTHE ICRP AND NCRP RESPIRATORY TRACT DOSIMETRY MODELS



V_T = 770 mL; f= 13/min; σ_g = 1.0; ρ = 1.0 g/cm^3; FRC = 3000 mL

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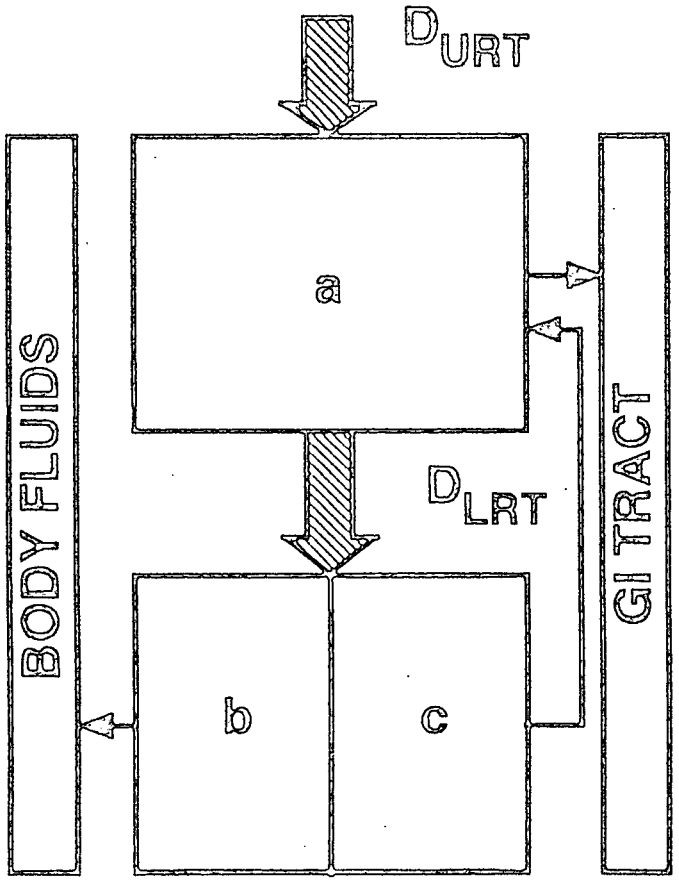
3503-1

