Forty-Ninth
Annual Meeting Program

Radiation Dose and the Impacts on Exposed Populations

March 11–12, 2013

Hyatt Regency Bethesda
One Bethesda Metro Center
7400 Wisconsin Avenue
Bethesda, MD 20814

NCRP®
National Council on Radiation Protection & Measurements

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Introduction

Radiation Dose and the Impacts on Exposed Populations

Forty-Ninth Annual Meeting of the National Council on Radiation Protection and Measurements (NCRP)

This meeting is dedicated to the Japanese people affected by the Fukushima accident and the great earthquake of 2011.

The program will provide balanced discussions between past and present exposed populations including: atomic-bomb survivors, medical patients/caregivers, public populations exposed to routine operations and accidents at nuclear facilities (*e.g.*, Fukushima, Chernobyl and others), individuals exposed occupationally in industrial energy work, and veterans exposed during nuclear testing. Presentations will be given by the leading experts in each area with opportunities to ask questions verbally or textually.

Session one is an overview of the issues with answers to “who are the exposed?,” “why study exposed populations?,” “what are the potential deterministic/stochastic impacts?,” and “what are the psychosocial/other impacts?” Session two covers exposures and impacts from medical practices including nuclear medicine, diagnostic imaging, and therapeutic doses with potential health impacts such as increased cancer/leukemia morbidity, cardiovascular disease, ocular opacities/cataracts, etc. Session three discusses exposures and impacts to occupational workers from all practices with a special lecture on military populations. Session four focuses on accidental or intentional public exposures that can have short-, medium- and long-term physical, emotional and political impacts.

NCRP and the Radiation Research Society (RRS) are pleased to welcome the first NCRP/RRS Scholars to this year’s Annual Meeting. The three young scientists below received competitive travel awards made possible by the generosity of RRS. This new initiative is aimed at encouraging and retaining young scientists in the field of radiation science. Eligible applicants included junior faculty or students in the radiation sciences or junior health or medical physicists:

- Rebecca Abergel, Lawrence Berkeley National Laboratory
- Caitlin Mills, McMaster University
- Christopher E. Nielsen, Battelle-Pacific Northwest National Laboratory

The American Academy of Health Physics and the American Board of Medical Physics have approved six Continuing Education Credits for attendance.

Monday, March 11, 2013

Opening Session

8:15 am **Welcome**
John D. Boice, Jr., *President*

Tenth Annual Warren K. Sinclair Keynote Address

8:30 am **Fukushima Nuclear Power Plant Accident and Comprehensive Health Risk Management**
Shunichi Yamashita
Fukushima Medical University

Overview

S.Y. Chen, *Session Chair*

9:30 am **Exposed Populations: Who Are They?**
Steven L. Simon
National Cancer Institute

9:55 am **Why Study Radiation-Exposed Populations?**
Martha S. Linet
National Cancer Institute

10:20 am **Radiation Impacts on Human Health: Certain, Fuzzy and Unknown**
Roy E. Shore
Radiation Effects Research Foundation

10:45 am **Break**

11:05 am **Emotional Consequences of Nuclear Power Plant Disasters**
Evelyn Bromet
SUNY Stony Brook

11:30 am **Q&A**

11:50 am **Lunch**

Medical

Kathryn D. Held, *Session Chair*

1:15 pm **Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement**
Lawrence T. Dauer
Memorial Sloan Kettering Cancer Center

1:40 pm **Dose Tracking and Rational Exam Selection for the Medically-Exposed Population**
James A. Brink
Massachusetts General Hospital / Harvard Medical School

2:05 pm **Second Malignant Neoplasms and Cardiovascular Disease Following Radiotherapy**
Lois B. Travis
University of Rochester Medical Center

2:30 pm **Q&A**

2:50 pm **Break**

Worker Exposures

Christopher H. Clement, *Session Chair*

3:10 pm **Characterization of Exposures to Workers Covered Under the U.S. Energy Employees Compensation Act**
James W. Neton
National Institute for Occupational Safety & Health

3:35 pm **Increased Occupational Exposures: Nuclear Industry Workers**
Andre Bouville
National Cancer Institute

4:00 pm **Radiation Exposure of U.S. Military Individuals**
Paul K. Blake
Defense Threat Reduction Agency

4:25 pm **Q&A**

4:45 pm **Break**

Thirty-Seventh Lauriston S. Taylor Lecture on Radiation Protection and Measurements

5:00 pm **Introduction of the Lecturer**
F. Ward Whicker

When Does Risk Assessment Get Fuzzy?
John E. Till
Risk Assessment Corporation

6:00 pm **Reception in Honor of the Lecturer**
Sponsored by Landauer, Inc.

Tuesday, March 12

8:15 am **NCRP Annual Business Meeting**

9:15 am **Break**

Public Exposures

David J. Pawel, *Session Chair*

9:30 am **Impact on the Japanese Atomic-Bomb Survivors of Radiation Received from the Bombs**
Harry M. Cullings
Radiation Effects Research Foundation

9:55 am **Joint U.S./Russian Studies of Population Exposures Resulting from Nuclear Production Activities in the Southern Urals**
Bruce A. Napier
Pacific Northwest National Laboratory

10:20 am **Populations Living Near Nuclear Power Plants**
Daniel O. Stram
University of Southern California

10:45 am **Nuclear Reactor Accidents: Exposures and Health Effects Among Members of the Public**
Maureen Hatch
National Cancer Institute

11:10 am **Q&A**

11:30 am **Break**

Summary

Paul A. Locke, *Session Chair*

11:45 am **Implications of Radiation Dose and Exposed Populations on Radiation Protection in the 21st Century**
John D. Boice, Jr.
National Council on Radiation Protection & Measurements

12:15 pm **Q&A**

12:30 pm **Closing Remarks**
John D. Boice, Jr.

12:45 pm **Adjourn**

Radiation Dose and the Impacts on Exposed Populations

Monday, March 11, 2013

Opening Session

8:15 am **Welcome**
John D. Boice, Jr., *President*
National Council on Radiation Protection and Measurements

Tenth Annual Warren K. Sinclair Keynote Address

8:30 am

Fukushima Nuclear Power Plant Accident and Comprehensive Health Risk Management

Shunichi Yamashita
Fukushima Medical University

Just 2 y have passed since the TEPCO-Fukushima Daiichi Nuclear Power Plant (NPP) accident followed a multidimensional disaster that combined to destroy the local infrastructure on which the safety systems depended and strongly impacted the world. Countermeasures including evacuation, sheltering, and control of the food chain were implemented in a timely manner by the government. However, there is much room for improvement, especially not only on nuclear safety issues themselves but also on radiation risk communication to members of the public during and after the accident. To date there have been no acute radiation injuries from the nuclear accident. Stable iodine was not generally administered to members of the public. Even so, according to the reported monitoring results, the thyroid doses were low. Taking these factors into account, together with the magnitude of the reported levels of radioactive substances released into the atmosphere and the ocean, the radiation-related physical health consequences on the general public, including evacuees, are likely to be limited and much lower than those from the Chernobyl nuclear reactor accident, where the only conclusive short- and mid-term radiation-induced health effect in the population was thyroid cancer in children drinking milk contaminated with high levels of radioactive iodine. However, the social, psychological and economic impact of the Fukushima Daiichi NPP accident is expected to be considerable.

Because of these impacts, we should consider the importance of radiation biology, the possible stochastic effects of low-dose radiation exposure, and the general consensus of radiation safety and protection. Furthermore, we should take on the social responsibility to answer the questions of low-dose/low dose-rate radiation-related issues with a transparency in risk assessment and decision making, and a reliable relationship with members of the public during not only the acute but also the recovery phases from the nuclear accident.

Currently, continued monitoring and characterization of the levels of radioactivity in the environment and foods in Fukushima are vital for obtaining informed consent to the decisions on various issues such as the extent to which populations can return to their homes. Now we are handling the official plans for the Fukushima Health Management Survey, which includes a basic survey for individual external dose estimation and four detailed surveys: thyroid ultrasound examination, comprehensive health check-up, mental health and life-style survey, and pregnancy and child survey, to prospectively care for all of the residents of Fukushima for a long time. In this presentation, the lessons learned from Fukushima will be addressed so that we will be able to prepare for unpredictable accidents at NPPs around the world as exemplified by the existing issues in Fukushima such as the difficult challenge of solution of the image evoked by the impact of contamination and its psycho-social consequences.

Overview

S.Y. Chen, *Session Chair*

9:30 am

Exposed Populations: Who Are They?

Steven L. Simon
National Cancer Institute

All persons on earth are exposed to natural and man-made sources of ionizing radiation, hence, exposed populations exist within all nationalities, ethnic groups, age groups, and within many professions.

While the identities of a few exposed populations are well known by members of the public and press because of their relationship to major historical news events, there are many other populations exposed to ionizing and nonionizing radiation during the course of routine life that are less well known, but whose exposures may be significant in terms of their potential for scientific study and for contributing useful information on radiation health risks.

Because the degree, nature, frequency, length, and other characteristics of radiation exposure vary widely across the totality of persons on Earth, it is useful for scientific purposes to consider these aspects so that informative studies can be envisioned and planned. One way to categorize exposed populations is to distinguish them according to the type and origin of the source of radiation, leading to three partitions:

- environmental exposures (*e.g.*, from terrestrial gamma rays, radon, cosmic rays, nuclear weapons testing fallout, and accidental releases);
- medical exposures (*e.g.*, from diagnostic imaging and therapeutic procedures); and
- occupational exposures (*e.g.*, from the use of radiation in medicine, nuclear power, defense, and military activities).

A modest amendment to this partitioning scheme is to divide environmental exposures into those from (1) the natural environment, and (2) those that are created as an outcome of unintended events (*e.g.*, accidents and terrorist events). Sources of nonionizing radiation are often overlooked, including those that are universal (ultraviolet solar radiation) or widely present in industrialized societies (*e.g.*, radiofrequency and microwave radiation from cell phones and communication devices and extremely low-frequency radiation from power lines and household appliances).

In this presentation, numerous radiation-exposed populations will be identified, briefly characterized, and evaluated in light of their potential for providing useful information on radiation-related health risks. The characteristics of each population that might make them useful for study of radiation health risks will be briefly considered, including:

- public health or clinical importance of the exposure;
- whether findings can be generalized to other similarly-exposed population;
- whether the exposure can be reliably estimated for individuals in the population;
- variability of the level of exposure in the population, thus allowing for determination of a radiation-related dose response;
- whether disease outcomes can be completely ascertained and well-characterized;
- population size in relation to the level of statistical power needed to identify relatively-small risks;
- population composition (*e.g.*, does the population include poorly studied or susceptible persons); and
- availability of information on important covariates and confounding exposures (*e.g.*, smoking or other lifestyle attributes).

As discussed elsewhere in this meeting, ensuring adequate radiation protection of members of the public and workforce as well as addressing public concerns about safety in medicine is important to a society that is committed to using radiation for beneficial purposes. Identification of exposed populations is the first of several important steps in conducting studies to accomplish this outcome.

9:55 am

Why Study Radiation-Exposed Populations?

Martha S. Linet
National Cancer Institute

Everyone is exposed to natural and man-made sources of ionizing radiation in environmental, medical and occupational settings. Increasingly ubiquitous are nonionizing radiation exposures from ultraviolet, radio- and microwave frequency, and extremely low-frequency sources. Serious health effects associated with ionizing radiation were reported in the first half of the 20th century in radiologists and in workers exposed to radium used in watch dials. For several decades, ultraviolet radiation exposure has been linked with increased risks of certain types of skin cancer, but studies of health risks in relation to other types of nonionizing radiation are more recent and associations with health effects are less certain.

The specialized field of radiation epidemiology assesses health risks in relations to radiation exposure levels. Increasingly this work involves multidisciplinary teams of epidemiologists, statisticians, and experts in radiation physics and dosimetry. During the past six decades, epidemiologic studies have evaluated a growing number of health outcomes potentially linked with radiation including malignant and benign neoplasms, birth defects, reproductive outcomes. and transgenerational effects as well as diseases of the cardiovascular, hematologic, neurologic, ophthalmologic (particularly cataracts), and other systems. Psychological health effects have also been examined. Understanding the link between radiation exposure and health outcomes is important because of the widespread and evolving exposure to radiation from a broad range of technologies employed in medical, residential and workplace settings as well as natural background sources.

In this presentation, reasons for epidemiologic investigations of radiation-exposed populations are discussed. The first and foremost reason is to provide members of the public and the scientific community with an understanding of radiation associated health outcomes. We need to develop a strong database with consistently repeated results for health outcomes associated with radiation exposure. Key questions to address include:

- What health effects are associated with radiation exposure?
- How does the incidence of radiation-related disease outcomes compare with the baseline occurrence of these diseases?
- Do the types of health effects vary depending on if the exposure is acute or protracted?
- How does energy, type of radiation risk, and dose rate affect the outcomes?

The second reason is to quantify the radiation-related risks and to consider other criteria in determining causality. Important questions to consider include:

- Does risk increase with increasing radiation dose? If yes, what is the pattern of the dose-response relationship?
- Is cancer risk increased at low doses (<200 mSv)?
- Are there any exposures that may confound the relationship (such as cigarette smoking, reproductive factors, and chemotherapy given in conjunction with radiotherapy or other factors)?
- Is the statistical association modified by type of radiation, age at first radiation exposure, the interval between first exposure and outcome (latency), age at outcome, gender, and genetic or other susceptibility factors?
- Do data from animal or other experimental studies support the statistical association seen in studies of humans?

A third goal of epidemiologic studies of radiation-exposed populations is to enhance understanding of mechanisms of radiation-related disease pathogenesis. Epidemiologic studies can assess whether radiation exposure is associated with intermediate biomarkers on the causal pathway to cancer or other medical conditions, cell transformation or cell killing, inflammatory factors in disease pathogenesis, and increased disease risks in genetically-susceptible persons.

Epidemiologic studies can provide critical information about radiation-associated health outcomes that is central to quantifying risks in relation to benefits. Such studies are also important to address public concerns, societal and clinical needs in relation to radiation exposure, and to provide the database needed for establishing recommendations for radiation protection.

10:20 am

Radiation Impacts on Human Health: Certain, Fuzzy and Unknown

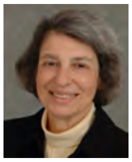
Roy E. Shore
Radiation Effects Research Foundation

The atomic bomb and other studies have long shown with certainty that moderate-to-high doses of radiation cause many types of solid cancer and leukemia. As we move down the dose scale to the vicinity of 100 to 200 mSv the risks become fuzzy, and become unknown at low doses on the order of 10 to 20 mSv. Nor have low-dose experimental studies provided definitive answers: some have suggested there may be adverse biological effects in the range of 5 to 50 mSv, while others support a "no risk" interpretation. Epidemiologic data contain intrinsic "noise"—variation by known and unknown factors related to genetics, lifestyle, other environmental exposures, sociodemographics, diagnostic accuracy, etc.—so are generally too insensitive to provide compelling answers in the low-dose range. However, there have been recent provocative reports regarding risk from relatively low-dose occupational and medical radiation exposures that warrant careful consideration. Knowledge about possible interactions between radiation exposure and genetic variants with respect to cancer risk is currently very limited and inconsistent, and some of the more "striking" findings are based on methodologically-weak data. Recently, interest in health endpoints other than cancer also has risen sharply, in particular the degree of cardiovascular and cataract risk following doses under 1 Sv. Data regarding these endpoints are limited and nominally inconsistent, making them fuzzy areas, and risk at low doses is essentially unknown. The magnitude of radiation impacts on human health require fuller documentation, which from the epidemiology vantage point will require longer observation of existing irradiated cohorts and sometimes improved dose assessments. Additional studies of newly identified irradiated cohorts also can be of value if the cohorts have characteristics to make them statistically informative: a sufficient range of doses and a large enough cohort size to be able to detect risks; reasonably accurate individual dose information; an infrastructure that permits complete, unbiased ascertainment of the diseases of interest; and information on major confounding risk factors. The lessons of Fukushima and other radiation scenarios also teach us that we need to learn how to more effectively communicate radiation risk information to the media and public; that may be the radiation risk impact about which we know the least.

10:45 am **Break**

11:05 am

Emotional Consequences of Nuclear Power Plant Disasters



Evelyn Bromet
SUNY Stony Brook

The emotional consequences of disasters involving radiation exposure include depression, anxiety, post-traumatic stress disorder, medically-unexplained somatic symptoms, and stigma. These effects are often long term and associated with fears about developing cancer. A review of research on disasters involving radiation, particularly evidence from Chernobyl, indicates that clean-up workers and mothers of young children are the highest risk groups. The findings are independent of actual exposure level. Data on children who were raised in the shadow of the Chernobyl nuclear reactor accident suggest that compared to their peers, they perceive their health more negatively but their emotional, academic and psychosocial development is comparable. Findings from general population surveys also show that the distress associated with exposure may be long term, but it does not reach the level of a psychiatric diagnosis. Preliminary data from Fukushima confirms that workers and mothers of young children are at risk for impairments in mental health. Psychiatric epidemiology has demonstrated four important issues that are germane to a discussion of the mental health effects of radiation disasters:

- mental health and physical health are highly co-morbid;
- around the world, individuals with common mental disorders like depression and anxiety consult with nonmental health medical professionals, not psychiatrists;
- mental disorders are highly stigmatized; and
- depression is a leading cause of disability and mortality.

Given the increase in mental health problems following events like Chernobyl and Fukushima, it is important that nonmental health providers learn to recognize and manage psychological symptoms and that medical programs can reduce stigma and alleviate psychological suffering by integrating psychiatric treatment within the walls of their clinics.

11:30 am **Q&A**

11:50 am **Lunch**

Medical

Kathryn D. Held, *Session Chair*

1:15 pm

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

Lawrence T. Dauer
Memorial Sloan Kettering Cancer Center

NCRP Report No. 160, *Ionizing Radiation Exposure of the Population of the United States* (2009) noted that in 2006, medical staff exposures contributed the most (39 %) to U.S. occupational exposures and represented 2.5 million monitored workers of which 0.75 million received recordable doses, a collective effective dose of 550 person-Sv, and an average effective dose of 0.75 mSv. In 1994, the United Nations Scientific Committee on the Effects of Atomic Radiation estimated worldwide annual collective effective dose and average effective dose for the exposed population of 760 person-Sv and 1.4 mSv, respectively; and 3,540 person-Sv and 1.24 mSv, respectively, in 2002. As the use of radiation and radioactive materials in medicine continues to rapidly increase, medical staff exposures will likely also increase.

Three current exposure potentials represent unique challenges for radiation protection of medical staff.

***Fluoroscopically-guided interventional (FGI) medical procedures*:** Medical individuals performing FGI procedures are typically the most exposed occupational group in diagnostic radiation and several studies have shown that they may also be exposed to a relatively high ocular dose, especially when protection tools are not utilized, and that this may result in increased risk of lens opacification or cataracts. The use of adequate eye protection is clearly a necessity, especially for high-volume practices. The International Commission on Radiological Protection (ICRP) Publication 118, *ICRP Statement* *on Tissue Reactions / Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context* (2012) reviewed recent studies on cataracts (including medical staff exposure studies) and indicated the threshold in absorbed dose is now considered to be 0.5 Gy (lower by a factor of 10 than deduced in earlier studies). ICRP now recommends an equivalent dose limit for the lens of the eye of 20 mSv y^{-1}, averaged over defined periods of 5 y, with no single year exceeding 50 mSv.

NCRP Report No. 122, *Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low-LET Radiation* (1995), Report No.133, *Radiation Protection for Procedures Performed Outside the Radiology Department* (2000), and Report No. 168, *Radiation Dose Management for Fluoroscopically-Guided Interventional Medical Procedures* (2010) provided specific recommendations for radiation monitoring of individuals and current algorithms for estimating effective dose to staff tending to overestimate effective dose. Equivalent dose to the lens of the eye is typically assessed using a monitor at the collar level outside any radiation protective garments or near the eyes. Readings on a collar dosimeter may be somewhat higher than the actual dose to the lens of the eye. Improvements in the understanding of the operational assessment of $H_p(3)$ for diagnostic radiology energies are still necessary.

Although numerous advances in fluoroscopic equipment design and shielding approaches (both body and eye protection) have occurred in the last two decades, training and credentialing is still an area requiring improvement. Europe still leads the United States in regard to operator training. According to the American Medical Association, as of 2011, only 27 states had enacted legislation regarding radiation education for fluoroscopy operators. Most guidelines for training in radiation protection and management have come from professional societies.

Expanding use of radioactive materials in diagnostic imaging: Increasing the use of radioactive materials in diagnostic imaging, especially positron emission tomography (PET), multimodality imaging (PET/CT, PET/MR), nuclear-medicine imaging (stress tests, scans), and localization studies (sentinel node, radioactive seed localization) have increased the potential for staff exposures. This is especially true for patient positioning, injection of dosage, and preparation of doses, both in the nuclear-medicine suites and outside traditional radiology departments. Dose rates from nuclear-medicine patients are about 10, 50, or 90 μSv h^{-1} GBq^{-1} at 1 m for ^{99m}Tc, ^{131}I, or ^{18}F, respectively, and close contact with PET patients can result in 0.5 to 3 μSv min^{-1}. Preparation and assay of radiopharmaceuticals are associated with highest occupational exposures in nuclear medicine (up to 5 mSv y^{-1} whole body and 500 mSv y^{-1} extremity). Clearly there is a need to develop and implement more advanced shielding, dispensing, assay, and delivery methods.

Novel uses of radiation in medicine: There is increasing use of novel treatment approaches utilizing beta emitters, targeted alpha particle therapy, therapeutic and diagnostic radiolabeled monoclonal antibodies, and intraoperative radioactive material use for brachytherapy or PET-guided interventions/surgery that represent new challenges for medical staff. In addition, several institutions are building in-house cyclotron and radiopharmaceutical facilities and the development of nontraditional PET isotopes such as ^{64}Cu, ^{68}Ga, ^{86}Y, ^{89}Zr, and ^{124}I that involve emission of high-energy gamma rays, in addition to 0.511 MeV annihilation photons, present challenges for occupational exposures with respect to shielding and radiation safety issues.

1:40 pm

Dose Tracking and Rational Exam Selection for the Medically-Exposed Population

James A. Brink
Massachusetts General Hospital / Harvard Medical School

Tracking the radiation exposure to medically-exposed populations can promote adoption of best practices among medical facilities that use ionizing radiation. In May 2011, the American College of Radiology (ACR) launched a Dose Index Registry that allows imaging facilities to submit patient-specific dose data for comparison of average dose indices among similar practices across the country. The Dose Index Registry provides an important tool for practices to benchmark their radiation exposures for medical imaging and highlight areas where improvements may be made.

While some U.S. states have passed legislation to require the reporting of individual patient doses and potentially tracking those doses over time, individual patient dose tracking has many confounding variables to consider. First, it is not clear which dose measures should be tracked. Second, the variation among these dose measures must be understood relative to the variations in body habitus that are encountered in clinical practice, both for constant levels of image noise and for various levels of image noise that can be accommodated with different clinical indications. Estimation of stochastic risk is the primary driver behind cumulative radiation exposure tracking on an individual basis. However, there are many uncertainties associated with risk estimation from low-dose radiation that relate to the age, gender, and life expectancy of the affected individual.

While substantial variation is expected in medical radiation exposures and their estimated risks, other sources of variation in the use of ionizing radiation for medical imaging are concerning. Specifically, deviation from best practice in the use of medical imaging should be reduced, if not eliminated. The over-utilization of chest computed tomography examinations both with and without intravenous contrast material is a good example of wasted radiation. A recent report in the lay press noted that more than 200 hospitals administered these “double scans” more than 30 % of the time when best practice is less than 5 %. Moreover, failure to adopt best practice tends to cluster geographically suggesting that local influences may drive resistance to adoption.

Several tools exist to help reduce variation among practices when it comes to rational exam selection. The ACR’s Appropriateness Criteria provide a mechanism for guiding practitioners to the appropriate imaging examination. The Appropriateness Criteria return a numeric score for any given combination of medical topic, variant, and imaging examination, and multidisciplinary diagnostic algorithms are needed that go beyond the Appropriateness Criteria to guide practitioners to the appropriate diagnostic pathway for a given clinical scenario. Work is under way in this regard, however, the pressure for rapid throughput, particularly in the emergency room, confounds our ability to implement such tools on a wide scale. Computerized order entry with decision support offers the promise to introduce these tools at the point of care, which should increase their use and adoption in the medical community at large.

2:05 pm

Second Malignant Neoplasms and Cardiovascular Disease Following Radiotherapy

Lois B. Travis
University of Rochester Medical Center

Second malignant neoplasms (SMNs) and cardiovascular disease (CVD) are among the most serious and life-threatening late adverse effects experienced by the growing number of cancer survivors worldwide and are due in part to radiotherapy. The National Council on Radiation Protection and Measurements (NCRP) convened an expert scientific committee to critically and comprehensively review associations between radiotherapy and SMNs and CVD, taking into account radiobiology, genomics, treatment (*i.e.*, radiotherapy with or without chemotherapy and other therapies), type of radiation, and quantitative considerations (*i.e.*, dose-response relationships). Major conclusions of the NCRP include the:

- relevance of older technologies for current risk assessment when organ-specific absorbed dose and the appropriate relative biological effectiveness are taken into account; and
- identification of critical research needs with regard to newer radiation modalities, dose-response relationships, and genetic susceptibility.

Recommendation for research priorities and infrastructural requirements include:

- long-term large-scale follow-up of extant cancer survivors and prospectively treated patients to characterize risks of SMNs and CVD in terms of radiation dose and type;
- biological sample collection to integrate epidemiological studies with molecular and genetic evaluations;
- investigation of interactions between radiotherapy and other potential confounding factors, such as age, sex, race, tobacco and alcohol use, dietary intake, energy balance, and other cofactors, as well as genetic susceptibility;
- focusing on adolescent and young adult cancer survivors, given the sparse research in this population; and
- construction of comprehensive risk prediction models for SMNs and CVD to permit the development of follow-up guidelines and prevention and intervention strategies.

2:30 pm **Q&A**

2:50 pm **Break**

Worker Exposures

Christopher H. Clement, *Session Chair*

3:10 pm

Characterization of Exposures to Workers Covered Under the U.S. Energy Employees Compensation Act

James W. Neton

National Institute for Occupational Safety & Health

Since the mid-1940s, hundreds of thousands of workers have been engaged in nuclear weapons-related activities for the U.S. Department of Energy (DOE) and its predecessor agencies. In 2000, Congress promulgated the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA), which provides monetary compensation and medical benefits to certain energy employees who have developed cancer. Under Part B of EEOICPA, the National Institute for Occupational Safety and Health (NIOSH) is required to estimate radiation doses for those workers (or their survivors) who have filed a claim. To date, over 38,000 dose reconstructions have been completed for workers from more than 200 facilities. These reconstructions have included assessment of both internal and external exposure at all major DOE facilities, as well as at a large number of private companies [known as Atomic Weapons Employer (AWE) facilities in the Act] that engaged in contract work for DOE and its predecessor agencies. To complete these dose reconstructions, NIOSH has captured and reviewed thousands of historical documents related to site operations and worker/workplace monitoring practices at these facilities.

Using the data collected and reviewed pursuant to NIOSH's role under EEOICPA, this presentation will characterize historical internal and external exposures received by workers at DOE and AWE facilities. To the extent possible, use will be made of facility specific coworker models to highlight changes in exposure patterns over time. In addition, the effect that these exposures have on compensation rates for workers will be discussed.

3:35 pm

Increased Occupational Exposures: Nuclear Industry Workers

Andre Bouville

National Cancer Institute

This presentation will focus on the increased occupational exposures resulting from the Chernobyl nuclear reactor accident that occurred in Ukraine in April 1986, the reactor accident of Fukushima that took place in Japan in March 2011, and the early operations, in the 1940s and 1950s, of the Mayak Production Association, which is located in Russia.

The Chernobyl nuclear reactor accident is the most serious that ever occurred in the nuclear industry. In addition to the ~800 emergency workers involved during the first few days after the accident in firefighting and closing down unaffected units of the power plant, more than 500,000 cleanup workers took part in 1986 to 1990 in the mitigation of the consequences of the accident, including decontamination and construction of the sarcophagus. Among the emergency radiation workers, special attention is paid to the 134 persons who had been diagnosed with acute radiation sickness; they received bone-marrow doses due to external gamma radiation ranging from 0.8 to 16 Gy. The average effective dose received by the 530,000 clean-up workers, also called liquidators or recovery operation workers, was mainly due to external irradiation and is estimated to have been ~0.12 Sv. The recorded worker doses varied from <0.01 to >1 Sv, although ~85 % of the recorded doses were in the range from 0.02 to 0.5 Sv.

The accident at the Fukushima Daiichi Nuclear Power Plant of the Tokyo Electric Power Company was the consequence of an earthquake of magnitude 9.0, which triggered a major tsunami that submerged the emergency diesel generators, resulting in serious damage to the reactor. During the first year following the accident (from March 2011 to March 2012), ~21,000 workers were involved in activities on the reactor site, six of those workers received effective doses (external plus internal) >0.25 Sv, 167 workers received effective doses >0.1 Sv, and about two-thirds of the workforce received effective dose ≤0.01 Sv.

The Mayak Production Association was the first industrial complex in the former Soviet Union built for the production of plutonium. The complex included reactors, chemical processing plants, and plutonium production facilities. In the early years, there was poor understanding of the consequences of relatively-high occupational radiation exposures. The highest external gamma doses were recorded in 1948 to 1952, that is, during the start-up and adaptation phase of the reactor and radiochemical plants. Average values of annual doses amounted to 1 Gy, and maximum individual annual doses were up to 8 Gy. High internal doses were due to the exposure to plutonium.

4:00 pm

Radiation Exposure of U.S. Military Individuals

Paul K. Blake
Defense Threat Reduction Agency

The U.S. Department of Defense (DOD) employs over three million military (active and reserve) and civilian workers. Approximately 70,000 DOD workers (2 %) are annually monitored for ionizing radiation exposure. DOD workers and their dependents can also potentially be exposed to ionizing radiation during nuclear war scenarios or operations other than war. DOD uses many thousands of radioactive sources in performing its mission. These sources are predominately self-regulated (91B - military application of atomic energy) or fall under U.S. Nuclear Regulatory Commission regulation. DOD's radiation safety programs arose during the Manhattan Project in World War II. These programs expanded with the U.S. development of nuclear weapons and nuclear power applications. This has resulted in the development of a significant regulatory, technical and acquisition infrastructure to support DOD's global missions. Some of these missions are unique in human history. For example, the U.S. Navy operates 104 operational nuclear reactors (including submarines and aircraft carriers), and recently surpassed 150 million miles safely steamed on nuclear power. The Naval reactor program contributed 51 % of the government, DOE, and military dose in 2006. This predominately occurred at four naval shipyards that repaired Naval nuclear powered ships. DOD also operates unique radiation research facilities, such as the Armed Forces Radiobiology Research Institute in Bethesda, Maryland, and military-focused, real-time modeling support at the Defense Threat Reduction Agency.

DOD radiation monitoring infrastructure includes three nationally-accredited external personal radiation dosimetry programs (Army, Navy, and Air Force), a variety of internal personal monitoring programs, various environmental and food radiological analysis laboratories, and five radiation dose repositories with records on over two million individuals [Atomic Veterans, Army, Navy, Air Force, and Operation Tomodachi Registry (OTR)]. The OTR includes radiation doses of DOD individuals exposed to the radiological releases in 2011 from the Fukushima Daiichi Nuclear Power Plant. It is unique in that it includes dependents, in addition to military and civilian adults. DOD dose repositories also include Coast Guard and Merchant Marine exposures and non-DOD visitor exposures. DOD also supports the efforts of the U.S. Department of Veterans Affairs, the U.S. Department of Justice, and the U.S. Department of Labor that have radiogenic disease compensation programs for DOD employees.

4:25 pm **Q&A**

4:45 pm **Break**

Thirty-Seventh Lauriston S. Taylor Lecture on Radiation Protection and Measurements

5:00 pm **Introduction of the Lecturer**
F. Ward Whicker

When Does Risk Assessment Get Fuzzy?

John E. Till
Risk Assessment Corporation

This lecture examines the more than 60 y (1950 to 2012) evolution of risk assessment as a scientific methodology. For the purpose of today's lecture, risk assessment is defined as the estimation of health risk to humans exposed to radioactive materials released to the environment by a source. Today, the outcomes of risk assessment provide information necessary for determining compliance with regulations, formulating emergency response, designing facilities, estimating health effects of populations, among others.

Although risk assessment has become an essential component of radiation protection and our understanding of radiation exposure, some critics find the scientific integrity of risk assessment problematic. They describe risk assessment as "fuzzy" and cite a lack of cohesion, clear ground rules, quantification, and verification as concerns.

However, in order to comprehend risk assessment as credible scientific inquiry, it is essential to understand how the parts—various components and disciplines—

merge into a whole. The formula below describes the fundamental elements required to estimate risk.

Each factor of the risk equation builds upon the integration of foundational sciences such as engineering, physics, mathematics, chemistry and physiology. Each is examined in turn and examples provided to explain how it is quantified and serves as a building block for the next component.

$$\text{Risk} = (S \bullet T \bullet E \bullet D \bullet R)_{uvpc}$$

S = source term
T = environmental transport
E = exposure
D = conversion to dose
R = conversion to risk
u = uncertainty
v = validation
p = participation of stakeholders
c = communication of results

The source term (S) is the heart of risk assessment. It defines not only the amount of radioactivity released to the environment, but its physico-chemical characteristics, and its temporal and in some cases spatial distribution. It is what we must know first to quantitatively estimate risk. Without a valid estimate of the source, the steps that follow in the equation will be affected commensurately. Determining the source term is often the most resource-intensive part of the analysis.

Once we know the source term, we can estimate how radioactive materials are transported (T) through the environment. The ultimate goal of this component of risk assessment is to determine the concentration in air, soil, water and biota. Fortunately, early pioneers in radioecology, meteorology and hydrology helped lay a solid foundation that is still used today to quantify transport of radionuclides through environmental media.

Understanding the way in which people interact with the environment is a fundamental component of determining how much exposure they receive. Physiological data together with habit and dietary information about people allow concentrations of specific radionuclides in the environment to be converted into exposure (E).

The development of dose (D) and risk (R) coefficients, which specify the dose or risk per unit exposure, has its genesis in the early days of the atomic age when we first began to study the distribution of radionuclides in the human body and their accumulation in specific organs. These coefficients have been compiled from hundreds of studies of animals and people. Today these coefficients are distilled and published by international organizations such as the International Commission on Radiological Protection, the United Nations Scientific Committee on the Effects of Atomic Radiation, and the U.S. Environmental Protection Agency.

Of course, each of the components of risk assessment described above is subject to uncertainty (u). Uncertainty analysis is a relatively new component to risk assessment compared to the other elements, and its implementation has been accelerated by advances in computer technology over the past two decades.

Historical dose reconstruction studies performed on present and former nuclear weapons complex sites have supplied environmental measurement data. Data collected during the early years of operation of these facilities have provided an invaluable resource for validating (v) the mathematical models often used in risk assessment.

We have learned that engaging stakeholders as citizen participants (p) in the risk assessment process can have far reaching effects. Not only can they provide valuable local knowledge, such as diet and habit information, thereby making the results more accurate and credible, but their active involvement in the risk assessment process can represent the difference between success or failure of an entire study.

The key to understanding and acceptance of risk assessment is communication (c). This important element is just now receiving the attention it deserves, and although progress is being made, there are barriers to overcome. Some of the barriers are self-inflicted because we, as scientists, have seldom had to communicate our work with anyone other than our peers. Although this insular focus have sufficed in the past, risk assessment today has a far broader audience, and we are honing our skills to be more effective at translating quantitative estimates of risk to our colleagues, decision makers, and members of the public.

As each building block of risk assessment is put together, an interdependence of collective analyses emerges in quantitative outcomes. Risk assessment has clearly evolved into a multidisciplinary field of scientific research that is widely accepted as valid, reliable and essential.

So when does risk assessment get fuzzy?

6:00 pm **Reception in Honor of the Lecturer**

Sponsored by Landauer, Inc.

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Tuesday, March 12

8:15 am **NCRP Annual Business Meeting**

9:15 am **Break**

Public Exposures

David J. Pawel, *Session Chair*

9:30 am

Impact on the Japanese Atomic-Bomb Survivors of Radiation Received from the Bombs

Harry M. Cullings
Radiation Effects Research Foundation

The Radiation Effects Research Foundation (RERF) studies a number of cohorts of Japanese atomic-bomb survivors, of which the largest is the Life Span Study (LSS) cohort, which includes 93,741 persons who were in Hiroshima or Nagasaki at the time of the bombings. RERF also studies smaller cohorts of persons who were exposed *in utero*, and a cohort of survivors' children. Since the doses received by the survivors ranged from vanishingly small at longer distances to the acutely-lethal range, some survivors experienced acute signs and symptoms of radiation exposure in addition to being at risk of late effects. The numbers of estimated excess cancers and hematopoietic malignancies were relatively small compared to the size of the exposed population, due to the highly-skewed nature of the dose distribution, with the preponderance of survivors in the LSS receiving small doses. For example, in the latest report on cancer incidence, 853 of 17,448 incident solid cancers were estimated to be attributable to radiation from the bombs. The same is true of the noncancer late effects such as heart disease, which appear to be in excess in proportion to radiation dose, but at relatively-small abundance (*i.e.*, 353 of 35,685 deaths in the latest LSS report on mortality, with an excess relative risk about one-third that of solid cancer). This presentation will describe the risk of these late effects from both the population perspective (estimated numbers of excess occurrences) and the individual perspective (risk in terms of both age-specific and integrated lifetime risk, along with some examples of other measures that impart additional information about how the risk affects a particular individual given age at exposure, etc.). RERF research indicates that risk of radiation-associated cancer varies among sites and that some benign conditions such as uterine myoma are also associated with radiation. For noncancer disease, specific risks exist for some subcategories such as diseases of the blood, respiratory and digestive systems, as well as specific subcategories of circulatory disease such as stroke and precedent conditions such as hypertension. The excess risk of cataract in atomic-bomb survivors is well known, and evidence of risk at lower dose levels than previously appreciated has been found in recent years. Risk has also been found for thyroid disease and hyperparathyroidism. Developmental deficits associated with *in utero* exposure, notably cognitive impairment, have also been described. Interaction of radiation with other risk factors has been demonstrated in relation to both cancer (smoking and lung cancer) and noncancer diseases (chronic liver disease and hepatitis). Current research interests include whether radiation increases risk of diabetes or conditions of the eye apart from cataract, and there continues to be keen interest in the question of whether there are heritable effects in survivors' children, despite negative findings to date. RERF research offers clues to some of these questions and also to the mechanisms of observed effects through elucidation of intermediate risk factors such as proinflammatory alterations of immune function and chromosomal aberrations. In addition to somatic effects, psychosocial effects must be considered, including uncertainty, social stigma or rejection, and other social pressures.

9:55 am

Joint U.S./Russian Studies of Population Exposures Resulting from Nuclear Production Activities in the Southern Urals

Bruce A. Napier
Pacific Northwest National Laboratory

Beginning in 1948, the Soviet Union initiated a program for production of nuclear materials for a weapon's program. The first facility for production of plutonium was constructed in the central portion of the country east of the southern Ural Mountains, about halfway between the major industrial cities of Ekaterinburg and Chelyabinsk. Initially known only by its secret post office box number, Chelyabinsk-40, and then Chelyabinsk-65, the facility now known as the Mayak Production Association and its associated town, now known as Ozersk, were built to irradiate uranium in reactors, separate the resulting plutonium in reprocessing plants, and prepare plutonium metal. The rush to production, coupled with inexperience in handling radioactive materials, lead to large radiation exposures, not only to the workers in the facilities, but also to the surrounding public. The early graphite-moderated reactors used air as a cover gas, resulting in releases of ~83 EBq (1 x 10^{18} Bq) of ^{41}Ar. Fuel leaks resulted in the release of ~89 EBq of noble gases, primarily ^{89}Kr, ^{138}Xe, and ^{87}Kr. Fuel processing started with no controls on releases, and fuel dissolution and accidents in reactors resulted in release of ~37 PBq (1 x 10^{15} Bq) of ^{131}I between 1948 and 1967. Although much smaller, releases of plutonium particulates from the purification facilities resulted in releases such that today plutonium concentrations in regional soils are about 30 times higher than global averages. All of these atmospheric releases impacted the residents of the town of Ozersk and many of the smaller villages in the region. In addition, designed disposals of low- and intermediate-level liquid radioactive wastes, and accidental releases *via* cooling water from tank farms of high-level liquid radioactive wastes, into the small Techa River caused significant contamination and exposures to residents of numerous small riverside villages downstream of the site. Discovery of the magnitude of the aquatic contamination in late 1951 caused revisions to the waste handling regimes, but not before over 200 PBq of radionuclides (with large contributions of ^{90}Sr and ^{137}Cs) were released. Starting in 1956, many villages were evacuated—the most recent being the village of Muslyumovo in 2009. Liquid wastes were diverted to tiny Lake Karachay (which today holds over 4 EBq); cooling water was stopped in the tank farms. In 1957, one of the tanks in the tank farm, containing over 700 PBq, overheated and exploded. About 10 % of the tank contents, over 70 PBq, disproportionately ^{90}Sr, was blown over a large area to the northeast of the site; a large area was contaminated and many villages evacuated. This area today is known as the East Urals Radioactive Trace (EURT). Each of these releases was significant; together they have created a group of cohorts unrivaled in the world for their chronic, low dose-rate radiation exposure. The city of Ozersk today has ~80,000 residents, many who have lived there their entire lives. A cohort of individuals raised as children in Ozersk is under evaluation for their exposures to radioiodine. The Techa River Cohort consists of over 30,000 people who were born before the start of exposure in 1949 and lived along the Techa River. The Techa River Offspring Cohort consists of ~21,000 persons born to one or more exposed parents of this group—many of whom also lived along the contaminated river. The EURT Cohort consists of ~18,000 people who were evacuated from the EURT soon after the 1957 explosion—many of this group were also previously exposed on—and evacuated from—the Techa River. These groups together are the focus of dose reconstruction and epidemiological studies funded by the United States, Russia, and the European Union to address the question “Are doses delivered at low-dose rates as effective in producing health effects as the same doses delivered at high dose rates?”

10:20 am

Populations Living Near Nuclear Power Plants

Daniel O. Stram
University of Southern California

The U.S. Nuclear Regulatory Commission (NRC) sought advice from the National Academy of Sciences (NAS) on the analysis of cancer risks in populations near nuclear power plants (NPPs) envisioning a two-phase project. In early 2012 Phase 1 of this study (the scoping study) was completed. The statement of task for the study committee included the identification of scientifically-sound approaches for “carrying out the cancer epidemiology study that has been requested by the NRC” including methodological approaches for assessing off-site dose and for assessing cancer risk (study populations, geographical areas, cancer types, availability of cancer data, designs, power, confounding). The background for this request includes:

- that the only previous comprehensive report on cancer risk in populations around U.S. NPPs was published by the National Cancer Institute (NCI) in 1991;
- that there are now 104 licensed U.S. NPPs in 65 sites in 31 states with approximately one million people living within ~8 km of a facility; and
- that a new study covering a longer period of follow-up and utilizing new data resources could ameliorate perceived shortcomings in the NCI report.

Among the perceived shortcomings of the NCI report was that it mainly relied upon cancer-mortality data with only limited available incidence data and that these data are only available as yearly aggregates at the county level, and that no dose estimation was attempted.

The committee examined the feasibility and data sources available to carry out many different types of studies that might update and improve upon the NCI study design. The committee determined that two basic study designs were potentially feasible but that a large-scale pilot study was required and recommended seven facilities in six states be included in the pilot, before broadening to a U.S.-wide study.

The first study design that was recommended for consideration in the pilot is an update of the previous NCI methodology, to rely upon mortality and incidence data aggregated at a finer geographical level (census tract) than the county level used previously, and to take into account data (at the census tract level) about population size, age, socioeconomic status variables, ethnic makeup, migration patterns, and estimated dose to residents from NPP releases, as well as distance and other dose surrogates. The second recommended study would monitor birth cohorts of children born in regions centered around NPPs (a ~48 km region was discussed) for childhood cancer incidence using state tumor registries and birth registries and would relate cancer incidence in those children to dose and dose surrogates.

Reported releases and hence the statistical power of these studies is recognized to be very low. Nevertheless the committee also recognized that other considerations (*e.g.*, public concerns about safety) may be assessed by NRC in prioritizing whether to proceed with further work.

On October 23, 2012 NRC announced that it would ask NAS to carry out the pilot study.

10:45 am

Nuclear Reactor Accidents: Exposures and Health Effects Among Members of the Public

Maureen Hatch
National Cancer Institute

The first notable nuclear reactor accident occurred in 1957 at the Windscale Plant in Britain. Radioactive ^{131}I was released from the reactor building into the surrounding area but a 50 y follow-up of the highest-exposed group—workers involved in cleanup—found no exposure-related effects on cancer or mortality rates.

This presentation will focus on the three more recent reactor accidents: namely, Three Mile Island (TMI) in Pennsylvania in 1979; Chernobyl in the Former Soviet Union in 1986; and Fukushima in Japan in 2011. In all three cases, exposures to members of the public were primarily to internal radiation, principally ^{131}I, although concentrations varied markedly. The release and deposition of ^{131}I at Fukushima was an order of magnitude lower than at Chernobyl, and levels at TMI were lower still. Health surveys at Fukushima are ongoing but the results of epidemiologic studies of populations exposed at TMI and Chernobyl are reflective of their relative exposures.

Radioactive iodine is taken up by the body and stored in the thyroid gland, where it has the potential to cause benign and malignant thyroid disease. Exposure to members of the public occurs largely *via* ingestion of contaminated milk and other foods. Because the thyroid dose from ^{131}I is roughly proportional to milk consumption and inversely proportional to thyroid mass, children—with their high milk consumption and small thyroid glands—generally receive the highest doses. Indeed, currently the most widely recognized adverse health effect from Chernobyl fallout is the approximately fivefold increase in thyroid cancer among exposed children and adolescents in the most affected regions of Ukraine and Belarus—a risk that is comparable to that from external radiation. Risks for noncancer thyroid diseases such as follicular adenoma and subclinical hypothyroidism in children and adolescents exposed to ^{131}I as a result of Chernobyl have been reported as well. This presentation will cover the limited literature on effects among those exposed prenatally, another potentially radiosensitive group, as well as those exposed as adults; recent evidence from a study by the International Agency for Research on Cancer suggests an increased risk in this group from ingestion doses received in contaminated residential areas. Finally, the potential for future genetic research based on biomaterials from thyroid cancer cases in Chernobyl-affected areas will be touched upon.

Although radiation doses from the accident at TMI were very low, health studies were conducted to respond to public concerns. Efforts to reconstruct dose and to evaluate dose-response patterns in cancer incidence and mortality in the populations living within ~8 to 16 km of the plant have been reported, with largely null results. Psychosocial stress from the accident has also been investigated and stress levels have been found to be elevated, particularly in susceptible subgroups such as pregnant women. However, the effects of accident stress on other health outcomes are not clear. Radiation doses from the Fukushima Daiichi nuclear reactor accident were also much lower than at Chernobyl, both because of a smaller release and timely countermeasures to minimize exposure. For this reason, as well as the circumstances leading to the accident (*i.e.*, the earthquake and tsunami and the associated loss of life and dislocation of so many people), psychosocial outcomes will likely emerge as the most significant health effect of this most recent nuclear accident.

11:10 am **Q&A**

11:30 am **Break**

Summary

Paul A. Locke, *Session Chair*

11:45 am

Implications of Radiation Dose and Exposed Populations on Radiation Protection in the 21st Century

John D. Boice, Jr.
National Council on Radiation Protection & Measurements

This NCRP 2013 Annual Meeting on the impact of radiation dose and exposed populations highlights the substantial need and remarkable opportunities available to radiation scientists and the radiation protection community in the 21st century. The demand and need for radiation protection guidance is correlated with the increases in population exposures from medical sources; the earthquake and tsunami in Japan that led to the Fukushima nuclear reactor accident; the awareness of natural sources of radiation from indoor radon in homes and cosmic radiation in planes and in space craft; concern about radiation in the workplace that led to compensation programs; the threat of nuclear terrorist attacks; the expansion of nuclear power to generate electricity and public concern about living near such facilities; and even the use of, until recently, backscatter x-ray screening devices in airports. The presentations and extended abstracts have highlighted the doses associated with public, environmental and workplace exposures and point to the need for enhanced guidance and specific recommendations as new sources and potential sources of radiation exposure arise.

Constant vigilance is needed for the continued strengthening of the culture of safety surrounding the uses of ionizing radiation. Protection guidance should take into account the beneficial effects of radiation use—that cannot be overstated but are often overlooked. Radiation saves lives in medicine by properly diagnosing illnesses and effectively treating cancer. Nuclear power generates much needed electricity for members of the public. Employment in radiation occupations provides livelihood for workers and their families. The requirements for providing protection to workers and members of the public should not unduly limit the benefits from the uses of radiation or result in costs that far exceed the anticipated level of protection afforded proposed protection actions.