1959 ICRP CLEARANCE MODEL

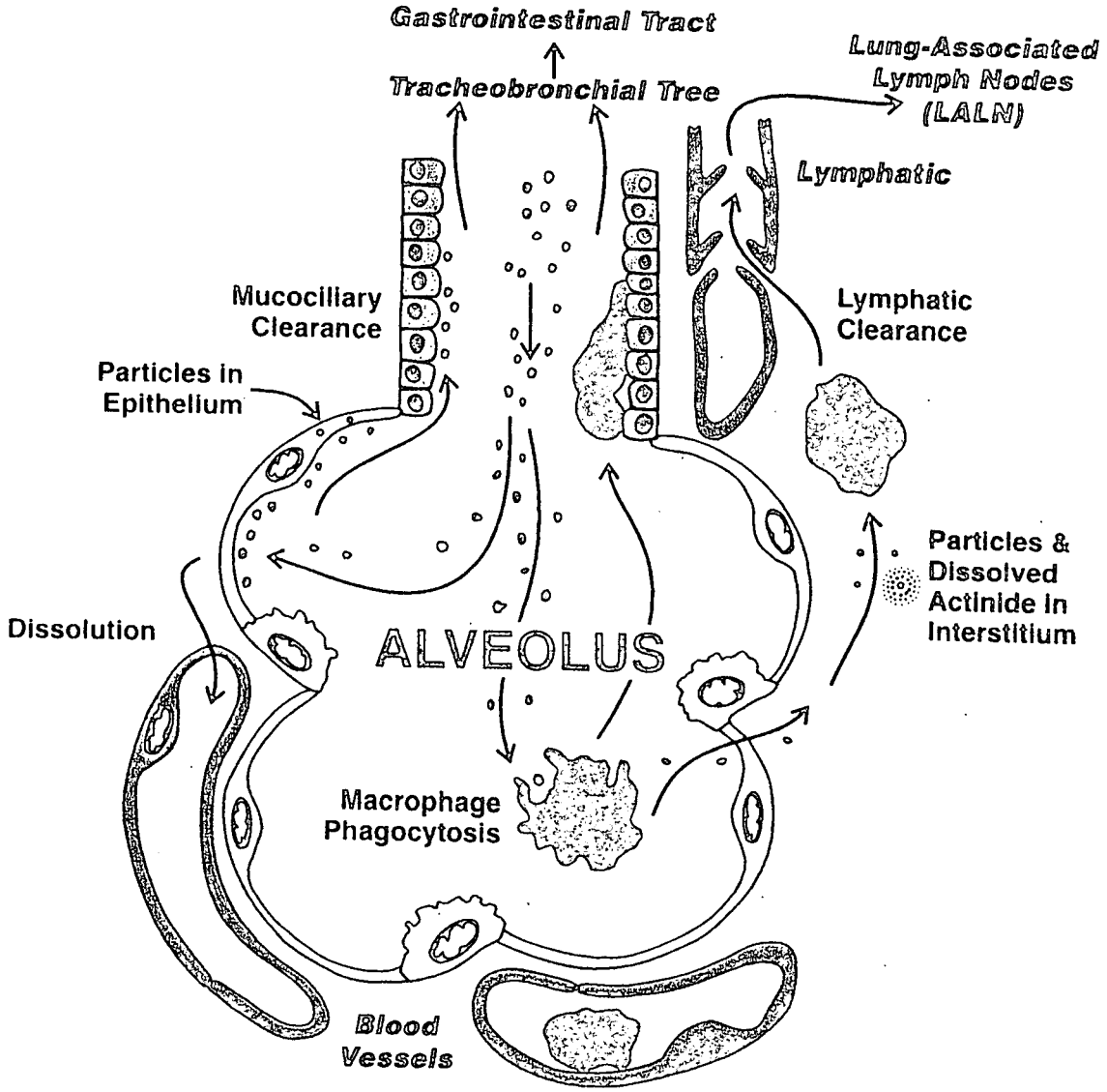


- URT/LRT DIVISION UNDEFINED
- URT ONLY AN AIR PASSAGE
- CLASSES:

	T_B (d)
SOLUBLE	<<1
INSOLUBLE	120
Pu	365
Th	1460

- NO LYMPH NODES
- DOSE TO 1000g LUNG

RETENTION AND CLEARANCE MECHANISMS



3443-2a

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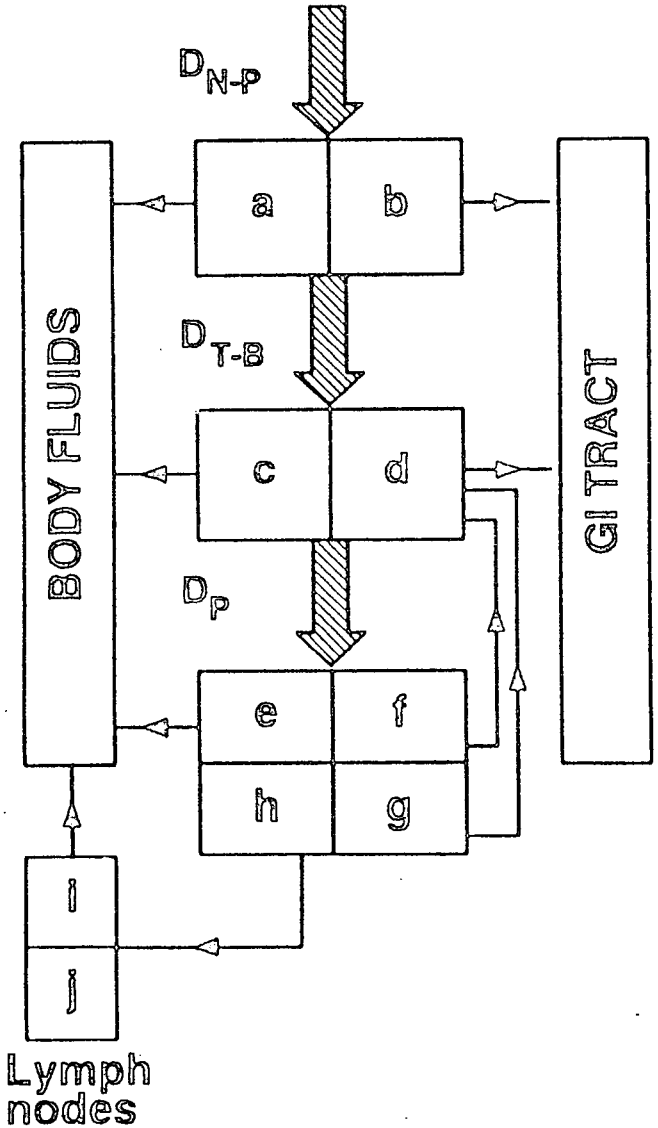
1979 ICRP CLEARANCE MODEL

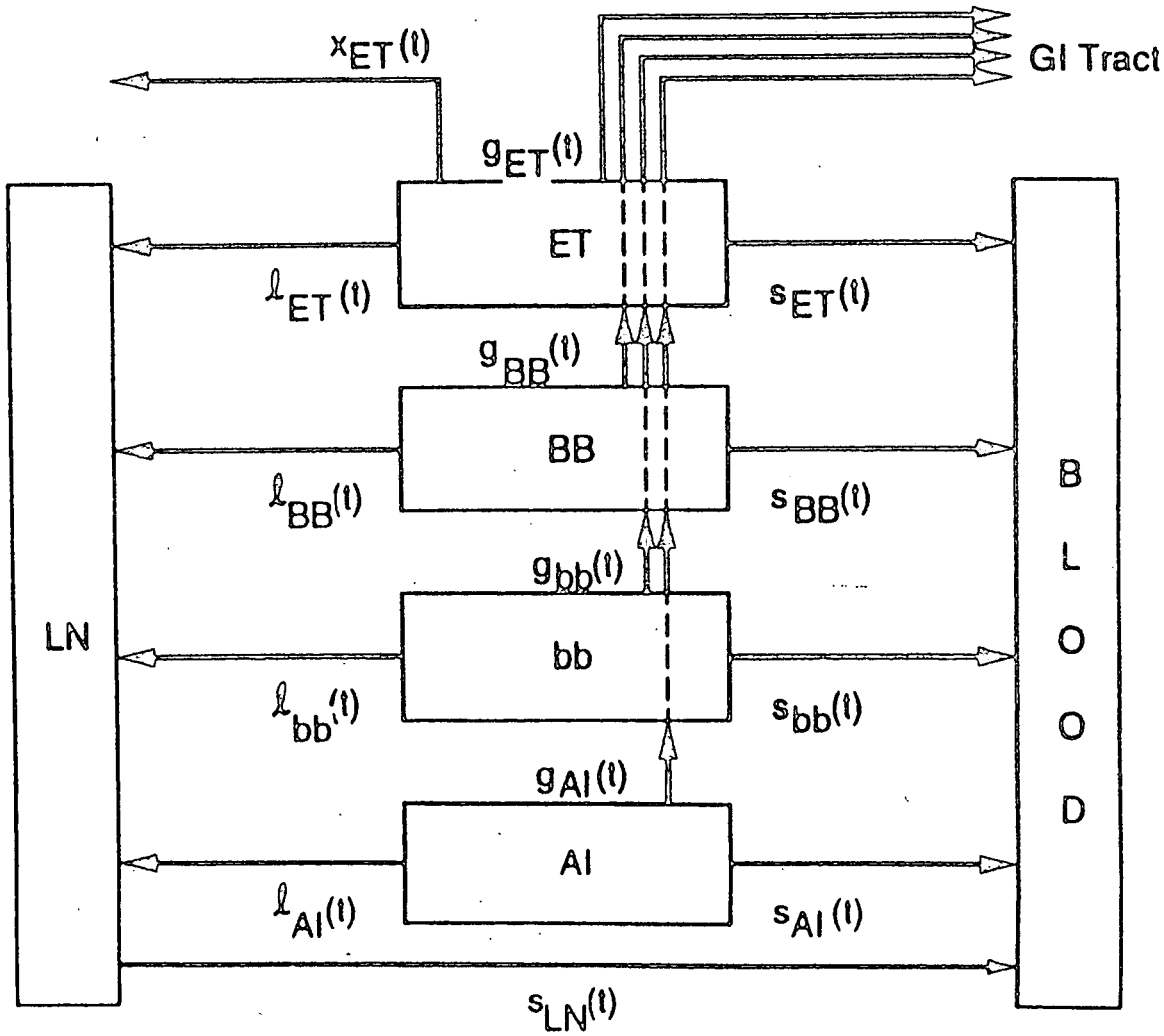


- ABSORPTION & TRANSPORT FROM EACH REGION
- CLASSES:

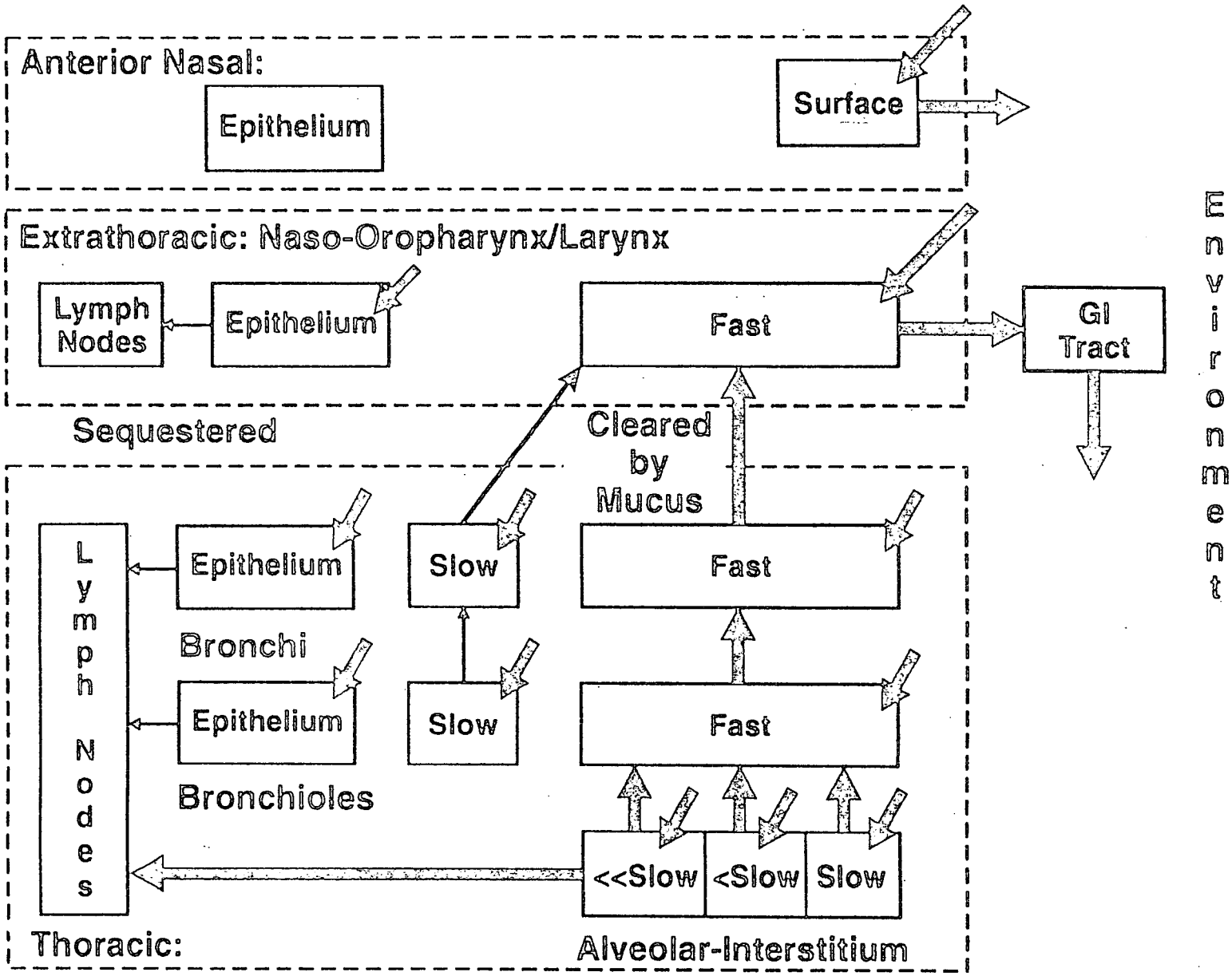
	T_B (d)
D	0.5
W	50
Y	500

- SAME T_B FOR ABSORPTION & TRANSPORT
- LYMPH NODES INCLUDED
- DOSE TO 1000g LUNG AND LN

COMPETITIVE CLEARANCE PROCESSES — 1993 ICRP MODEL



PATHWAYS OF PARTICLE TRANSPORT WITHIN THE RESPIRATORY TRACT (ICRP 66)



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SOLUBILITY PATHWAYS FOR PARTICLES WITHIN THE RESPIRATORY TRACT (ICRP66)