- **Fukushima:** It is fitting that at this 2 y anniversary of the March 11, 2011 earthquake, tsunami, and reactor accident in Japan, that the NCRP annual meeting be dedicated to the people of Fukushima who were so severely affected. Gaps in radiation protection guidance became vividly displayed and will be described. Although population exposures appear minimal and at or substantially below the levels of natural background exposures (because of the effective measures taken to shelter in place, evacuate, and restrict the food supply), there was concern and uncertainty because information surrounding the accident was not being shared in an effective or timely manner to members of the public, media, scientists and governments. There was a need for better communication during the developing crisis and subsequently about remediation and possible radiation risks. The lessons being learned are continuing to evolve and while many problems have been delineated, solutions have yet to be presented. For example, it is taken as self-evident that special guidance is needed for children and pregnant women, and yet such guidance on dose limits, constraints, and reference levels for children does not exist! Opportunities for the radiation protection community to provide improved guidance abound and will be described.
- **Medicine:** The greatest source of population exposure in developing countries is from medical diagnostic procedures that have greatly advanced the understanding and diagnosis and treatment of disease. The computed tomography (CT) scans and positron emission tomography imaging procedures are now basic components of good medical care, and it is now estimated that over 86 million CT examinations occur each year in the United States alone (*i.e.*, about one for every four persons). The medical benefits are unquestioned, but these procedures are not even close to your grandfather's chest x-ray (*i.e.*, organ doses are substantially higher). Because of the higher dose levels and the extent of population exposure, there is a continuing need to provide guidance on ways to minimize exposure without reducing clinical benefit.
- **New Recommendations:** The International Commission on Radiological Protection published recommendations in 2007 as an evolution in guidance with regard to radiation protection issues. These new recommendations coincide with the interest in the United States to improve,

update and enhance our guidance for protection of workers and members of the public. There is new knowledge on radiation effects, both cancer and non-cancer, and an appreciation of the need for protection guidance in all aspects of the use of radiation in our society. An opportunity exists to improve upon the international guidance.

- **Improved Radiation Risk Estimates:** The major unanswered question in radiation epidemiology of critical interest to the radiation protection community and regulators and compensators, is an accurate estimate of organ-specific risks following exposures that occur gradually over time and at a low-dose rate. NCRP is coordinating the study of over one million U.S. radiation workers and atomic veterans. The populations studied include Manhattan Project workers of the U.S. Department of Energy (DOE), atomic veterans of the U.S. Department of Defense (DOD), nuclear utility workers and industrial radiographers under license requirements of the U.S. Nuclear Regulatory Commission (NRC), and early radiologists and technologies. This national effort is supported by DOE, NRC, DOD, the National Cancer Institute, the U.S. Department of Veterans Affairs, the National Aeronautics and Space Administration, and the U.S. Environmental Protection Agency.

NCRP is poised and ready to meet the challenges of the 21st century. There is a need to train, engage and retain radiation scientists. Improved risk communication and education and outreach are sorely needed. The integration of basic radiation biology with epidemiology is required to understand and provide improved estimates of risks associated with low-dose and low dose-rate exposures. Emergency response and disaster management have come to the forefront. There is much to be done!

12:15 pm **Q&A**

12:30 pm **Closing Remarks**
John D. Boice, Jr.

The 2014 NCRP Annual Meeting will celebrate the 50th anniversary of its Congressional charter. The program will not only touch upon radiation protection accomplishments over these past 50 y, but will highlight the current initiatives and opportunities for the future. Stay tuned!

12:45 pm **Adjourn**

Biographs

PAUL K. BLAKE is the Program Manager of the Nuclear Test Personnel Review Program, Nuclear Technologies Department, Defense Threat Reduction Agency (DTRA), Fort Belvoir, Virginia. DTRA safeguards the United States and its allies from weapons of mass destruction (chemical, biological, radiological, nuclear, and high-yield explosives) by providing capabilities to reduce, eliminate and counter the threat, and mitigate its effects. He leads the U.S. Department of Defense efforts to confirm participation and reconstruct radiation doses for veterans involved in U.S. atmospheric nuclear weapons testing (1945 to 1962), and the post-World War II occupation forces of Hiroshima and Nagasaki, Japan. Dr. Blake retired from the U.S. Navy as a captain, after serving 26 y on active duty. He is a diplomate of the American Board of Health Physics and is a member of the U.S. Naval Institute and Health Physics Society. He earned a doctorate degree in medical physics from the University of Wisconsin-Madison.

JOHN D. BOICE, JR. is President of the National Council on Radiation Protection and Measurements (NCRP), Bethesda, Maryland, and Professor of Medicine at Vanderbilt University School of Medicine, Nashville, Tennessee. He is an international authority on radiation effects and currently serves on the Main Commission of the International Commission on Radiological Protection and as a U.S. advisor to the United Nations Scientific Committee on the Effects of Atomic Radiation. During 27 y of service in the U.S. Public Health Service, Dr. Boice developed and became the first chief of the Radiation Epidemiology Branch at the National Cancer Institute. Dr. Boice has established programs of research in all major areas of radiation epidemiology, with major projects dealing with populations exposed to medical, occupational, military and environmental radiation. These research efforts aimed at clarifying cancer and other health risks associated with exposure to ionizing radiation, especially at low-dose levels. Dr. Boice's seminal discoveries and over 440 publications have been used to formulate public health measures to reduce population exposure to radiation and prevent radiation-associated diseases. He has delivered the Lauriston S. Taylor Lecture of NCRP and the Fessinger-Springer Lecture at the University of Texas at El Paso. In 2008, Dr. Boice received the Harvard School of Public Health Alumni Award of Merit. He has also received the E.O. Lawrence Award from the U.S. Department of Energy — an honor bestowed on Richard Feynman and Murray Gell-Mann among others — and the Gorgas Medal from the Association of Military Surgeons of the United States. In 1999 he received the outstanding alumnus award from the University of Texas at El Paso (formerly Texas Western College).

ANDRE BOUVILLE was born and educated in France. He came to the United States in 1984 to work for the National Cancer Institute (NCI). His initial assignment was to estimate the thyroid doses received by the American people from ^{131}I released by the nuclear weapons tests that were conducted at the Nevada Test Site in the 1950s. This study led to the assessment of doses from nuclear weapons tests conducted at other sites all over the world, as well as to a large number of dosimetry studies related to the Chernobyl nuclear reactor accident. He was the head of the Dosimetry Unit of the Radiation Epidemiology Branch at NCI until he retired at the end of 2010. Throughout his career, Dr. Bouville actively participated in the preparation of scientific reports under the umbrella of international organizations, notably the United Nations Scientific Committee on the Effects of Atomic Radiation, the International Commission on Radiological Protection, the International Commission on Radiation Units and Measurements, the World Health Organization, the International Atomic Energy Agency, and the Nuclear Energy Agency. Regarding U.S. organizations, Dr. Bouville was a member of NCRP for 12 y and became a Distinguished Emeritus Member in 2011. He has served on numerous National Academy of Science committees and is a Lifetime Associate of the National Academies. For all his achievements, Dr. Bouville was a recipient of the Presidential Rank Meritorial Award in 2003.

JAMES A. BRINK is Radiologist-in-Chief at Massachusetts General Hospital (MGH). He earned a BS degree in Electrical Engineering at Purdue University and an MD at Indiana University before completing his residency and fellowship at Massachusetts General Hospital. He joined the faculty at the Mallinckrodt Institute of Radiology at Washington University School of Medicine where he rose to the rank of Associate Professor prior to joining the faculty at Yale University in 1997. Promoted to Professor in 2001, Dr. Brink was appointed Interim Chair in 2003 and Chair of the Yale Department of Diagnostic Radiology in 2006. On February 1, 2013, Dr. Brink left Yale to serve as Radiologist-in-Chief at MGH. While he has broad experience in medical imaging, including utilization and management of imaging resources, he has particular interest and expertise in issues related to the monitoring and control of medical radiation exposure. Dr. Brink is a fellow of the Society for Computed Body Tomography/Magnetic Resonance and a fellow of the American College of Radiology (ACR). For ACR, he serves on the Executive Committee and Board of Chancellors as Chair of the Body Imaging Commission, Chair of the Imaging Communication Network, and Co-Chair of the Global Summit on Radiology Quality and Safety. For the American Roentgen Ray Society, Dr. Brink is a member of the Executive Council and immediate Past President. For NCRP, Dr. Brink is the Scientific Vice President for Radiation Protection in Medicine, and chaired the NCRP scientific committee that defined diagnostic reference levels for medical imaging in the United States (NCRP Report No. 172, 2012). For the International Society of Radiology, Dr. Brink serves as Chair of the International Commission for Radiology Education, and for the Radiological Society of North America, he serves as Co-Chair of the “Image Wisely” initiative, a social marketing campaign to increase awareness about adult radiation protection in medicine.

EVELYN J. BROMET received her undergraduate degree in history from Smith College and her PhD in epidemiology from Yale University. After post-doctoral training at Stanford University, she joined the faculty at the University of Pittsburgh from 1976 to 1986. She is currently Distinguished Professor of Psychiatry and Preventive Medicine at Stony Brook University. Dr. Bromet’s research focuses on a range of psychiatric conditions, including alcoholism, depression, post-traumatic stress disorder, and psychosis. Her research on disaster mental health started with a groundbreaking study of the psychological impact of the Three Mile Island Nuclear Power Plant accident on mothers of young children, workers at the plant, and psychiatric patients in the public treatment sector. She later collaborated with the Ukrainian Psychiatric Association in Kyiv on research examining the psychological impact of the Chernobyl Nuclear Power Plant accident on evacuees in Kyiv. She also headed the first national epidemiologic survey of mental and physical disorders in Ukraine as part of the World Health Organization’s World Mental Health Survey Consortium. Her work has resulted in more than 200 papers, chapters, and reports, and two co-authored books, *Toxic Turmoil: Psychological and Societal Consequences of Ecological Disasters* (2002) and *Psychiatric Epidemiology: Searching for the Causes of Mental Disorders* (2006). She received the Rema Lapouse mental health research award from the American Public Health Association (1989), the Brigitte Prusoff Memorial Prize from the Department of Epidemiology at Yale University (2007) and was named honorary fellow of the Ukrainian Psychiatric Association in 2005. Her research has been funded by grants from the National Institute of Mental Health, the W.T. Grant Foundation, and the Stanley Medical Research Institute. Dr. Bromet has been a member of the National Institute of Health Director’s Council of Public Representatives, Institute of Medicine, and National Institute of Mental Health review panels, and advisory panels to the National Cancer Institute, World Health Organization, the United Nations Educational, Scientific and Cultural Organization, and the National Vietnam Veterans Readjustment Study. She reviews for several mental health journals and is on the Editorial Board of Psychological Medicine. She is currently President of the American Psychopathological Association.

HARRY M. CULLINGS is Chief of the Statistics Department at the Radiation Effects Research Foundation (RERF) in Hiroshima and Nagasaki, Japan, where he has worked since 1999. He has been a member of the bi-national working group that created the DS02 Dosimetry System for RERF and a special scientist for the National Research Council’s Committee on Dosimetry for the RERF. Prior to a U.S. Department of Energy multidisciplinary postdoctoral fellowship in Radiation Sciences at the University of Pittsburgh, he worked for some 20 y as a health physicist and radiation safety officer in medical and biomedical research centers, where he was responsible for programs such as personnel radiation monitoring, bioassay, contamination surveys, a radioactivity counting laboratory, and radioactive and mixed waste disposal. He holds an MS in Radiological Physics and a PhD in Biometrics from the University of Colorado Health Sciences Center in Denver. His current interests include the statistical treatment of dosimetric uncertainty and the application of spatial statistical methods and Bayesian hierarchical models to risk estimation at RERF.

LAWRENCE T. DAUER is Assistant Attending Health Physicist, and Assistant Clinical Member in the Departments of Medical Physics and Radiology at Memorial Sloan-Kettering Cancer Center (MSKCC) in New York City. He earned an MS in Health Physics and a PhD in Adult Education. He is certified in comprehensive health physics by the American Board of Health Physics and is past chair of the Radiation Safety Committee of the American Association of Physicists in Medicine (AAPM), past President of the Greater New York Chapter of the Health Physics Society (HPS), Executive Council Member of the Medical Physics Section of HPS, a Member of the Joint Safety Committee of the Society for Interventional Radiology and the American College of Radiology, past council member of the Radiological and Medical Physics chapter of the AAPM, and a member of editorial and review boards of several scientific journals. He serves as the Chair of the MSKCC Emergency Management Committee, a member of the Radiation Injury Treatment Network. In 2005, he received the Elda E. Anderson Award from HPS. He is currently a Council member of the NCRP. He also serves as a member of International Commission on Radiological Protection Committee 3 on Protection in Medicine, a member of the Science Council for the International Organization for Medical Physics, and was on the program committee for the International Atomic Energy Agency's International Conference on Radiation Protection in Medicine-Setting the Scene for the Next Decade. He has several publications in the topical areas of radiation protection and risks in the fields of detection, radiology, interventional radiology, x-ray imaging, nuclear medicine, and radiation oncology, as well as surgery and medicine.

MAUREEN HATCH received her PhD in Epidemiology from Columbia University and subsequently served as a faculty member at Columbia's School of Public Health, where she led a study of cancer incidence following the accident at Three Mile Island. She later became Director of the Division of Epidemiology at Mount Sinai Medical Center. In 2002 she joined the Radiation Epidemiology Branch at the National Cancer Institute (NCI) and was Head of the Chernobyl Research Unit through 2009. She is currently leading an NCI/National Institute of Child Health and Human Development study on the adverse effects of Chernobyl fallout on an *in utero* exposed cohort in Ukraine. Dr. Hatch has been a member of two National Academy of Science committees on radiation research and an adviser on Chernobyl research for the World Health Organization and the International Agency for Research on Cancer. She is a past president of the Society for Epidemiologic Research and an Associate Editor of the *American Journal of Epidemiology*.

MARTHA LINET has served as Chief of the Radiation Epidemiology Branch of the National Cancer Institute since 2002. Dr. Linet has studied risk of childhood leukemia in relation to residential magnetic fields from power lines, electrical appliances, and to radon; risk of brain tumors and cell phone use; and strategies for improving questionnaire assessment of ultraviolet radiation exposures. She leads studies quantifying cancer risks in large cohorts of medical radiation workers in relation to work history, occupational radiation doses, ultraviolet radiation, and other risk factors. Dr. Linet is internationally recognized for etiologic studies of childhood and adult hematopoietic malignancies investigating the role of benzene, occupational, environmental, medical, and genetic factors. Her service includes President of the American College of Epidemiology (2004 to 2005), advisory and site visit review committees (International Agency for Research on Cancer and the United Kingdom

Leukemia and Lymphoma Research Society), and membership on NCRP (2010 onward), the National Academy of Sciences Nuclear and Radiation Studies Board (2011 onward), and journal editorial (American Journal of Epidemiology) and advisory (Journal of the National Cancer Institute) boards. Dr. Linet's awards include NIH Merit and Director's Awards, and election to the American Epidemiological Society and the Johns Hopkins Society of Scholars.

BRUCE A. NAPIER is a Staff Scientist in the Radiological Science and Engineering Group at Pacific Northwest National Laboratory in Richland, Washington and has been for the past 35 y. Mr. Napier works with the development and operation of models concerned with the environmental transport of radiological and chemical contaminants. His expertise and experience lie in the areas of radiation dose reconstruction, computer modeling, environmental analysis, and human health risk analysis. He is an author of the widely-used GENII computer code. Mr. Napier was the Chief Scientist for the Hanford Environmental Dose Reconstruction Project that evaluated releases from the Hanford Site during production of plutonium. He is now a Principal Investigator for the U.S./Russian Joint Coordinating Committee on Radiation Effects Research, working on the dose reconstructions at the Russian Mayak Production Association for both the workers at and the populations living near the points of atmospheric release and along the Techa River downstream. Mr. Napier is a member of the Board of Directors of NCRP, a committee member of the U.S. Environmental Protection Agency's Science Advisory Board and the National Academy of Sciences, a Fellow of the Health Physics Society, and Chair of oversight panels for the National Cancer Institute's Chernobyl Studies.

JAMES W. NETON is the Associate Director for Science within the Division of Compensation Analysis and Support at the National Institute for Occupational Safety and Health. He has over 30 y experience in the measurement and dose assessment of occupational radiation exposure. For the last 13 y, Dr. Neton's principal responsibility has been oversight of the scientific basis for the reconstruction of radiation doses and risk models under the U.S. Energy Employees Occupational Illness Compensation Program Act. Dr. Neton holds a PhD in Environmental Health Sciences from New York University where he specialized in internal radiation exposure measurement methods. His career has been broad-based, including work as a consultant for a large radiological engineering firm and as a product manager for a radiation instrument manufacturing company. In addition, he has managed occupational radiation dosimetry programs at Argonne National Laboratory and the Fernald Environmental Management Project. Dr. Neton has been a member of the Health Physics Society (HPS) for over 30 y and is certified in the comprehensive practice of health physics by the American Board of Health Physics. In 2012 he was awarded fellow status in the Society. He has served as a scientific advisor or working group member for a number of organizations, including the International Atomic Energy Agency, the World Health Organization, the International Commission on Radiation Units and Measurements, NCRP, the American National Standards Institute, the HPS Standard's Committee, and the U.S. Department of Energy's Laboratory Accreditation Program.

ROY E. SHORE was a Professor and Chief of the Epidemiology Division at New York University School of Medicine before going to the Radiation Effects Research Foundation (RERF) in Hiroshima and Nagasaki as Vice Chairman and Chief of Research. He is an author of ~100 radiation-related publications and is currently working with other RERF investigators on studies of radiation and various diseases. He has served on numerous governmental and scholarly committees, including as a long-time member of the International Commission on Radiological Protection and NCRP, and has served on various committees or task groups for the United Nations Scientific Committee on the Effects of Atomic Radiation, the World Health Organization, the National Academy of Sciences, the National Cancer Institute, and the U.S. Environmental Protection Agency, among others. His interests include the effects of radiation on both cancer and noncancer disease incidence, and understanding the epidemiologic and biological modification of radiation effects by various environmental, genetic and age factors.

Biographs

STEVEN L. SIMON received a BS in Physics from the University of Texas, an MS in Radiological Physics from the University of Texas Health Sciences Center in Dallas, and a PhD in Radiological Health Sciences from Colorado State University. Early in his career, he worked in medical physics and was the first treatment planner for clinical trials of treatments of solid tumors with negative pi-mesons at the Los Alamos Physics Meson Facility. Later specializing in environmental radioactivity, he directed the first nationwide monitoring program of the Marshall Islands for residual contamination from nuclear testing. He also participated in the radiological monitoring of numerous other nuclear test sites worldwide including Johnston Island, French Polynesia, and Algeria and has lead, or participated in, health risk studies of fallout exposures in Utah, the Marshall Islands, and Kazakhstan. In 2000, Dr. Simon joined the National Cancer Institute's Radiation Epidemiology Branch as an expert in dose reconstruction and presently heads the Dosimetry Unit in that group. Steve is a member of NCRP and has been an Associate Editor of *Health Physics* for 20 y. In 2011 during the Fukushima crisis, Steve was deployed by the U.S. Department of Health and Human Services to the U.S. Embassy in Japan to assist with the protection of American citizens.

DANIEL O. STRAM is Professor in the Department of Preventive Medicine at the Keck School of Medicine of the University of Southern California. He received his PhD in statistics from Temple University in 1983 and served as a postdoctoral fellow in the Biostatistics Department of the Harvard School of Public Health from 1984 to 1986. From 1986 to 1989 he was a research associate at the Radiation Effects Research Foundation in Hiroshima, Japan. Dr. Stram's main areas of research are in the statistical problems that arise in the design, analysis and interpretation of epidemiological studies of cancer and other diseases. His work on radiation epidemiology studies includes: (1) helping to characterize the statistical nature of errors in dose estimates for the atomic-bomb survivor study, (2) developing a multi-level variance components model for the dosimetry used in the Colorado Plateau uranium miners cohort for the purpose of better understanding dose and dose-rate effects in those data, and (3) characterizing study power and sample size issues in epidemiologic studies in which a complex dosimetry system is used to estimate radiation dose. Besides the field of radiation epidemiology his past and current research has focused on statistical issues relevant to clinical trials of treatment for pediatric cancer, nutritional epidemiology studies, and to studies of the genetics of complex diseases. He is an elected fellow of the American Statistical Association and has authored or co-authored over 200 peer reviewed articles.

JOHN E. TILL is President of Risk Assessment Corporation. He is a graduate of the U.S. Naval Academy and served in the U.S. Navy Nuclear Submarine Program and retired a Rear Admiral in the U.S. Naval Reserve in 1999. Dr. Till received an MS from Colorado State University in 1972 and a PhD from the Georgia Institute of Technology in 1976. In 1977 Dr. Till formed Risk Assessment Corporation to perform research on radionuclides released to the environment by nuclear facilities. His career has focused on the development of methods to estimate dose and risk to humans from radionuclides and chemicals in the environment. He has served on committees for the National Academy of Sciences, the International Commission on Radiological Protection, and the International Atomic Energy Agency. He has published widely in the open literature including the first textbook on radiological risk assessment published by the U.S. Nuclear Regulatory Commission in 1983 and an updated version, *Radiological Risk Assessment and Environmental Analysis* (2008). In 1995, Dr. Till received the E.O. Lawrence Award from the U.S. Department of Energy in the field of Environmental Science and Technology. In addition to his scientific work, Dr. Till also owns and operates his family farm, growing corn and soybeans near Neeses, South Carolina.

LOIS B. TRAVIS is a Professor in the Department of Radiation Oncology and Director of the newly established Rubin Center for Cancer Survivorship at the University of Rochester School of Medicine. Dr. Travis received her BS in Biology from Florida State University in 1977; a DSc and an MSc in

Epidemiology from Harvard School of Public Health in 1994 and 1982, respectively; and an MD from the University of Florida College of Medicine in 1980. She was trained at the Mayo Clinic and Harvard School of Public Health, and for two decades conducted research as a Principal Investigator at the National Cancer Institute. Dr. Travis is known for her transdisciplinary, international research in cancer survivor populations that have provided new information with regard to the late effects of cancer treatment. Dr. Travis' primary research interests center in the long-term physiologic and psychosocial effects of cancer and its treatment, with a goal of providing a foundation for risk-adapted evidence-based follow-up. Her current work focuses on selected, young adult cancers as a model for the construction of comprehensive survivorship studies (2010), with the eventual expansion of this approach to other populations. Dr. Travis' research interests also include the development of translational molecular approaches to identify patients at the highest risk of late effects (*e.g.*, cardiovascular, pulmonary, renal) in order to develop preventive and interventional strategies.

F. WARD WHICKER is Professor Emeritus at Colorado State University (CSU), where he taught graduate level courses in radioecology and radionuclide transport modeling for over 40 y. He and his graduate students conducted research in these fields, leading to the development of approximately 175 open literature publications, dozens of technical reports, many book chapters, and five books. His formal teaching extended to organizations such as the International Atomic Energy Agency, the International Union of Radioecologists, and the U.S. Environmental Protection Agency. In 1989 he founded the Par Pond Radioecology Laboratory at the Savannah River Site, where he spent 3 y studying the behavior of radionuclides in aquatic ecosystems. Dr. Whicker is regarded as one of the founders of radioecology, the field addressing the fate and effects of radioactivity in the environment. His early work on fallout radionuclides in ecosystems had implications for health effects in human, plant and animal populations. His research on the effects of ionizing radiation on plants and animals has contributed to the development of national and international guidelines for protecting the general environment from radioactive contamination. His work on radionuclide transport processes played a role in the understanding of mineral cycles and energy flows in terrestrial and aquatic ecosystems. He led the development of the PATHWAY food-chain transport model to predict internal doses from fallout radionuclides to residents of nine states near the Nevada Test Site. He also was a pioneer in using field measurement data to test the accuracy of computer models for prediction of radionuclide behavior in the environment. Dr. Whicker also helped develop probabilistic uncertainty/sensitivity analysis in environmental transport and dose codes. His service to the NCRP includes the Board of Directors, Scientific Vice President, Council member, and member or chair of several committees. He has served on committees of the National Academy of Science/National Research Council in the area of environmental problems of the U.S. Department of Energy's (DOE) Weapons Complex. He has chaired national and international working groups and scientific writing teams, for example, for the International Atomic Energy Agency, the International Commission on Radiation Units and Measurements, and the NCRP. He has served on review panels for many organizations, consulted for private organizations, and is frequently called as an expert witness on litigation issues concerning radioactivity in the environment. He served as Associate Editor for the Americas for the Journal of Environmental Radioactivity. His awards include the Sigma Xi CSU Chapter Honor Scientist, the CSU Glover Gallery of Distinguished Faculty, the Award for Significant Scientific Contributions from the Health Physics Society, the E.O. Lawrence Award from DOE, and the International Union of Radioecology's first V.I. Vernadsky Award. In "retirement," he guides mountain trips for the Colorado Mountain Club, and volunteers time to lecture and advise graduate students at CSU.

SHUNICHI YAMASHITA graduated from Nagasaki University School of Medicine in March 1978 and spent almost 3 y from July 1984 to March 1987 as an endocrine research fellow at the Cedars-Sinai Medical Center. In 1990, Dr. Yamashita became a full Professor of Molecular Medicine and International Radiation Health at the Atomic Bomb Disease Institute, Nagasaki University School of Medicine. He has been deeply involved in Chernobyl and Semipalatinsk medical aid projects for more than 20 y. Professor Yamashita is Adviser to the Governor of Fukushima Prefecture on Health Risk Management. He has been dispatched from Nagasaki University to Fukushima since the Fukushima Nuclear Accident and is now the Vice President of Fukushima Medical University. He is President of the Japan Thyroid Association and also a council member of the Asia and Oceania Thyroid Association, and Director of the World Health Organization Collaborating Center for Research on Radiation Emergency Medical Preparedness and Response Network. He is currently the member of Science Council of Japan.

Program Committee

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Kazuo Sakai
National Institute of Radiological Sciences, Japan

Steven L. Simon
National Cancer Institute

John E. Till
Risk Assessment Corporation

Shunichi Yamashita
Fukushima Medical University

Registration

Monday, March 11, 2013	7:00 am – 5:00 pm
Tuesday, March 12, 2013	7:00 am – 11:00 am

Register online: http://civclients.com/ncrp

2014 Annual Meeting

NCRP – Achievements of the First 50 Years and Opportunities for the Future

John D. Boice, Jr. & Jerrold T. Bushberg, *Co-Chairs*

March 10–11, 2014
Bethesda, Maryland

Overview

S.Y. Chen, *Chair*

Exposed Populations: Who Are They?
Steven L. Simon
National Cancer Institute

Radiation Impacts on Human Health: Certain, Fuzzy and Unknown
Roy E. Shore
Radiation Effects Research Foundation

Why Study Radiation-Exposed Populations?
Martha S. Linet
National Cancer Institute

Emotional Consequences of Nuclear Power Plant Disasters
Evelyn Bromet
SUNY Stony Brook

National Cancer Institute

Radiation Exposed Populations, Who Are They?

Steven L. Simon
Division of Cancer Epidemiology and Genetics
National Cancer Institute
National Institutes of Health

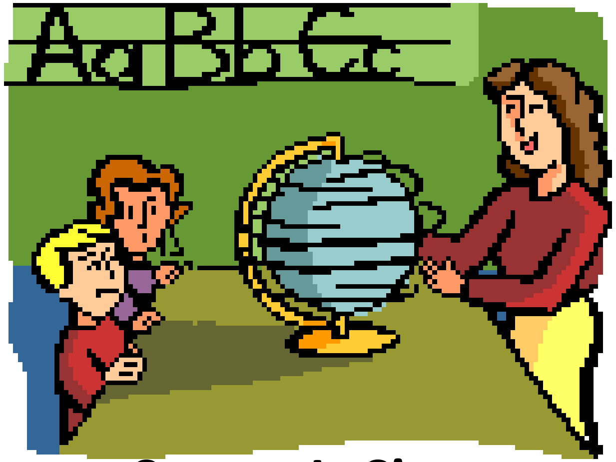
National Council on Radiation Protection and Measurements
March 11, 2013

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES

National Institutes of Health

National Cancer Institute

The ABCs of Radiation Exposed Populations



Steven L. Simon
Division of Cancer Epidemiology and Genetics
National Cancer Institute
National Institutes of Health

National Council on Radiation Protection and Measurements
March 11, 2013

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

The ABCs of Radiation Exposed Populations

- Who are the exposed populations?
- What are the sources of radiation exposure for each?
- What is the estimate of range of doses received in each - recognizing that the “true” doses may be impossible to know?
- What are the attributes of each population that distinguish them and that should be considered in the context of planning or designing a health risk study?

Who is Exposed? (1/2)

- **Identifying exposed populations suggests that you may want to know: "Who are the exposed individuals?"**
- **However, on an individual level, the difficulty in answering the question, "Who is exposed?", may vary from simple to very great.**
- **Answering "Who is exposed?" may depend on the definition of exposure or on estimation method used.**
- **Some measurement-based strategies (*e.g*., biodosimetry) can be used to identify persons exposed, with the caveat that the exposure is above the threshold of the measurement technique.**
- **In some cases, "exposure" may be based on well-founded individual records (*e.g*., medical or occupational records).**

Who is Exposed? (2/2)

- ❖ Because of the difficulties mentioned in defining or determining exposure on an individual basis, the "true" number of exposed persons in an "exposed population" may never be known.
- ❖ Generally, health risk studies identify a target population for "exposure assessment" and and do not try and answer the questions "Who?" or "How many?".
- ❖ Exposed populations may be generally distinguished based on one or more attributes, *e.g*.:
  - Residing or working in a particular place,
  - A particular occupation,
  - A particular gender, age group, ethnic group,
  - Proximity to an event or source of radiation,

The ABCs of Radiation Exposed Populations

Who are they?

The degree, frequency, duration, and circumstances of radiation exposure varies widely across the world and its population groups – as well as an understanding about exposure and how to take protective measures.

Exposed populations can be indentified by the source (categorical) of the exposure

1) **Medical exposures (patient doses)**
    a) Diagnostic medicine
    b) Therapeutic medicine

2) **Occupational exposures**
    a) Medical radiation practitioners
    b) Nuclear fuel cycle and nuclear energy workers
    c) Industrial, Educational, and Research
    d) Production activities (mining, etc.)
    e) Defense and military activities

3) **Environmental exposures (public doses)**
    a) Natural environment
    b) Man-made activities/events
    c) Unintended events, e.g., accidents, terrorist events, combat

4) **Consumer Products and Energy**

Category 1:
Populations Exposed to Diagnostic Medical Radiation (patients)

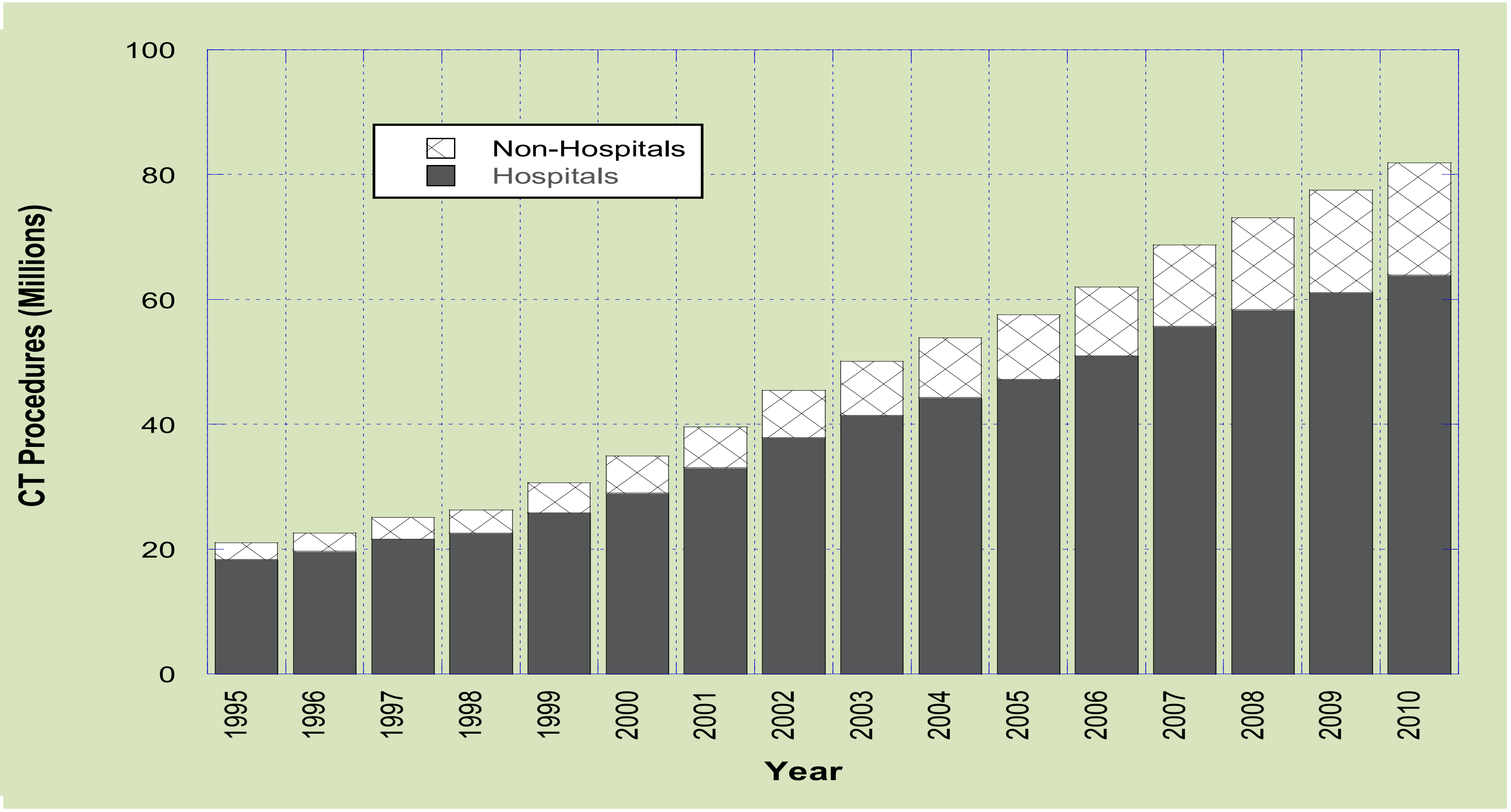
Computed Tomography

Radiography

Fluoroscopy

Nuclear Medicine (diagnostic)

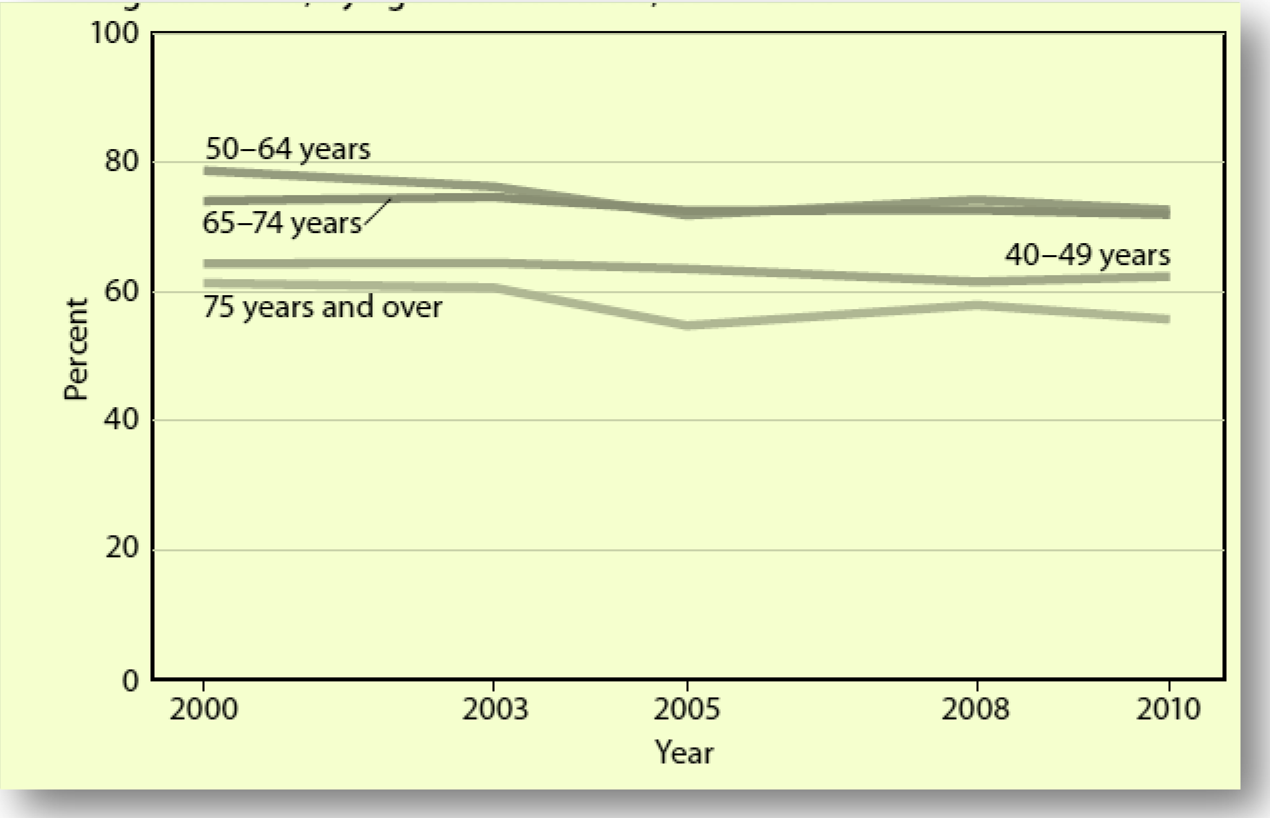
CT procedures: Annual number in the United States increased from ~20 million in 1995 to >80 million in 2010*



In U.S. emergency rooms in 1996 - 2007, use of CT procedures increased 11x greater than the number of visits to the emergency rooms (source: Univ. of Michigan).

*Source: IMVinfo, 2012 CT Benchmark Report

<u>Mammography</u> use in U.S for women >40 y of age → 65 million women in U.S. have mammograms (~2 mGy per view)



SOURCE: CDC/NCHS, Health, United States (2011)

Estimated Annual Collective Effective Dose from Medical Exposures (1997 - 2007)

Health Care Level	World population (x 10^6)	Diagnostic (person-Sv)	Dental x-ray (person-Sv)	Nuclear Medicine (person-Sv)	Total (person-Sv)
I	1,540	2,900,000	9,900	186,000	3,100,000
II	3,153	1,000,000	1,300	16,000	1,000,000
III	1,009	33,000	51	82	33,000
IV	744	24,000	38	-	24,000
World	**6,446**	**4,000,000**	**11,000**	**202,000**	**4,200,000**

Source: UNSCEAR (2008)

Populations Exposed to Therapeutic Medical Radiation (patients)

Conventional Radiotherapy

IMRT

Proton

Brachytherapy

Nuclear Medicine (therapeutic)

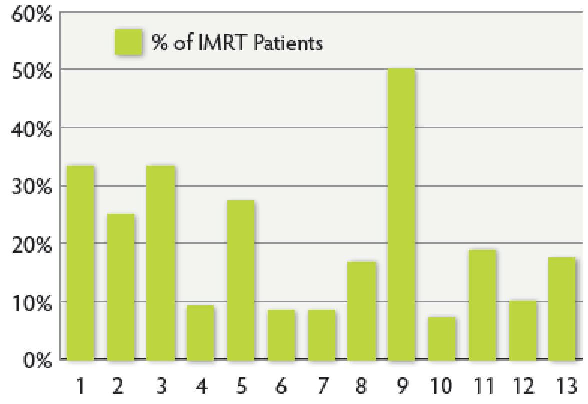
Estimated annual number of radiotherapy treatments in the world (1997 - 2008)

Health-care level	World population x 10^6	Annual number of teletherapy treatments x 10^6	Annual number of brachytherapy treatments x 10^6	Annual total number of radiotherapy treatments x 10^6
I	1540	3.5	0.18	3.6
II	3,153	1.2	0.2	1.4
III	1,009	0.06	<0.05	0.1
IV	744	0.03	<0.01	0.03
World	**6,446**	**4.7**	**0.4**	**5.1**

Source: UNSCEAR (2008)

Radiotherapy Advances Have Created New Populations

IMRT Treatments of breast cancer in Michigan*



Proton Therapy Treatments are gaining in popularity. Mayo Clinic estimates 140,000 patients in U.S. could benefit from treatment. Current capacity is ~11,000.

5 centers operational in U.S.
At least 5 more under construction.

Q: Why does the Radiotherapy Modality matter to health risk studies?

A: The depth dose profiles, radiation scattering properties, machine head leakage and neutron contamination all differ.

"Out-of-field" dose to healthy tissues/organs differ.

More complex treatment modalities require more complex treatment plans and are susceptible to different kinds of errors and uncertainties.

*CHRT.org (2012)

Category 2:
Populations Exposed to Occupational Sources of Radiation

Medical radiation practitioners
(Radiology, Dentistry, Vet med)

Nuclear energy workers
(fuel production, reactor
operations and emergency)

Industrial applications
(radiographers
and welders)

Category 2:
Populations Exposed to Occupational Sources of Radiation con't.

Research

Mining

Military

Civilian aviation

Astronauts

How many people receive occupational radiation exposures?

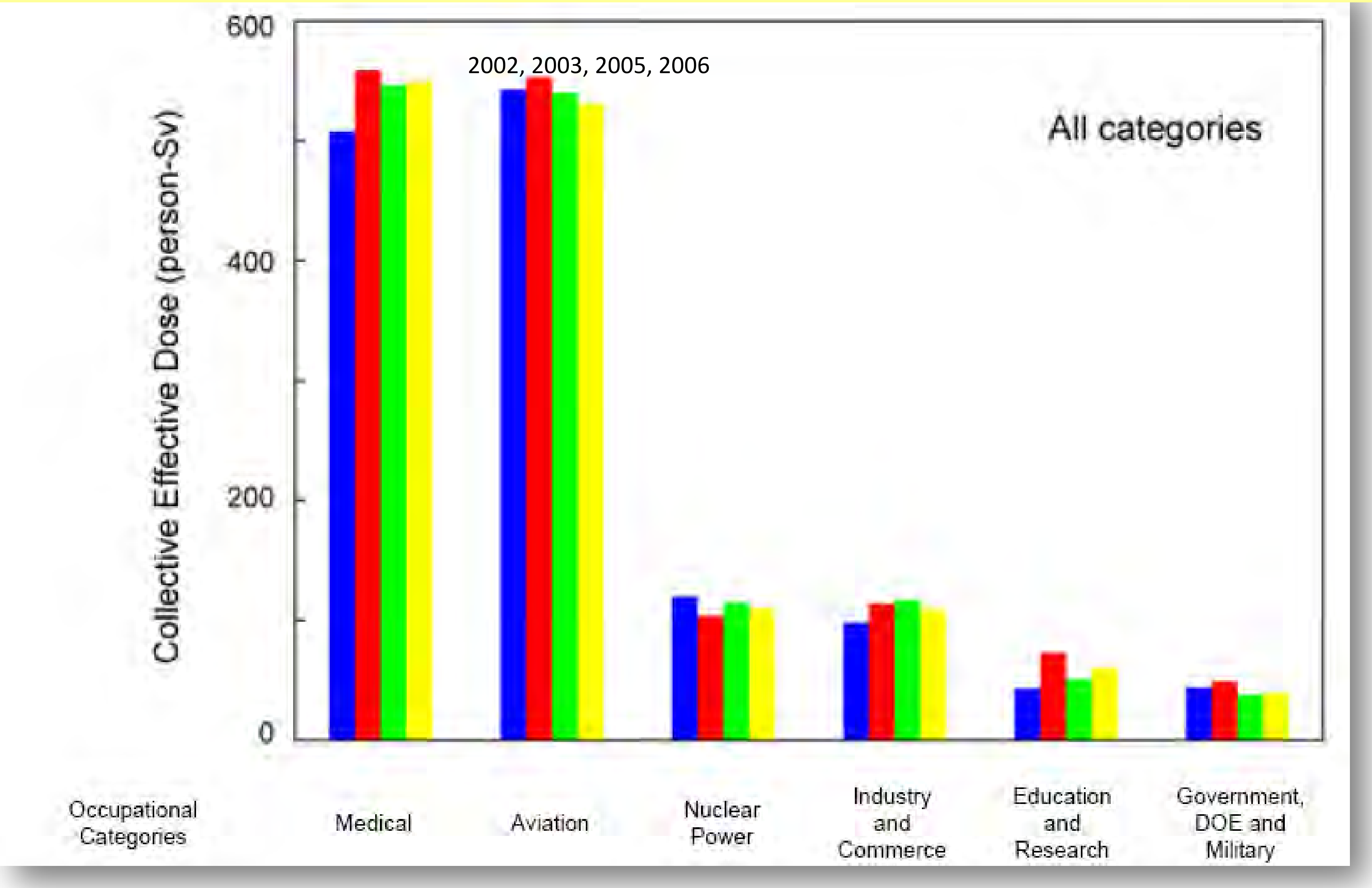
According to Frachette (2007)*:

- United States, 1.5 million radiation workers with 300,000 employed in the commercial nuclear power industry.
- Canada, whose population is one tenth that of the United States, >550,000 radiation workers in more than 80 occupations (commercial nuclear-power, academic research, food processing, industrial imaging, weld-defect inspection, leak tracing, automobile-steel testing, mineral-deposits activities).
- Switzerland, radiation workers number 60,000;
- South Korea, 65,000.

According to NCRP Report 160 (2009): 3.8 million monitored workers in the U.S. across occupations of medical, aviation, nuclear power, industry, education/research, and government/military: 1,400 person-Sv, average effective dose = 1.14 mSv (2006),

Data: Frachette, K. Am. J. Public Health 97(10) (2007)

Annual Collective Effective Dose for Occupational Categories



Source: NCRP Report No. 160 (2009)

Occupational exposure of aircrews
(the forgotten radiation worker?)

Country	Number of workers	Collective Dose (person-Sv)	Average annual effective dose (mSv)
United States	**150,000**	**~ 30 to 750**	**0.2 – 5**
United Kingdom	40,000	80	2.0
Germany	31,000	60	2.0
Netherlands	12,500	17	1.3

Source: UNSCEAR (2008)

ASTRONAUTS: An Occupation with Many Risks (Besides Radiation)

As of mid-2011, 529 people qualify as having reached space, above 50 miles (80 km) altitude.

Space travelers have spent over 30,400 man-days (83 man-years) in space, including over 100 astronaut-days of spacewalks

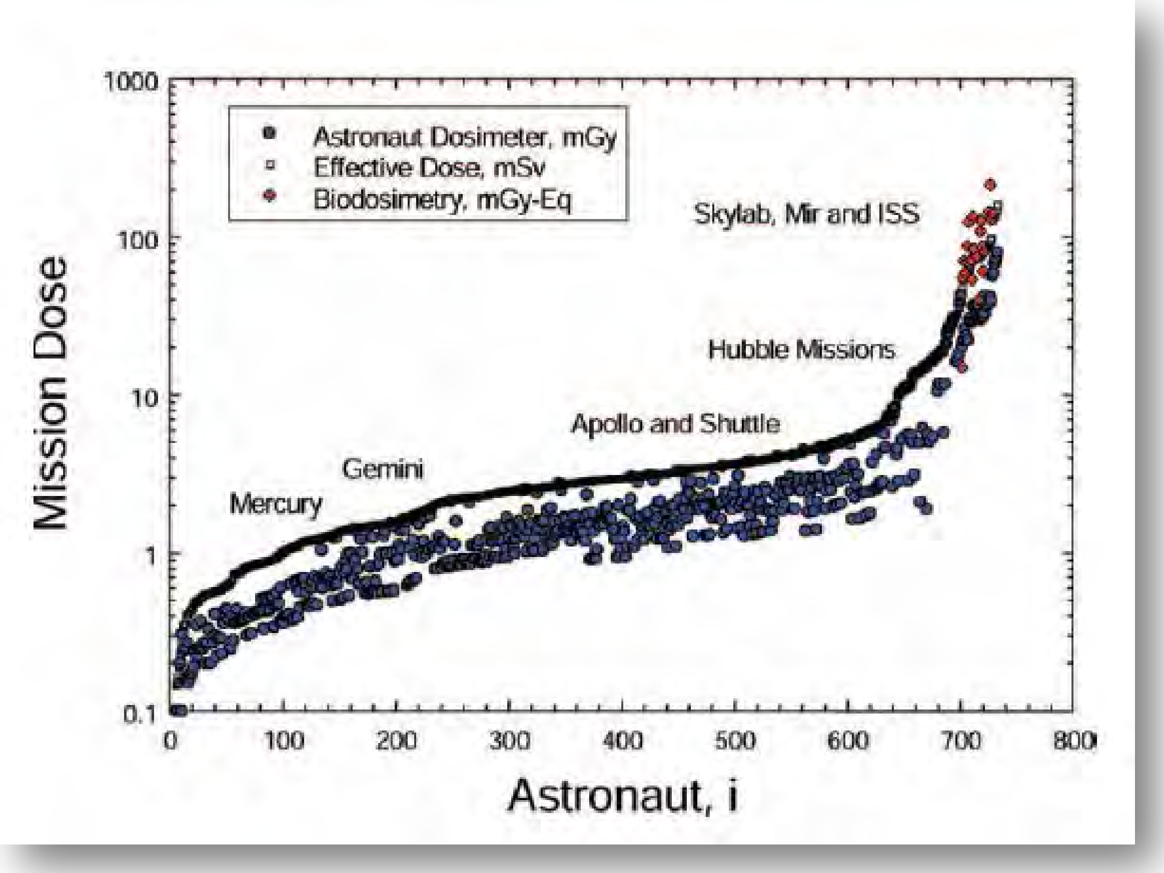
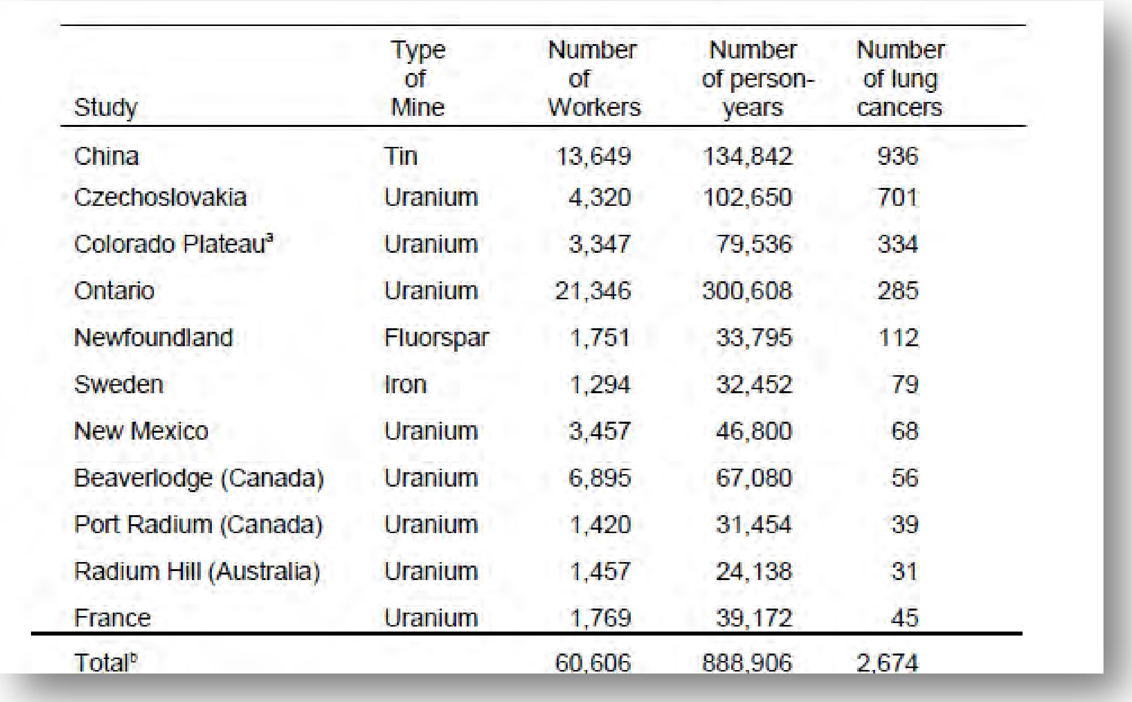


Photo: Data from Cucinotta et al. Radiation Research (2008)

Cohorts of radon exposed miners – unique and informative populations on inhalation risks – located worldwide



Study	Type of Mine	Number of Workers	Number of person-years	Number of lung cancers
China	Tin	13,649	134,842	936
Czechoslovakia	Uranium	4,320	102,650	701
Colorado Plateau[a]	Uranium	3,347	79,536	334
Ontario	Uranium	21,346	300,608	285
Newfoundland	Fluorspar	1,751	33,795	112
Sweden	Iron	1,294	32,452	79
New Mexico	Uranium	3,457	46,800	68
Beaverlodge (Canada)	Uranium	6,895	67,080	56
Port Radium (Canada)	Uranium	1,420	31,454	39
Radium Hill (Australia)	Uranium	1,457	24,138	31
France	Uranium	1,769	39,172	45
Total[b]		60,606	888,906	2,674

Source: NAS (1999)

Atomic veterans: Who are they?