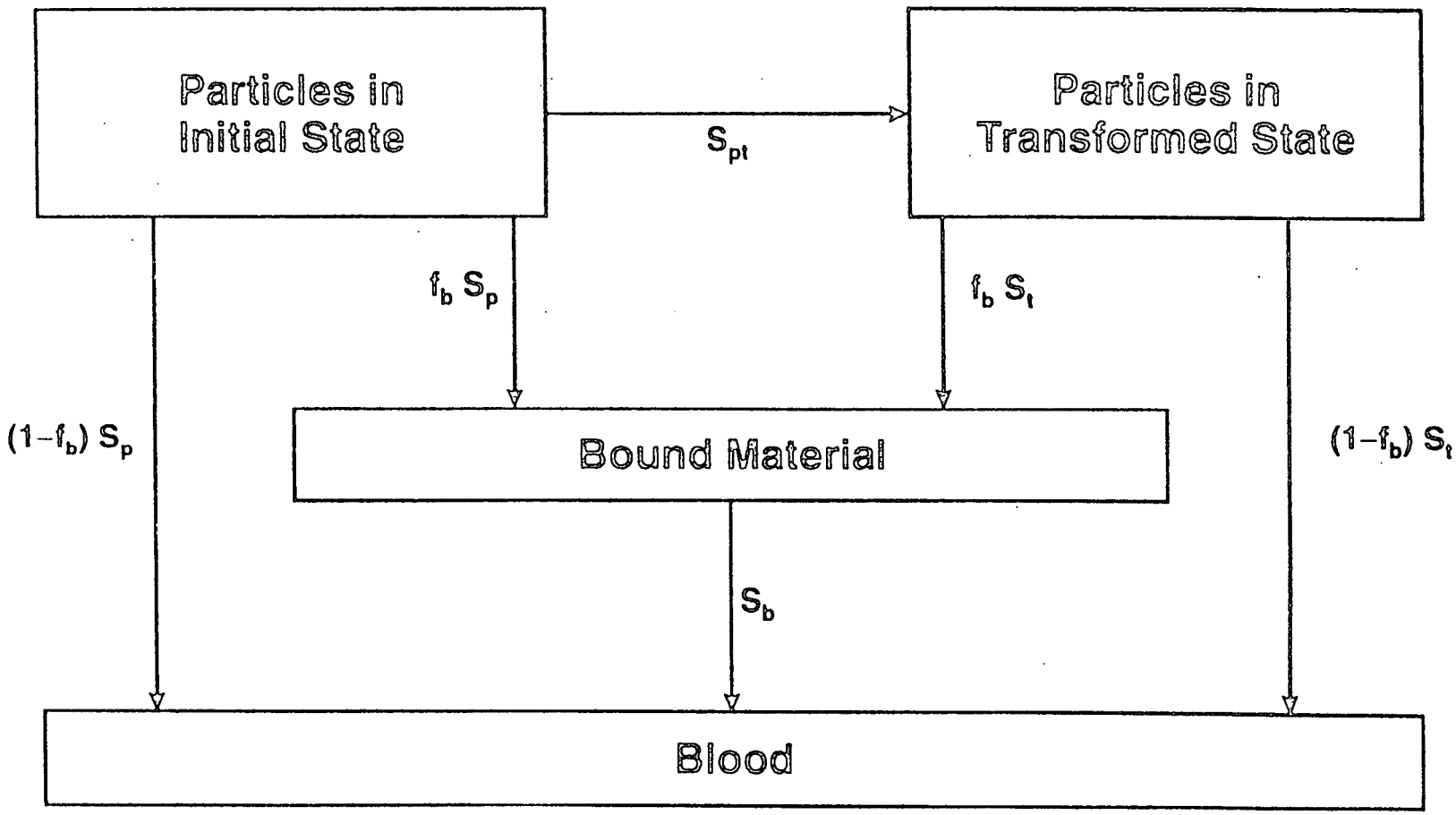

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Table 18. Default absorption parameters for Type F, M, and S materials

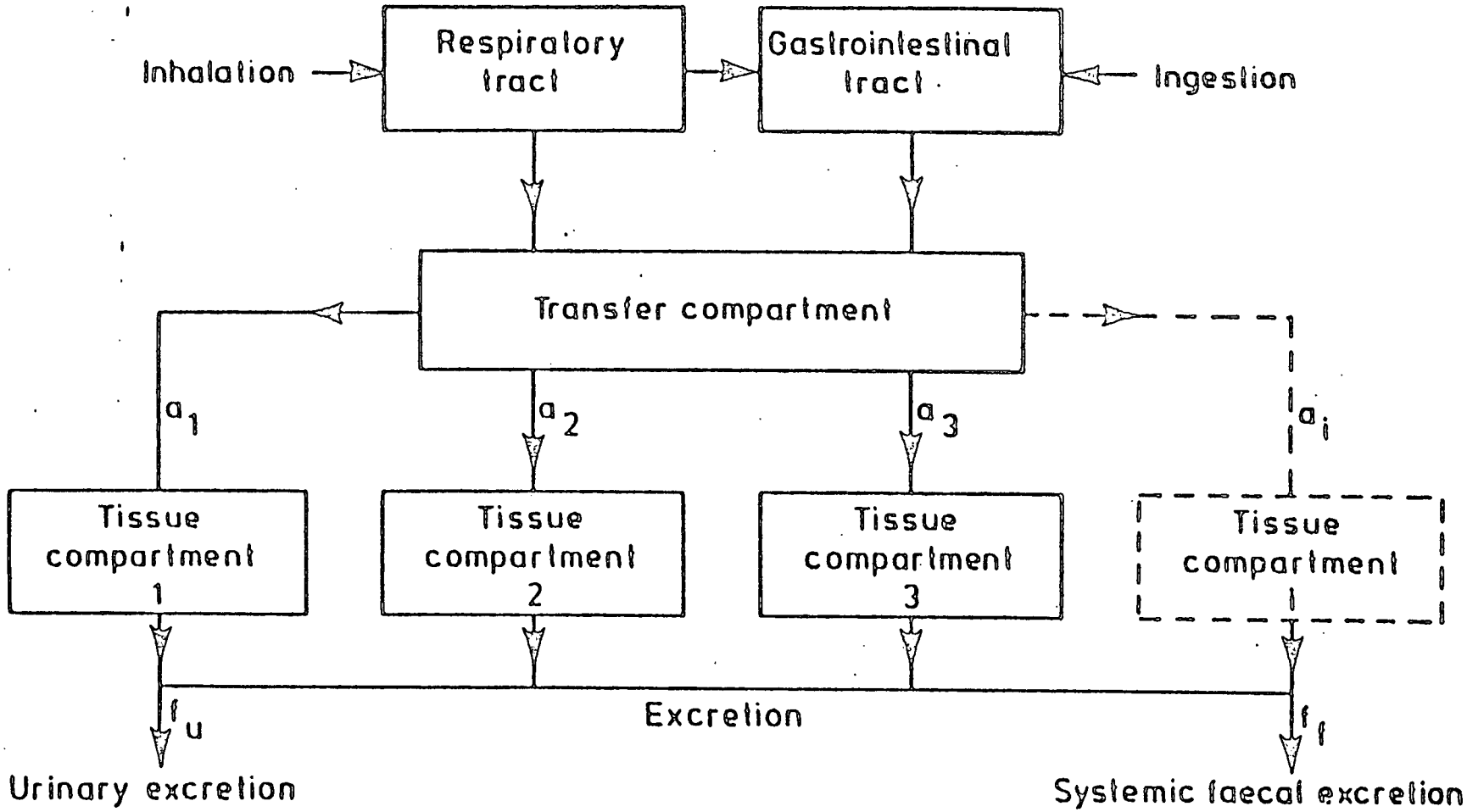
ICRP Publication 30 class:	D (days)	W (weeks)	Y (years)
Type of absorption behaviour:	F (fast)[a]	M (moderate)[b]	S (slow)[c]
Fraction dissolved rapidly, f_r	1	0.1	0.001
Approximate dissolution rate:			
Rapid (d^{-1}), s_r	100	100	100
Slow (d^{-1}), s_s	—	0.005	0.0001
Model parameters:			
Initial dissolution rate (d^{-1}), s_p	100	10	0.1
Transformation rate (d^{-1}), s_{pt}	0	90	100
Final dissolution rate (d^{-1}), s_t	—	0.005	0.0001
Fraction to bound state, f_b	0	0	0
Uptake rate from bound state (d^{-1}), s_b	—	—	—

[a] F (fast)—materials that are readily absorbed into blood (corresponding to "Class D"). There is significant absorption from ET_2 and BB, but some material in these regions will remain in solution in mucus and be swallowed, rather than be absorbed through the epithelium. Hence the default for such materials is $s_r = 100\ d^{-1}$ ($t_{1/2} \sim 10$ min).

[b] M (moderate)—materials with intermediate rates of absorption (corresponding to "Class W"). For such materials the percentage absorbed rapidly is on the order of 10%, and the slow-phase retention time on the order of 100 d. This is represented by $f_r = 0.1$; $s_r = 100\ d^{-1}$; and $s_s = 0.005\ d^{-1}$.

[c] S (slow)—relatively insoluble materials (corresponding to "Class Y"). It is assumed that for most of the material the rate of absorption to blood is $0.0001\ d^{-1}$. This equals the particle transport rate from the most slowly cleared AI compartment. However, it is characteristic of even very insoluble materials that some rapid uptake to blood occurs immediately after inhalation. As a default it is assumed that 0.1% of the deposited material is rapidly absorbed. While the effect of this on doses is likely to be negligible, it may significantly affect the interpretation of measurement of activity in urine. This is represented by $f_r = 0.001$; $s_r = 100\ d^{-1}$; and $s_s = 0.0001\ d^{-1}$.