- U.S. military who were potentially exposed to ionizing radiation while stationed in Hiroshima and Nagasaki during the American occupation of Japan before 1946,

- U.S. military took part in atmospheric nuclear tests (1945 - 1962) in the U.S. and the Pacific.

- Number about 125,000.

Source: Boice, J. Health Phys. 100(1), (2011)

Category 3:
Public Populations Exposed to Environmental Sources of Radiation

Natural environment

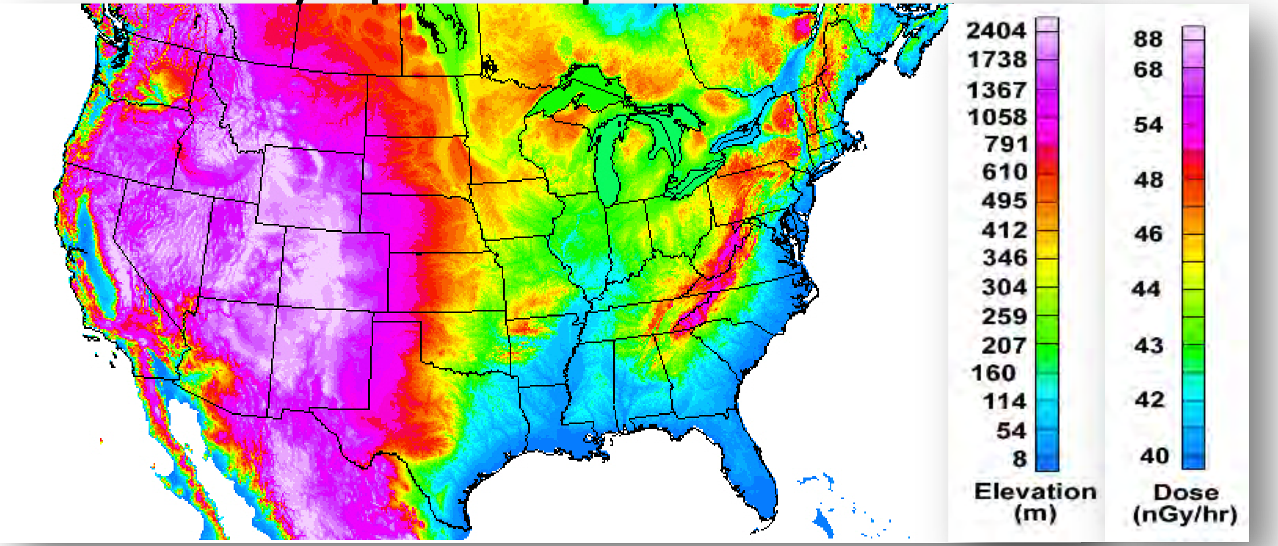
Man-made activities

Unintended events (accidents and disasters)

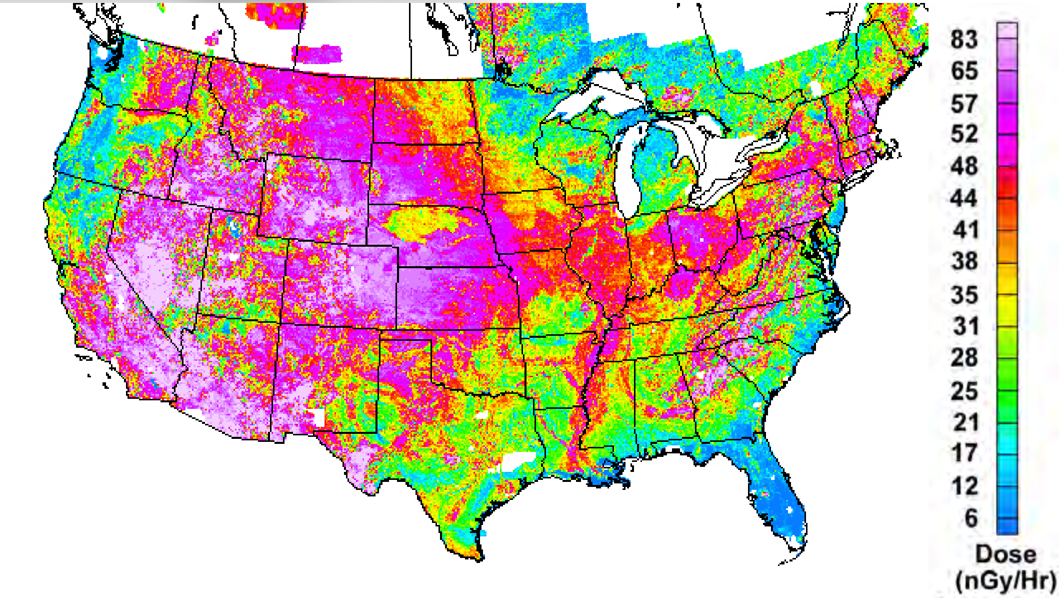
Contaminated Land

Everyone is exposed to (i) Cosmic Rays and (ii) Terrestrial Gamma Rays

Cosmic ray exposure map

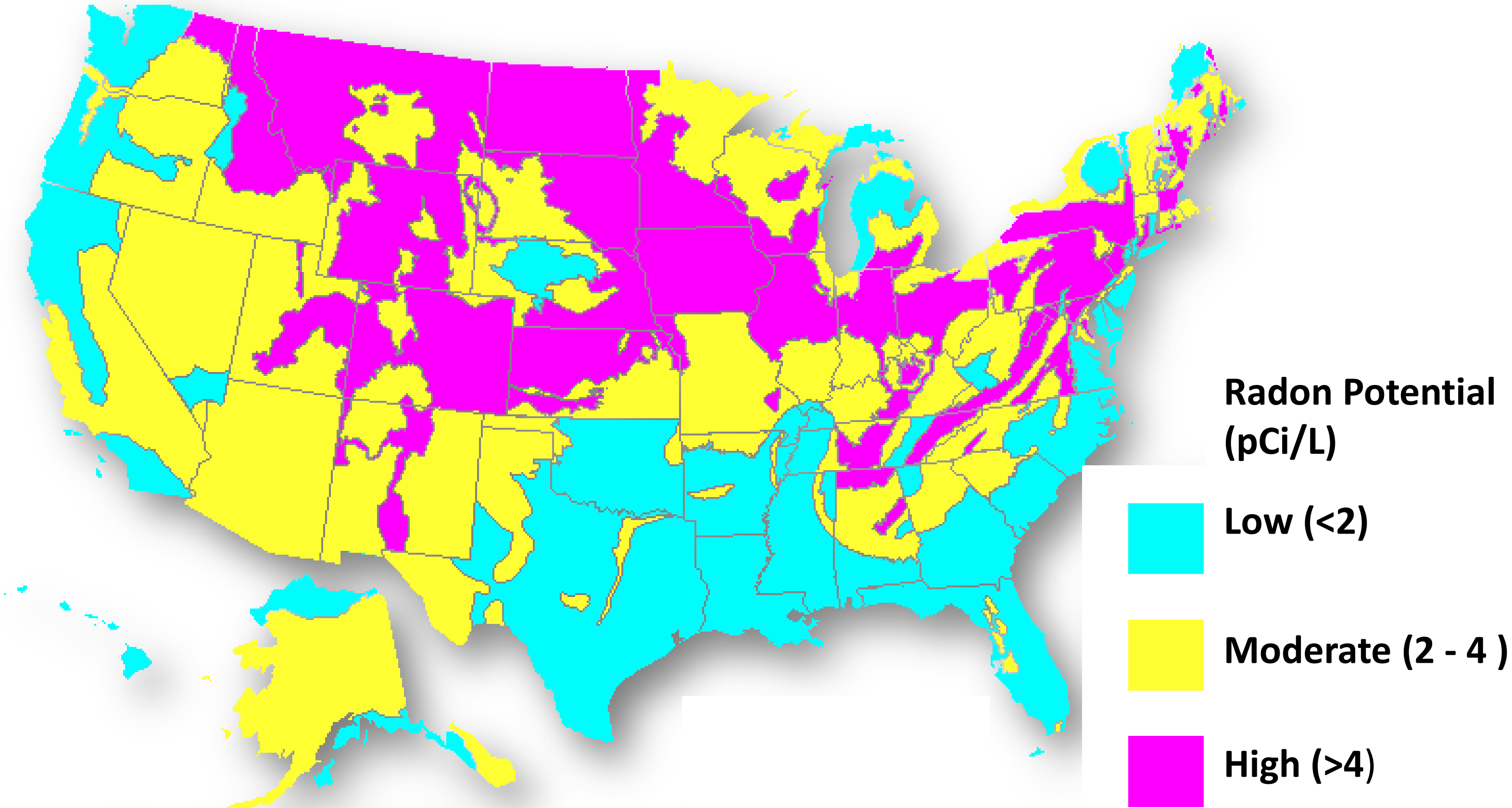


Terrestrial Gamma Ray exposure map



http://pubs.usgs.gov/of/2005/1413/maps.htm

Everyone is exposed to Radon – Geologic Radon Potential depends on mineral content and soil type.



Average outdoor concentration is 0.4 pCi/L
Average indoor concentration is 1.3 pCi/L
EPA Action Level is 4 pCi/L

Total inhalation dose = 0.2 – 10 mSv/y (avg = 1.26)

Source: http://energy.cr.usgs.gov/radon/usrnpot.gif , Other data: UNSCEAR (2008)

Public exposure to natural radiation summarized

Source of exposure	Annual effective dose (mSv)	
	Average	Typical range
Total cosmic	**0.39**	0.3 – 1.0
Total external terrestrial radiation	**0.48**	0.3 – 1.0
Total inhalation exposure	**1.26**	0.2 – 10
Total ingestion exposure	**0.29**	0.2 – 1.0
TOTAL	**2.4**	**1.0 - 13**

Source: UNSCEAR (2008)

Smaller Size Populations are Exposed to High Natural Background Radiation (HNBR)

Brazil: 6,000 persons reside in the HBNR area in Pocos de Caldas, 1,300 in Arax`a, and 12,000 in Guarapari, average annual effective dose ~6.4 mSv

China: >125,00 people, primarily farmers, average annual effective dose ~6.4 mSv

India (Kerala): 360,000 inhabitants, on average, external whole-body doses of about 4.5 mGy from gamma-rays plus an internal dose of 2.4 mSv (effective dose) from exposure to radon.

Iran (Ramsar): ~1,000 people, external from 0.7 - 131 mSv, Rn-222 dose 2.5 - 72 mSv

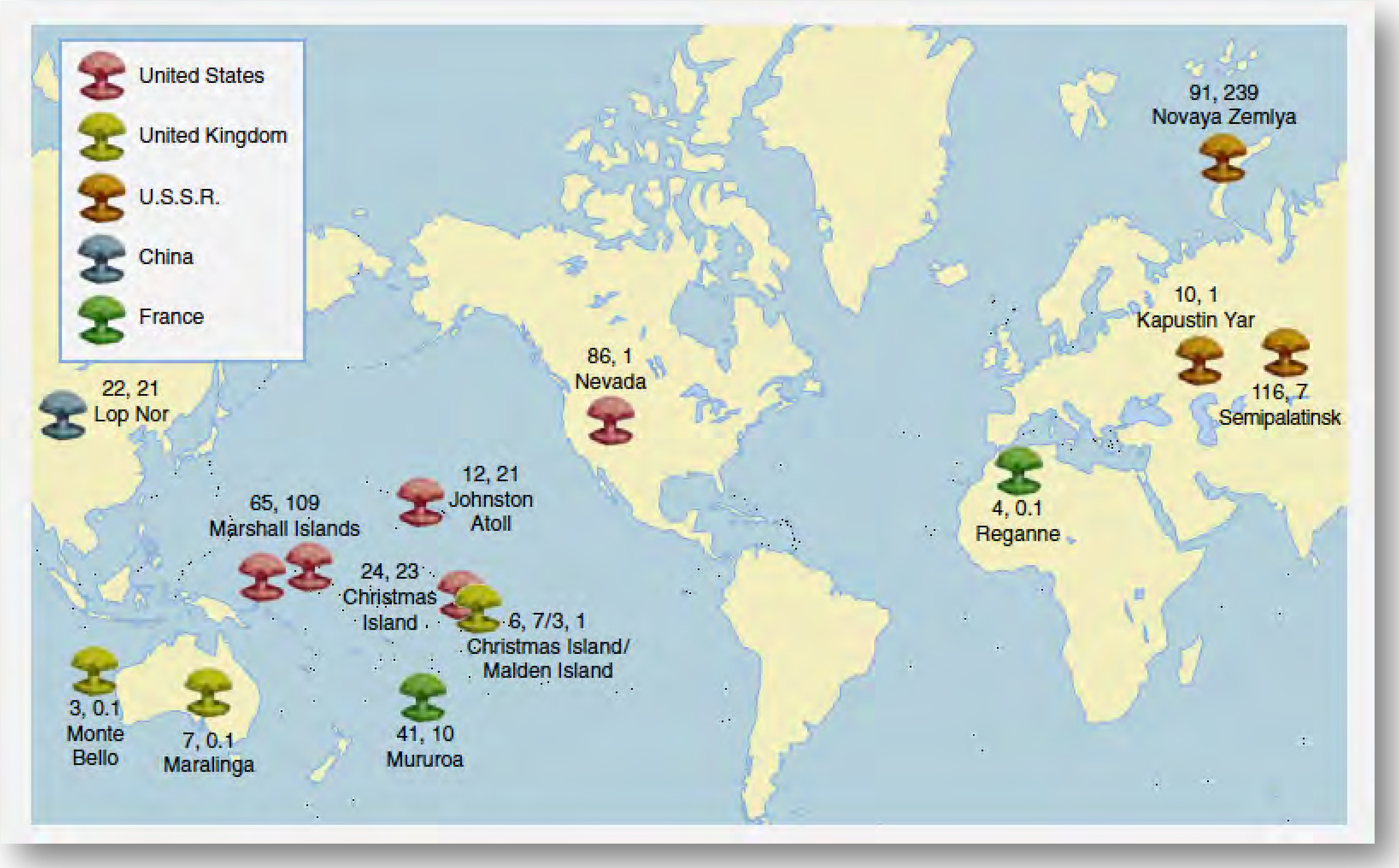
Data from Hendry et al. (2009)

Other Sources of Environmental Exposures of the Public

Man-made activities

Contaminated Land

Much of the Populated World Has Received Contamination from One or More of the Primary Atmospheric Nuclear Weapons Testing Sites

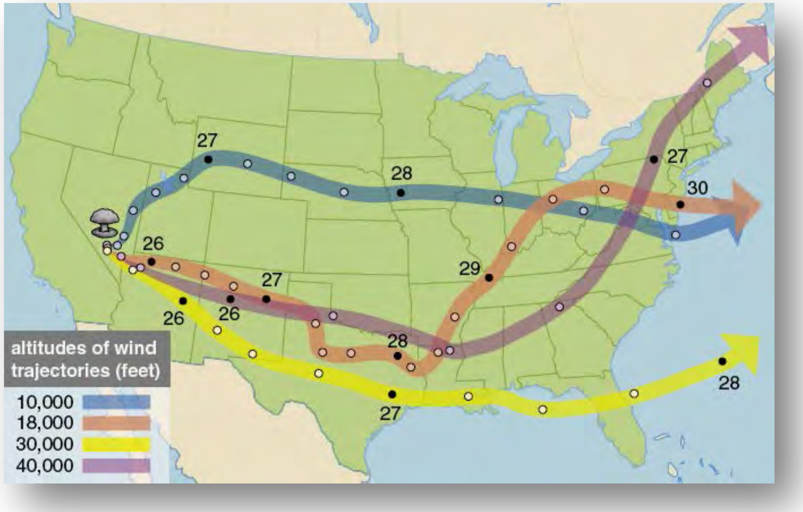


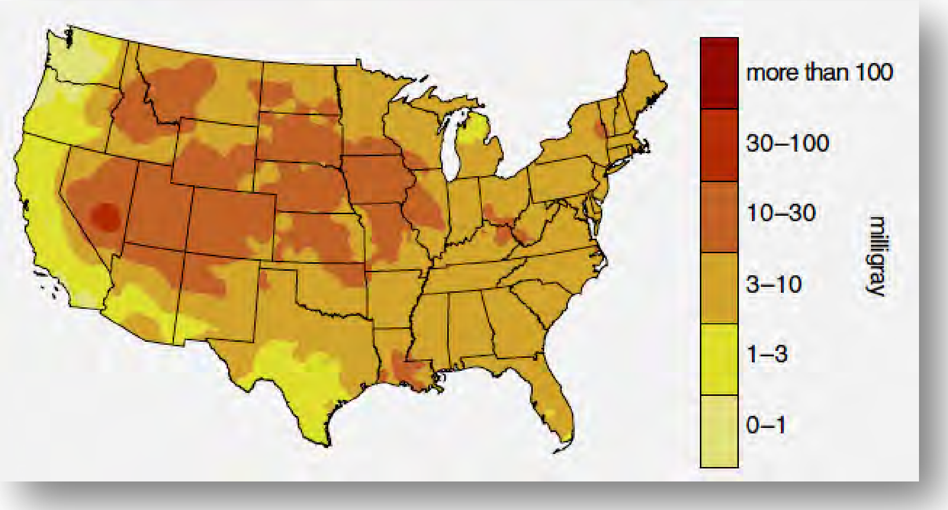
http://www.americanscientist.org/issues/feature/fallout-from-nuclear-weapons-tests-and-cancer-risks

U.S. Average Doses for Populations Directly Exposed to Nevada and Global Weapons Testing Fallout

Nevada Test Site fallout			Global fallout		
Thyroid or RBM external dose (mGy)	Thyroid internal dose (mGy)	RBM internal dose (mGy)	Thyroid or RBM external dose (mGy)	Thyroid internal dose (mGy)	RBM internal dose (mGy)
0.5	**5 (adult)** **30 (child*)**	**0.1**	**0.7**	**0.7 (adult)** **2 (child*)**	**0.6 (adult)** **0.9 (child*)**

*born Jan. 1, 1951





https://ntsi131.nci.nih.gov/2006-01Simon.pdf,
http://www.americanscientist.org/issues/feature/fallout-from-nuclear-weapons-tests-and-cancer-risks

Other Sites of Environmental Release of Radionuclides (non-accident situations) Resulting in Environmental Exposures of the Public

Trinity nuclear test, NM 1945

Marshall Islands nuclear tests, 1946-1958

Hanford, WA, 1944-1957

Techa River, 1949-1956

Semipalatinsk Nuclear Test Site, Kazakhstan, 1949-1962

Sites of Contaminated Land Potentially Expose Native People – Vulnerable Populations

Native Americans
(*e.g.*, Navajo nation)

Aboriginal people,
Maralinga, Australia

Marshall Islanders

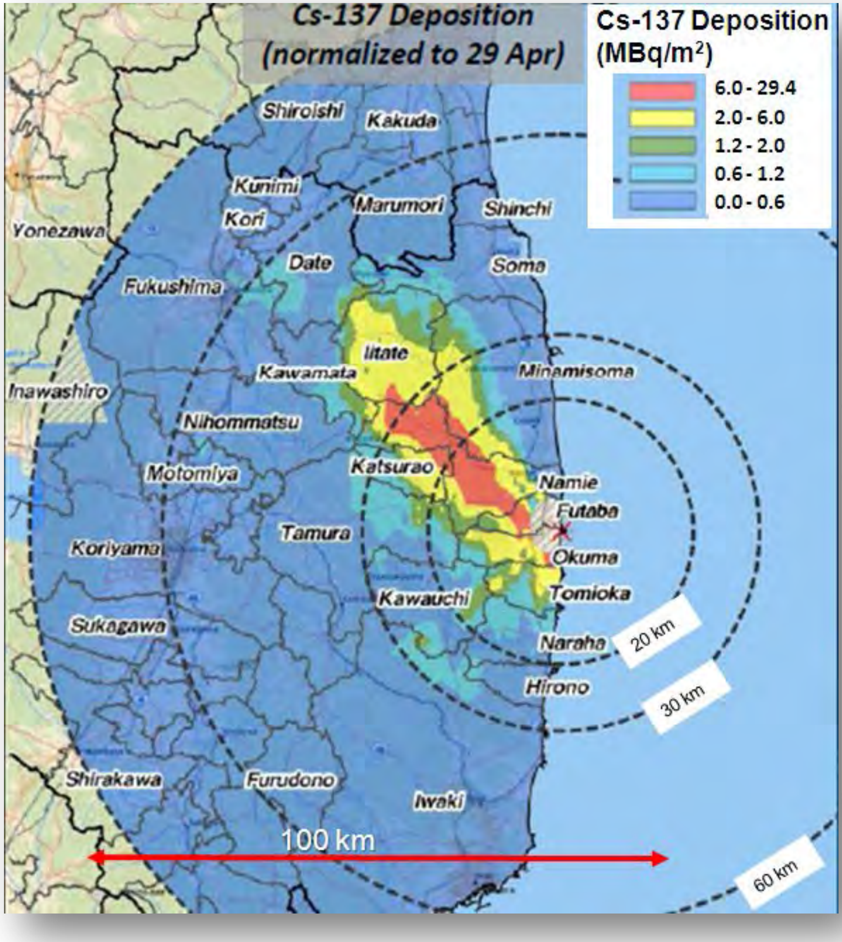
Populations that live traditional lifestyles with close contact to the soil are particularly susceptible to exposure.

Environmental Exposures cont.
Unintended events (accidents, disasters, combat)

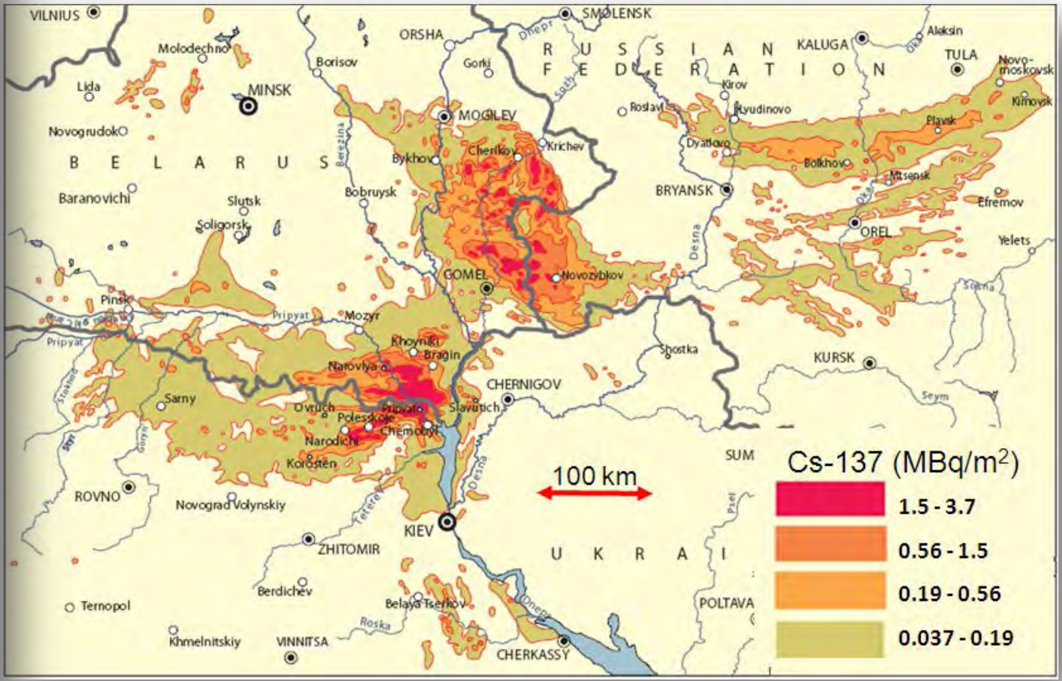
Important populations exposed to unintended events and accidents include:

- A-bomb survivors
- Residents near to Chernobyl
- Residents near to Fukushima

Reactor Accidents Potentially Lead to Exposures of Large Civilian Populations

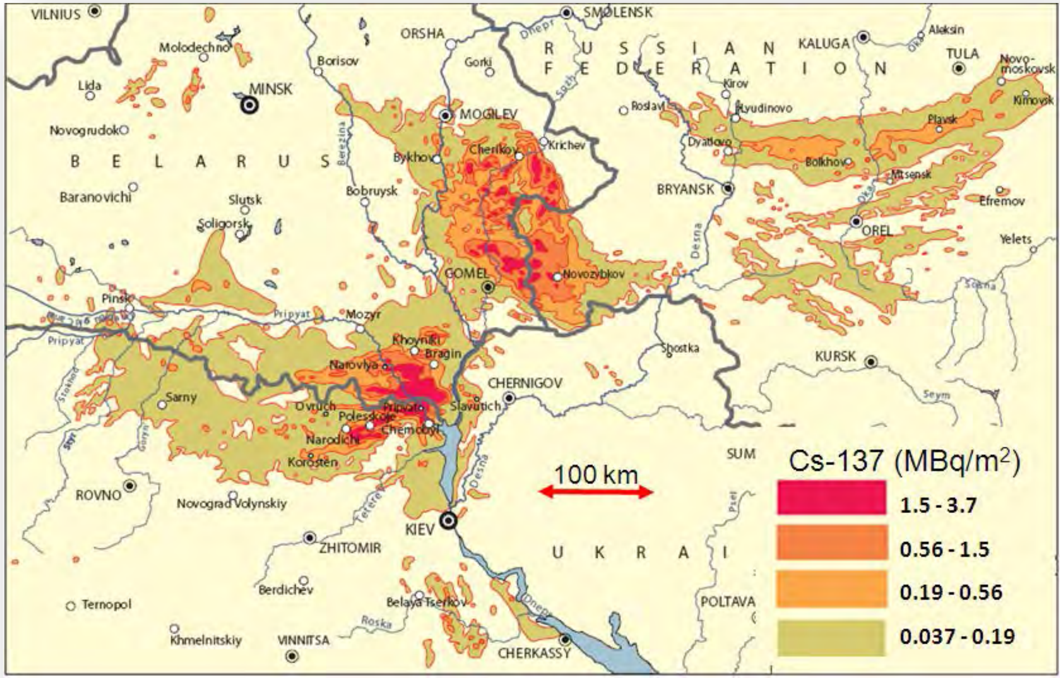


Fukushima region (map: DOE, NNSA)

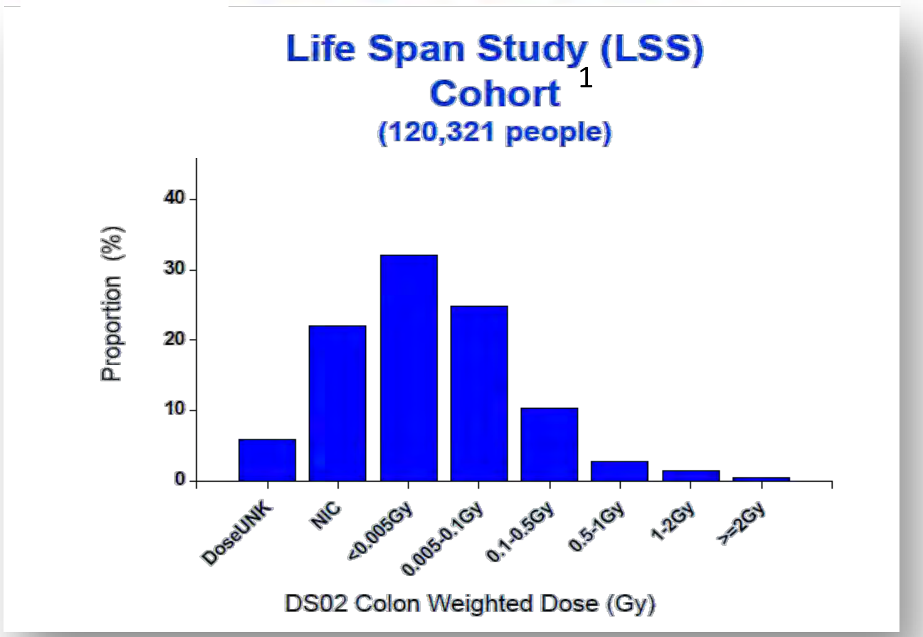


Chernobyl region

Comparison of Size of Regions Contaminated with Cs-137 at Fukushima and in Chernobyl Region



Hiroshima and Nagasaki A-bomb survivors



Doses estimated for 120,000+ people
5 mGy to >2 Gy

Public affected by Chornobyl Accident[2]

116,000 evacuated
5,000,000 living in contaminated territories

Thyroid doses to evacuees: 170 – 1,000 mGy
Whole Body Doses: few mGy – few tens of mGy

---

[1] http://dels.nas.edu/resources/static-assets/nrsb/miscellaneous/ShorePresentation.pdf
[2] Bouville, A., NCRP Proceedings (2006)

Category 4:
Populations Exposed to Radiation from Consumer Products and Energy Production

Uranium pottery glazes

Porcelain dentures

Smoke detector

Thorium mantle lanterns

Thorium sand weighted utensils

Fertilizers

Low Na Salt

Tobacco

Coal-fired power plants

Nuclear power plants

http://www.orau.org/ptp/collection/consumer%20pr oducts

Populations Exposed to Radiation from Consumer Products and Energy Production

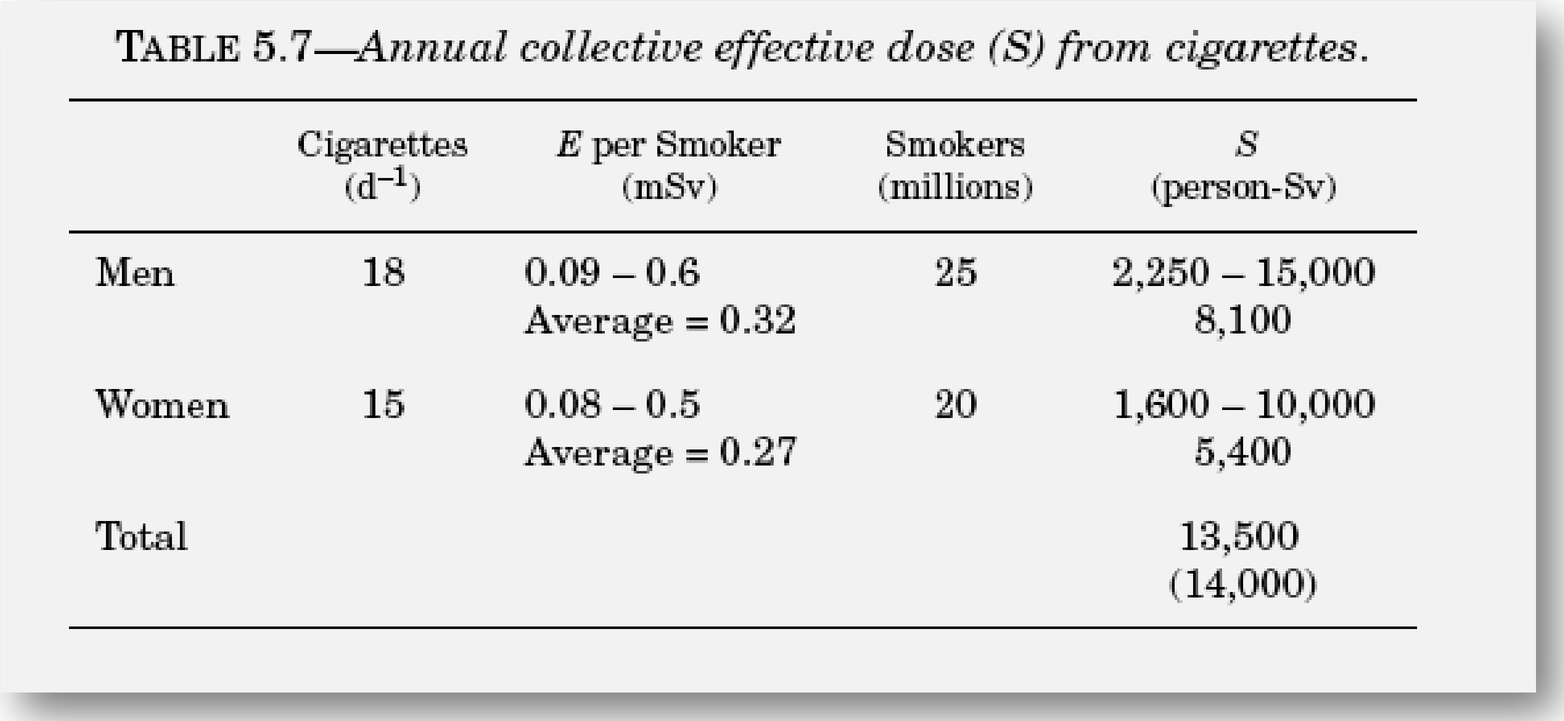


TABLE 5.7—*Annual collective effective dose (S) from cigarettes.*

	Cigarettes (d^{-1})	E per Smoker (mSv)	Smokers (millions)	S (person-Sv)
Men	18	0.09 – 0.6 Average = 0.32	25	2,250 – 15,000 8,100
Women	15	0.08 – 0.5 Average = 0.27	20	1,600 – 10,000 5,400
Total				13,500 (14,000)

Source: NCRP Report No. 160 (2009)

Populations Exposed to Radiation from Consumer Products and Energy Production

Routine Operation of
Coal-fired power plants

Routine Operation of
Nuclear power plants

“Americans living near coal-fired power plants are exposed to higher radiation doses than those living near nuclear power plants that meet government regulations.” [1]

“…fly ash emitted by a coal-fired power plant—carries into the surrounding environment 100 times more radiation than a nuclear power plant producing the same amount of energy”[2]

Source: http://www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html

[1]McBride et al., Science, December (1978), [2]Scientific American (2007)

Attributes of Exposed Populations - The Human Element

Attributes of populations can vary in many ways:

- The number of individuals,
- Behaviors and lifestyle,
- Age/gender distribution,
- Susceptibility to contamination and exposure,
- Availability of information on important covariates and confounding exposures (*e.g.*, smoking),
- Whether exposure can be estimated on an individual basis,
- Whether findings can be generalized to other populations.

National Cancer Institute

Why Study Radiation-Exposed Populations?

Martha S. Linet, M.D., M.P.H.
Chief, Radiation Epidemiology Branch
National Cancer Institute

National Council on Radiation Protection and Measurements
March 11, 2013

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
National Institutes of Health

Outline

- Why study radiation-exposed populations: rationale
- Strategies to estimate radiation-related health risks
- Epidemiologic studies: what, how, who, when, where
- Radiation and health risks: identifying hazards, quantifying risks, understanding radiation-related disease mechanisms, characterizing susceptible populations
- Primary source of data for radiation protection

Why Study Radiation-Exposed Populations?

- Evaluate issues of public health importance
  - Does low-dose radiation (radon, fallout) increase cancer or circulatory disease risks?
- Answer questions of clinical importance
  - Do pediatric CT examinations increase cancer risk?
  - Does radiation therapy increase risk of 2nd cancers, myocardial infarction, stroke?
- Address topics of societal concern
  - Do cell phones increase brain tumor risk?
  - Do tanning beds increase risk of melanoma?

Strategies to Estimate Radiation-Related Health Risks

- Epidemiologic studies
- Risk projection studies
  - Use of radiation risk epidemiologic data (usually from atomic bomb survivors study), dose data, and statistical models to estimate future risks
- Experimental studies
  - Animals
  - Cell lines
- Combination of epidemiologic and experimental studies to assess whether radiation *causes* serious health conditions

Epidemiologic Studies of Radiation: Goal

To identify, understand, and quantify health effect risks in radiation-exposed populations

To advance understanding of mechanisms of radiation-related health outcomes

Epidemiologic Studies

- What?
- How?
- Who?
- When?
- Where?

What is an Epidemiologic Study?

- Study of the patterns, causes, and effects of health & disease in defined populations
- Cornerstone of public health
- Informs policy & evidence-based medicine by identifying risk factors for disease and targets for preventive medicine

What is Risk and How is it Assessed in Study Populations?

Types of Risk	Definitions of Risk	Examples
Relative risk	incidence (new occurrence or new diagnosis) of disease in an exposed group divided by incidence of disease in an non-exposed group	Incidence of lung cancer is 10-fold higher in smokers than the incidence of lung cancer in non-smokers
Absolute risk	the observed or calculated probability of occurrence of an event in a population related to a specific exposure	20 of 10,000 second cancer cases are due to radiation therapy for the first cancer
Attributable risk	the maximum proportion of a disease attributable to a given exposure	11 % of solid cancers in the atomic bomb survivors with doses >0.005 Gy were associated with radiation from the bombings

What is a Statistical Association?

Definition: Statistical dependence between two or more events or characteristics or other variables. An association is present if the probability of occurrence of an event or characteristic depends on the occurrence of one or more other events or characteristics

Example: Radiation exposure to the atomic bomb survivors is statistically associated with increased risk of developing leukemia

Limitations: A statistical association is not the same as a causal association and null findings are not an indication that there is no increase in risk

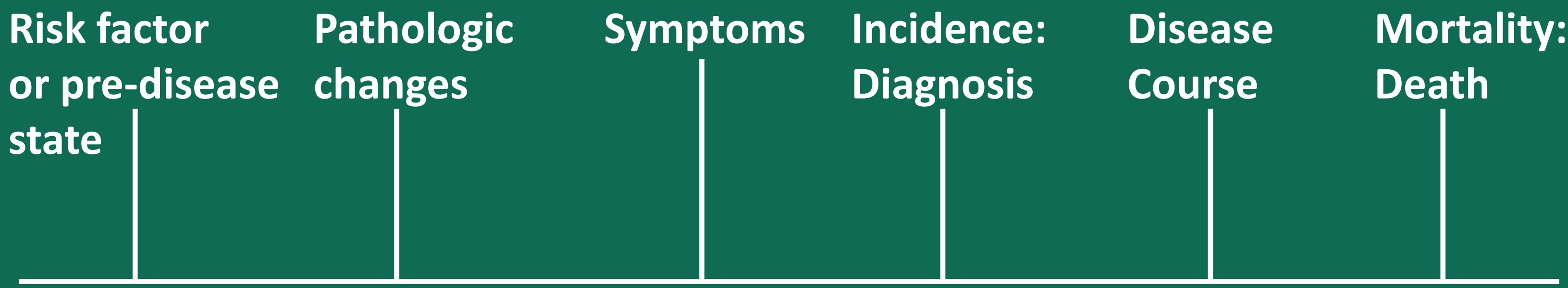
What are the Criteria for Causation:

Evidence that a Statistical Association is Causal

- Strength of the association
- Consistency of the association
- Specificity of the association
- Plausibility: should not conflict with known natural history and biology of disease; confirmed by experimental studies
- Analogy with other similar associations shown to be causal in nature

How is Risk Measured in Epidemiologic Studies ?

Background: Natural History of Chronic Disease



Risk factor or pre-disease state

Pathologic changes

Symptoms

Incidence: Diagnosis

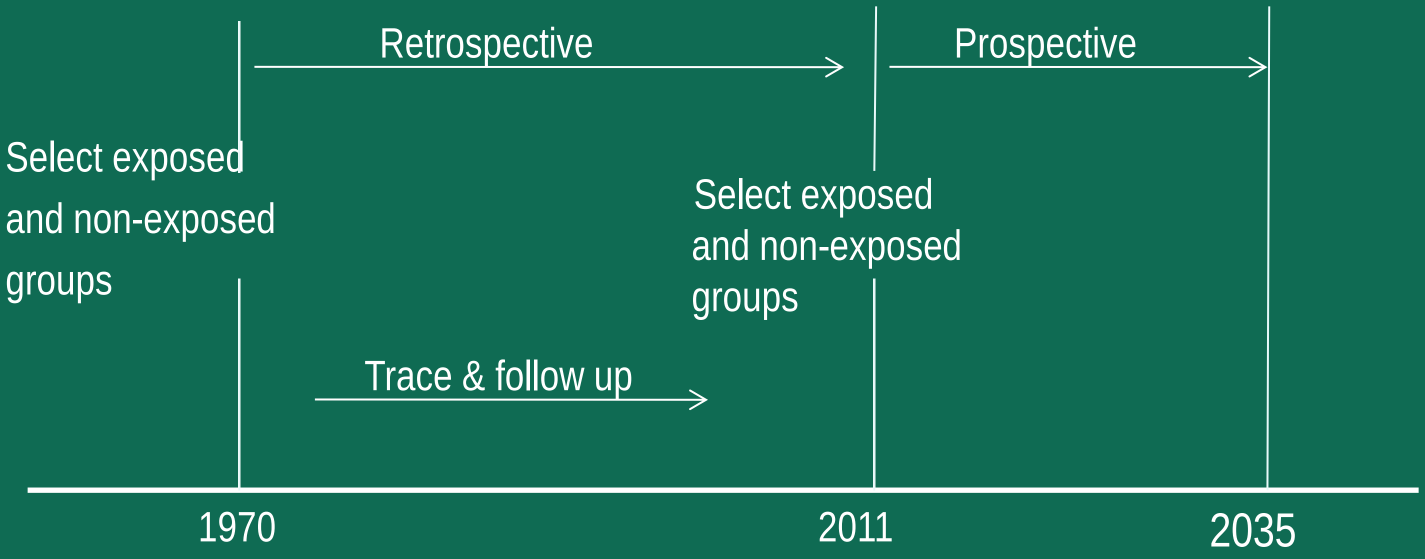
Disease Course

Mortality: Death

How to Evaluate Risks: Cohort Studies

- Distinguishing features
  > population defined by exposures prior to onset of disease
  > population followed over time to estimate disease/death rate
  > compare rates in exposed vs unexposed groups

- Retrospective vs prospective follow-up



Retrospective

Prospective

Select exposed
and non-exposed
groups

Select exposed
and non-exposed
groups

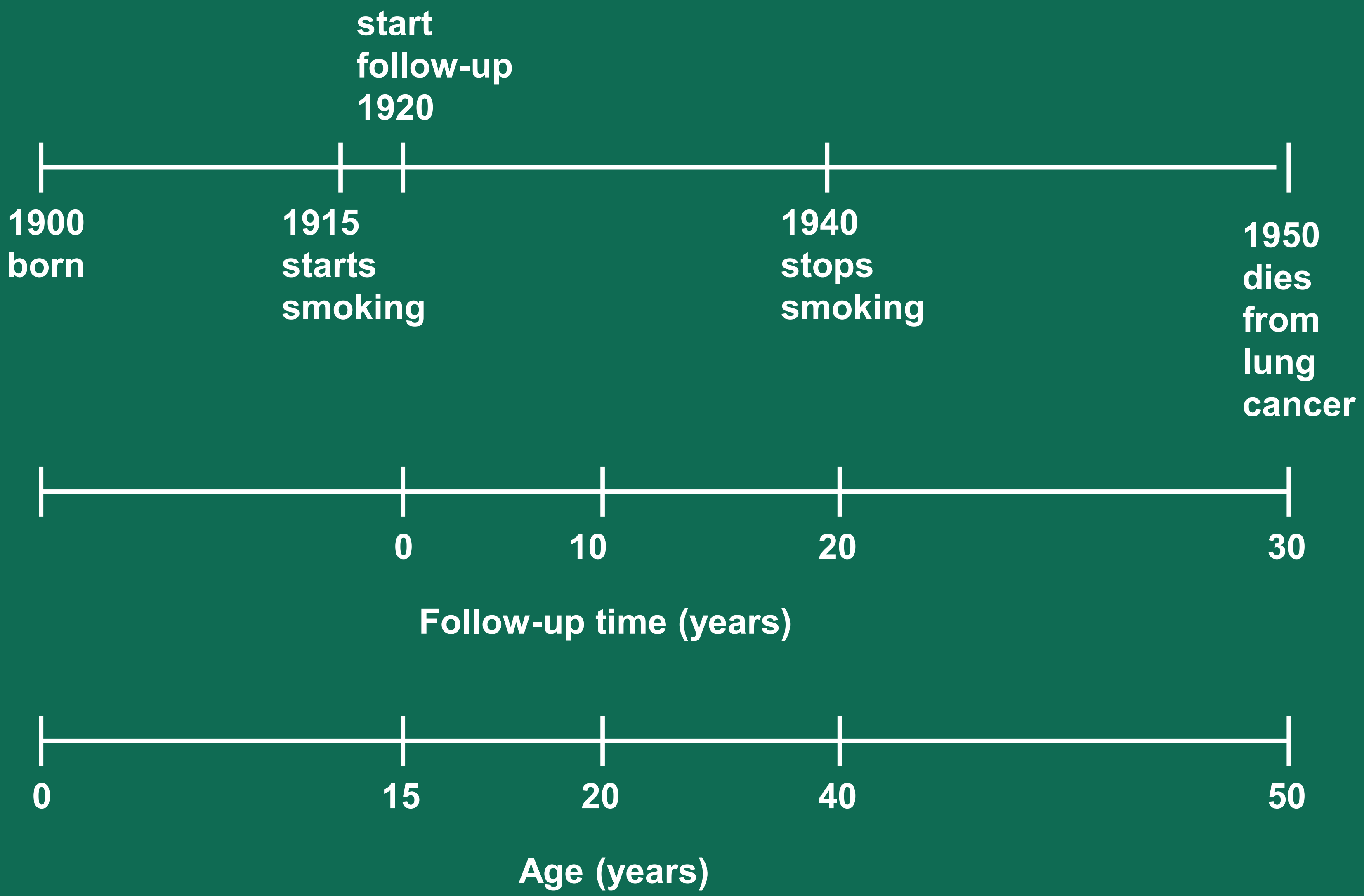
Trace & follow up

1970

2011

2035

How to Conduct Follow-up in Cohort Studies?



start
follow-up
1920

1900
born

1915
starts
smoking

1940
stops
smoking

1950
dies
from
lung
cancer

0 10 20 30

Follow-up time (years)

0 15 20 40 50

Age (years)

How to Evaluate Risks: Case-Control Studies

- Distinguishing features
  - > determine exposures prior to diagnosis/referent date using interviews, medical records or other records
  - > compare proportion of cases with exposure to proportion of controls with exposure
- Framework

Characteristics	With disease	Without disease	Total
With exposure	a	b	a + b
Without exposure	c	d	c + d
Total	a + c	b + d	a + b + c + d

Epidemiologic Studies: Who, When, Where?