ICRP 54 BIOKINETIC MODEL



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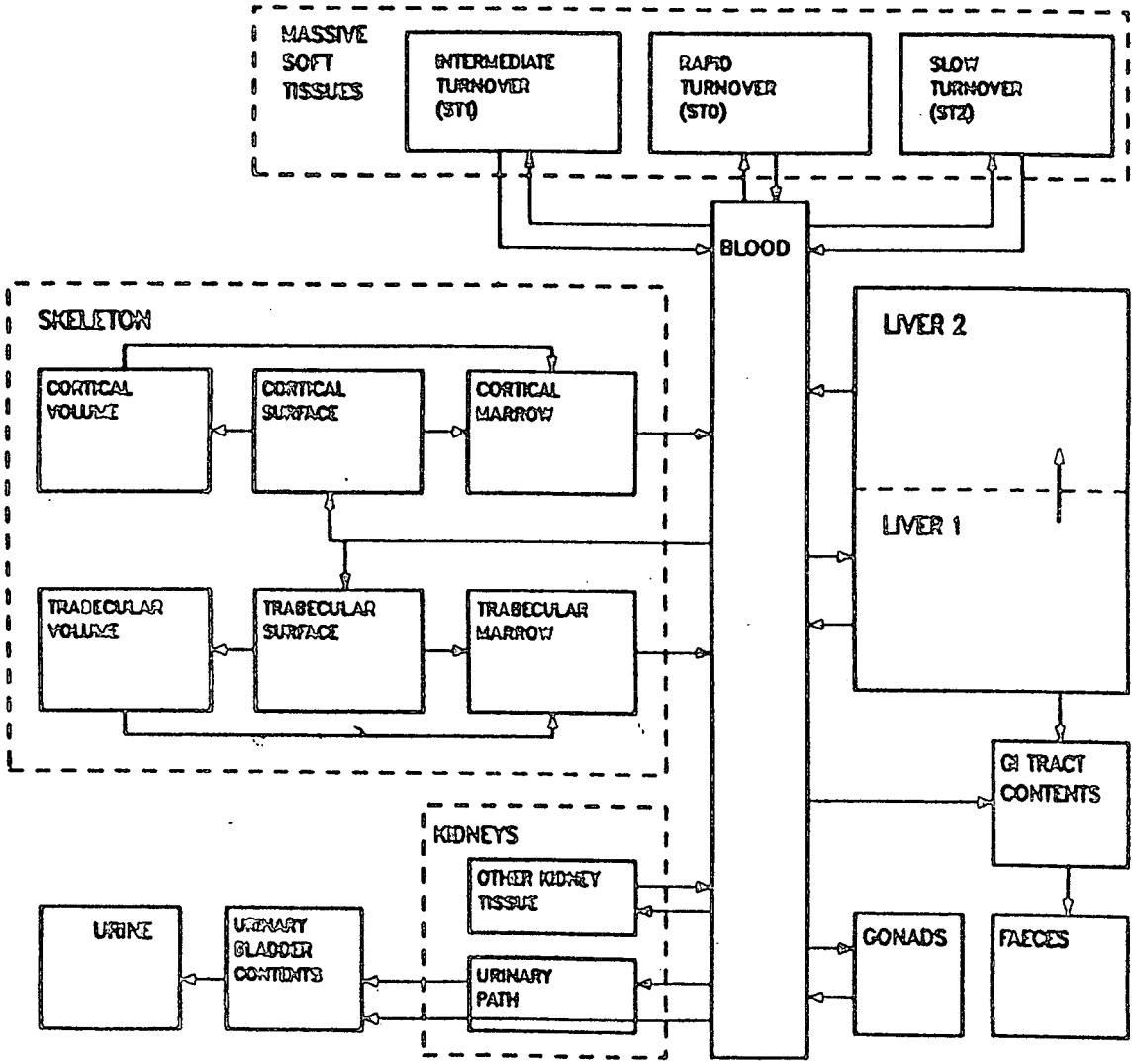
SCHEMATIC REPRESENTATION OF THE ICRP SYSTEMIC MODEL FOR PLUTONIUM (ICRP 67 1993)



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COMPUTATIONS FOR ICRP DOSIMETRY
LUNG MODELS

- "BACK OF THE ENVELOPE" (1959)
- LOOK-UP TABLES (1979)
- PC SOFTWARE - LUDEP (1993)

RISK WEIGHTING FACTORS FOR CALCULATING EFFECTIVE DOSES

ICRP MODEL		W_T
1959		NOT APPLICABLE
1979	0.12	FOR LUNG (T-B, P AND LN) N-P NOT SPECIFIED
1993	0.12 x	(0.33) FOR BB
		(0.33) FOR bb
		(0.33) FOR AI
		(0.001) FOR LN_{TH}
	0.001	FOR ET_1 — ADD TO REMAINDER TISSUES
	1.0	FOR ET_2 — ADD TO REMAINDER TISSUES
	0.001	FOR LN_{ET} — ADD TO REMAINDER TISSUES

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COMPARISON OF EFFECTIVE DOSES CALCULATED WITH ICRP MODELS

RADIONUCLIDE	μSv/Bq for 1 μm AMAD	
	1979 MODEL (PUB.61)	1993 MODEL
^{239}Pu	W: 70	M: 53
	Y: 60	S: 16
^{241}Am	W: 70	M: 55
^{242}Cm	W: 4	M: 5.1
^{60}Co	W: 0.009	M: 0.0084
	Y: 0.06	S: 0.027
^{144}Ce-Pr	W: 0.05	M: 0.032
	Y: 0.1	S: 0.045

118.

CONTINUING LUNG MODELING ISSUES

- Process- and site-specific aerosol characterizations
- Slow clearance from conducting airways
- Critical cells at risk
- Importance of dose-modifying factors (source and host)
- Application fo nonradioactive particles, gases, and vapors