- Who? Define target population for study
- When? Define time period for
  - start and end of follow-up (cohort design)
  - years of diagnosis of health outcomes (case-control design)
- Where? Define geographic region (population-based), workplaces (occupational), medical facilities (patients)

Examples of Cohort & Case-Control Studies

- Cohort studies

Author, Yr	Population	Exposure	Outcome
Preston, 2007 Radiation Res	A-bomb survivors	Gamma rays, neutrons	All solid cancers
Tronko, 2006 JNCI	Chernobyl young residents	Fallout	Thyroid cancer
Pearce, 2011 Lancet	Children undergoing CT	X-rays	All cancers, leukemia, brain

- Case-control studies

Author, Yr	Population	Type of radiation	Outcome
Boice, 1991 JAMA	HMO members	Medical record reports of x-rays	Leukemia, NHL, MM
Cardis, 2010 Int J Epidemiol	General population	Cell phone use (RF)	Glioma, meningioma
Zablotska, 2013 EHP	Ukraine liquidators	External	CLL and other leukemias

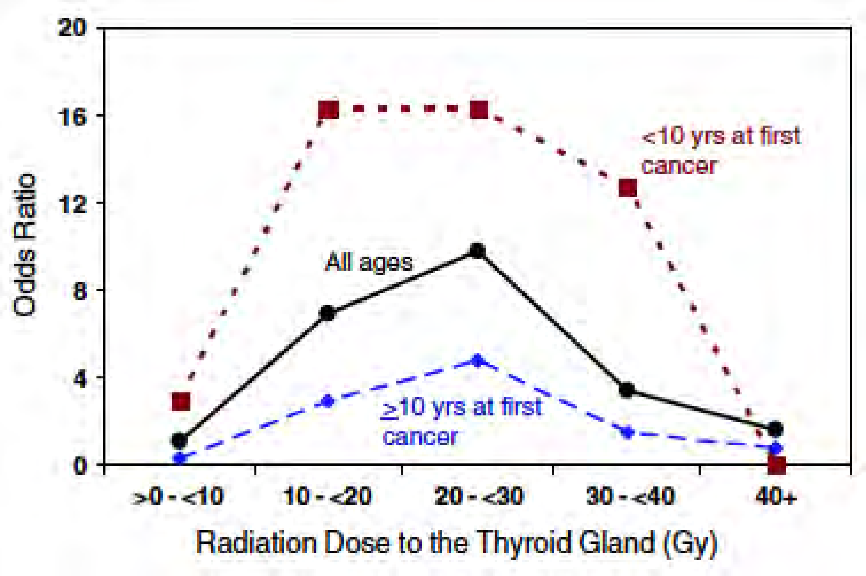
Radiation and Health Risks:

Does Radiation Cause a Serious Health Risk?

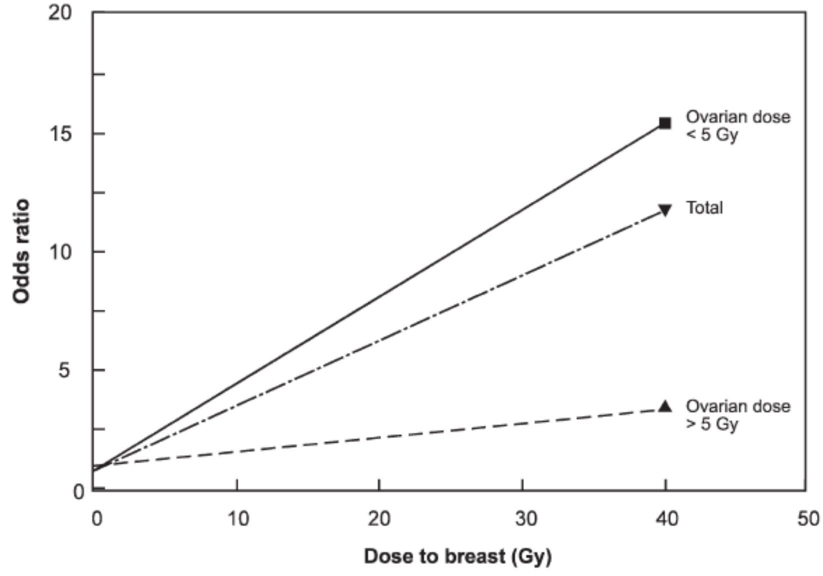
- Is ionizing radiation exposure associated with chronic lymphocytic leukemia?
- Is low-dose ionizing radiation associate with circulatory diseases?
- Does ultraviolet radiation reduce or increase risks of cancers other than skin cancers?
- Is cell phone use by young persons associated with brain tumor risk?

Radiation and Health Risks:

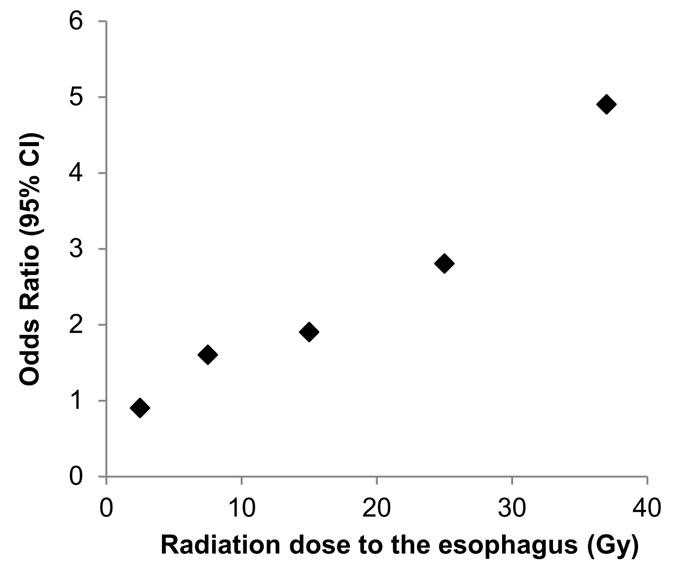
What is the Pattern of Radiation-Disease Dose-Response?



Thyroid 2nd cancers in CCSS
Sigurdson et al. Lancet (2005),
Bhatti et al. Radiat. Res. (2010)



Breast 2nd cancers in CCSS
Inskip et al. J. Clin. Oncol. (2009)



Esophageal 2nd cancer after breast cancer, 7 countries
Morton et al. Ann. Oncol. (2012)

Radiation and Health Risks:

Understanding Radiation Disease Mechanisms

- What is the latency (period between radiation exposure and onset of disease) for leukemia in atomic bomb survivors?
- What is the mechanism for radiation-related circulatory disease?
- Is there a threshold for occurrence of radiation-related subcapsular cataracts in Chernobyl clean-up workers?

Radiation and Health Risks:

Characterizing Susceptible Populations

- Children are at higher risk of cancer from exposure to ionizing radiation
- Retinoblastoma patients with the hereditary form are more susceptible to radiation-related second cancers than retinoblastoma patients with the non-hereditary form.
- Patients with certain genetic disorders (ataxia telangiectasia, nevoid basal cell carcinoma syndrome) are highly susceptible to radiation-related carcinogenesis.

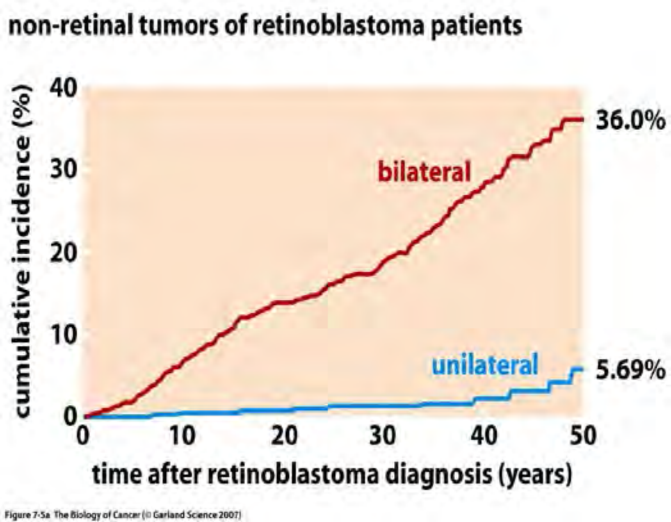


Figure 7-5a The Biology of Cancer (© Garland Science 2007)

Radiation Epidemiologic Studies

Primary Source of Data for Radiation Protection

- The radiation risk data that form the basis for radiation protection by expert committees are derived from epidemiologic studies of certain populations (A-bomb survivors, populations with radon exposure)
- Corroborating evidence is provided by a myriad of diverse epidemiologic studies with different types of radiation exposures according to:

  > dose levels

  > dose rate

  > radiation energy types and levels

  > radiation sources

  > individual characteristics

Radiation Epidemiologic Studies:

Can Challenge Beliefs & Paradigms in Radiation Protection

Examples

- Lack of evidence for genetic risk to offspring of exposed (a-bomb survivor analyses) (1958)
- Risk of cancer among atomic bomb survivors may be greater for exposure in early childhood than *in utero* (2008)
- Reduction in dose limit for cataract induction (2011)
- Possible thyroid cancer risk among those exposed as adults (2012) [see IARC (2012), Mabuchi et al. (2013)]

Why Study Radiation-Exposed Populations?

- Public health importance
- Clinical guidance & decision-making
- Societal concern

Radiation Impacts: Cancer and Noncancer Risks

NCRP Annual Meeting

April 2013, Bethesda, MD

Roy Shore

Radiation Effects Research Foundation
Hiroshima, Japan
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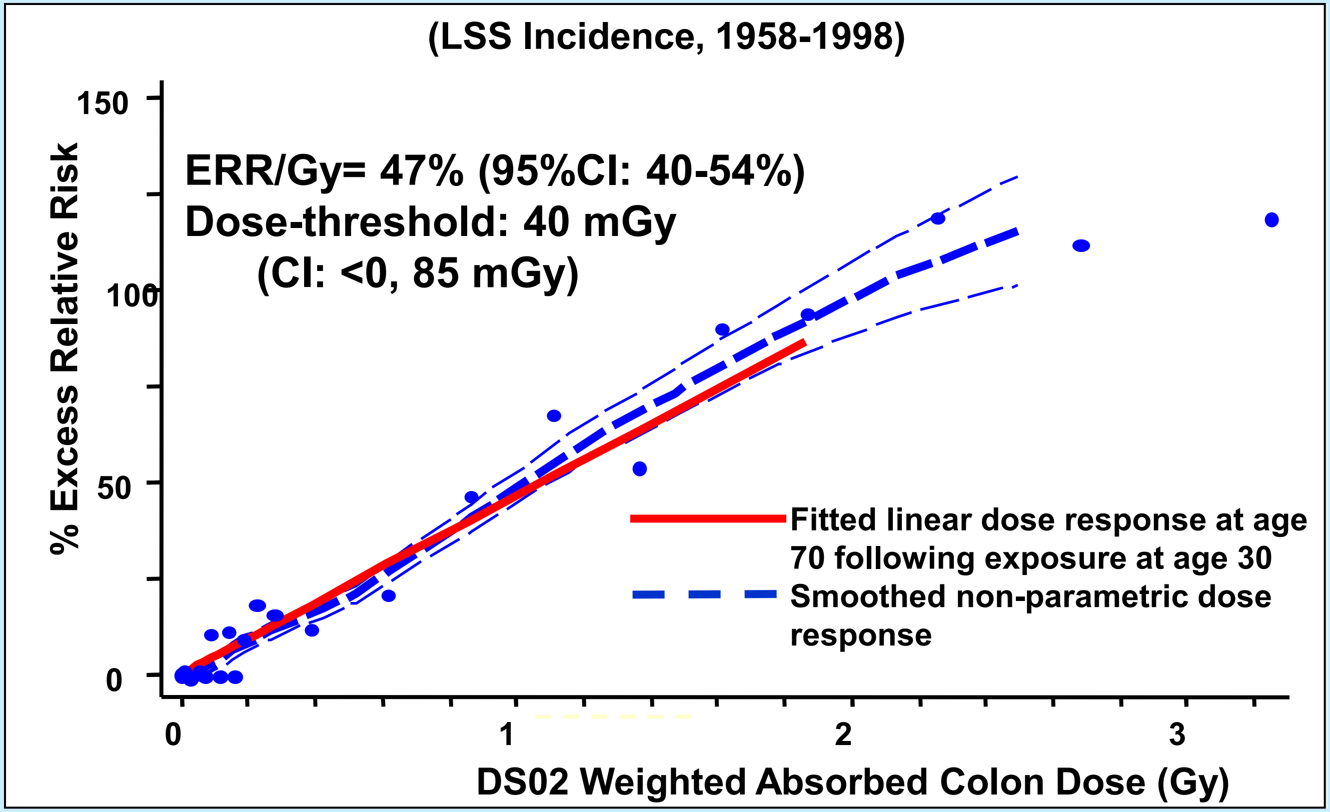
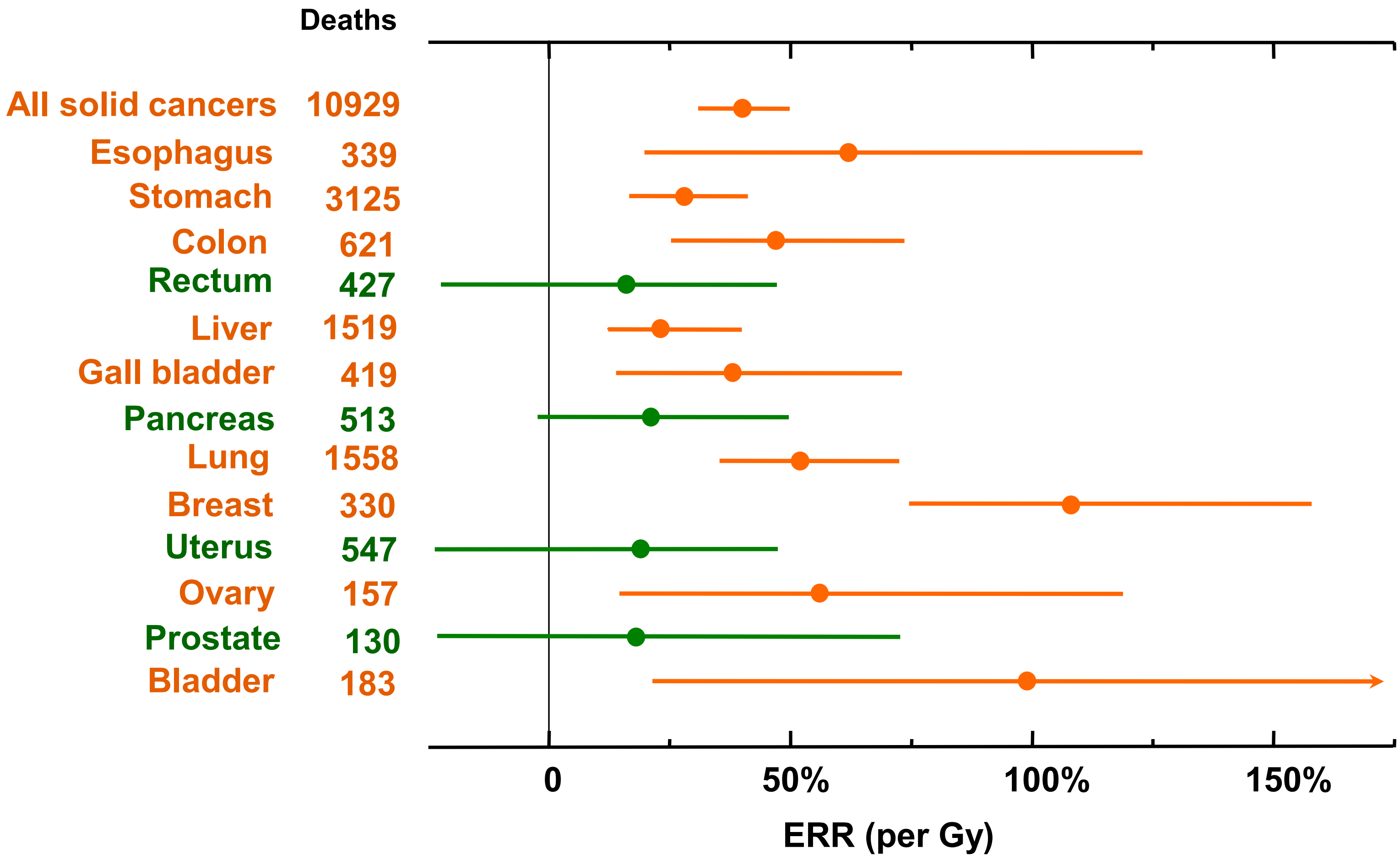
A-bomb dose response: Solid-cancer incidence

- No evidence of non-linearity in the dose response
- Significant dose response on 0 - 150 mGy
- Low dose-range slope consistent with full range



(Preston et al. Radiat. Res. 168, 1-64, 2007)

Excess Relative Risk (ERR) per Gray for Various Solid Cancers (LSS Mortality, 1950 - 2003)



Note: The estimates are standardized to age 70 y after exposure at age 30 y and averaged, where appropriate, over sex.

(Ozasa et al., Radiat. Res. 177, 229- , 2012)

Low, but Potentially Significant, Exposures Have Become Very Common

- About 25 million patients in the US received CT exams in 2007
- Sodickson study – large representative sample of 31,000 U.S. patients receiving CT exams in 2007
- The distribution of cumulative effective doses from CT over the past 20 y showed:
  - 15% (~3.8 million) with ≥100 mSv
  - 4% (~1 million) with ≥250 mSv

(Sodickson et al., Radiol. 251, 175, 2009; adapted from slide by D Brenner)

What do the epidemiologic data show regarding risk from low-dose, protracted or highly fractionated (LDPF) radiation exposures?

Strategy: Choose Largest Studies of Solid-Cancer or Leukemia Risk after LDPF Radiation Exposures

- To avoid choosing a biased set of studies that favor a particular (positive or negative) viewpoint, an essentially unbiased inclusion method was chosen:
- Assemble all the low-dose or protracted/fractionated (LDPF) radiation exposure studies that meet a criterion of number of study cancers. Criteria:
  - ≥400 solid cancers
  - ≥30 leukemias
- Inclusive: Dose-response preferable, but not required. Must have legitimate study design and some type of estimate of the Relative Risk.

Expectations for the Tabulation of Studies of Low-Dose or Protracted/Fractionated (LDPF) Exposures

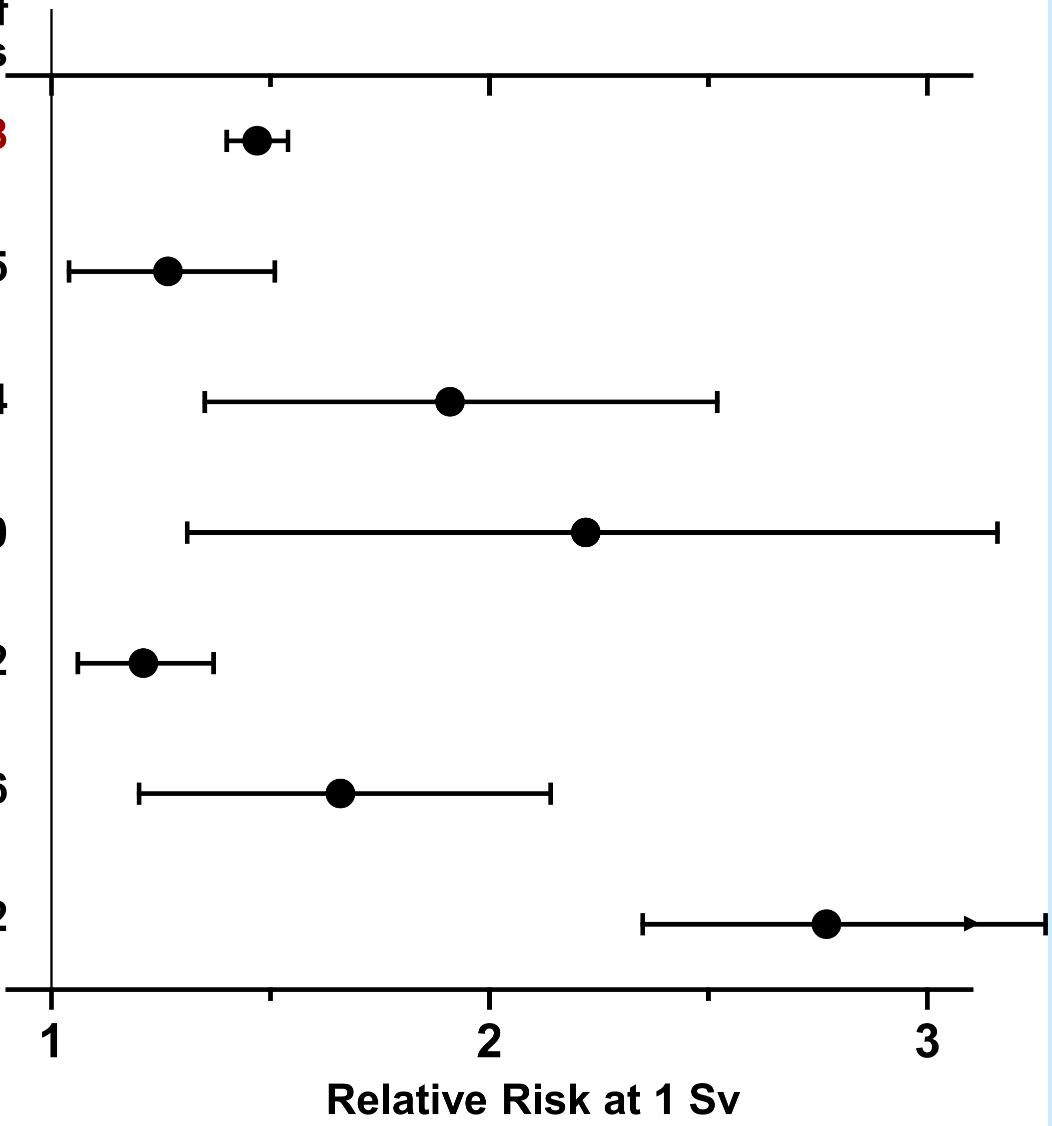
- **Publication bias?**
  - **Nearly all large radiation cohort studies publish results for total solid cancers and leukemia**
  - **Most large radiation case-control studies also are published**
- **To the degree there is an association, substantially more than 5% will be positive (*i.e.*, statistically significant)**

All Solid Cancers:

Summary results of the largest studies (≥400 cancer cases) with low-dose or protracted/fractionated (LDPF) radiation exposures

Total Solid Cancers after LDPF Radiation Exposures: Statistically Significant ("Positive") Associations

Study	No. of cancers
Japanese A-Bomb (Preston '07)	17,488
UK nuclear workers (Muirhead '09)	10,855
Techa River (Eidemuller '10)	2,064
^{131}I, hyperthyroidism (Holm '91)	1,460
Mayak workers (Shilnikova '03)	1,062
Chinese medical workers (Wang '02)	836
Semipalatinsk fallout (Bauer '05)	532



Total Solid Cancers after LDPF Radiation Exposures: Statistically Null (“Negative”) Results

Study	Mean Dose (mSv)	No. of Cancers	RR at 1 Sv (95% CI)
UK background gamma, child cancer (Kendall ‘12)	4.0	18,389	21 (<1-61)
15-country worker study (Cardis ’07)	19.4	5,024	1.6 (0.9-2.4)[A]
Diagnostic 131I (Holm ’91) [C]	~8	3,746	1.01 (0.98-1.04)[B]
Hanford workers (Wing ’05) [C]	27.9	2,265	1.3 (0.7-2.0)[C]
French nuclear workers (Metz-Flamant ’11)	21.5	2,035	1.5 (0.5-2.5)
^{131}I for hyperthyroidism (Ron ’98)	~40	1,597	~1.5 (~0.5-2.8)
Chernobyl clean-up workers (Ivanov ’07)	215	1,370	1.3 (0.6-2.2)
High-background area, Kerala (Nair ’09)	161	1,349	0.9 (0.4-1.5)
Canadian medical workers (Zielinski ’09)	3.8	1,205	0.8 (0.7-0.8)[B]
High-background area, China (Tao ’12)	63	941	4.0 (~0.3-49)
Rocketdyne workers (Boice ’11)	13.5	651	0.8 (~0.3-2.7)
Multiple fluoroscopic exams (Davis ’89)	~250	429	0.8 (0.7-0.9)[B]

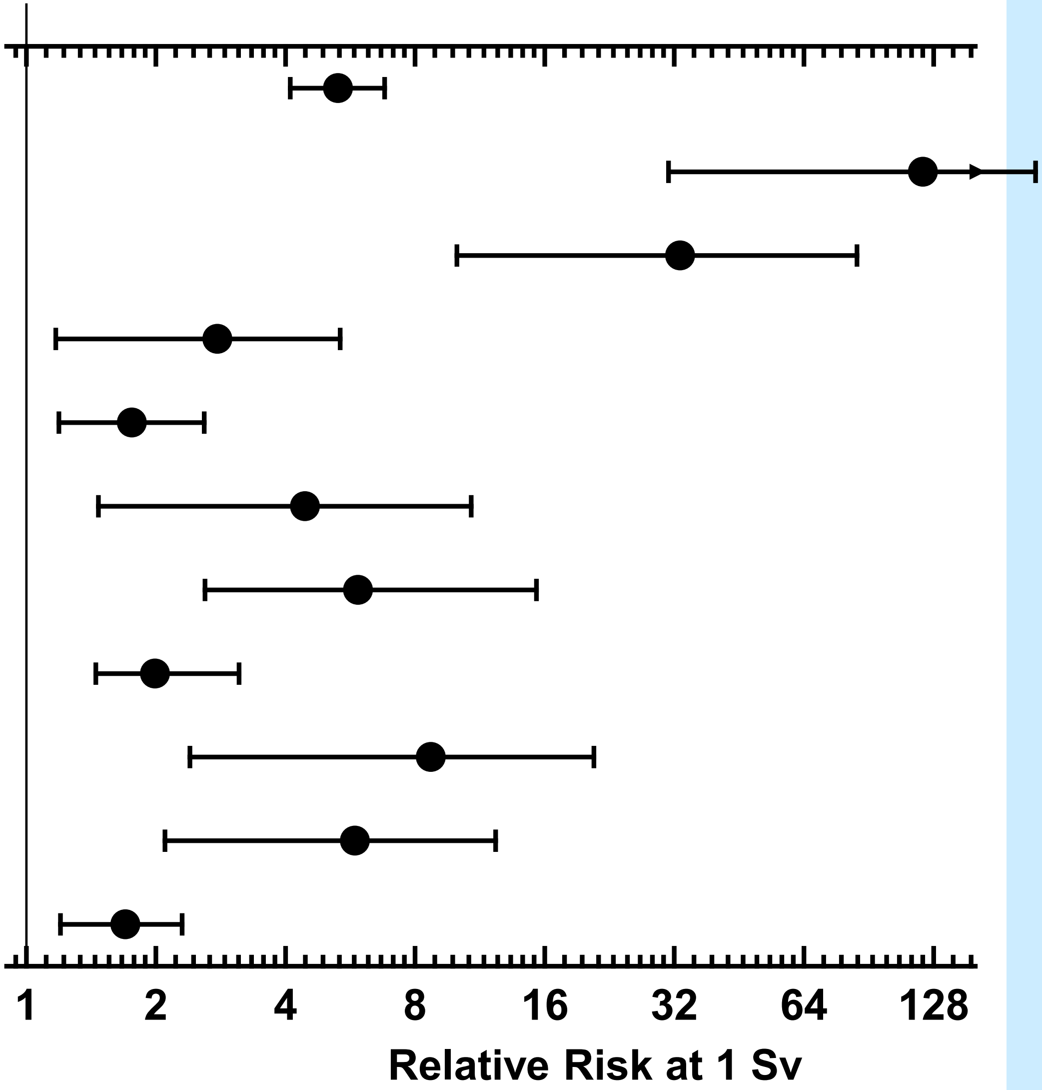
[A] Excluding Canada due to dosimetry problem. [B] SIR or SMR value presented, not RR at 1 Sv. [C] Total cancers.

Leukemia:

Summary results of the largest studies (≥30 leukemia cases) with low, protracted or fractionated radiation exposures

Statistically Significant Leukemia Studies: LDPF Occupational or Environmental Radiation Exposures

Study	No. of cancers
Japanese A-bomb (Ozasa '12)	318
UK background gamma, child leukemia (Kendall '12)	27,447
Chernobyl fallout (Davis '06)	421
UK nuclear workers (Muirhead '09)	234
Semipalatinsk child leukemia (Zaridze '94) [A,B]	151
Chernobyl workers, Ukraine (Romanenko '08)	71
Techa River (Krestinina '10)	70
Mayak workers (Shilnikova '03)	66
Savannah River workers (Richardson '07)	62
China medical workers (Wang '02)	44
US radiologists (Matanoski '87) [B]	33



[A] >400 vs <200 km from site. [B] SIR or SMR, not RR at 1 Gy.

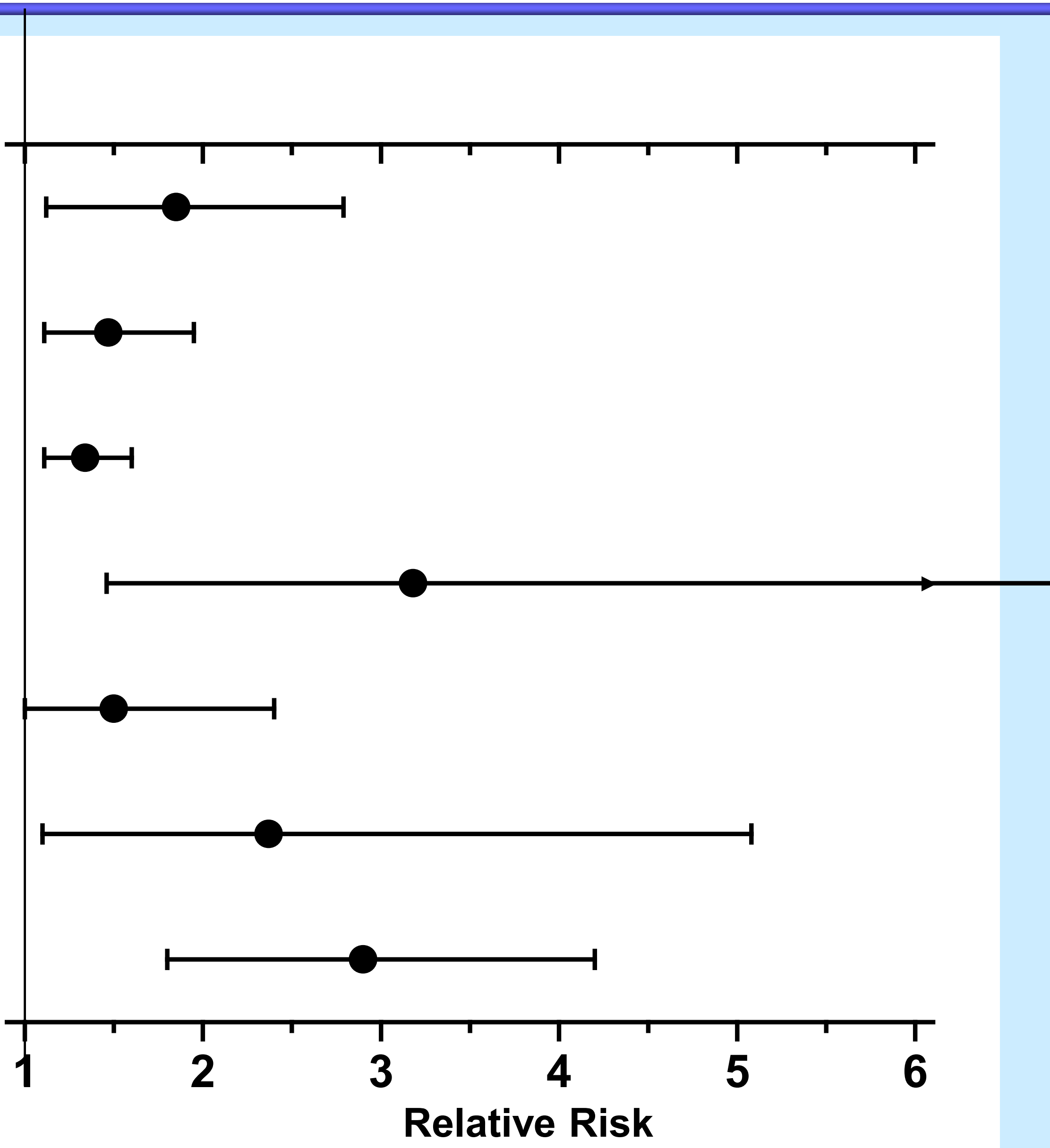
Statistically Null Leukemia Studies: LDPF Occupational or Environmental Radiation Exposure

	Mean Dose (mGy)	Number of Leukemias	RR at 1 Sv (95% CI)
Workers, Hanford, ORNL, Savannah River, Portsmouth (Schubauer-Berigan ’07)	30.6	206	3.4 (<1-10)
15-country worker study (Cardis ’07)	19.4	196	2.9 (<1-9.4)
Chernobyl clean-up workers, Russia (Ivanov ’07)	107	71	5.4 (<1-17)^{A} <1 (<1-3.6)^{B}
Idaho National Lab (Daniels ’11)	13.1	52	6.4 (<1-25)
Los Alamos National Lab (Wiggs ’94)	~16	44	1.0 (0.7-1.4)
Rocketdyne workers (Boice ’11)	13.5	33	1.1 (0.8-1.5)

^{A} 1-10 y after exposure. ^{B} >10 y after exposure.

Statistically Significant Leukemia Studies: LDPF Medical Radiation Exposure

Study	No. of cancers
Dx x-ray, child ALL (Bartley ‘10)	711
Dx x-ray, child ALL (Infante-Rivard ’03)	701
Dx ^{131}I (Holm ’89)	119
Pediatric CT (Pearce ’12)	74
Dx x-ray (Gibson ’72)	69
Dx x-ray (Preston-Martin ’89)	55
^{226}Ra, uterine bleeding (Inskip ’90)	34



Statistically Null Leukemia Studies, LDPF Medical Radiation Exposure

Study	Mean Dose, mGy or [subgroup]	No. of Leukemias	Relative Risk: RR (95% CI)
Dx x-ray & child ALL (Shu ‘02)	[≥3 x-rays]	1,842	1.2 (1.0-1.6)^A
Dx x-ray & child leukemia (Meinert ’99)	[≥4 x-rays]	1,145	1.0 (0.7-1.6)^A
Dx x-ray & adult AML (Pogoda ’11)	[>20 mGy]	412	1.6 (0.8-3.2) ^{A}
Dx x-ray & adult leukemia (Boice ’91)	[≥1 x-ray]	316	1.4 (0.9-2.2) ^{A}
Dx x-ray & non-lymphatic adult leukemia (Stewart ‘62)	[>10 x-rays]	297	0.7 (~0.5-1.0) ^{A}
Dx x-ray & adult leukemia (Yuasa ‘97)	?	247	0.8 (0.5-1.2)^A
Dx x-ray & child AML (Bartley ‘10)	[≥3 x-rays]	116	1.1 (0.9-1.2)^A
^{131}I for hyperthyroidism, adult leuk. (Ron ‘96)	42	82	<1 ^{B}
Dx x-ray & child leukemia (Rajaraman ‘11)	[x-ray at <100 days old]	67	1.4 (0.8-2.3) ^{A}
^{131}I for hyperthyroidism (Holm ‘91)	~60	34	0.9 (0.4-1.5) ^{B}

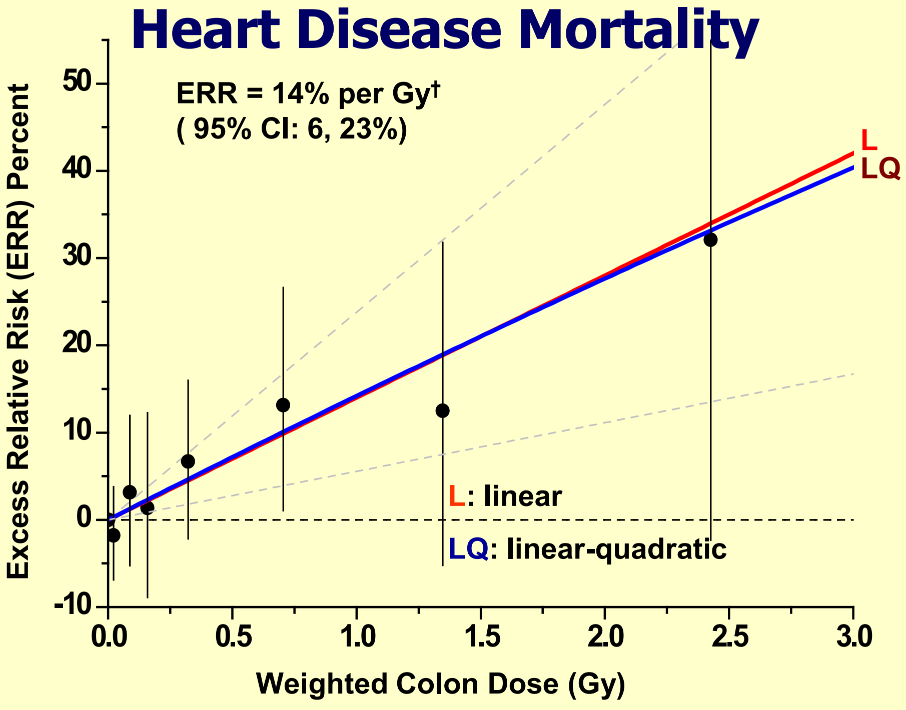
^{A} Odds ratio. ^{B} SMR or SIR.

Cardiovascular Disease:

Low-Dose Risk?

Radiation and Heart Disease Mortality
(A-bomb, Life Span Study)

- Clear evidence of heart disease risk at doses below 4 - 5 Gy
- Dose-response for heart disease mortality appears linear, but there is considerable uncertainty below about 0.5 Gy.



†Adjusted for gender, age at exposure, attained age, diabetes, obesity, etc.

(Shimizu et al, *Br Med J*, 340:193, 2010)

Corroborative AHS Clinical Evidence for Radiation Effects

- ↑ Circulatory system inflammation – numerous markers of inflammation are ↑
- Blood lipids – ↑ total cholesterol, triglycerides; ↓ HDL cholesterol
- Cardiovascular risk factors – ↑ blood pressure and calcification of arteries

Studies of LDPF Radiation Exposures and Ischemic Heart Disease (from Little et al)

Study	Mean Dose, mSv or [subgroup]	No. IHD Cases	Relative Risk at 1 Sv (95% CI)
Life Span Study, A-bomb (Shimizu '10) [M] ^{A}	200	1,252	1.02 (0.90, 1.15)
Adult Health Study, A-bomb (Yamada '04) [I]	570	1,546	1.05 (0.95, 1.16)
Mayak workers (Azizova '12) [I]	630	6,134	1.10 (1.04, 1.15)
Chernobyl cleanup workers (Ivanov '06) [I]	109	10,942	1.41 (1.05, 178)
French electric company (Laurent '10) [M]	22	79	5.1 (<1, 14.7)
Eldorado uranium mining/processing (Lane '10) [M]	52	1,235	1.15 (0.86, 1.58)
UK radiation worker registry (Muirhead '09) [M]	25	7,168	1.26 (0.95, 1.61)
IARC 15-country worker study (Vrijheid '07) [M]	21	5,821	0.99 (0.41, 1.69)
Meta-analysis of above studies (Little '12)	--	**34,177**	**1.10 (1.05, 1.15)**

(Adapted from: Little et al., Environ Health Perspect. 120, 1503-1511, 2012). ^{A} **M = mortality, I = incidence**

LDPF Radiation Exposures and Circulatory Disease Mortality (Additional Studies)

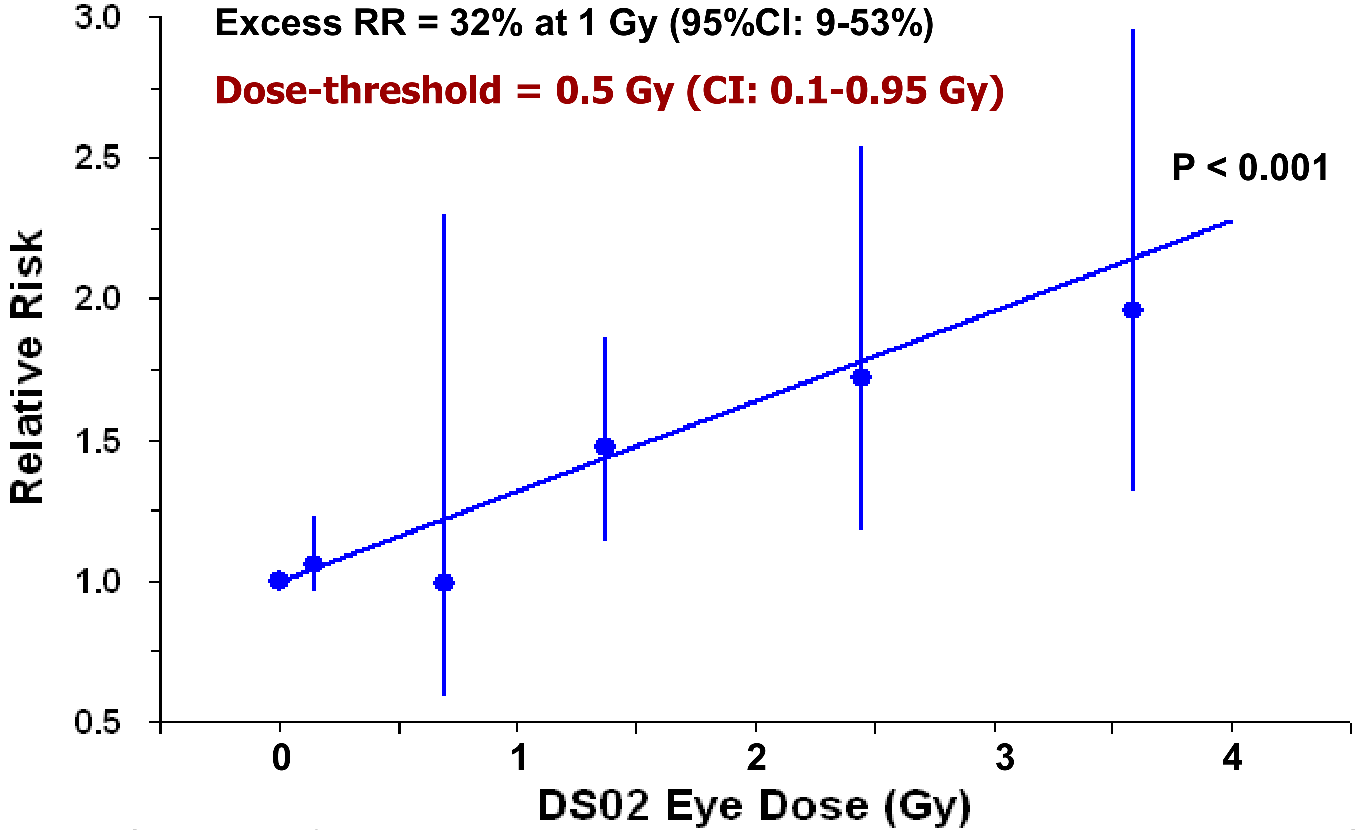
Study	RR estimate or description	Dosimetry & Comments
Japanese radiologic techs (Aoyama '89)	1.03 (0.81, 1.28)[H]	0.47 Gy in early subcohort
US radiologic techs (Hauptmann '03)	Trend p<0.001[C]	RR=1.42 if began <1940
UK radiologists (Berrington '01)	0.84 (0.77, 0.91)[C]	Pre-1940 doses ~1 Gy/y. Trend by date entry n.s.
US radiologists (Logue '86)	1.03 (~0.85, 1.23) [I]	No occupational dose info.
US radiologists (Matanoski '84)	1.15 [I] 1.15 [I]	SMR, Began 1920-39 SMR, Began 1940-69
US nuclear shipyard (Matanoski '91)	0.93 (0.82, 1.07)[H]	Mean ~50mSv; >5 vs <5 mSv comparison
German uranium miners (Kreuzer '13)	0.97 (0.62, 1.32)[I]	RR at 1 Sv
Techa River cohort (Krestinina '13)	1.06 (1.00, 1.12)[I]	RR at 100 mSv; Doses lagged 15 y
Fluoroscopy, TB patients (Davis '89)	0.9 (0.8, 1.0)[C]	Mean dose ~0.84 Gy

[C] All circulatory disease. [H] Heart disease. [I] Ischemic heart disease.

Cataract:
Dose Threshold?
Risk after Low-dose, Protracted or Fractionated Exposures?

Radiation Dose and Cataract-Surgery Incidence, 1986 - 2005 (A-bomb, Adult Health Study)

Radiation protection agencies had long believed there was no risk for vision-impairing cataracts below about 2 - 5 Gy and set safety standards accordingly. **More protective safety standards for the eye (≤0.5 Gy) are now being implemented, with the A-bomb study as a primary data source.**



Excess RR = 32% at 1 Gy (95%CI: 9-53%)

Dose-threshold = 0.5 Gy (CI: 0.1-0.95 Gy)

P < 0.001

(Adjusted for city, gender, age at exposure, attained age and diabetes)

(Neriishi, Nakashima et al, *Radiol*, 265:167-74, 2012)

Cataract Studies: Medical Radiation Workers with LDPF Exposures

	Mean Dose (Gy)	Number Examined	RR at 1 Gy (95% CI)
Radiological technologists (Chodick ‘08)	0.028	35,705[A]	3.0 (0.3-5.7)
Interventional cardiologists & nurses/technicians (Vano ‘10)	6.0 [C]	58	1.4 (1.1-1.9)
	1.5 [N]	52	1.5 (<1-2.8)
Interventional cardiologists & nurses/technicians (Vano ‘13)	5.7 [C]	58	2.7 (~1.3, 8.8)
	2.2 [N]	69	4.4 (~1.2, 40)
Interventional cardiologists & nurses/technicians (Ciraj-Bjelac ‘10)	1.1 [B,C]	56	5.3 (1.5-20)
	0.64 [N]	11	7.3 (1.3-32)
Interventional cardiologists (Jacob ‘12)	0.42	106	3.9 (1.3-11)[D]
Medical radiation workers (Milacic ’09)	<0.05 *	1560	4.6 (~3.0, 7.1)[D]
Radiologists & cardiologists (Mrena ‘11)	0.06	59	5.0 (<1, 29)

[A] Mail questionnaire. [B] Median dose. [D] Odds ratio & not RR at 1 Gy. [C] Cardiologists; [N] Nurses/technicians.

* Dosimeters often under lead shielding; actual eye doses probably much higher

Summary and Conclusions

- Cancer risk at acute, higher doses is well established for many tumor sites.
- A major question is what about risk at low doses or with protracted/fractionated (LDPF) exposures?
- **Solid cancer:** probably some risk from LDPF exposures, but uncertain whether it is less per unit dose than at higher, acute doses.
- **Leukemia:** stronger evidence for leukemia risk from LDPF exposures than for solid cancer.
- **Cardiovascular disease:** evidence for risk down to 0.5 - 1 Gy has grown stronger. Evidence regarding risk from LDPF exposures is increasing but is still uncertain.
- **Cataracts:** New evidence for vision-impairing cataracts at doses <1 Gy. Most studies have looked at early opacities, whose health impact is currently unclear. Evidence of early opacities related to LDPF exposures is accumulating, with implications for radiation protection.

Emotional Consequences of Nuclear Power Plant Disasters

Evelyn J. Bromet, Ph.D.
Stony Brook University

March 11, 2013

Disclosures: none

Emotional consequences of disasters

- Traumatic effects of war described since Civil War (psychological and psychosomatic); *Death in Life*
- Research on natural and man-made disasters for >60 y
- Excess morbidity from depression, post-traumatic stress disorder, and alcoholism, one year post disaster ~20%
- The rates vary widely – from 25 to 75% during the first year - depending on the magnitude of the event
- By comparison, in the US, one-year prevalence rates:
  8% for depression, 3.5% for PTSD, and 4% for alcoholism

Natural vs human-made disasters

- Both have acute effects
- Human-made disasters have more long-term effects
- Events involving radiation may have the most prolonged and complex effects
- Not only depression, PTSD, alcoholism, and smoking, but also health-related anxiety, taking the form of medically unexplained physical symptoms

Multiple factors contribute to persistence after nuclear power plant accidents

- Perception of risk from non-medical sources of radiation exposure → very loud alarm bells
- Fear of cancer and other medical conditions
- Told by MD that health problems due to radiation
- Given specific disaster-related diagnoses
- Rumors and anecdotal reports
- Untelligible communications about radiation
- Contradictory information from ‘reliable’ sources
- Distrust in authority
- Ecological and socioeconomic disruption (unemployment)
- Stigma
- Media coverage (not always balanced; alarmist; ≠ “no”)

Headlines on Feb 28, after WHO report released

- The Guardian:

  Cancer risk 70% higher for females in Fukushima area, says WHO
- CNN.com: Fukushima's radiation damaged more souls than bodies
- Scientific American: Prevailing Winds Protected Most Residents from Fukushima Fallout

New York Times, Feb 28, 2013

- Headline: W.H.O. Sees Low Health Risks From Fukushima Accident
- First paragraph:

TOKYO — A study published on Thursday by the World Health Organization on the health risks associated with the disaster at the Fukushima Daiichi Nuclear Power Plant suggested that the risk for certain types of cancers had increased slightly among children exposed to the highest doses of radioactivity, but that there would most likely be no observable increase in cancer rates in the wider Japanese population.

Consequences of persistent depression, PTSD, alcoholism, & smoking

- WHO: leading causes of disability worldwide
- Poor physical health
- Complicates recovery from medical conditions
- ↑ use and cost of medical services
- ↓ quality of life
- ↓ productivity and ↑ family stress
- Suicide (veterans !!)
- Mortality

Focus of talk

- Consequences of Three Mile Island
- Consequences of Chernobyl
- Consequences of Fukushima?

Accident at Three Mile Island (TMI): March 28, 1979

- Loss of coolant in Unit 2 reactor → core to overheat
- Small amt of radioiodine released (0.4 - 1 terabecquerel3)
- Max. individual dose estimated as <1 mSv
- Advisory on March 30 for pregnant women and preschool children to evacuate the 5-mile area
- All together, 21,000 (60% of pop) people left.
- Within 15 miles, 144,000 (39% of pop) evacuated.
- Class action lawsuit to prevent re-start of Unit 1 as it constituted an environmental hazard to mental health (settled by Supreme Court in 1985)

Three Mile Island (TMI) accident, 1979

- President’s Commission on TMI included a Behavioral Effects Task Force
- Chaired by Bruce Dohrenwend, Professor of Epidemiology and Psychiatry at Columbia
- Data from local a variety of local sources covering the spring and summer of 1979; concluded acute psychological effects, especially in mothers of young children

- Commission report conclusion: biggest effect of TMI was mental health

Our study: first mental health disaster study to use systematic sampling and mental health measures

- Mothers of young children living within 10 miles of TMI, and controls living near nuclear & a coal fired plant
- Their children born shortly before the accident
- Workers at TMI and 2 comparison plants
- Children of workers and mothers at ~age 11 y

- Assessed 9 mos, 12 mos, 3 y, 4 y; moms also at 7 & 10 y

Results

Mothers

- TMI moms twice as likely as controls to have diagnosable depression/anxiety in year after the accident (25% v 14%)
- ↑ psychiatric symptoms up to 10 y later
- Risk perceptions = persistent and correlated with symptoms
- Symptoms spiked after the restart (data from year 7)
- 10 y later:
    - 42% of mothers believed health affected by TMI
    - Belief assoc with somatic and anxiety symptoms

Workers and Children: no differences from control groups

7 Years After TMI: Chernobyl Exploded

Immediately afterward:

- 31 deaths by the end of the summer
- Permanent evacuation of ~135,000 pop
- Abortion assembly-lines
- Evacuees battled for residency permits
- Intensive health monitoring by international community

Over time:

- Soviet Union broke up – economic collapse
- Increase in thyroid cancer in exposed children
- Distrust in authorities who withheld information and lied
- Contradictory reports in media
- Health concerns labeled “radiophobia”
- Diagnosis given for what are basically anxiety symptoms = vascular dystony
- Intensive health monitoring by international community

20 years later:
Chernobyl Forum Report

"The mental health impact of Chernobyl is the largest public health problem caused by the accident to date."

Similar conclusion drawn by President's Commission on TMI in 1979

What is the evidence on mental health?

- General populations in exposed areas
- Young children exposed
- Clean-up workers (liquidators)

- General populations in exposed areas

2 studies 6-7 years later

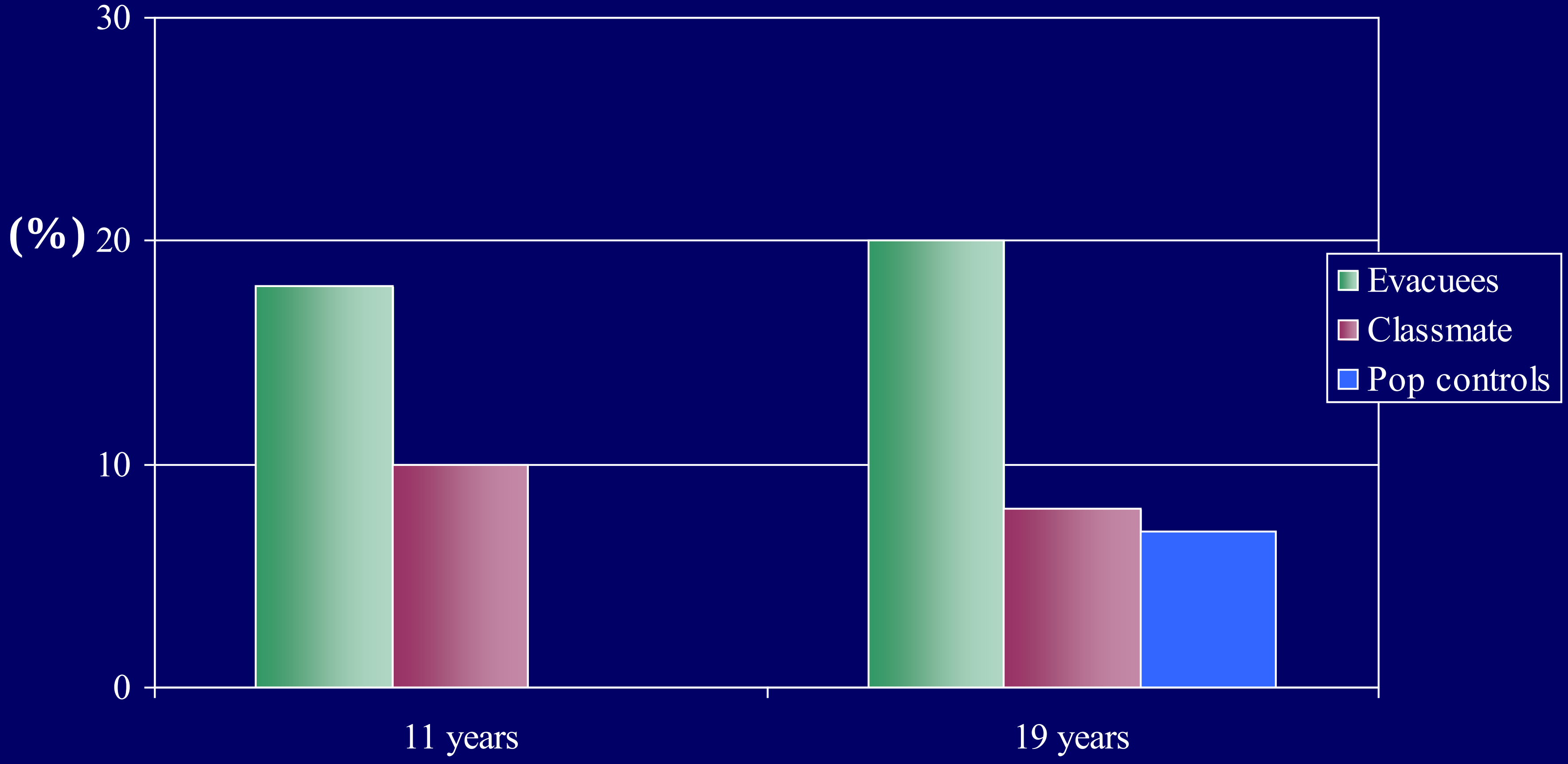
1. Bryansk, Russia: 325 adults in a contaminated village and 278 controls in non-contaminated village
2. Gomel, Belarus: 1,617 adults in Gomel to 1,427 controls in Tver, Russia

- Used the same standardized mental health questionnaire

Both found that > symptom levels in exposed than controls, especially women

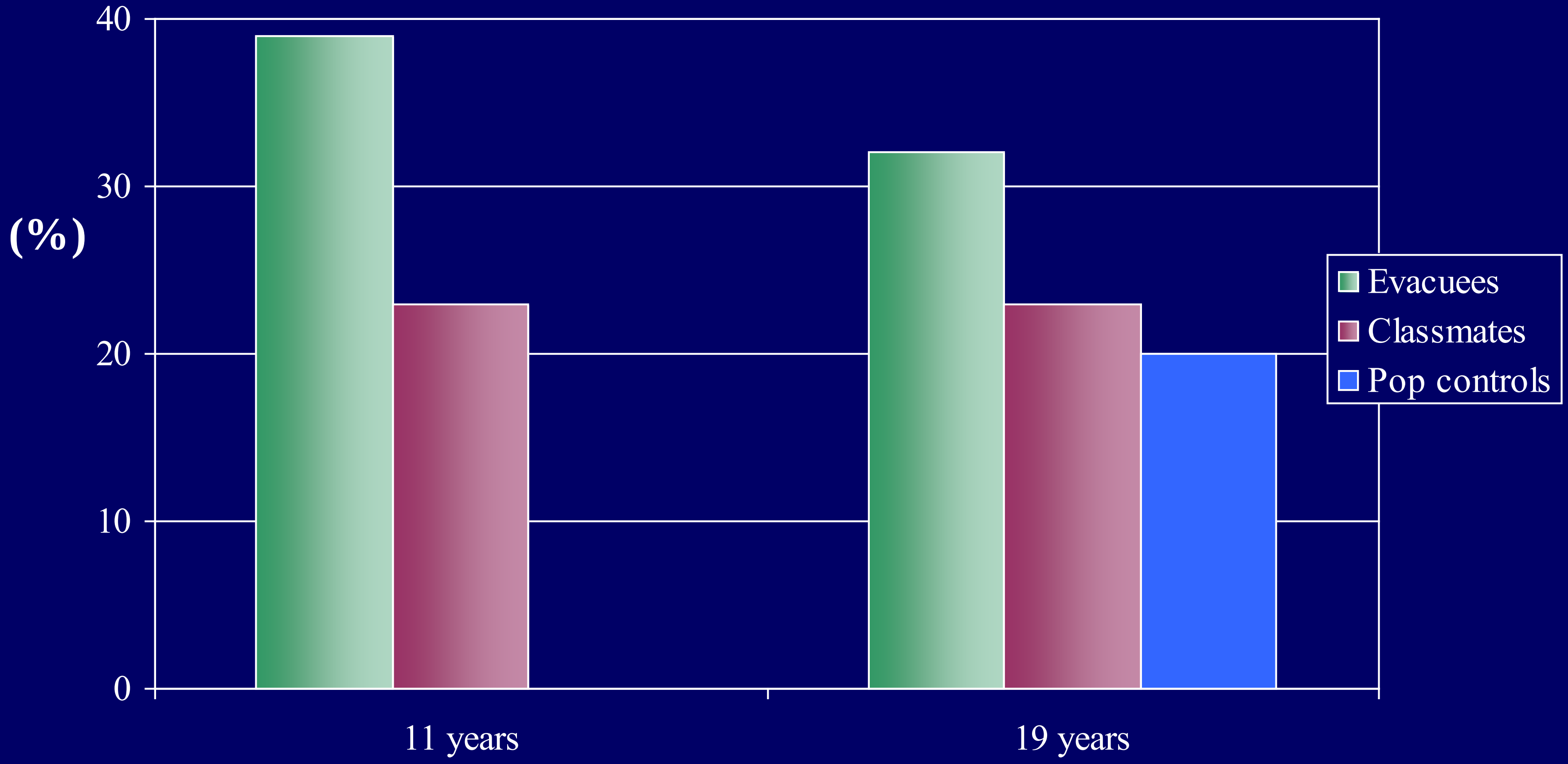
3. Our study of mothers of young children in Kiev: >depression and PTSD than comparison groups

Chernobyl-related post-traumatic stress disorder: Mothers



OR (11 vs 19 y) = 4.2; 95% C I= 2.3 - 7.6; strongest risk factor = risk perceptions

Self-rated health = poor/very poor



5 strongest Chernobyl risk factors

Belief that health very adversely affected by Chernobyl

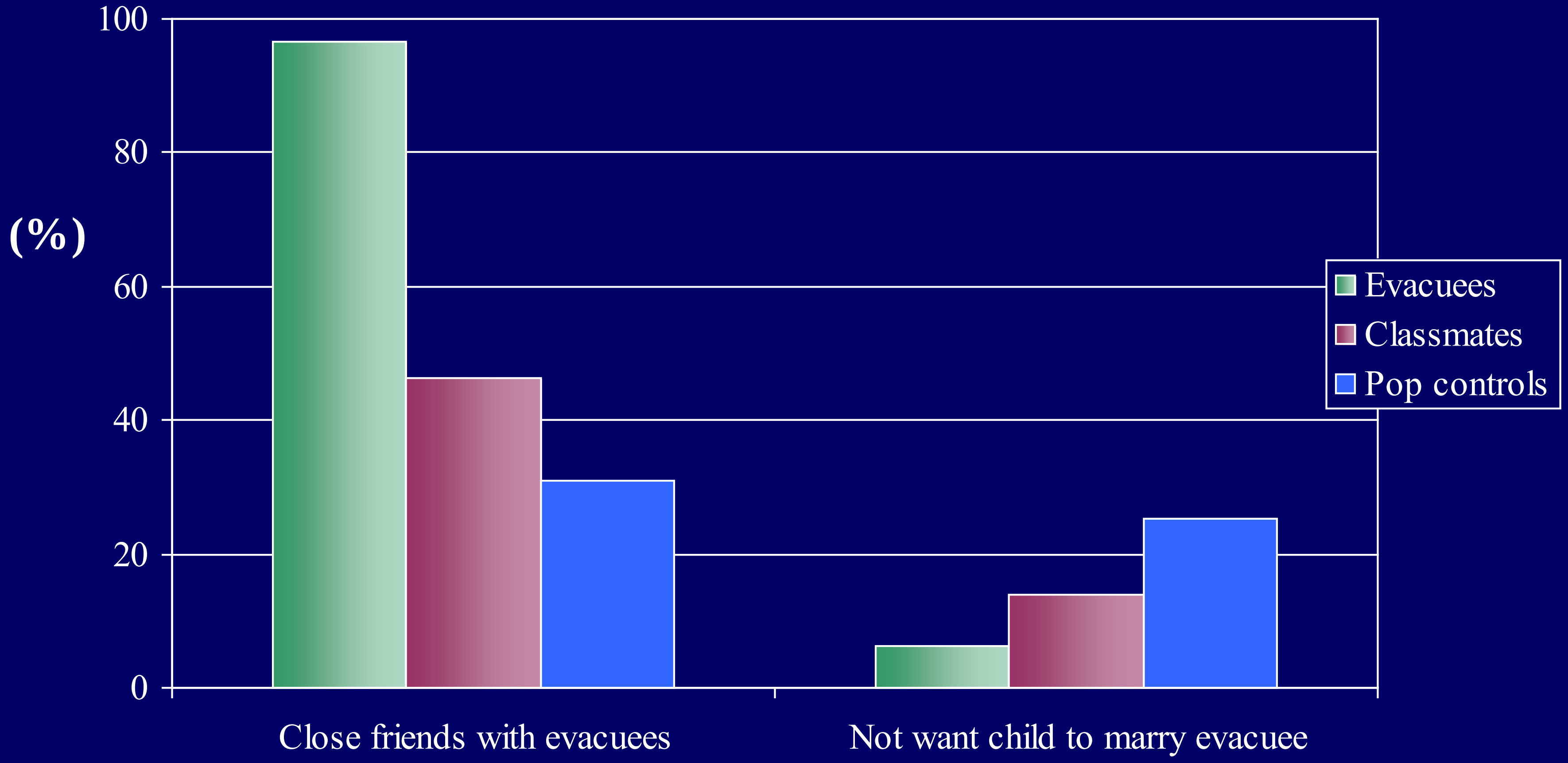
Told by MD that their health problems were due to Chernobyl

Diagnosed with vascular dystony

Belief that health of future generations very adversely affected

Distrust in authorities

Evidence of stigma 19 y later



Ukraine World Mental Health Survey: 2002

Prevalence and risk factor study; cross-sectional design

Representative national sample of 4,725 adults 18+ y

Kiev International Institute of Sociology & Ukrainian Psychiatric Association

After modules on depression, anxiety, neurasthenia, alcoholism, and service utilization, asked if ever lived in a Chernobyl-contaminated area or worked as liquidator

Diagnosable major depression since 1986:
Women: 23% exposed vs 19% not
Men: 14% exposed vs 9% not

General population: summary

Long-term emotional effects

Associated with persistent health concerns

Also associated with physician diagnoses

People don’t dwell on Chernobyl all the time

*19 y later, 36% of evacuees and 14% of controls say thoughts return to Chernobyl often or constantly

But the topic touches off a cascade of negative emotion

- Children

Cognitive impairment: findings are inconsistent

Local and international studies of:

- memory
- intelligence
- attention

Internationally-based studies

- WHO International Pilot Study of Brain Damage *In-Utero* (age 7 y): ns
- Stony Brook/Kyiv at ages 11 and 19 y: ns
- Israel: adolescents expo *in utero*-age 4 y: ns
- Norway at age 20 y: differences on verbal tasks only
- Finland: exposed (b Apr '86 – Jan '87) and non-exposed (b in year before and after) twins (419 pairs), age 14 y, >depression (6 v 3%), no other diffs

Local studies in Belarus and Ukraine

1. Ages 6 – 7 y; and 10 - 11 y
2. Higher rate of mental retardation and developmental delays in exposed vs controls
3. Ukraine: dose-response relationships
4. Belarus conclusion: socio-cultural explanations for the differences between exposed and non-exposed grps

Studies of emotional consequences

1. Local studies also reported > psychopathology
2. Stony Brook-Kiev study:
   - no differences on mental health measures from moms' or teens' perspectives
   - poorer self-rated health at age 19 y
   - on physician examination and blood test results, no significant differences among the groups

Summary of children's studies

Best evidence shows no significant effect of Chernobyl on the cognitive functioning and mental health of children who grew up in its shadow.

- Liquidators (clean-up workers)

  Neurocognitive impairment from radiation

  Emotional consequences of stress

Studies on neurocognitive impairment

RCRM: Radiation→schizophrenia and EEG abnormalities; recent paper on ARS patients assessed 14 y post

Institute of Gerontology in Kiev: Radiation→accelerated aging

Florida/Kyiv Polytechnic Institute Radiation→impairment in brain functioning

Methodological questions: samples? Controls? non-blinded raters, confounding of stress and radiation, if alcoholism was adjusted – how?

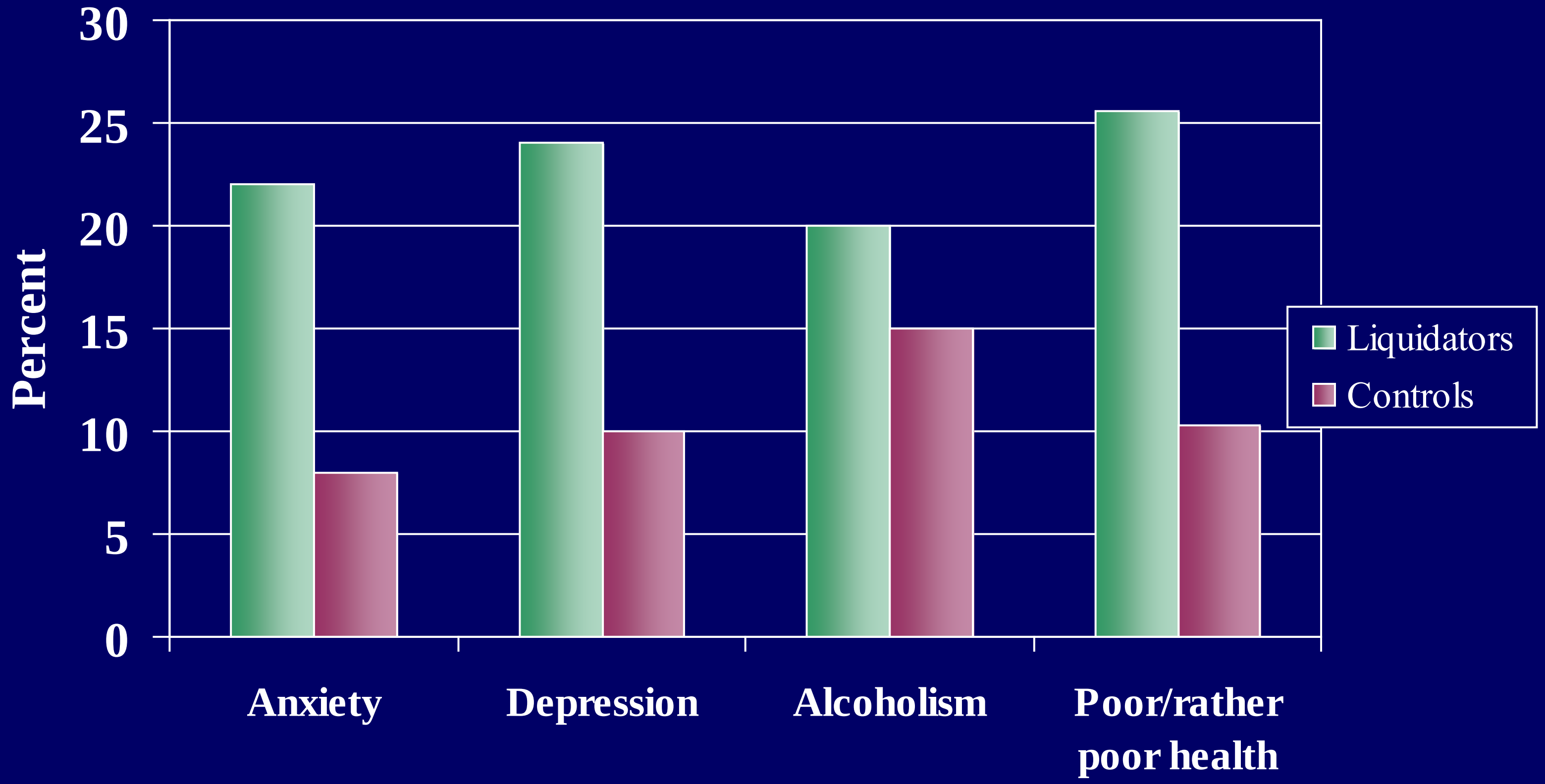
3 systematic studies of emotional consequences

1. Estonian liquidators (Rahu): Significant excess of suicide (1986 - 2011; SMR = 1.3 (CI 1.1 - 1.6)
2. RCRM/World Mental Health (Loganovsky):

   ↑ depression, PTSD, suicide ideation and severe headaches in liquidators vs controls

   liquidators with PTSD and depression had the most functional impairment by far

Comparison of 614 liquidators* and 706 age-matched controls in Tallinn 24 years later: mail survey; mean age of both groups = 55 y



Laidra/Rahu, in preparation

*all liquidators from Tallinn; rr = 80%; rr controls 58%

Summary on mental health of liquidators

- Long-term emotional consequences are compelling

Fukushima?

- From Three Mile Island, we know that there are acute mental health effects.
- Fukushima published findings:
  - Questionnaire survey of 885 Daiichi and 610 Daini workers in May - June 2011 (Shigemura et al., JAMA August 2012):
    - levels of distress and PTSD symptoms higher in Daiichi workers
    - Discrimination/slurs associated with higher distress

Fukushima?

- From Chernobyl, long-term mental health legacy.
- Can we extrapolate to northeast Japan?
- Today is the second anniversary of the triple catastrophe.
- Japanese-American TV station (NHK World) produced programs on people worried about their exposure, their likelihood of getting cancer, their fears about their children’s health.
- My question is: given the context of the meltdown and explosions, will the long-term psychological consequences be worse than Chernobyl?

Lessons for Fukushima

- Given physical/mental comorbidity, mental health measures should be integrated into medical research and surveillance studies (and vice versa)
- Educate primary care providers to recognize and manage health anxiety, depression, and impairment in daily functioning after exposure events
- Communication with the public and alliances with participants in the medical surveys (community advisors, community ambassadors, sharing findings directly)

Medical

Kathryn D. Held, *Chair*

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement
Lawrence T. Dauer
Memorial Sloan Kettering Cancer Center

Dose Tracking and Rational Exam Selection for the Medically-Exposed Population
James A. Brink
Massachusetts General Hospital / Harvard Medical School

Second Malignant Neoplasms and Cardiovascular Disease Following Radiotherapy
Lois B. Travis
University of Rochester Medical Center

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

-MEDICAL-

LAWRENCE T. DAUER

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

- PRINCIPLES
- EXPOSED MEDICAL STAFF
- IR/IC FGI MEDICAL PROCEDURES
- RAM IN DIAGNOSTIC IMAGING
- NOVEL USES IN MEDICINE
- CONCLUSIONS

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

RADIATION SAFETY PRINCIPLES

Objectives of Radiation Protection

- To prevent the occurrence of clinically significant radiation induced **deterministic effects** by adhering to dose limits that are below the apparent threshold levels and…
- To limit the risk of **stochastic effects, cancer and genetic effects** to a reasonable level in relation to societal needs, values, benefits gained and economic factors.

NCRP Report No. 116 (1993)

Principles of Radiation Protection

- **Justification** – on the basis that the expected benefits to society exceed the overall societal cost.
- **Optimization** – to ensure that the total societal detriment from justifiable activities is maintained ALARA, economic and social factors being taken into account.
- **Limitation** – application of individual limits to ensure that procedures of justification and ALARA do not result in individuals or groups exceeding levels of acceptable risk.

NCRP Report No. 91 (1987) & NCRP Report No. 116 (1993)

ICRP Concerned with Detriment (ICRP #103)

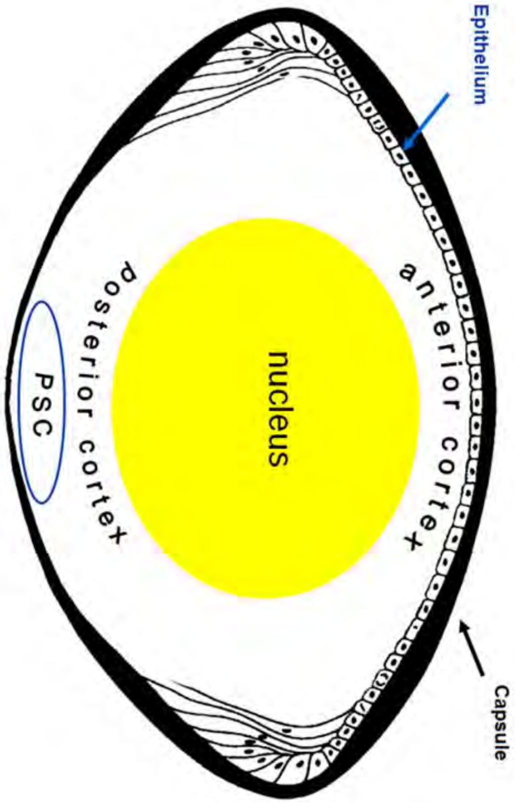
- ICRP aim is to contribute an appropriate level of protection against the **detrimental effects** of radiation exposure without unduly limiting desirable human actions associated with such exposure.
- Detriment – total harm to health as a result of exposure to a radiation source.
- **Tissue Reactions** (previously 'deterministic effects')
    - Detriment arising from non-cancer effects of radiation on health.
    - Some effects are not determined solely at the time of irradiation but can be modified after exposure.

Cataract

Ultimate expression of radiation damage to lens.

Latency depends on the rate at which damaged epithelial cells undergo fibrogenesis and accumulate.

PSC



Posterior Subcapsular Opacities

IAEA

Studies (ICRP Publication 118 App A – Roy Shore)

- A-Bomb
- Acute Radiation Exposures
- Clinical Patients
  - Diagnostic/Therapy/Hemangioma
- Radiation Workers
  - Radiologic Technologists
  - IR/IC FGI MDs
  - Chernobyl Cleanup
- Other workers
  - Pilots
  - Astronauts
- Residential Low-Dose Chronic exposures
  - Contaminated buildings
  - Chernobyl

ICRP Publication 118(2012) Cataract Epidemiology

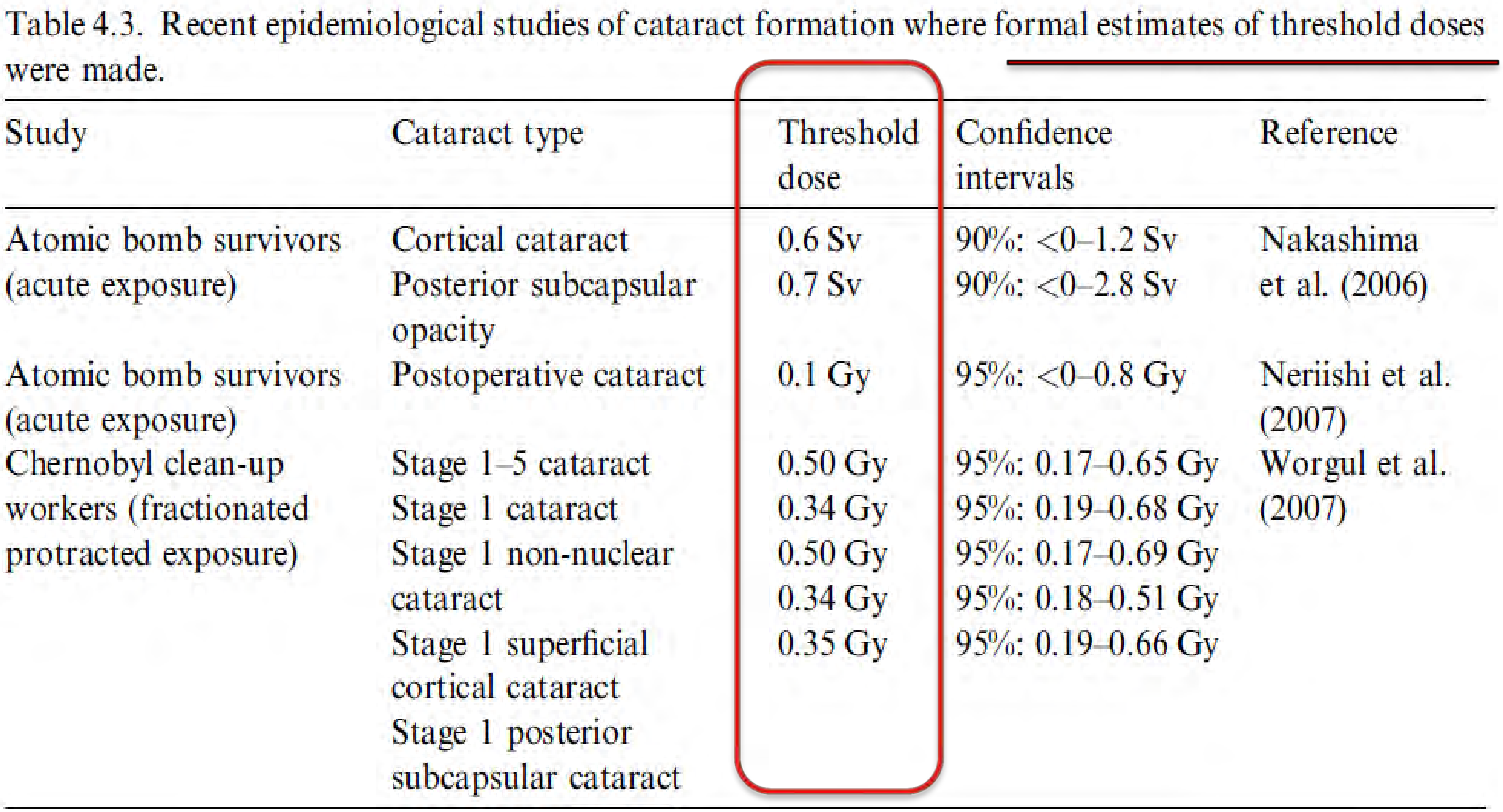
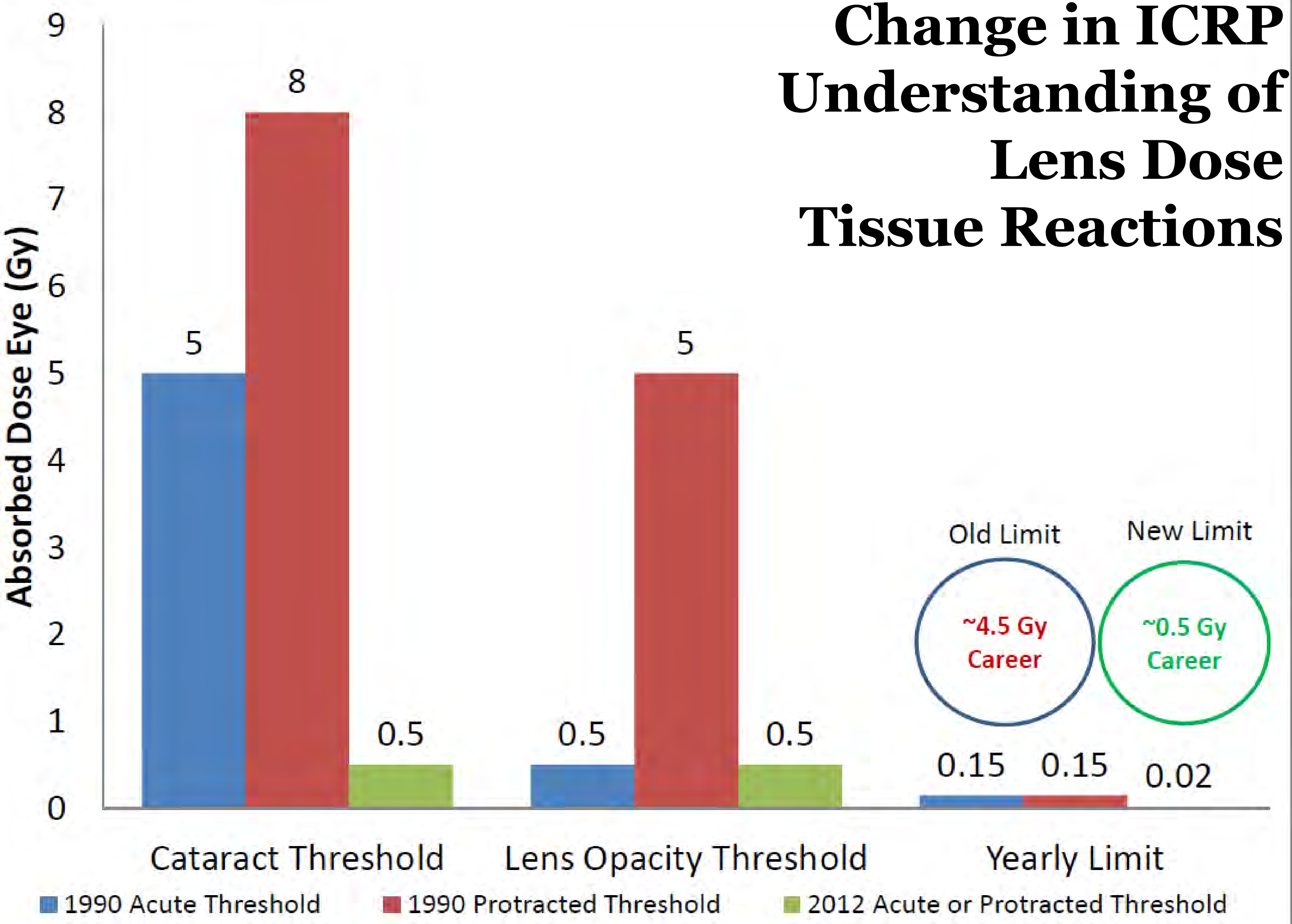


Table 4.3. Recent epidemiological studies of cataract formation where formal estimates of threshold doses were made.

Study	Cataract type	Threshold dose	Confidence intervals	Reference
Atomic bomb survivors (acute exposure)	Cortical cataract	0.6 Sv	90%: <0–1.2 Sv	Nakashima et al. (2006)
	Posterior subcapsular opacity	0.7 Sv	90%: <0–2.8 Sv	
Atomic bomb survivors (acute exposure)	Postoperative cataract	0.1 Gy	95%: <0–0.8 Gy	Neriishi et al. (2007)
Chernobyl clean-up workers (fractionated protracted exposure)	Stage 1–5 cataract	0.50 Gy	95%: 0.17–0.65 Gy	Worgul et al. (2007)
	Stage 1 cataract	0.34 Gy	95%: 0.19–0.68 Gy	
	Stage 1 non-nuclear cataract	0.50 Gy	95%: 0.17–0.69 Gy	
	Stage 1 superficial cortical cataract	0.34 Gy	95%: 0.18–0.51 Gy	
	Stage 1 posterior subcapsular cataract	0.35 Gy	95%: 0.19–0.66 Gy	

Change in ICRP Understanding of Lens Dose Tissue Reactions



Occupational Dose Limits (mSv)

Limit	NCRP #116	ICRP #103/118
Effective Dose		
- Annual	50 /y	20 /y
- Cumulative	10 x Age	Avg of 5 y, no y > 50
Equivalent Dose		
- Lens	150 /y	20/y
		Avg of 5 y, no y > 50
- Skin, Hands, Feet	500 /y	500 /y

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

EXPOSED MEDICAL STAFF

Worldwide **Cancer** Rates Continue to Rise

- 7.6 Million (13%) deaths in 2008 (WHO).
- Lung, stomach, liver, colon, breast, cervical …
- ~70% of all cancer deaths in 2008 were in low- and middle-income countries.
- Cancer expected to continue to rise up to ~**26.4** Million cases (IARC), **13.1** Million deaths by 2030.
- Imaging and Radiotherapy play important roles in cancer management.
- Advances of last 10 y shifting goals from life preservation to cure with increased quality of life.

Worldwide **CVD** Rates Continue to Rise

- 17.3 Million deaths from CVDs in 2008.
- 7.3 Million due to coronary heart disease.
- 6.2 Million due to stroke.
- >80% of CVD deaths take place in low- and middle-income countries.
- CVD expected to continue to rise up to **25** Million deaths by 2030.
- Imaging and esp. FGI procedures play important roles in CVD management.

Rising Use of Radiation in Medicine

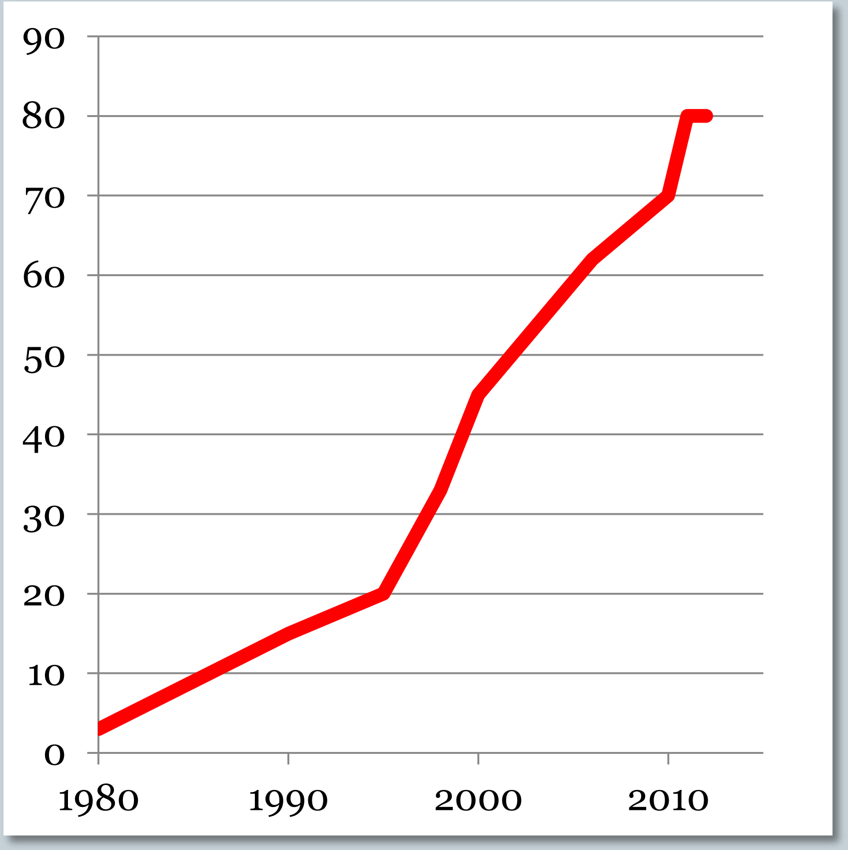
- Annual E per capita for Med Procedures:
  - United States 0.5 mSv (1980) to 3.0 mSv (2006)
  - Worldwide 0.3 mSv (1980) to 0.6 mSv (2007)
- United States (2006)
  - 337 M Diagnostic/Interventional Radiology
  - 18 M Nuclear Medicine
- Worldwide (2006)
  - **3.6** B Total
  - 3.1 B Diagnostic/Interventional Radiology
  - 0.5 B Dental
  - 37 M Nuclear Medicine

Mettler et al., Radiology 253 (2009)

Computed Tomography Usage

- Was growing ~10%/y
- Up to ~**80** M/y in U.S.
- ~10% in children
- Perhaps slowing some…
- ED CT usage continues to increase. (Larson 2011).
  - Growing ~16%/y
  - Double every 4.7 y

U.S. CT Usage Est. (Millions)



UNSCEAR (2008 Annex B)

- ~760 person-Sv worldwide in 1994.
- ~3540 person-Sv worldwide in 2002.
- **Physicians, technicians, nurses** and others involved constitute the largest single group of workers occupationally exposed to man-made sources of radiation.
- More than 80% of CT techs and general radiographers do not have measurable exposure.
- IR/IC FGI MDs are the most exposed in medicine.

UNSCEAR Mean DDE (mSv/y) - 2002

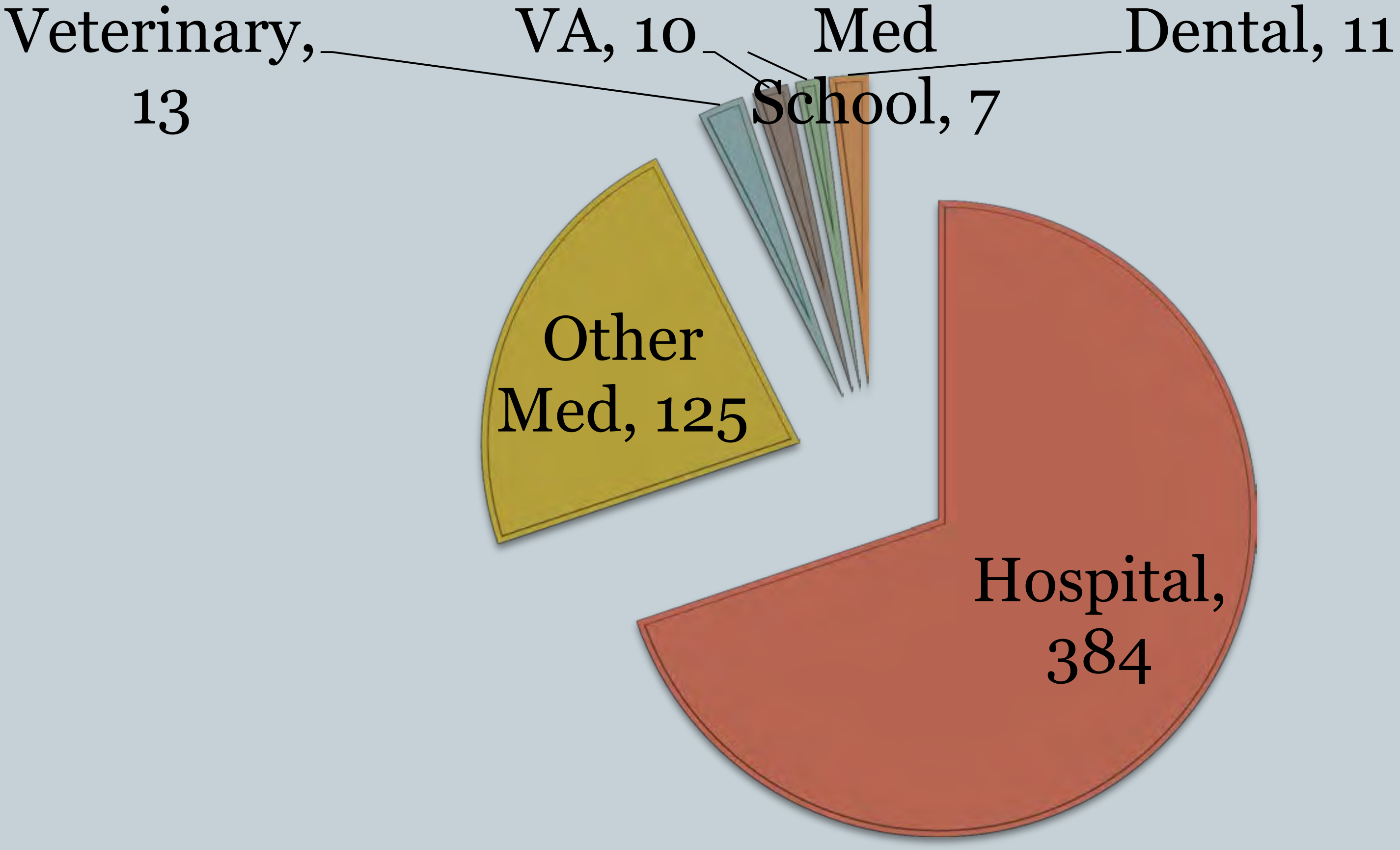
Category	Monitored	Measurable
IR/FGI MD	1.4	3.0
NM Nurse	0.9	1.3
NM Tech	0.8	1.2
Conventional Radiology	0.7	1.2
NM MD	0.7	1.2
All Medical Uses of Radiation **	0.5	1.6
Radiotherapy	0.5	

UNSCEAR, 2008

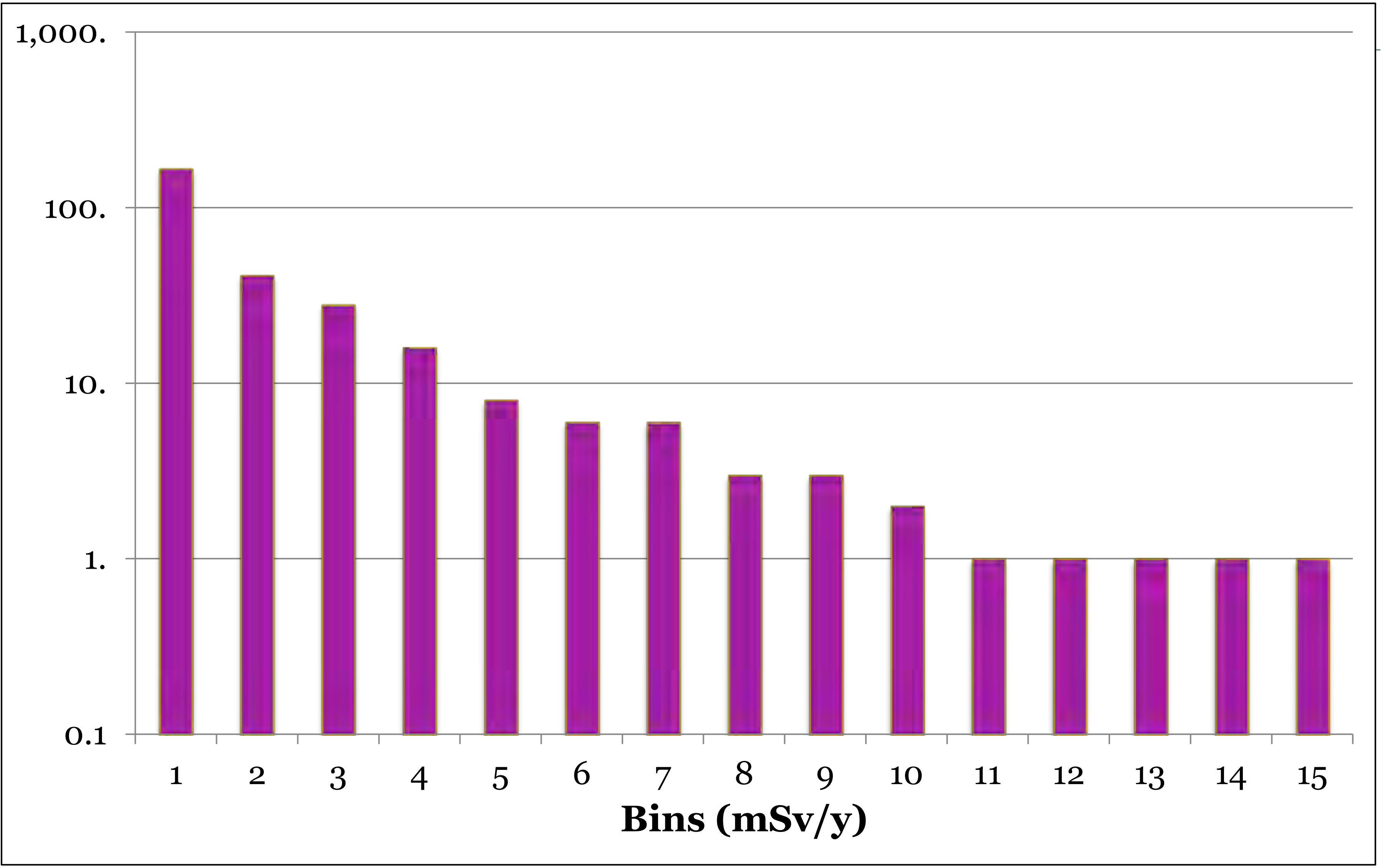
NCRP Report No. 160 (2009)

- Medical staff exposures contributed the most (39%) to the U.S. occupational exposures.
- ~2.5 Million monitored workers.
- ~0.75 Million received measured doses.
- ~550 person-Sv.
- Average E = 0.75 mSv.
- Data from ~2006.

NCRP Report No. 160 (2009) – Person-Sv - 2006



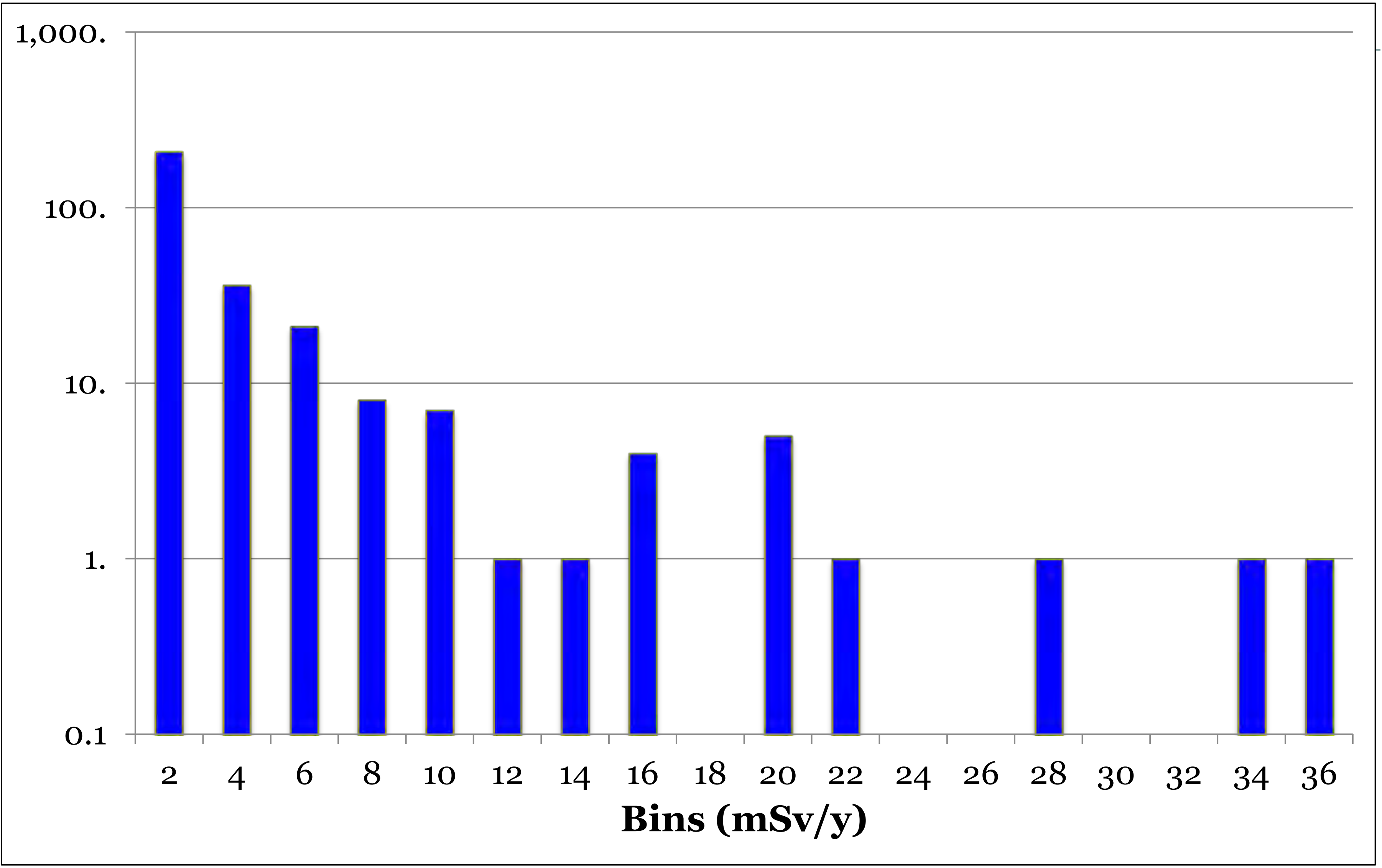
Measurable DDE (mSv/y) – 2011 MSKCC



Measurable DDE (mSv/y) – 2011

Exposed Medical Staff	Avg	Min	25%	50%	75%	95%	99%	Max
Radiopharmacist	4.6	0.1	4.2	4.8	6.4	8.0	8.4	8.5
NM Tech-Nurse	2.3	0.1	0.2	0.9	2.9	9.7	14.1	15.4
NM MD	1.9	0.1	0.5	1.3	2.6	6.2	7.1	7.5
IR/FGI MD	1.6	0.1	0.4	0.6	2.6	3.9	6.0	6.6
Research Radiochem	1.5	0.1	0.4	1.0	1.9	4.2	5.2	5.4
Commercial Radiopharm	1.5	0.1	0.1	0.3	1.2	6.9	22.2	47.4
Hospital Average **	1.5	0.1	0.2	0.5	1.9	6.2	11.0	15.4
Radiation Safety	1.1	0.1	0.5	1.0	1.8	2.2	2.3	2.3
IR/FGI Tech-Nurse	1.1	0.1	0.1	0.5	1.3	5.0	7.0	7.2
Inpatient Nurse	0.4	0.1	0.2	0.3	0.4	0.9	1.8	2.2

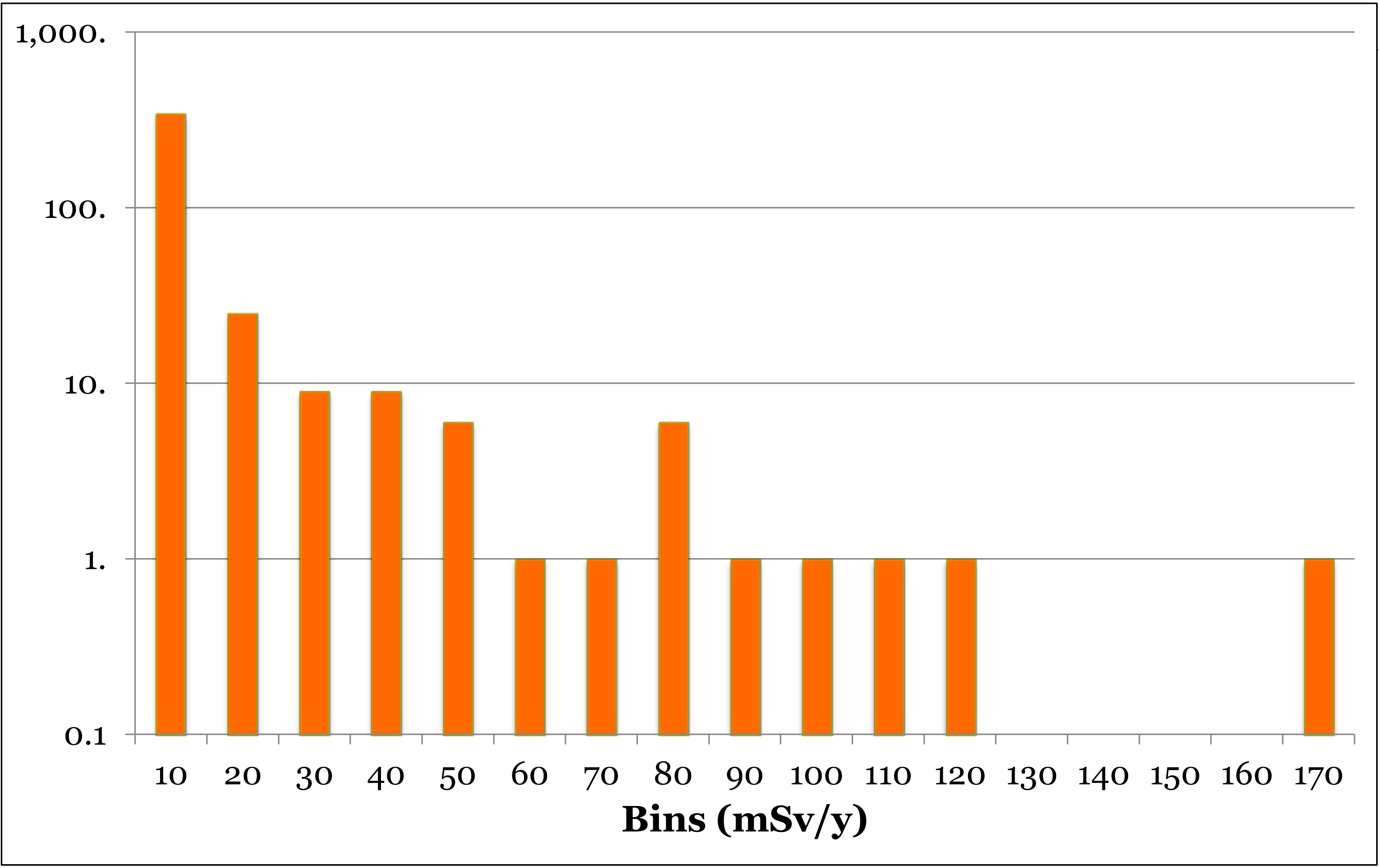
Measurable LDE (mSv/y) – 2011 MSKCC



Measurable LDE (mSv/y) - 2011

Exposed Medical Staff	Avg	Min	25%	50%	75%	95%	99%	Max
IR/FGI MD no Pb glasses	11.1	0.1	0.5	7.0	19.3	32.5	35.7	36.5
Radiopharmacist	4.7	0.1	4.3	5.0	6.4	8.0	8.5	8.6
IR/ FGI Tech-Nurse no Pb	2.5	0.1	0.4	1.1	1.9	12.0	19.1	19.3
NM Tech-Nurse	2.4	0.1	0.3	0.9	2.8	9.8	15.5	19.0
Hospital Average **	2.1	0.1	0.2	0.5	2.0	8.5	19.6	36.5
NM MD	1.9	0.1	0.5	1.4	2.6	6.2	7.2	7.6
Research Radiochem	1.9	0.1	0.1	0.6	3.3	6.3	7.8	8.2
Commercial Radiopharm	1.6	0.1	0.1	0.3	1.3	7.1	23.5	70.2
Radiation Safety	1.1	0.1	0.5	1.0	1.9	2.2	2.3	2.3
Inpatient Nurse	0.4	0.1	0.2	0.3	0.4	0.9	1.8	2.2

Measurable SDE-Extrem (mSv/y) – 2011 MSKCC



Measurable SDE-Extrem (mSv/y) - 2011

Exposed Medical Staff	Avg	Min	25%	50%	75%	95%	99%	Max
Commercial Radiopharm	50.5	0.3	2.3	16.5	84.1	187.6	243.0	363.5
Radiopharmacist	41.8	0.1	4.5	7.3	71.3	115.8	157.7	168.2
Research Radiochem	18.0	0.1	1.6	6.7	22.5	72.9	98.2	118.7
IR/FGI MD	11.3	0.1	0.9	7.0	19.3	32.5	35.7	36.5
Hospital Average **	6.0	0.1	0.3	0.9	3.4	32.6	77.3	168.2
NM Tech-Nurse	5.6	0.1	0.4	1.8	5.0	28.3	44.6	68.5
IR/FGI Tech-Nurse	2.7	0.1	0.5	1.2	2.0	13.6	19.1	19.3
NM MD	2.2	0.1	0.5	1.4	2.7	6.5	9.7	11.6
Brachy MD	2.1	0.1	0.4	1.3	2.0	6.9	8.7	9.1
Radiation Safety	1.4	0.1	0.5	1.0	2.1	3.4	4.2	4.4
Inpatient Nurse	0.4	0.1	0.2	0.3	0.4	0.9	1.8	2.2

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

FLUOROSCOPICALLY GUIDED INTERVENTIONAL PROCEDURES

IR/IC FGI Lens Doses Vary by Procedure

Unshielded LDE Nominal Estimates

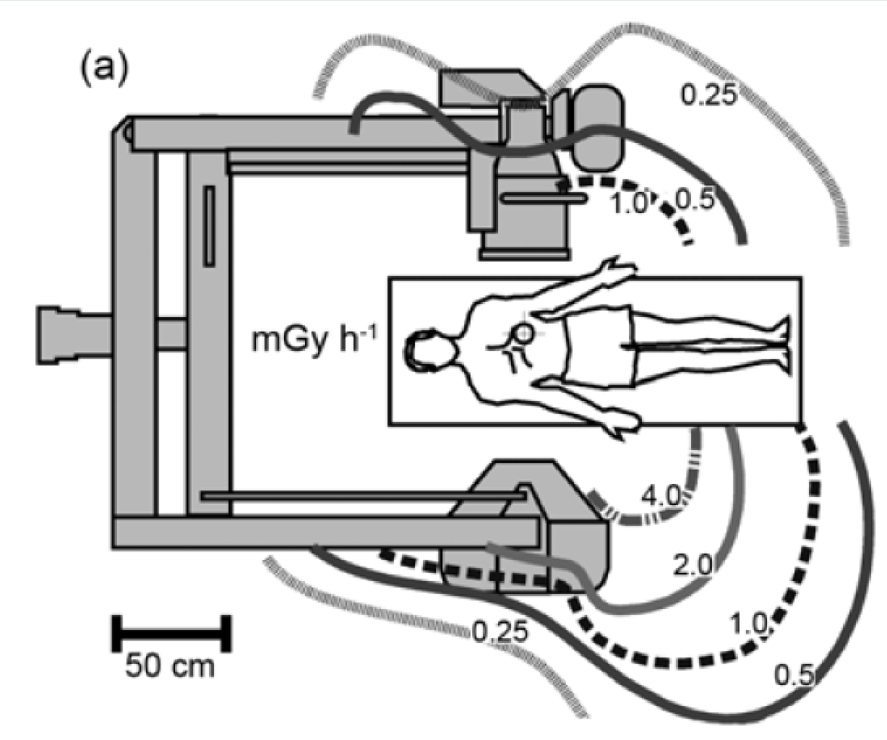
Procedure	**~~mSv/Procedure**
Embolization	0.8
Cardiology	0.5
ERCP	0.5
Biliary Stent/Drain	0.3
Vertebroplasty	0.1
TIPS	0.03
Cerebral Angio	0.02

- Training
- Methodology
- Complexity
- Patient Factors
- Equipment
- LDE correlates with Patient Dose

~4-7 µSv LDE /Gy cm²

FGI IR/IC Protection Controls (NCRP Report No. 168)

- Engineering
  - Equipment
  - Structural Shielding
  - Equipment Shielding
- Safe Work Practices
  - SOPs
  - 10 Commandments/Pearls
- Administrative
  - Training/Credentialing
  - Expectations
- PPE (aprons/collar/glasses, etc.)



NCRP-168

Operator Training / Credentialing

- Equipment design and shielding help…BUT
- Training and Credentialing needs improvement.
- Europe leads in operator training.
- As of 2011, only 27 states enacted legislation regarding radiation education for FGI operators

Shielding Strategies for FGI LDE reduction

Strategy	Reduction Factor
Leaded glasses	3 - 10
Shielded drape	25
Leaded glasses + drape	140
Ceiling shield	130
Rolling shield	1000

Thornton et al 2010 JVIR

How to Measure LDE?

Radiation Field	$H_p(0.07)/H_{lens}$	$H_p(3)/H_{lens}$	$H_p(10)/H_{lens}$
Photons < 30 keV	0.9 – 5	0.6 – 1	0.01 – 0.9
Photons > 30 keV	0.8 – 1.1	1 – 1.2	0.9 – 1.2
Electrons	1-500	~1	<<1 – 1.2
Adequate?	Perhaps for photon radiation	OK for Photons. Necessary for Beta	Not for low E photons or beta.

R. Behrens and G. Dietze
Phys Med Bio 55, 4047-4062 (2010)
Phys Med Bio 56, 511 (2011)

?What if Leaded Glasses are worn?

Practical LDE Dosimeter Choices
– Starts with actually wearing them!

- DDE dosimeters (Whole Body) $H_p(10)$:
  - On trunk or waist far from eyes.
  - Underestimate at low photon energies (too thick)
  - Under lead apron if in use.
- SDE dosimeters (Extremity) $H_p(0.07)$:
  - Must be worn facing the beam/scatter
  - Worn near eye (note NCRP Report No 168 factor of ~1 at collar)
  - OK for photons, overestimates for beta (too thin)
- LDE dosimeters (Eye) $H_p(3)$ – exist?:
  - Must be worn facing the beam/scatter
  - Only type OK for photons and beta.

Behrens, Oct. 2012, IAEA

Other FGI Strategies

- NCRP Report No. 168
- NCRP Report No. 122
- ICRP Publication 85
- ICRP Publication 117
- ICRP Publication 120
- SIR Safety Guidelines
- IAEA Guidance and Training
- RELID Program

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

RADIOACTIVE MATERIAL USE IN DIAGNOSTIC IMAGING

Expanding Use of Radioactive Materials

- Diagnostic Imaging
- PET Imaging
  - Scans and Rad Onc Sims
- Multimodality
  - PET/CT
  - PET/MRI
- Nuclear Medicine
  - Tracers
  - Stress Tests
  - Scan
- Localization
  - Sentinel Node
  - Rad Seed Localization

Radiopharmaceutical Doses

Radionuclide	Dose Rate from Patients µSv/h/GBq at 1 m
Tc-99m	~10
I-131	~50
F-18	~90

Whole Body Dose / Patient

- Bone Scan 0.1 - 0.5 µSv.
- MIBI SPECT 1.5 - 2 µSv.
- PET 4 - 6 µSv.
  - Injection 1 - 2 µSv.
  - Escort/Assist 2 - 4 µSv.
  - Prep Syringe <1 µSv.
- Close contact with PET patients can result in ~0.5 - 3 µSv/min.

Extremity Monitoring ORAMED Project

- Extremity Monitoring is Necessity in NM.
  - 35% of workers exceed 250 mSv.
  - 20% of workers exceed 500 mSv.
- Monitoring inner base of index finger of non-dominant hand – correlates with max (at tip).
  - Rough estimate of maximum is to multiply by 6.
- Shielding of vials and syringes are essential, but not a guarantee of low exposures.
- Tungsten: 2 mm for Tc-99m, 5 mm for F-18 or Y-90.
- Training, tools, distance over time, dispensing.

Vanhavere, 2012, IAEA

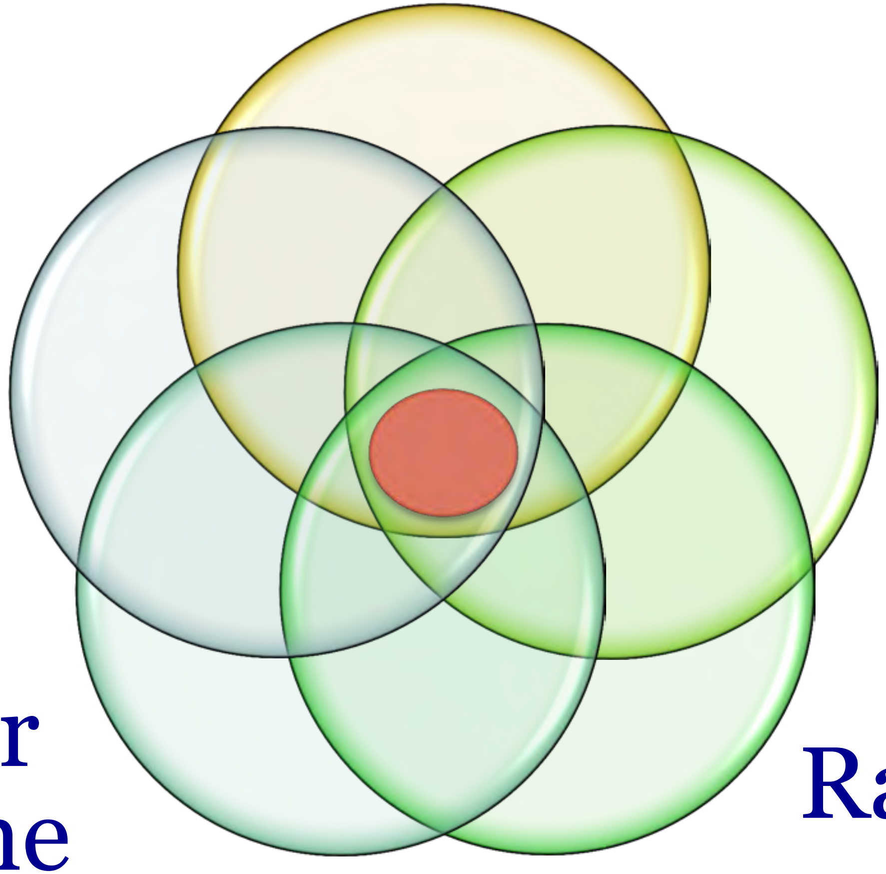
Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

NOVEL USES OF RADIOACTIVE MATERIAL IN MEDICINE

Novel? Examples of Radiation in Medicine

- Radiolabeled Mab Imaging/Therapy (I-131).
- Radiolabeled compounds (MIBG).
- Beta emitters (Y-90).
- Targeted alpha particle therapy:
  - MAb (Bi-213, At-211, Ac-225).
  - Chloride salts (Ra-223).
- Theragnostic Mab (I-124).
- Intraoperative Brachytherapy (P-32 plaque).
- PET-guided interventions/surgery (F-18).
- Radioactive Seed Localization (I-125).
- IGRT (Morphology and Physiology Targeting).

Blurring of Boundaries



Radiation Oncology

Fluoro - Guided

Medical Physics

Nuclear Medicine

Radiology

Unconventional PET Radionuclides

PET	Rx	T ½	Photons (MeV)	Probability	TVL (cm Pb)
^{18}F*	^{18}O (p,n)	1.8 h	0.511	1.9	1.6
^{68}Ga	^{66}Zn (α,2n)	68.3 m	0.511, 1.08	1.8, 0.03	1.7
^{82}Rb	^{85}Rb (p,4n)	1.2 m	0.511, 0.776	1.9, 0.14	1.7
^{86}Y*	^{86}Sr (p,n)	14.7 h	0.511, 1.1, 1.9, 1.8	0.7, 0.3, 0.2, 0.17	3.8
^{89}Zr*	^{89}Y (p,n)	3.3 d	0.511, 0.91	0.46, 0.99	3.2
^{124}I*	^{124}Te (p,n)	4.2 d	0.511, 0.603, 1.7	0.46, 0.59, 0.10	3.1

* Routine production – MSKCC cyclotron

Shipping Unconventional PET

- Standard PET shipping containers rated
  - 2500 mCi F-18
  - Yellow II
- Field Data
  - Not all PET equal
  - Quantities may vary

Nuclide	Est. max mCi (contact)	Est. max mCi (@ 1-meter)
^{18}F	2500	1100
^{86}Y	15	8
^{89}Zr	55	36

Williamson, 2010

Staff Doses – Patient Release Considerations

PET	T1/2 (d)	Release (mCi)	Release (mrem)	Instruct (mCi)	Instruct (mrem)
Ga-68	4.7E-2	557	307	111	61
Rb-82	8.8E-4	25478	16347	5096	3269
C-11	1.4E-2	1706	1016	341	203
N-13	6.9E-3	3504	2087	701	417
O-15	1.4E-3	17130	10214	3426	2043
F-18	7.6E-2	328	189	66	38
Cu-64	5.3E-1	255	27	51	**5**
Y-86	6.1E-1	12	24	**2**	**5**
Zr-89	3.3E+0	27	18	**5**	**4**
I-124	4.2E+0	21	14	**4**	**3**

Williamson & Dauer, HPS (2013)

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

CONCLUSIONS

Optimizing Radiation Protection

“Tried and True”
Defined Rad Prot

- J, O, L works
- Time, Distance, Shielding
- Planning
- Training
- Credentialing
- Quality Management
- Dosimetry

“Newer and Developing”
Need to define Rad Prot

- Dosimetry
- Lens Doses
- Extremity Dose
- Novel Uses
- Novel Radionuclides
- Cyclotron Facilities
- Current and future patterns of use

Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement

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Department of Radiology
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Dose Tracking and Rational Exam Selection for the Medically-Exposed Population

James Brink, MD
Massachusetts General Hospital

Diagnostic Uses for Radiation

Computed Tomography

Nuclear Medicine

Radiography

Fluoroscopy

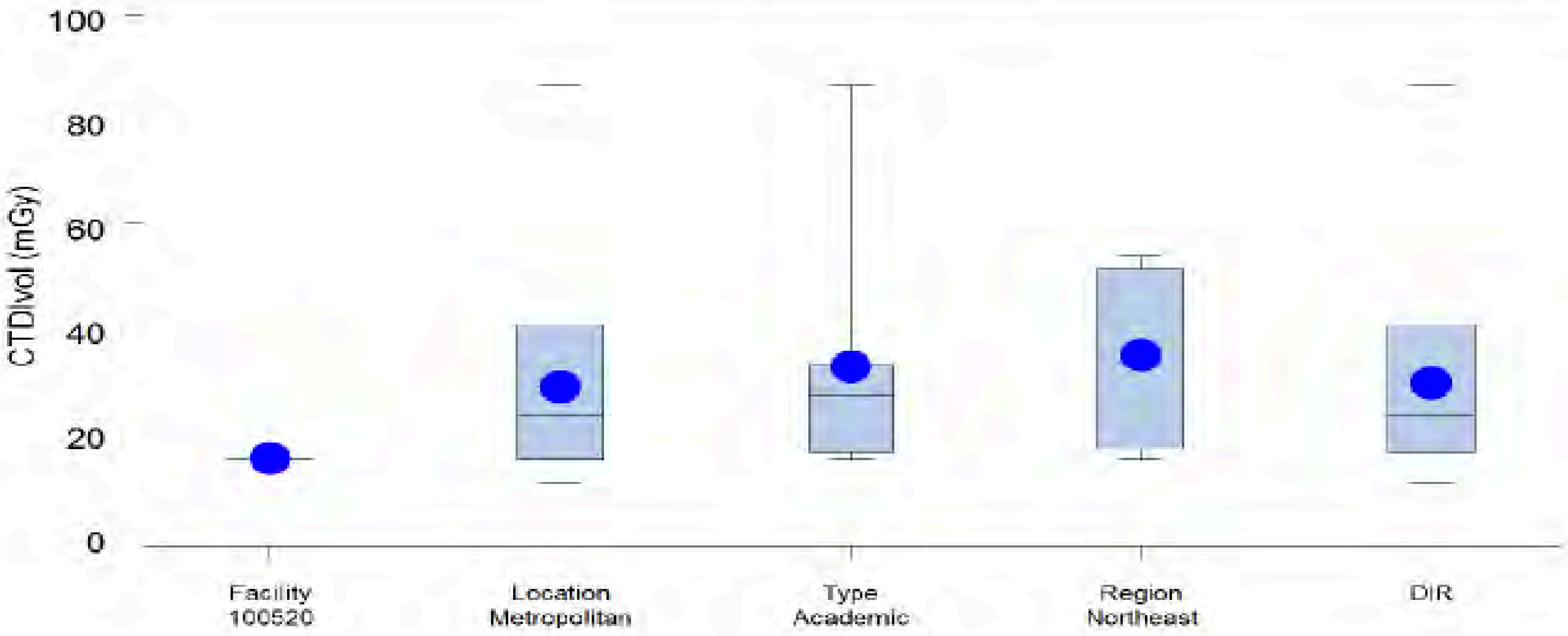
Dose Index Registry

- Collect and provide feedback on dose estimates
- Production program launched in May, 2011
  - DICOM feed of patient-specific dose data
  - Allows participants to compare average $\mathrm{CTDI}_{\mathrm{vol}}$ and DLP values across facilities

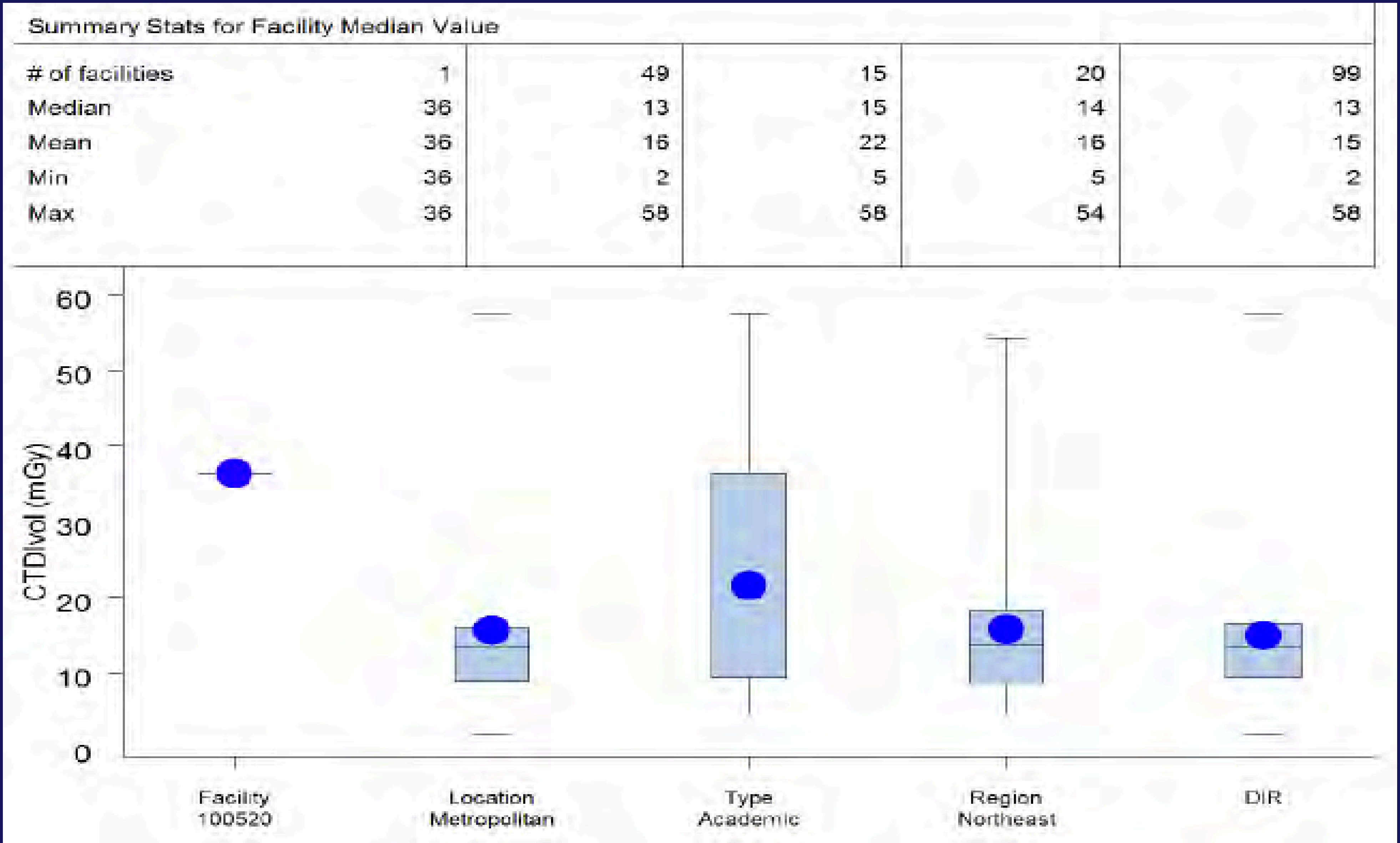
CT Abdomen (CTDI$_{vol}$ per Exam)

Summary Stats for Facility Median Value

# of facilities	1	19	9	11	29
Median	15	23	27	41	23
Mean	15	29	33	35	29
Min	15	10	15	15	10
Max	15	87	87	54	87



CT Chest (CTDI$_{vol}$ per Exam)



Summary Stats for Facility Median Value

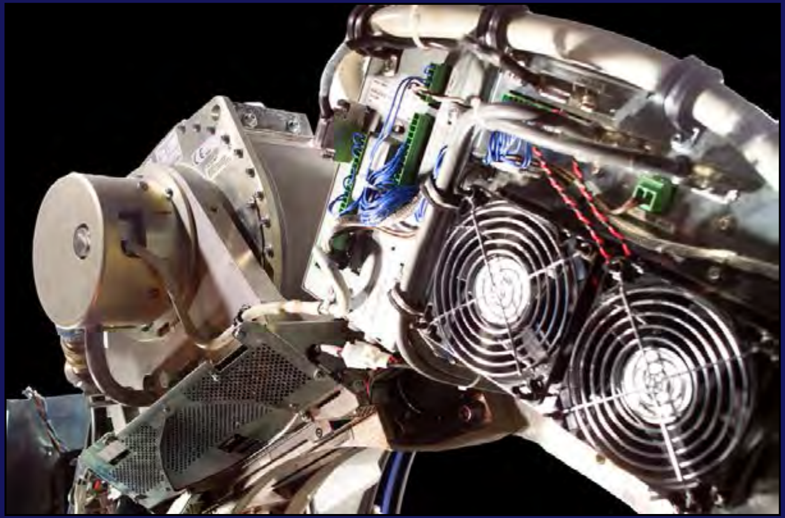
# of facilities	1	49	15	20	99
Median	36	13	15	14	13
Mean	36	16	22	16	15
Min	36	2	5	5	2
Max	36	58	58	54	58

Dose Tracking & Rational Exam Selection

- Patient Tracking
  - Dose Metrics
    - Impact of body habitus
  - Risk Estimates
    - Impact of age, life expectancy
    - Effective dose vs. organ dose

- Rational Exam Selection
  - Reducing Variation
    - Appropriateness criteria
    - Diagnostic algorithms
    - Decision support

Faster Rotation → Higher Tube Capacity



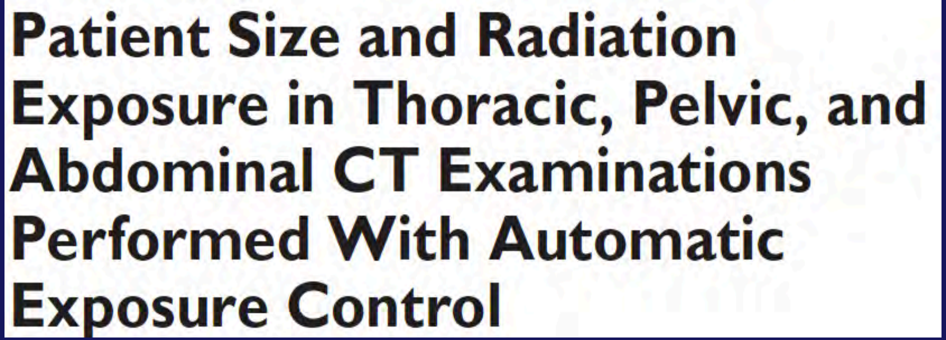
Rapid Tube Rotation (sec)

High Tube Power (mA)

"Adequate" mAs

Potential for Excessively High Dose

Impact of Patient Weight on ACTM



Patient Size and Radiation Exposure in Thoracic, Pelvic, and Abdominal CT Examinations Performed With Automatic Exposure Control

Gary M. Israel[1]
Lawrence Cicchiello[1]
James Brink[1]
Walter Huda[2]

- 91 pts for Chest, Abdomen, Pelvis CT w/ 64 DCT
  - NI = 11.5, 5 mm, rot = 1 s, pitch = 1, 120 kV, mA_{max}=800 mA
- CTDI_{vol} obtained from console + Impact Dose Calculator
  - organ doses computed for a 70 kg patient
- Patient doses were calculated by correcting for pt. size

AJR 2010; 195:1342–1346

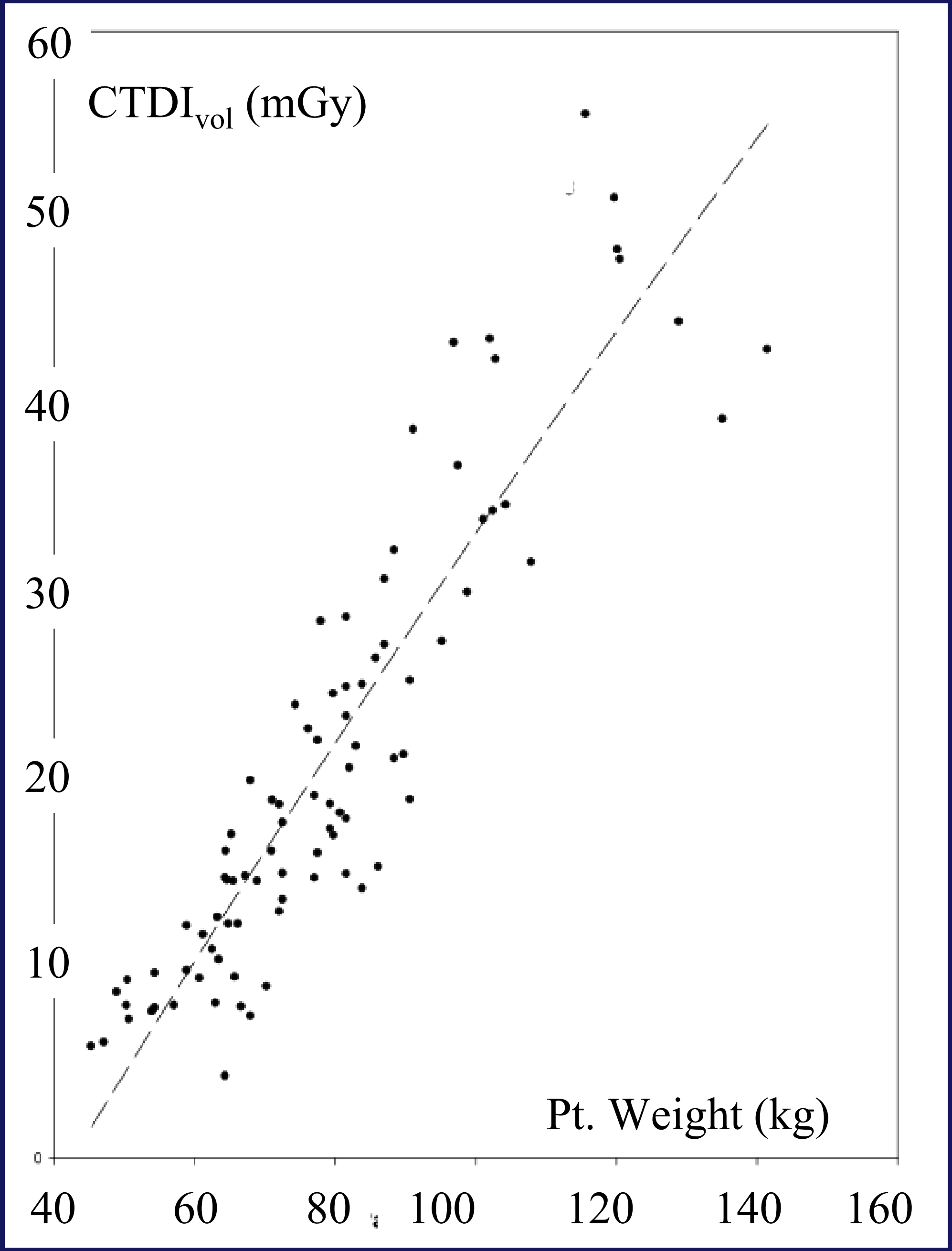
Dose vs. Weight

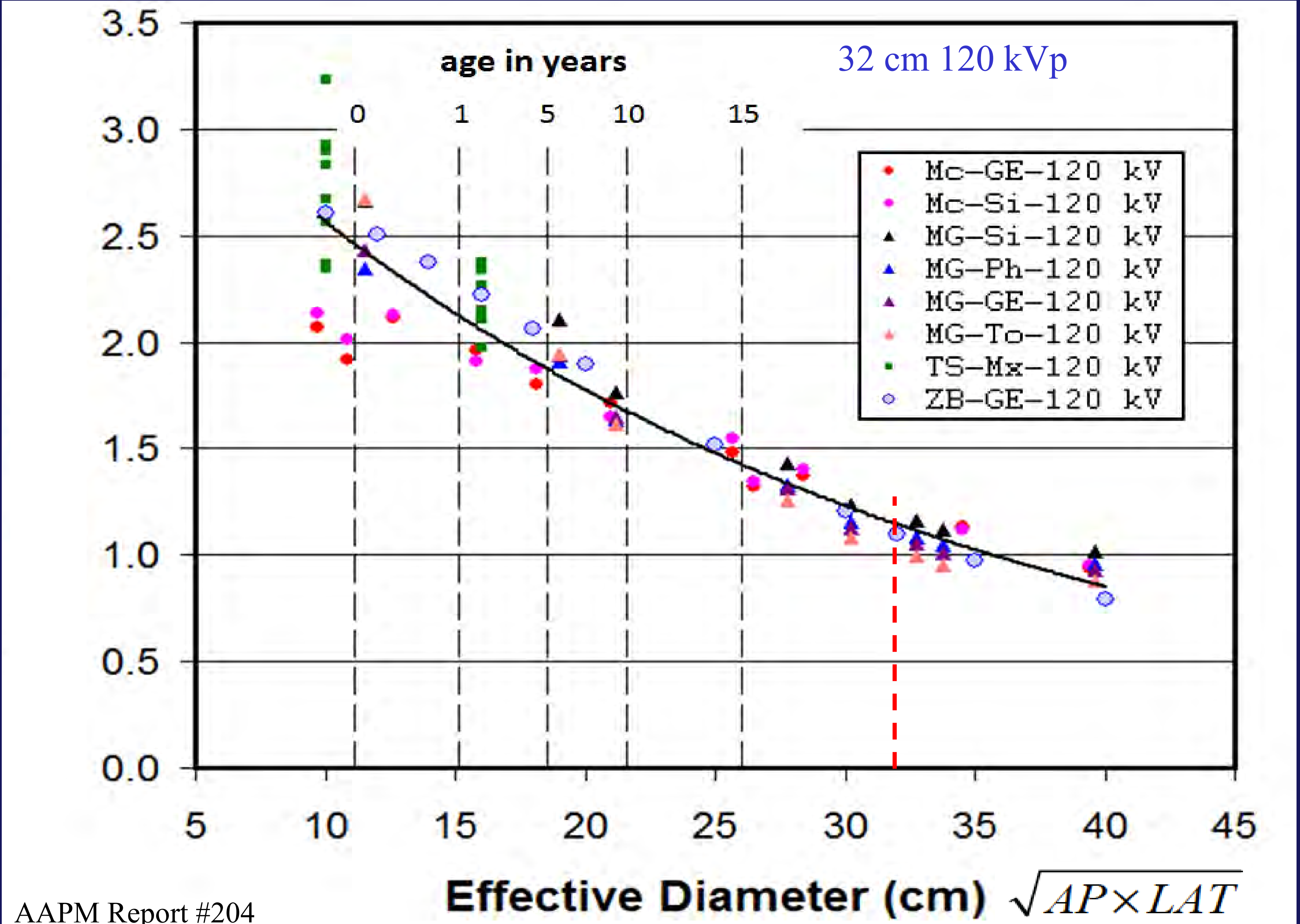
	60 kg	100 kg	
CTDI$_{vol}$	11	33	(3x)
Liver (mGy)	16	34	(2x)

Effective Dose:

Min – Max = 6 – 50 mSv

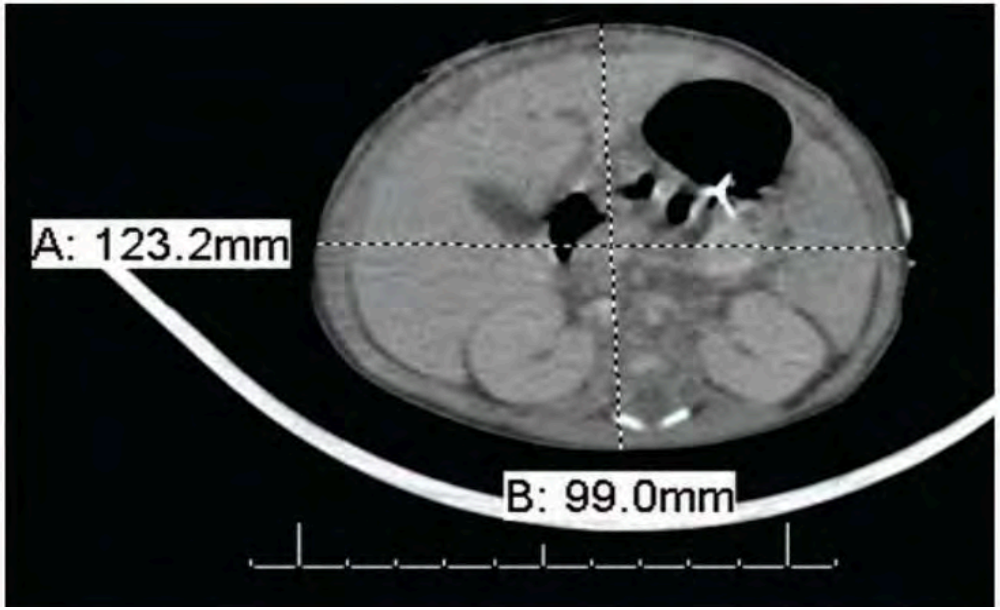
Israel, Cicchiello, Brink, Huda
AJR 195, 1342–1346 (2010)





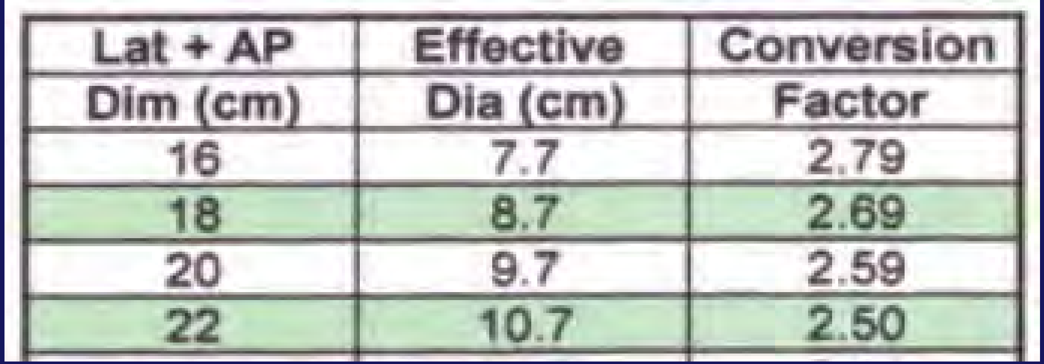
AAPM Report #204

Example: Abdominal CT in a Child



$CTDI_{vol}$ = 5.40 mGy (32 cm phantom)
AP = 9.9 cm   Lat = 12.3 cm
Sum = 22 cm

AAPM Report #204



Lat + AP Dim (cm)	Effective Dia (cm)	Conversion Factor
16	7.7	2.79
18	8.7	2.69
20	9.7	2.59
22	10.7	2.50

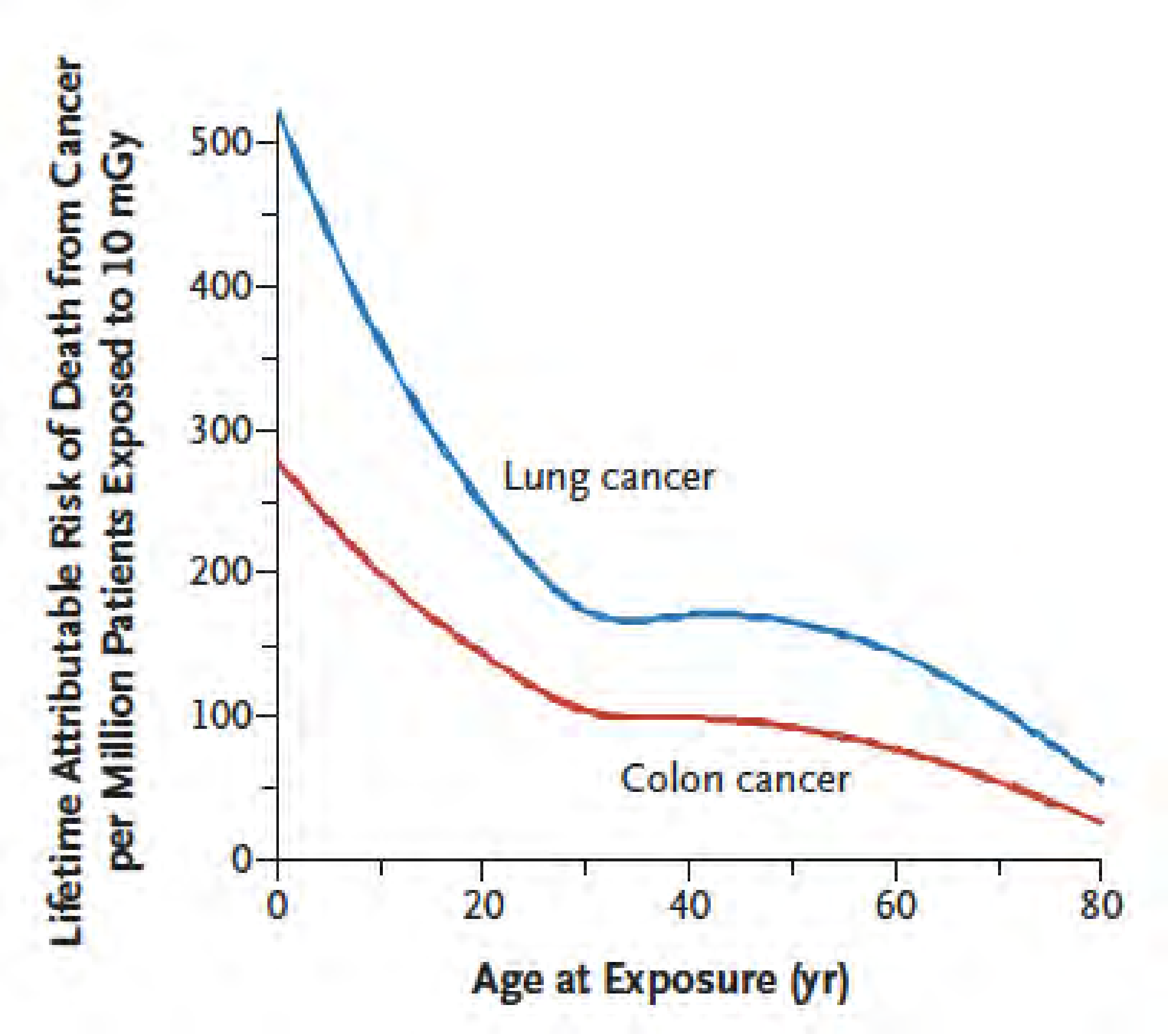
SSDE = 5.4 mGy x 2.50
= 13.0 mGy

Dose Tracking & Rational Exam Selection

- Patient Tracking
  - Dose Metrics
    - Impact of body habitus
  - Risk Estimates
    - Impact of age, life expectancy
    - Effective dose vs. organ dose

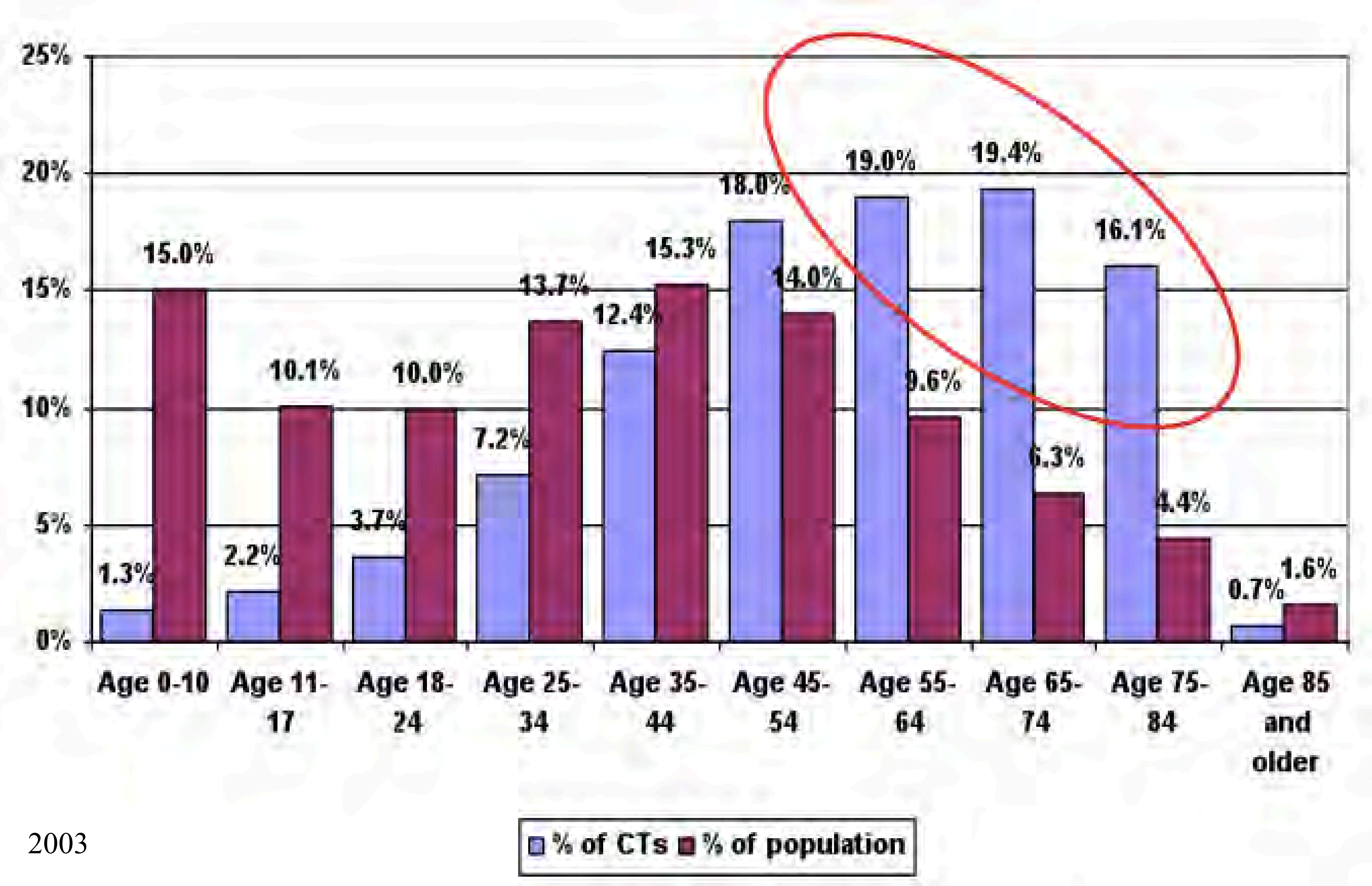
- Rational Exam Selection
  - Reducing Variation
    - Appropriateness criteria
    - Diagnostic algorithms
    - Decision support

Age vs. Risk of Ionizing Radiation



Health risks from exposure to low levels of ionizing radiation — BEIR VII
(National Academies Press, Washington, 2005)

Age Distribution of CT Scans



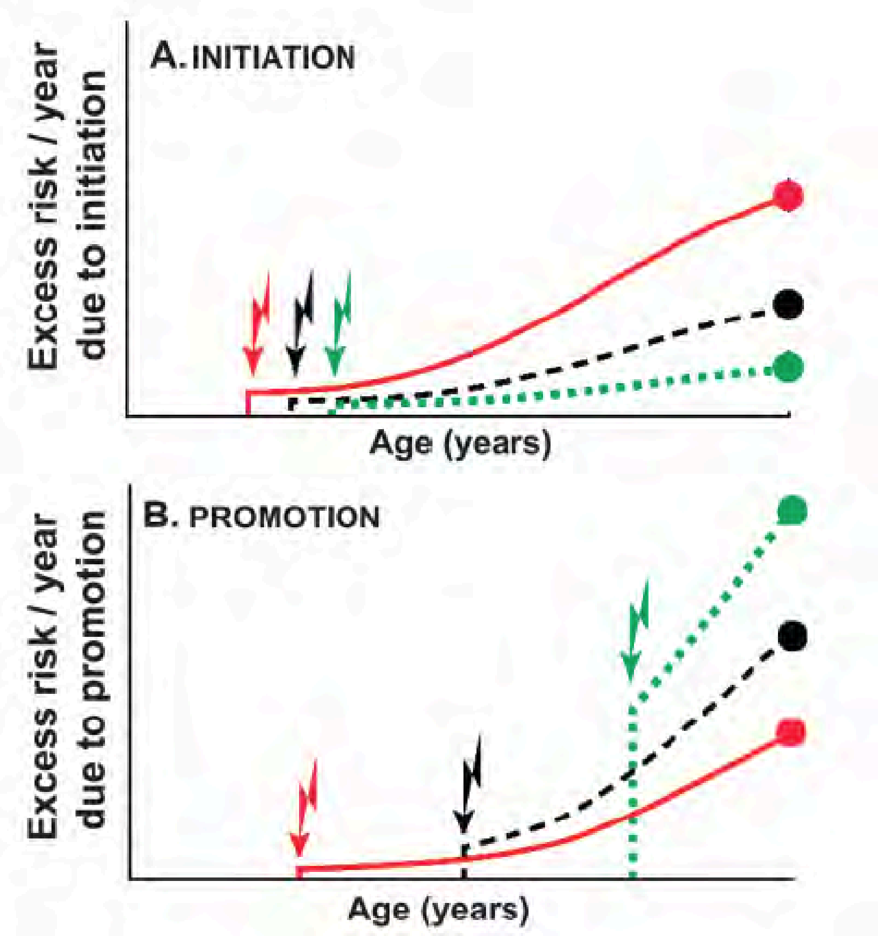
2003

Mettler et al. Health Phys. 95(5), 502-507 (2008)

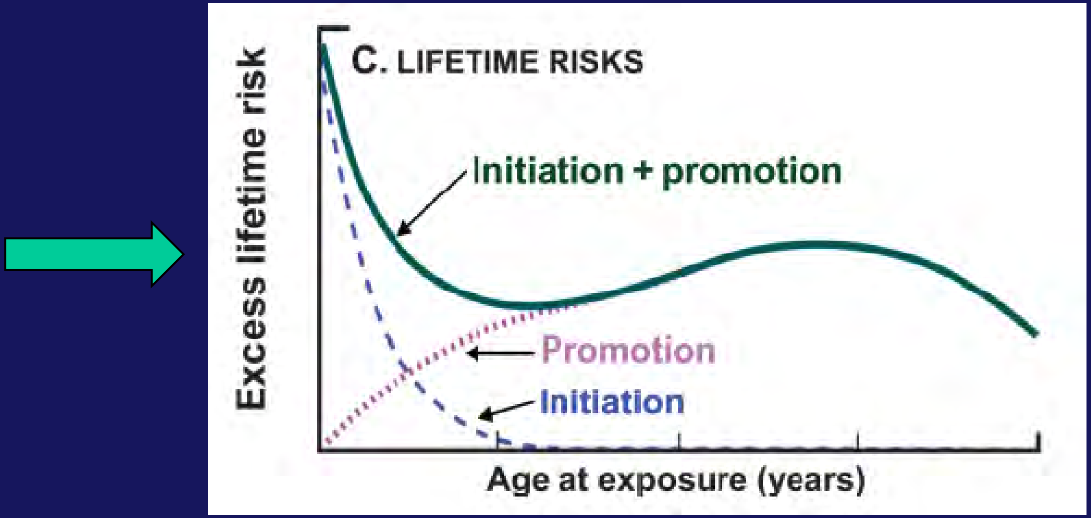
Cancer Risks After Radiation Exposure in Middle Age

Igor Shuryak, Rainer K. Sachs, David J. Brenner

J Natl Cancer Inst 2010;0:1–9



In people irradiated at younger ages, initiated cells have longer to exploit their growth advantage over normal cells.

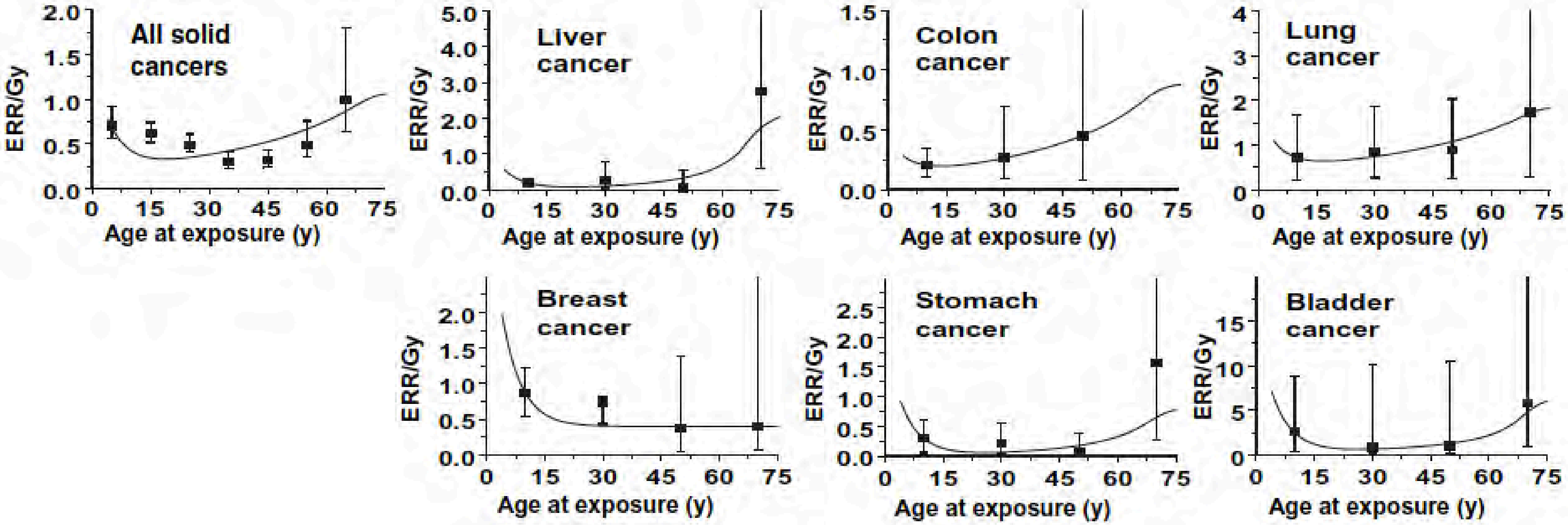


People irradiated at older ages, when there are more premalignant cells for promotion to act upon, are expected to have larger promotion-driven risks.

Cancer Risks After Radiation Exposure in Middle Age

Igor Shuryak, Rainer K. Sachs, David J. Brenner

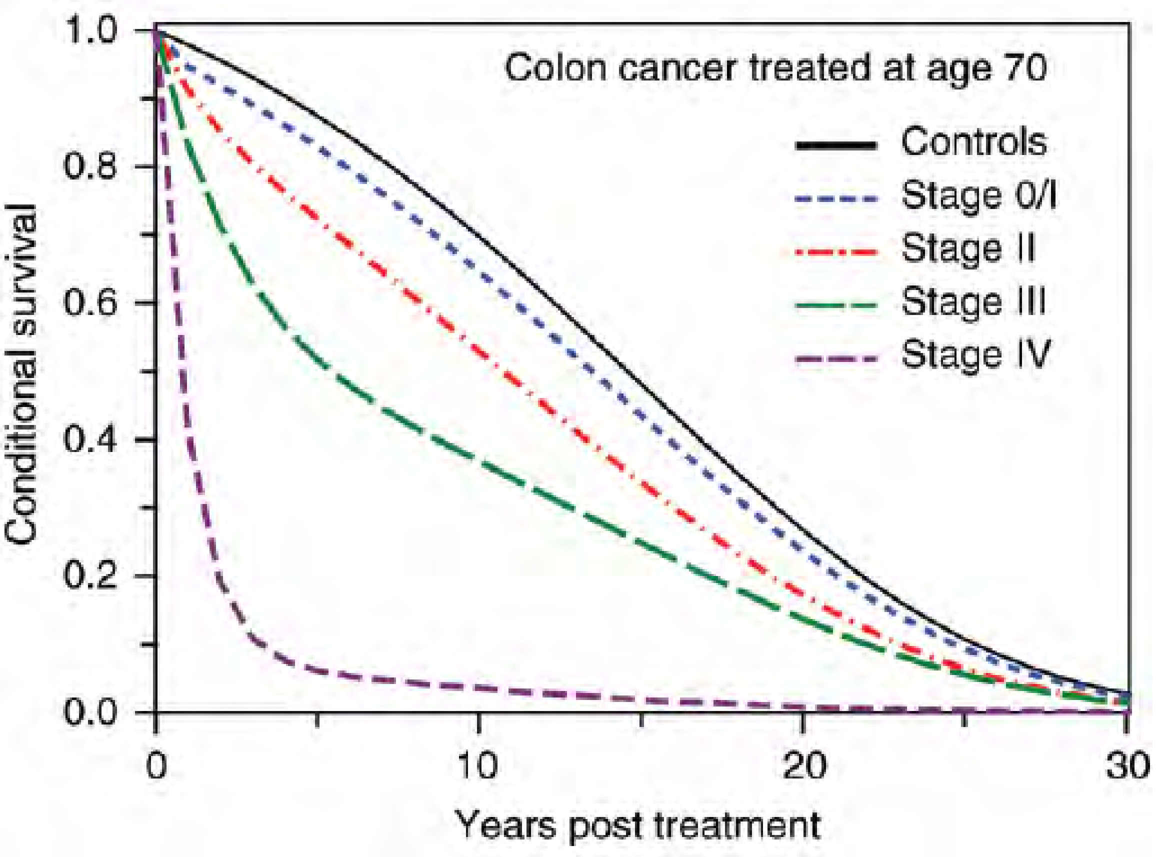
J Natl Cancer Inst 2010;0:1–9

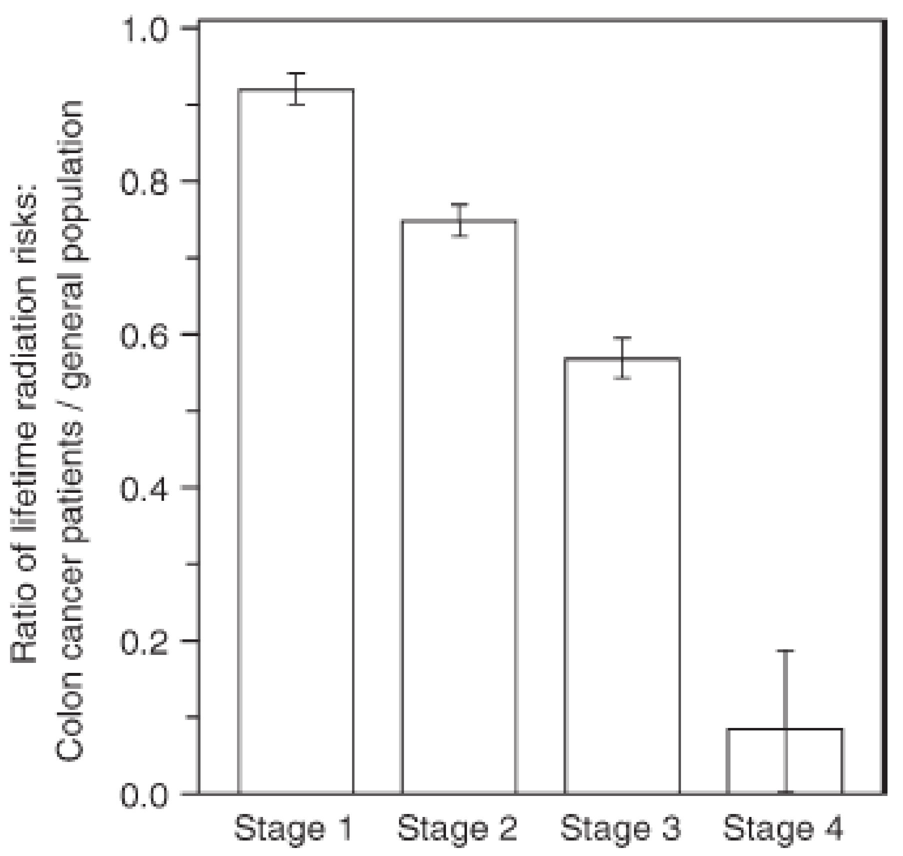


The relative contribution of initiation vs promotion is 10-fold larger for breast cancer than for lung cancer. Reflecting this difference, radiation-induced breast cancer risks decrease with age at exposure at all ages, whereas radiation-induced lung cancer risks do not.

Other interpretations are possible. For example, the data may be consistent with an abrupt age-dependent increase in smoking and/or drinking patterns among survivors.

Impact of Life Expectancy





“For a 70-year-old patient with colon cancer, the estimated reduction in lifetime radiation-associated lung cancer risk is approximately 92% for stage IV disease, versus 8% for stage 0 or I”

Brenner DJ, Shuryak I, Einstein AJ. Radiology 261, 193-198 (2011)

Dose Tracking & Rational Exam Selection

- Patient Tracking
  - Dose Metrics
    - Impact of body habitus
  - Risk Estimates
    - Impact of age, life expectancy
    - Effective dose vs. organ dose

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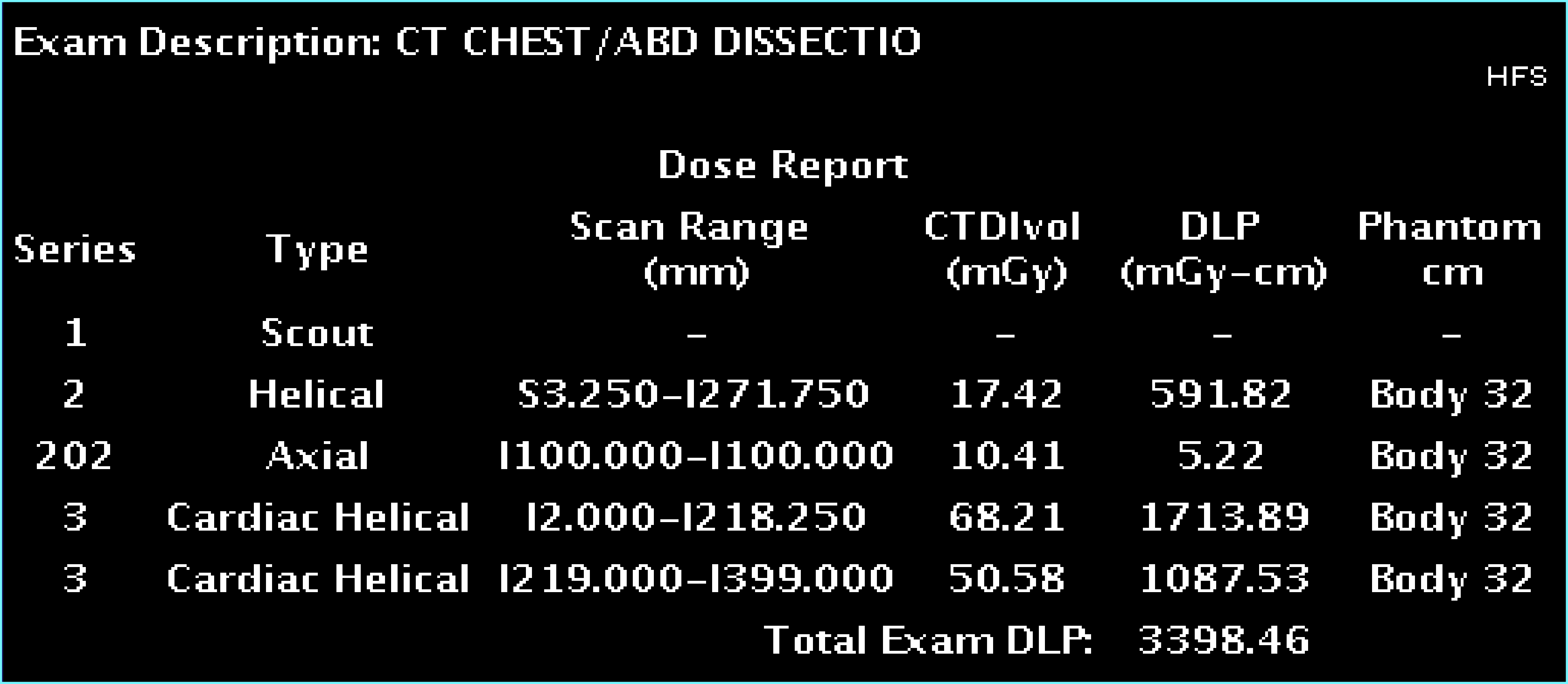
    - Diagnostic algorithms
    - Decision support



Exam Description: CT CHEST/ABD DISSECTIO

HFS

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	S3.250-I271.750	17.42	591.82	Body 32
202	Axial	I100.000-I100.000	10.41	5.22	Body 32
3	Cardiac Helical	I2.000-I218.250	68.21	1713.89	Body 32
3	Cardiac Helical	I219.000-I399.000	50.58	1087.53	Body 32
			Total Exam DLP:	3398.46	

Effective Dose = DLP x 0.017 mSv/mGy cm

= 57.8 mSv

(gated, but without tube current modulation)

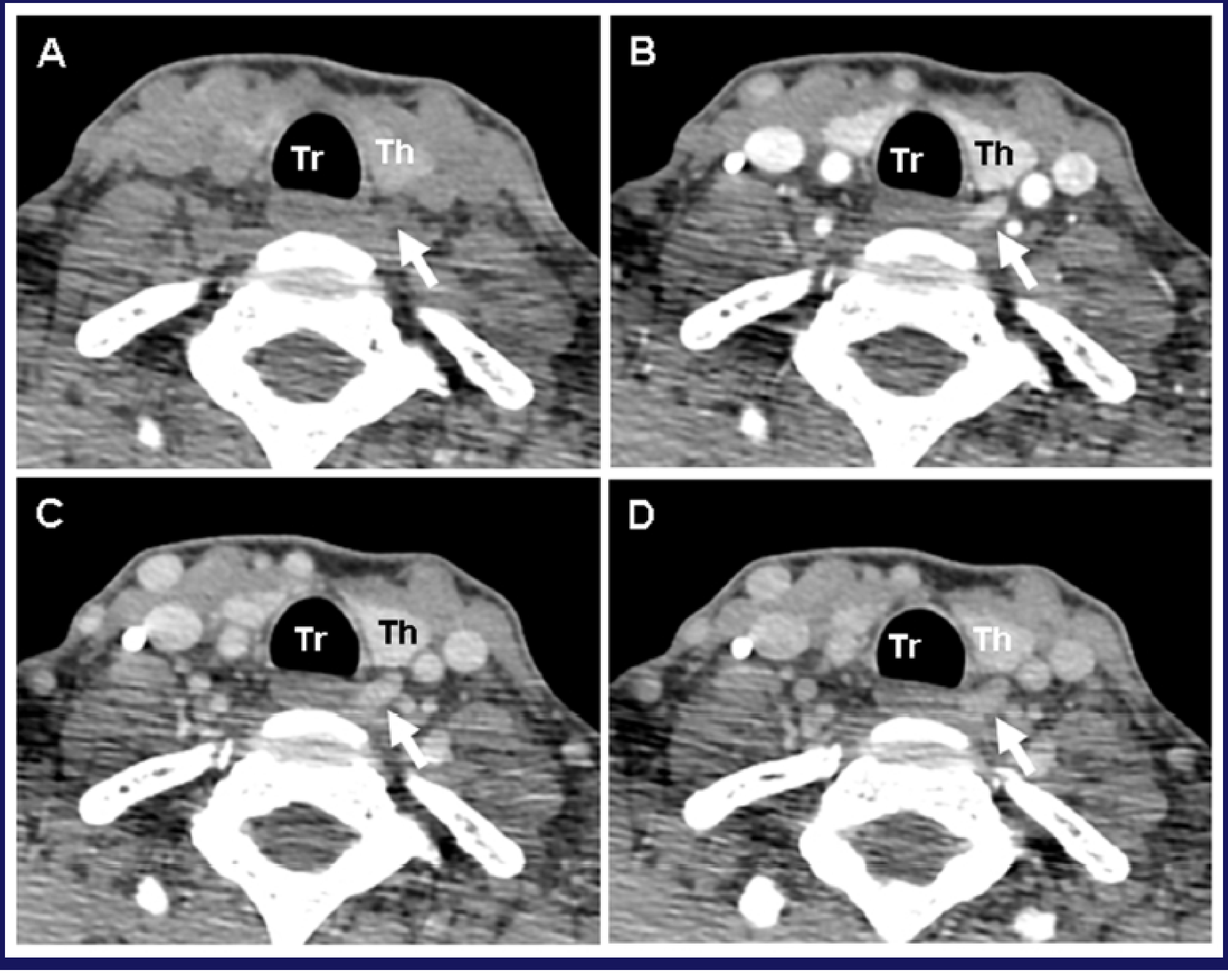
Effective Dose

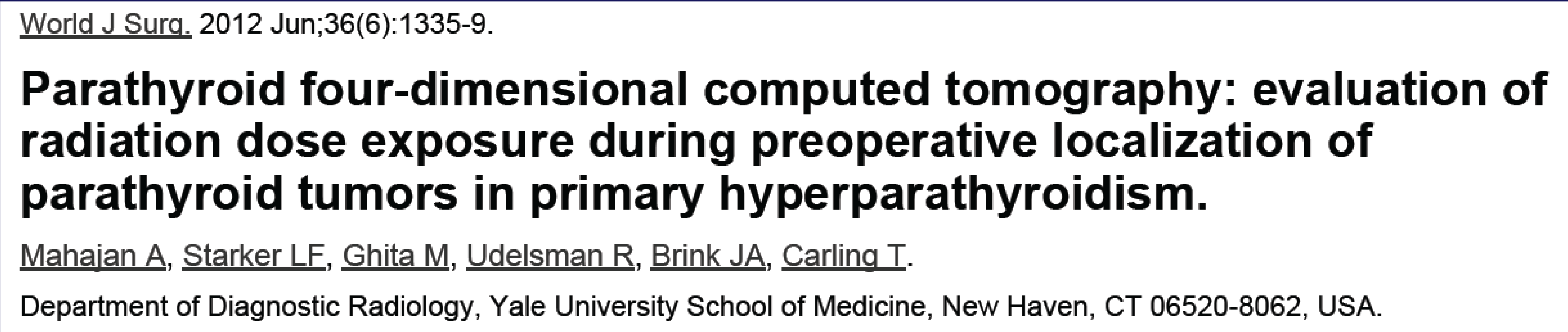
Estimate effective dose from DLP

Region	mSv / mGy cm
Head	0.0023
Neck	0.0050
Chest	0.017
Abdomen	0.015
Pelvis	0.019

Jessen KA. Appl. Radiat. Isotopes 165-172 (1999)
(This method is used in the ACR CT Accreditation Program)

Organ Dose and Risk Estimation




World J Surg. 2012 Jun;36(6):1335-9.

Parathyroid four-dimensional computed tomography: evaluation of radiation dose exposure during preoperative localization of parathyroid tumors in primary hyperparathyroidism.

Mahajan A, Starker LF, Ghita M, Udelsman R, Brink JA, Carling T.

Department of Diagnostic Radiology, Yale University School of Medicine, New Haven, CT 06520-8062, USA.

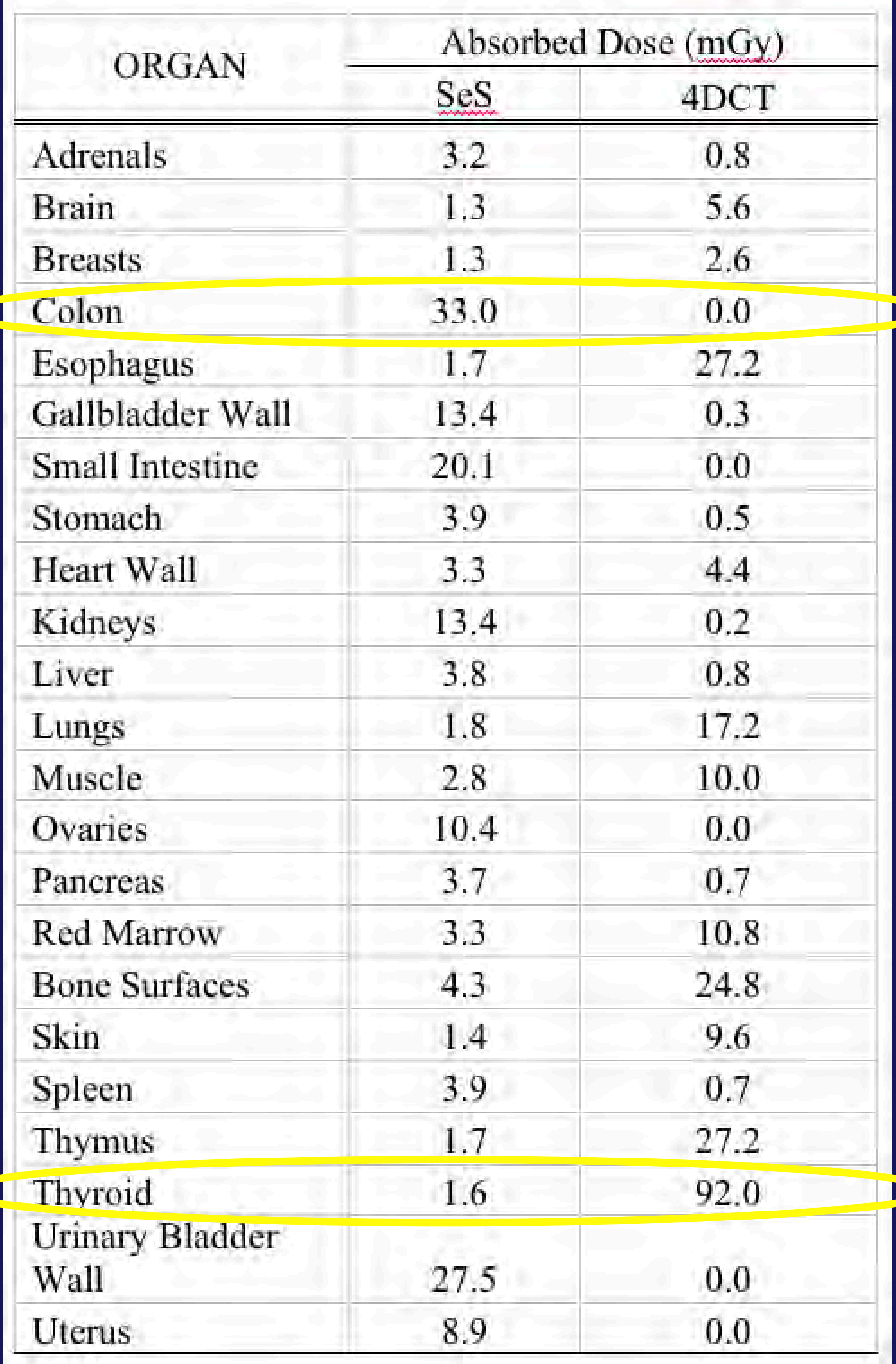
4-D CT vs. Sestamibi Scan

- 4-D CT: 1.25 mm helical scan at 0, 30, 60, 90 s
  - 120 kV, 128 mAs, CTDI_{vol} = 10.8 mGy, DLP = 248 mGy cm
- SeS: 20 mCi of Tc-99m sestamibi
- Dose Estimation:
  - 4-D CT: ImPACT Dose Calculator
  - SeS: NUREG Method (US Nuclear Regulatory Commission)
- Cancer Risk Estimation:
  - Age and gender-dependent risk factors from BEIR VII

Parathyroid Imaging

- Effective Dose:
  - 4-D CT: 10.4 mSv
  - SeS: 7.8 mSv

Organ Doses

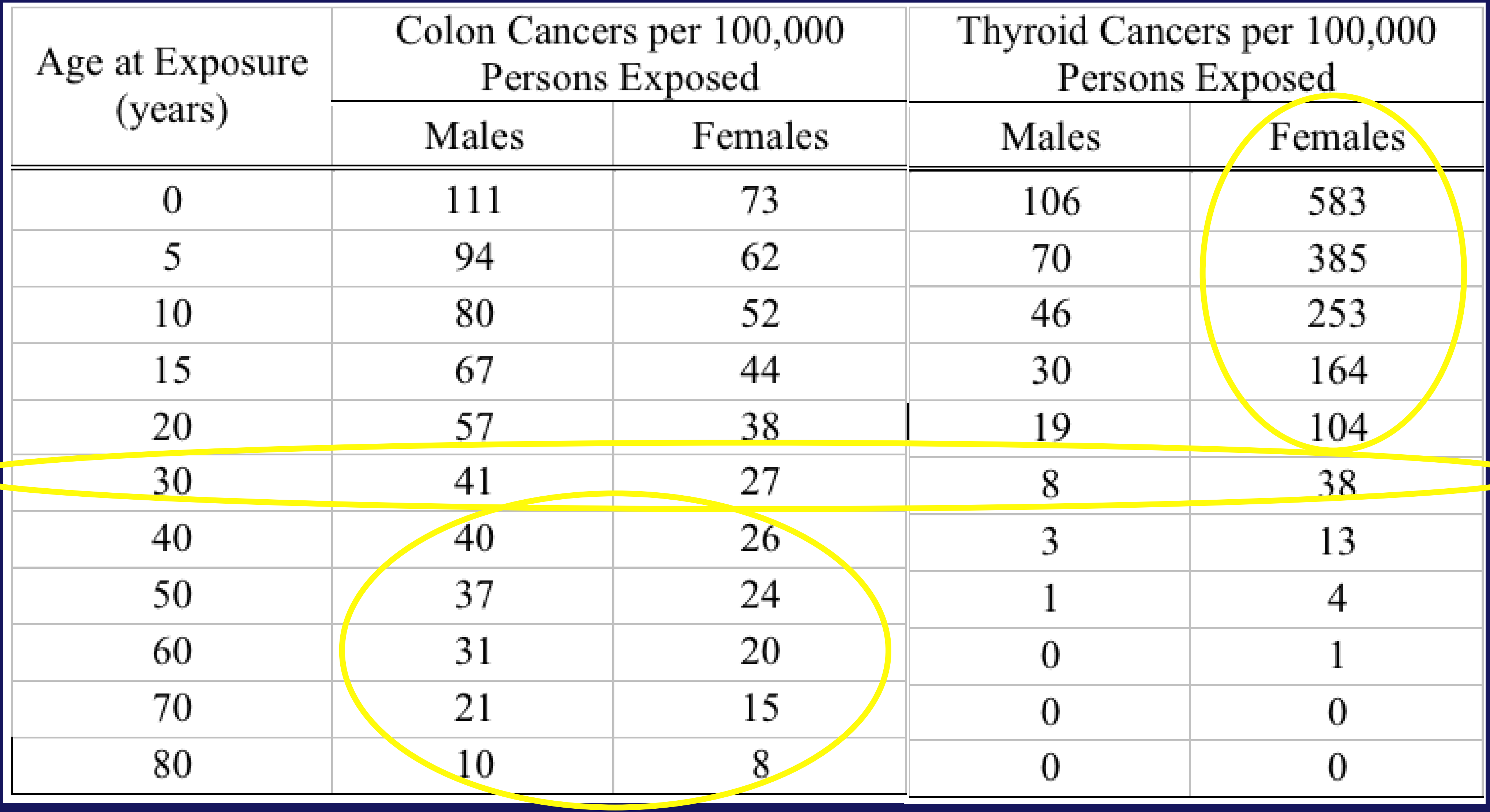


ORGAN	Absorbed Dose (mGy)	
	SeS	4DCT
Adrenals	3.2	0.8
Brain	1.3	5.6
Breasts	1.3	2.6
Colon	33.0	0.0
Esophagus	1.7	27.2
Gallbladder Wall	13.4	0.3
Small Intestine	20.1	0.0
Stomach	3.9	0.5
Heart Wall	3.3	4.4
Kidneys	13.4	0.2
Liver	3.8	0.8
Lungs	1.8	17.2
Muscle	2.8	10.0
Ovaries	10.4	0.0
Pancreas	3.7	0.7
Red Marrow	3.3	10.8
Bone Surfaces	4.3	24.8
Skin	1.4	9.6
Spleen	3.9	0.7
Thymus	1.7	27.2
Thyroid	1.6	92.0
Urinary Bladder Wall	27.5	0.0
Uterus	8.9	0.0

Cancer Risk

SeS

4-D CT



Age at Exposure (years)	Colon Cancers per 100,000 Persons Exposed		Thyroid Cancers per 100,000 Persons Exposed	
	Males	Females	Males	Females
0	111	73	106	583
5	94	62	70	385
10	80	52	46	253
15	67	44	30	164
20	57	38	19	104
30	41	27	8	38
40	40	26	3	13
50	37	24	1	4
60	31	20	0	1
70	21	15	0	0
80	10	8	0	0

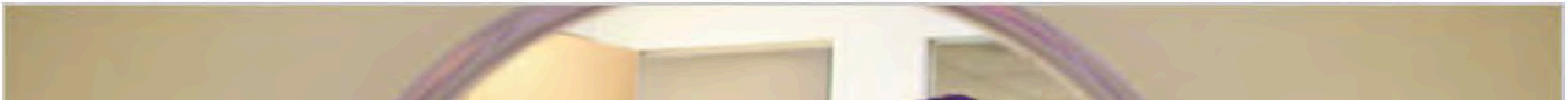
Dose Tracking & Rational Exam Selection

- Patient Tracking
  - Dose Metrics
    - Impact of body habitus
  - Risk Estimates
    - Impact of age, life expectancy
    - Effective dose vs. organ dose

- Rational Exam Selection
  - Reducing Variation
    - Appropriateness criteria
    - Diagnostic algorithms
    - Decision support

The New York Times

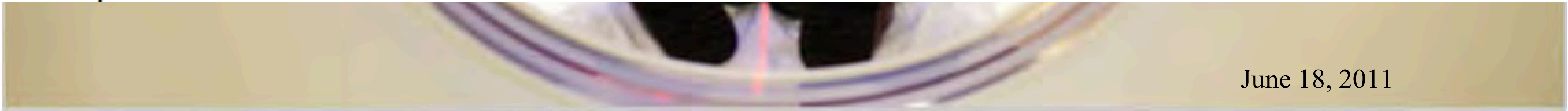
Hospitals Performed Needless Double CT Scans, Records Show



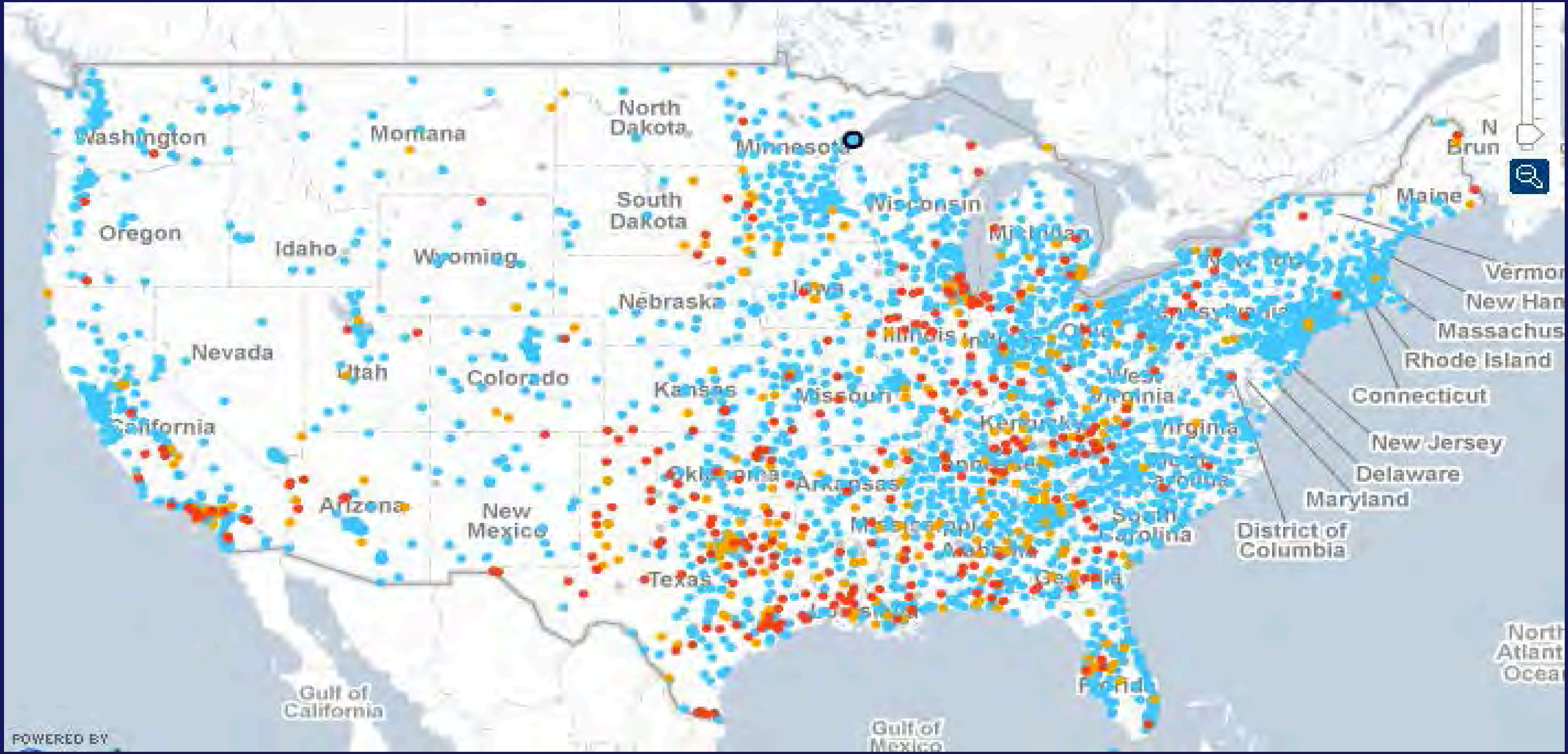
The Medicare agency distributed the data to hospitals last year to show how they performed relative to each other and to encourage more efficient, safer practices. The review of that data found more than 200 hospitals that administered double scans on more than 30 percent of their Medicare outpatients — a percentage that the federal agency and radiology experts considers far too high. The national average is 5.4 percent.

The figures show wide variation among states as well, from 1 percent in Massachusetts to 13 percent in Oklahoma. Overall, Medicare paid hospitals roughly $25 million for double scans in 2008.

Double scanning is more likely to occur at smaller, community hospitals such as Memorial Medical Center of West Michigan in Ludington. It gave two scans to 89 percent of its Medicare chest patients..



June 18, 2011



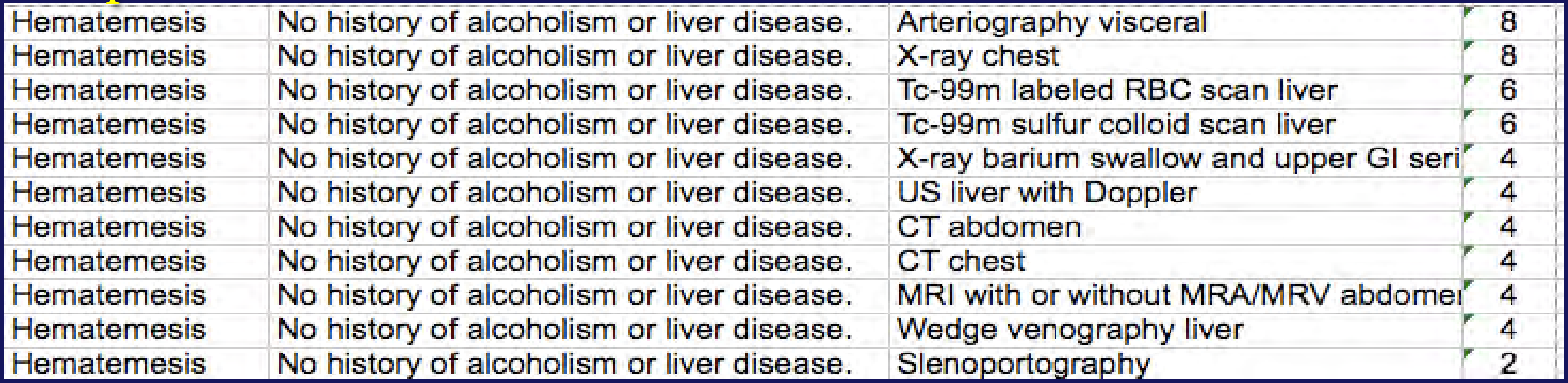
Percentage of patients receiving chest CT scans who were scanned twice

● Below 15% ● 15-29% ● 30% or more

National average: 5.4%

New York Times
June 18, 2011

ACR Appropriateness Criteria

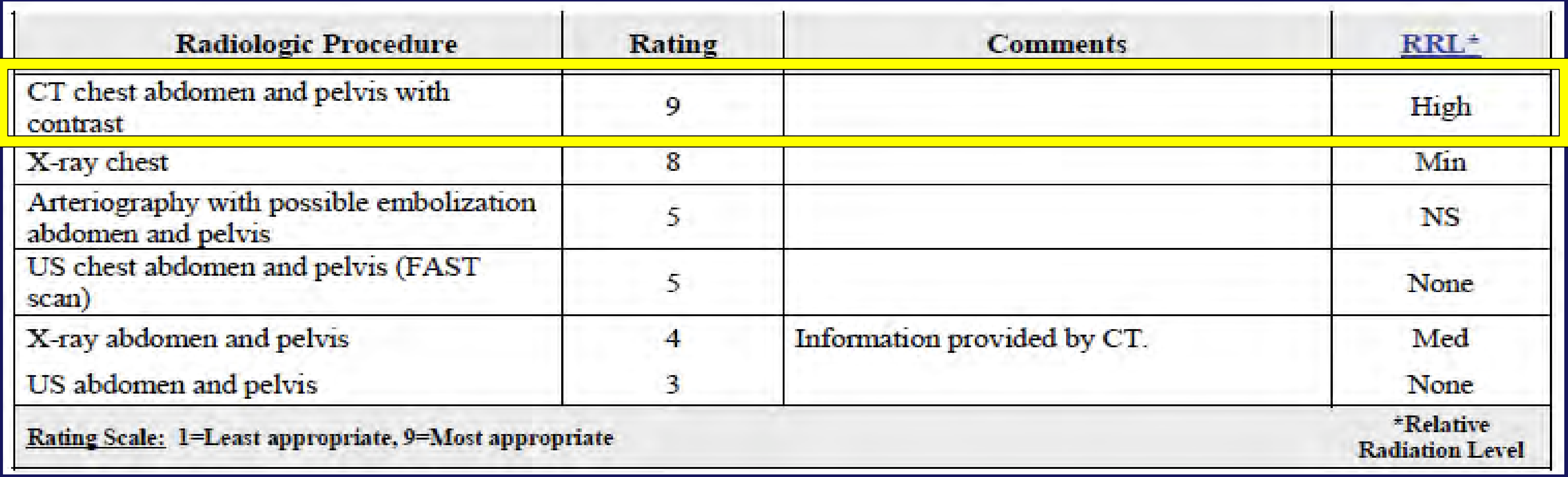


Topic	Variant	Test	AC
Hematemesis	No history of alcoholism or liver disease.	Arteriography visceral	8
Hematemesis	No history of alcoholism or liver disease.	X-ray chest	8
Hematemesis	No history of alcoholism or liver disease.	Tc-99m labeled RBC scan liver	6
Hematemesis	No history of alcoholism or liver disease.	Tc-99m sulfur colloid scan liver	6
Hematemesis	No history of alcoholism or liver disease.	X-ray barium swallow and upper GI seri	4
Hematemesis	No history of alcoholism or liver disease.	US liver with Doppler	4
Hematemesis	No history of alcoholism or liver disease.	CT abdomen	4
Hematemesis	No history of alcoholism or liver disease.	CT chest	4
Hematemesis	No history of alcoholism or liver disease.	MRI with or without MRA/MRV abdome	4
Hematemesis	No history of alcoholism or liver disease.	Wedge venography liver	4
Hematemesis	No history of alcoholism or liver disease.	Slenoportography	2

- 167 Topics, > 800 Variants
- 7578 Topics / Variants / Tests:
- CT is listed as a possible test in 931 / 7578 (12%)

Blunt Abdominal Trauma

Stable Patient – No Hematuria



Radiologic Procedure	Rating	Comments	RRL*
CT chest abdomen and pelvis with contrast	9		High
X-ray chest	8		Min
Arteriography with possible embolization abdomen and pelvis	5		NS
US chest abdomen and pelvis (FAST scan)	5		None
X-ray abdomen and pelvis	4	Information provided by CT.	Med
US abdomen and pelvis	3		None

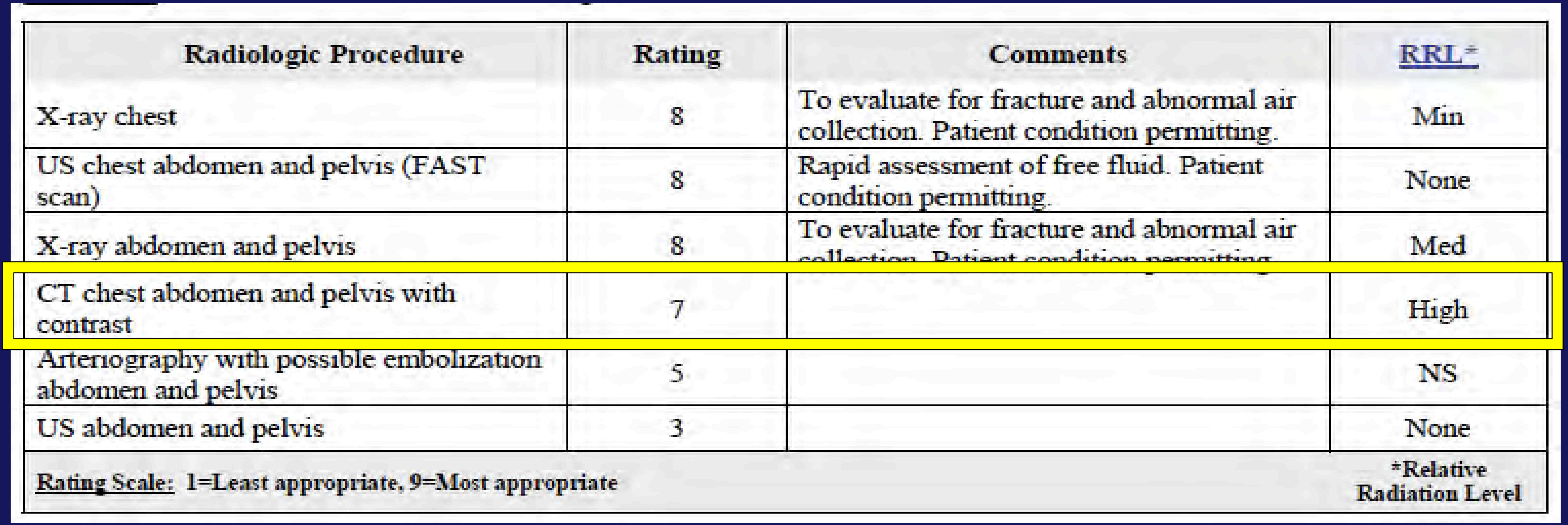
Rating Scale: 1=Least appropriate, 9=Most appropriate

*Relative Radiation Level

- CT is listed as "7, 8, or 9" in 285 / 931 (31%)
- CT is listed as "9" in 115 / 931 (12%)

Blunt Abdominal Trauma

Unstable Patient

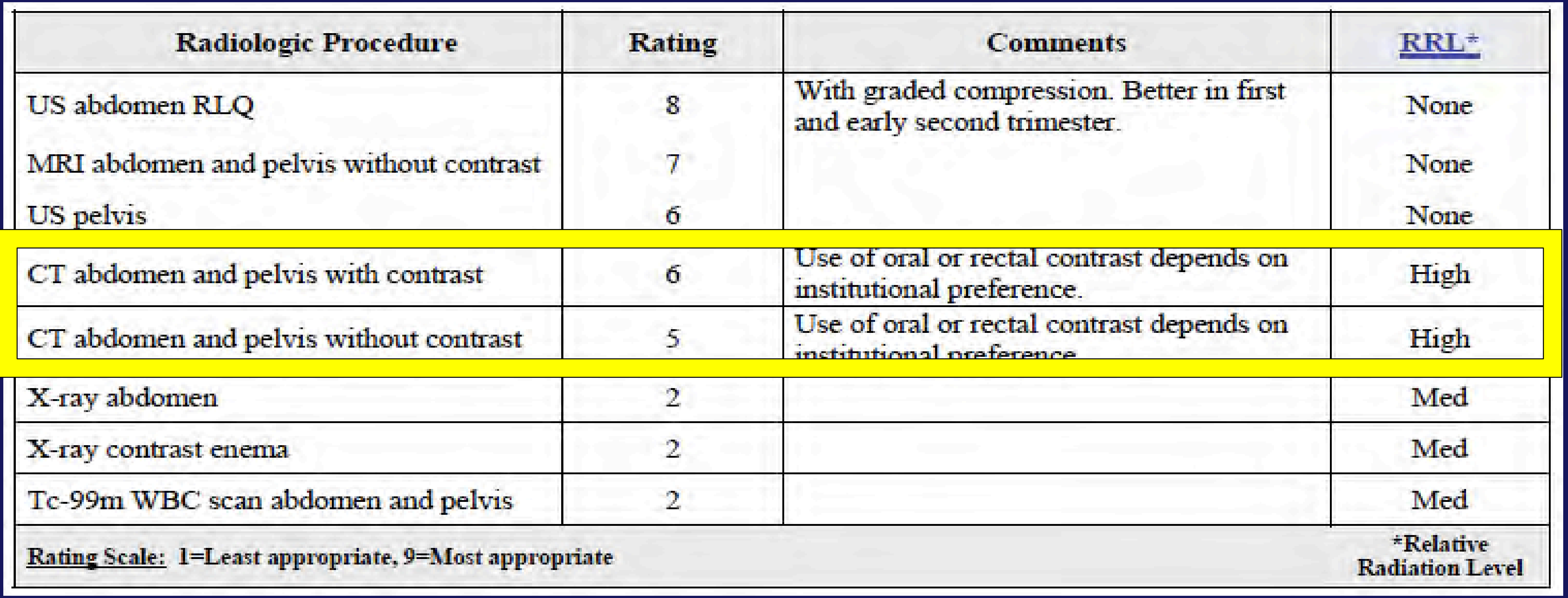


Radiologic Procedure	Rating	Comments	RRL*
X-ray chest	8	To evaluate for fracture and abnormal air collection. Patient condition permitting.	Min
US chest abdomen and pelvis (FAST scan)	8	Rapid assessment of free fluid. Patient condition permitting.	None
X-ray abdomen and pelvis	8	To evaluate for fracture and abnormal air collection. Patient condition permitting.	Med
CT chest abdomen and pelvis with contrast	7		High
Arteriography with possible embolization abdomen and pelvis	5		NS
US abdomen and pelvis	3		None

Rating Scale: 1=Least appropriate, 9=Most appropriate

*Relative Radiation Level

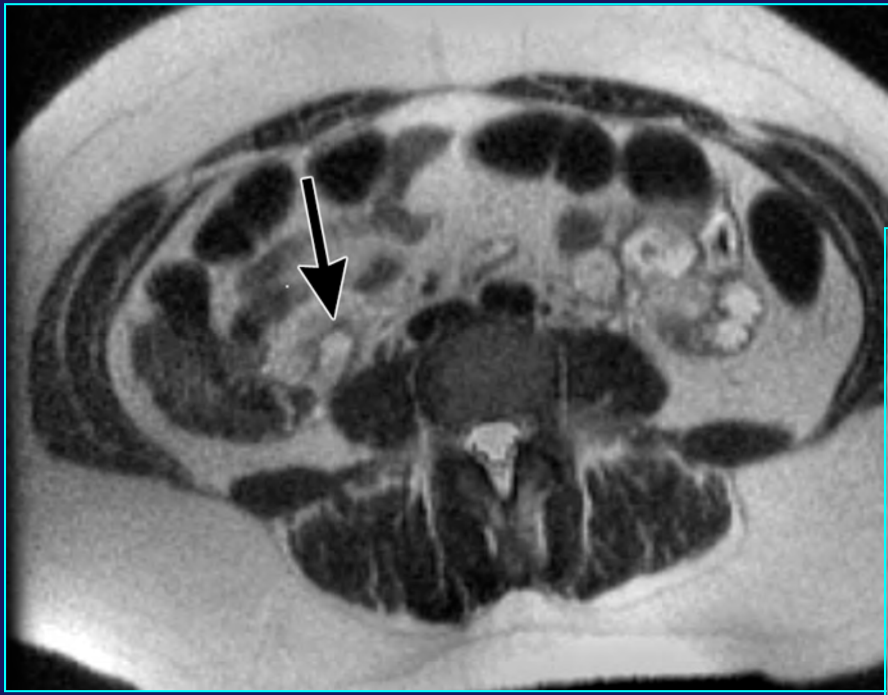
RLQ Pain in Pregnancy (w/ Fever, WBCs)

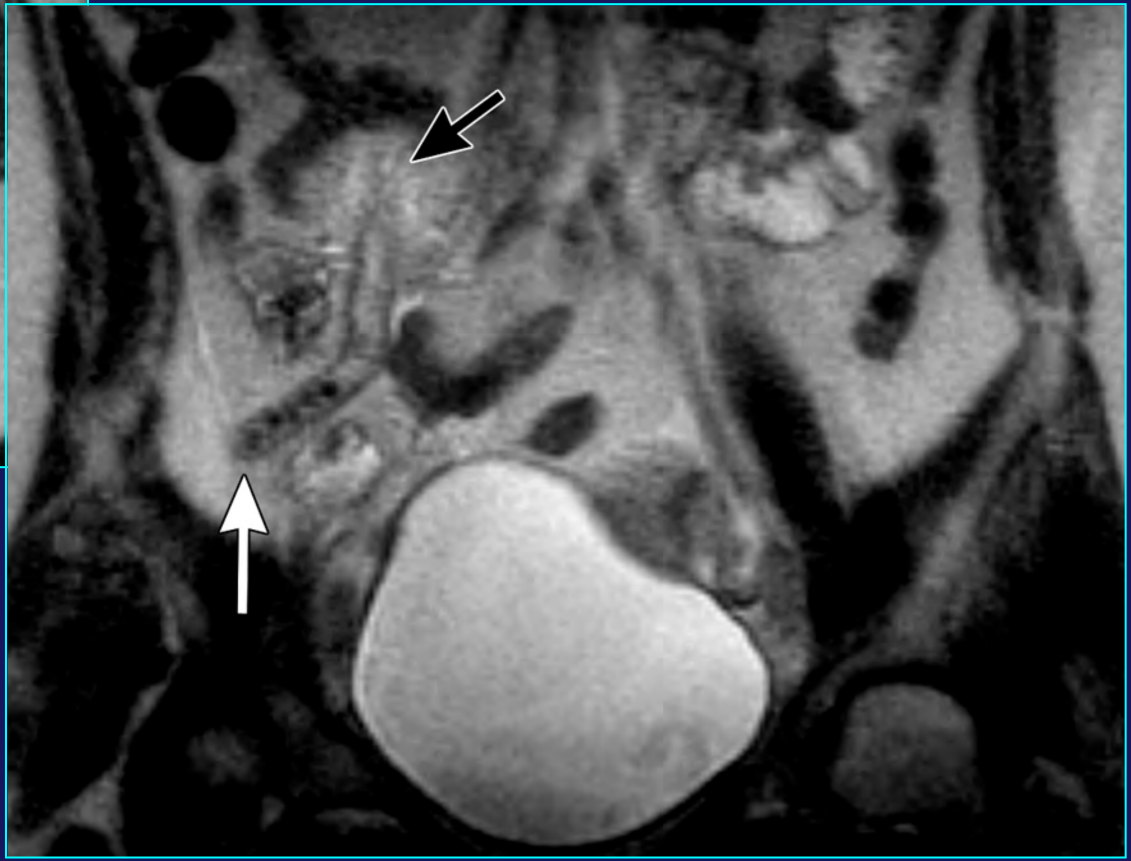


Radiologic Procedure	Rating	Comments	RRL*
US abdomen RLQ	8	With graded compression. Better in first and early second trimester.	None
MRI abdomen and pelvis without contrast	7		None
US pelvis	6		None
CT abdomen and pelvis with contrast	6	Use of oral or rectal contrast depends on institutional preference.	High
CT abdomen and pelvis without contrast	5	Use of oral or rectal contrast depends on institutional preference	High
X-ray abdomen	2		Med
X-ray contrast enema	2		Med
Tc-99m WBC scan abdomen and pelvis	2		Med
Rating Scale: 1=Least appropriate, 9=Most appropriate			*Relative Radiation Level

- US and MR are more appropriate than CT for RLQ pain in pregnant woman

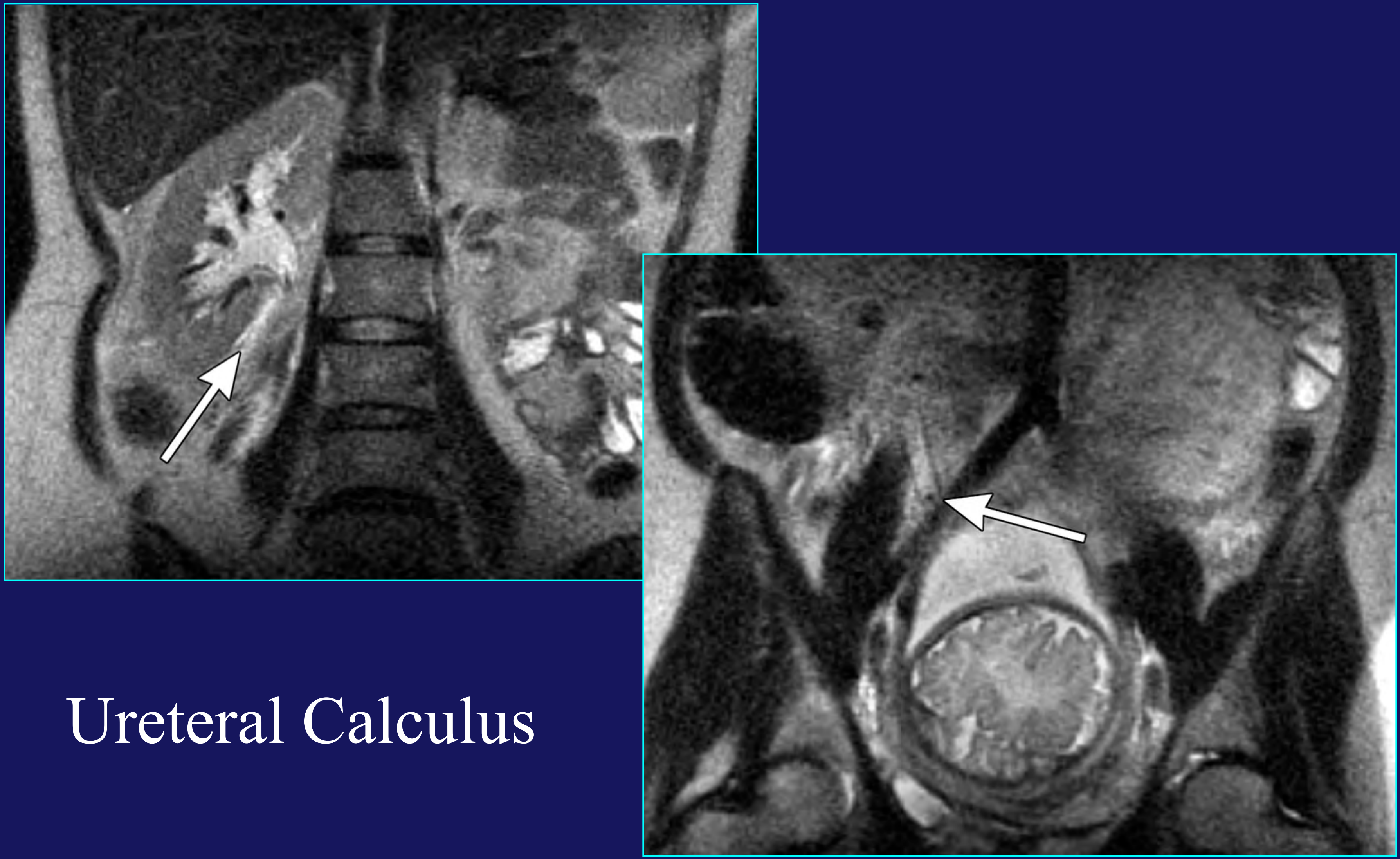
RLQ Pain: Pregnant (26 wks)





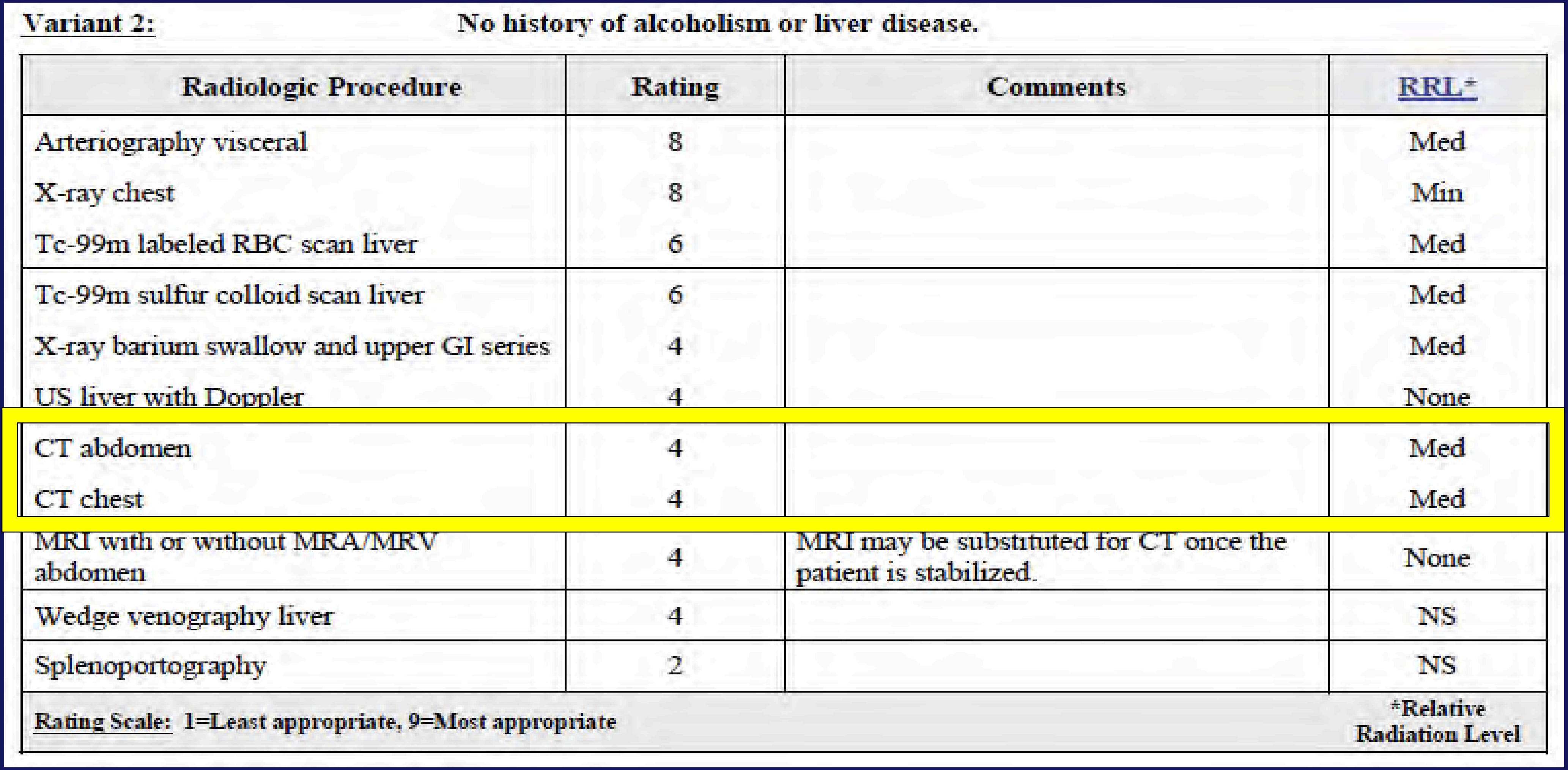
Appendicoliths

RLQ Pain: Pregnant (32 wks)



Ureteral Calculus

Hematemesis, No History of Alcoholism or Liver Disease



Variant 2: **No history of alcoholism or liver disease.**

Radiologic Procedure	Rating	Comments	RRL*
Arteriography visceral	8		Med
X-ray chest	8		Min
Tc-99m labeled RBC scan liver	6		Med
Tc-99m sulfur colloid scan liver	6		Med
X-ray barium swallow and upper GI series	4		Med
US liver with Doppler	4		None
CT abdomen	4		Med
CT chest	4		Med
MRI with or without MRA/MRV abdomen	4	MRI may be substituted for CT once the patient is stabilized.	None
Wedge venography liver	4		NS
Splenoportography	2		NS

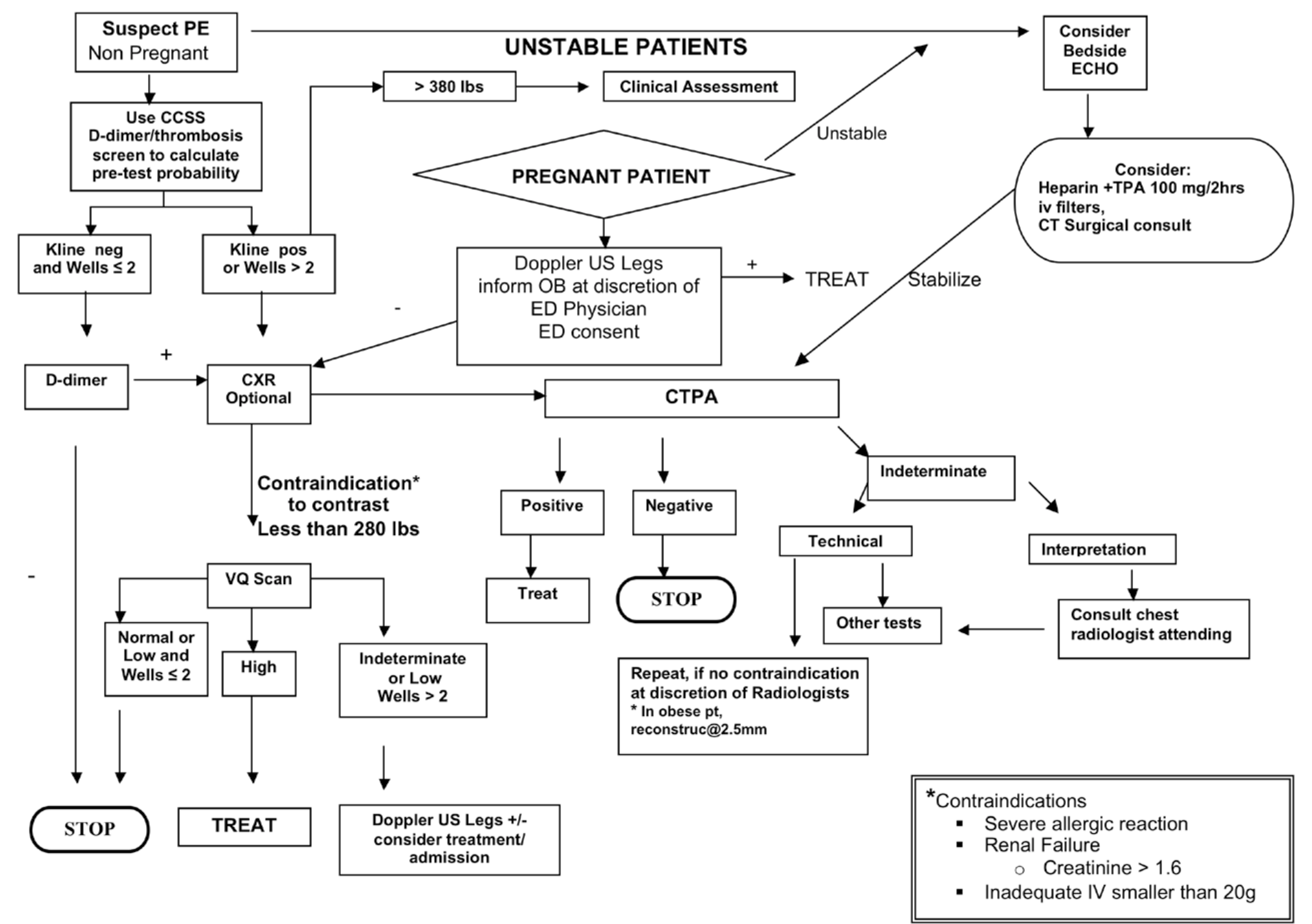
Rating Scale: 1=Least appropriate, 9=Most appropriate

*Relative Radiation Level

Imaging Pathways / Algorithms

- Practice of radiology is highly variable
  - Need to standardize our practices/processes among institutions across the country
    - Multidisciplinary diagnostic algorithms that go beyond appropriateness criteria

Diagnostic Algorithm for Suspected PE



Suspect PE
Non Pregnant

UNSTABLE PATIENTS

Consider Bedside ECHO

Consider:
Heparin +TPA 100 mg/2hrs
iv filters,
CT Surgical consult

Stabilize

Use CCSS D-dimer/thrombosis screen to calculate pre-test probability

Kline neg and Wells ≤ 2

Kline pos or Wells > 2

> 380 lbs

Clinical Assessment

PREGNANT PATIENT

Unstable

Doppler US Legs
inform OB at discretion of ED Physician
ED consent

+ TREAT

-

D-dimer

+

CXR Optional

CTPA

Contraindication* to contrast
Less than 280 lbs

-

VQ Scan

Normal or Low and Wells ≤ 2

High

Indeterminate or Low Wells > 2

STOP

TREAT

Doppler US Legs +/- consider treatment/ admission

Positive

Treat

Negative

STOP

Indeterminate

Technical

Interpretation

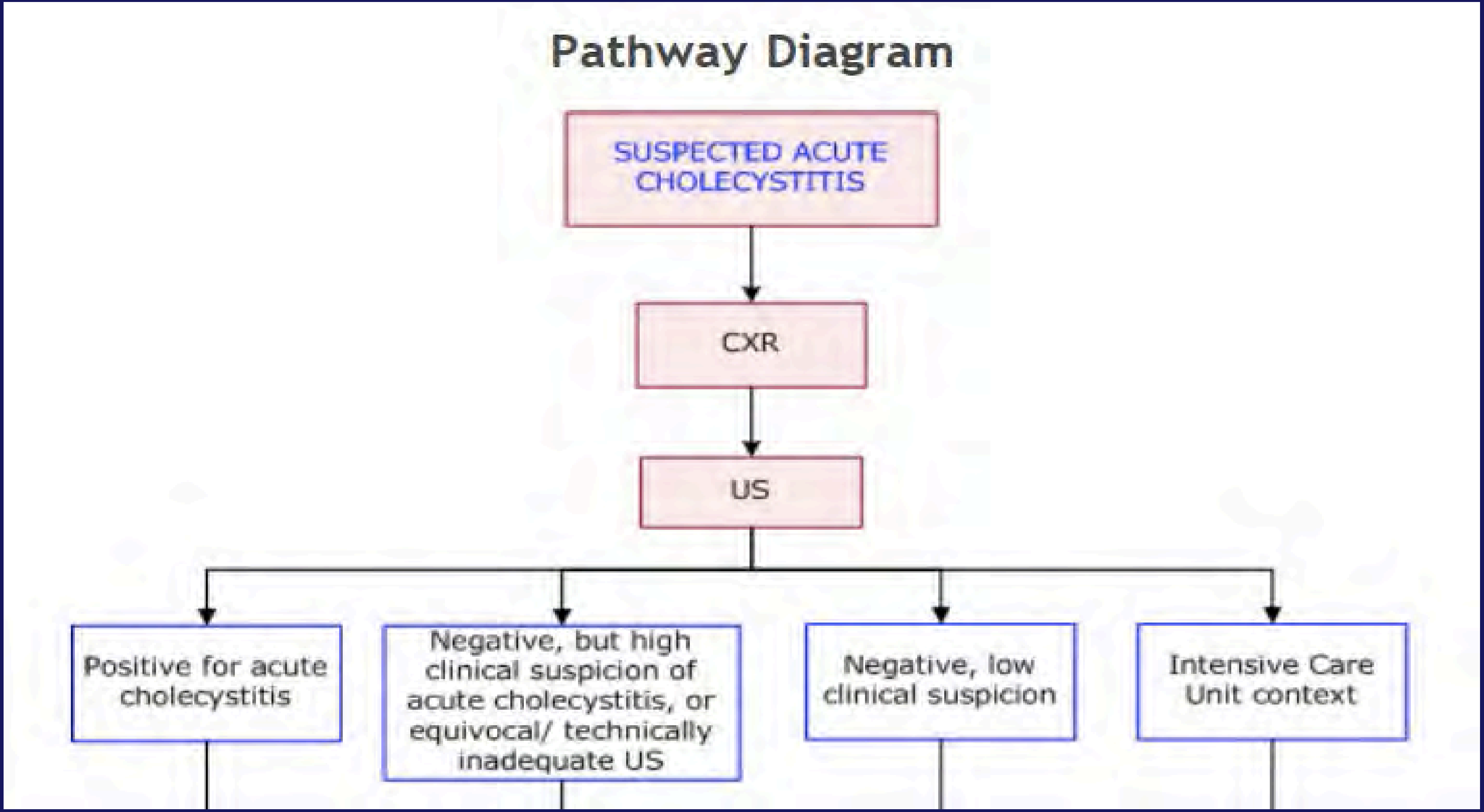
Other tests

Consult chest radiologist attending

Repeat, if no contraindication at discretion of Radiologists
* In obese pt, reconstruc@2.5mm

*Contraindications
- Severe allergic reaction
- Renal Failure
  - Creatinine > 1.6
- Inadequate IV smaller than 20g

Australian Diagnostic Pathways



Pathway Diagram

SUSPECTED ACUTE CHOLECYSTITIS

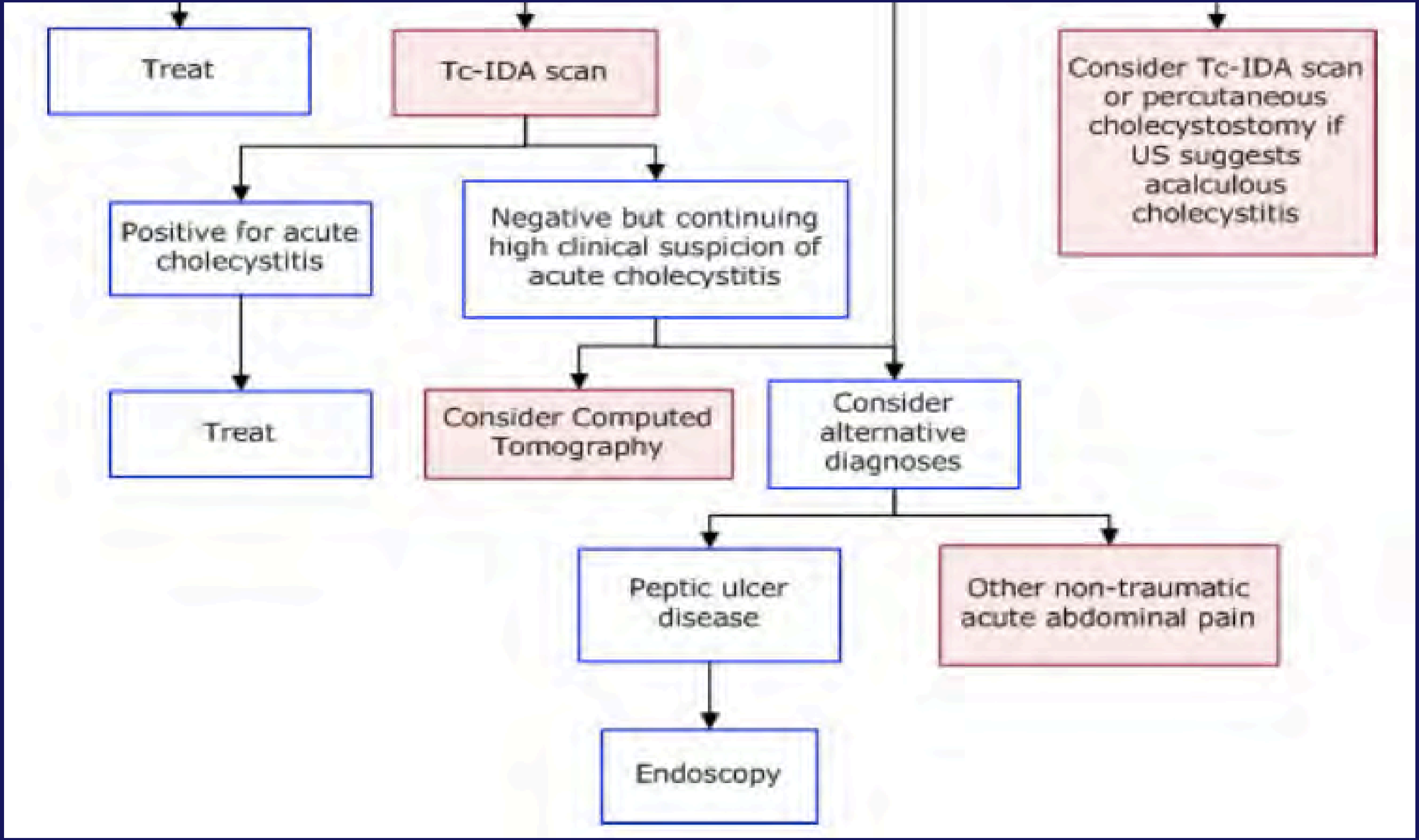
CXR

US

- Positive for acute cholecystitis
- Negative, but high clinical suspicion of acute cholecystitis, or equivocal/ technically inadequate US
- Negative, low clinical suspicion
- Intensive Care Unit context

http://www.imagingpathways.health.wa.gov.au

Australian Diagnostic Pathways



Treat

Tc-IDA scan

Consider Tc-IDA scan or percutaneous cholecystostomy if US suggests acalculous cholecystitis

Positive for acute cholecystitis

Negative but continuing high clinical suspicion of acute cholecystitis

Treat

Consider Computed Tomography

Consider alternative diagnoses

Peptic ulcer disease

Other non-traumatic acute abdominal pain

Endoscopy

http://www.imagingpathways.health.wa.gov.au

Australian Diagnostic Pathways

Endorsed by the Royal Australian and New Zealand College of Radiologists

The Royal Australian and
New Zealand College of Radiologists

Endorsed by the Royal Australian College of General Practitioners

THE ROYAL AUSTRALIAN
COLLEGE OF
GENERAL PRACTITIONERS

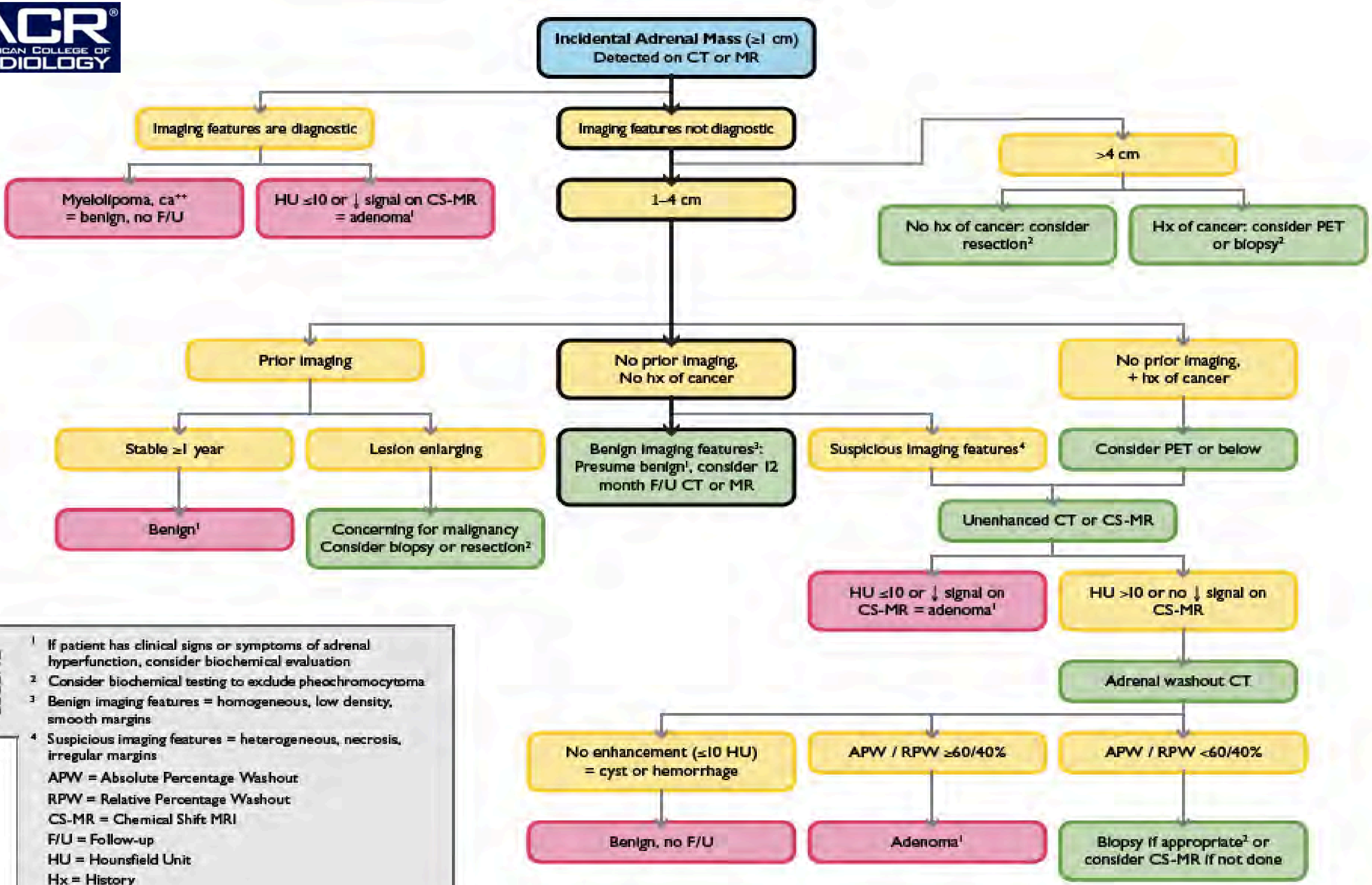
http://www.imagingpathways.health.wa.gov.au

Managing Incidental Findings on Abdominal CT: White Paper of the ACR Incidental Findings Committee

J Am Coll Radiol 2010;7:754-773.

- Algorithms for Liver, Pancreas, Kidney, Adrenal
- Next Steps:
  - Seek buy-in from other professional societies
  - New effort for Adnexa, Vasculature, GB/ Biliary Tree, Spleen, Lymph Nodes

ACR
AMERICAN COLLEGE OF RADIOLOGY



Incidental Adrenal Mass (≥1 cm)
Detected on CT or MR

Imaging features are diagnostic

- Myelolipoma, ca⁺⁺ = benign, no F/U
- HU ≤10 or ↓ signal on CS-MR = adenoma[1]

Imaging features not diagnostic

>4 cm

- No hx of cancer: consider resection[2]
- Hx of cancer: consider PET or biopsy[2]

1–4 cm

Prior imaging

- Stable ≥1 year → Benign[1]
- Lesion enlarging → Concerning for malignancy Consider biopsy or resection[2]

No prior imaging, No hx of cancer

- Benign imaging features[3]: Presume benign[1], consider 12 month F/U CT or MR
- Suspicious imaging features[4]

No prior imaging, + hx of cancer

- Consider PET or below

Unenhanced CT or CS-MR

- HU ≤10 or ↓ signal on CS-MR = adenoma[1]
- HU >10 or no ↓ signal on CS-MR

Adrenal washout CT

- No enhancement (≤10 HU) = cyst or hemorrhage → Benign, no F/U
- APW / RPW ≥60/40% → Adenoma[1]
- APW / RPW <60/40% → Biopsy if appropriate[2] or consider CS-MR if not done

LEGEND

[1] If patient has clinical signs or symptoms of adrenal hyperfunction, consider biochemical evaluation

[2] Consider biochemical testing to exclude pheochromocytoma

[3] Benign imaging features = homogeneous, low density, smooth margins

[4] Suspicious imaging features = heterogeneous, necrosis, irregular margins

APW = Absolute Percentage Washout
RPW = Relative Percentage Washout
CS-MR = Chemical Shift MRI
F/U = Follow-up
HU = Hounsfield Unit
Hx = History
\+ = Positive
↓ = decreased

J Am Coll Radiol 2010;7:754-773.

Appropriate Utilization

"I am an adult and a physician! I don't need your approval for CT scans that are necessary for my patients"

Anon – ER Physician

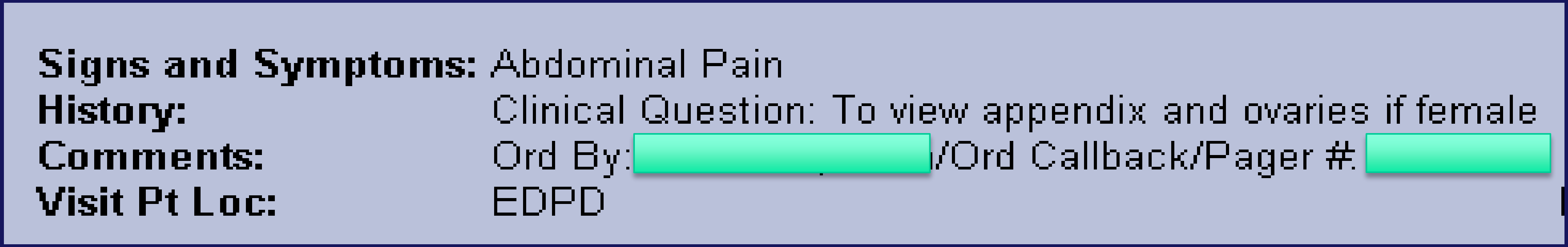
UK: IRMER* (2000)

- Medical Exposures Directive of Council of the European Union**
  - Strict referral criteria
  - Strict justification criteria
  - Dose optimization requirement
  - Dose exposure reference levels

**Ionizing Radiation (Medical Exposures) Regulations*

***Council Directive 97/43 Euratom*

Pressure for Rapid Throughput



Signs and Symptoms: Abdominal Pain
History: Clinical Question: To view appendix and ovaries if female
Comments: Ord By: [redacted] /Ord Callback/Pager #: [redacted]
Visit Pt Loc: EDPD

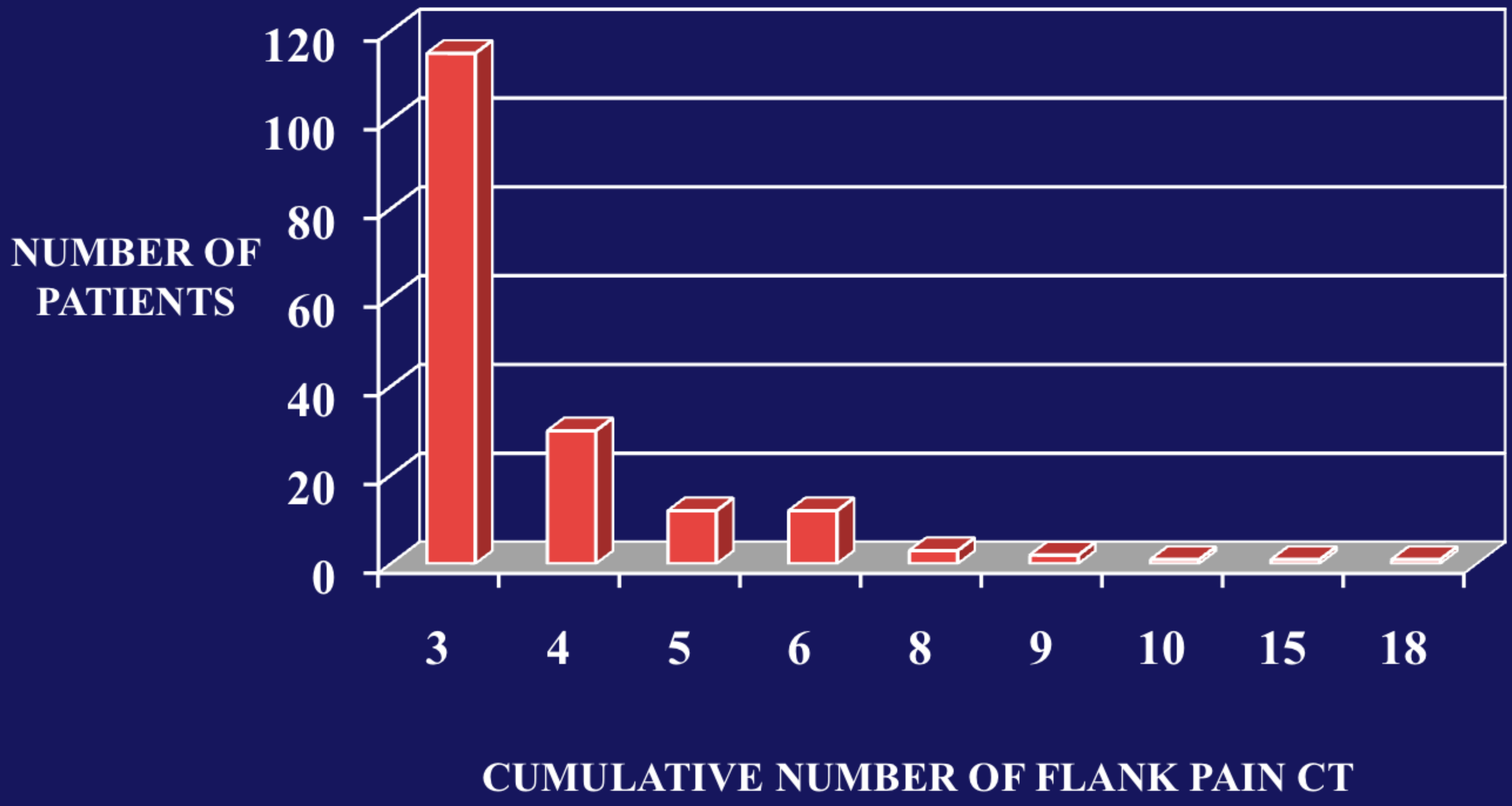
In the US, imaging orders are placed before anyone has seen the patient!

Repetitive CT for Renal Colic

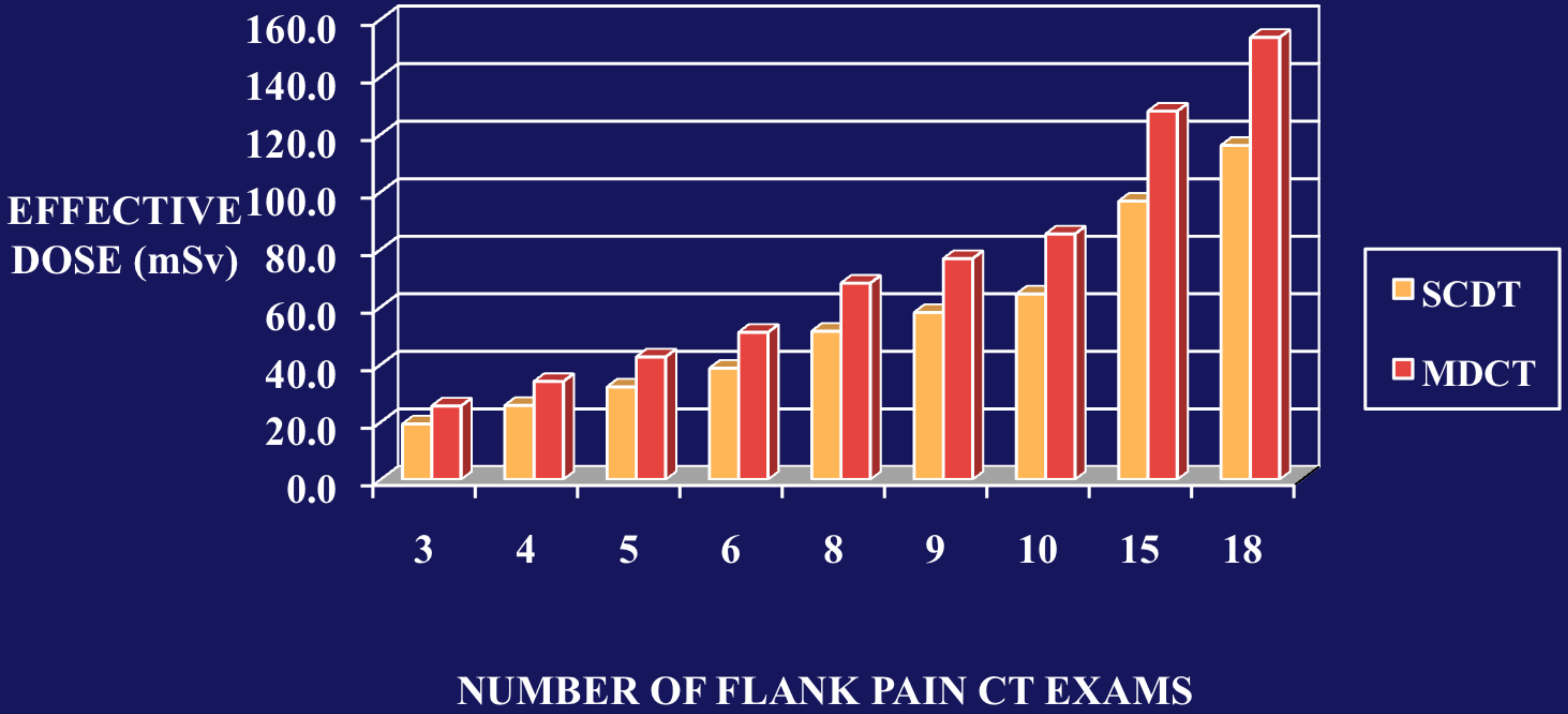
- 6 year period
- 4562 patients
- 5564 CT examinations
- Mean age: 45 years
  - 4% of exams were in children

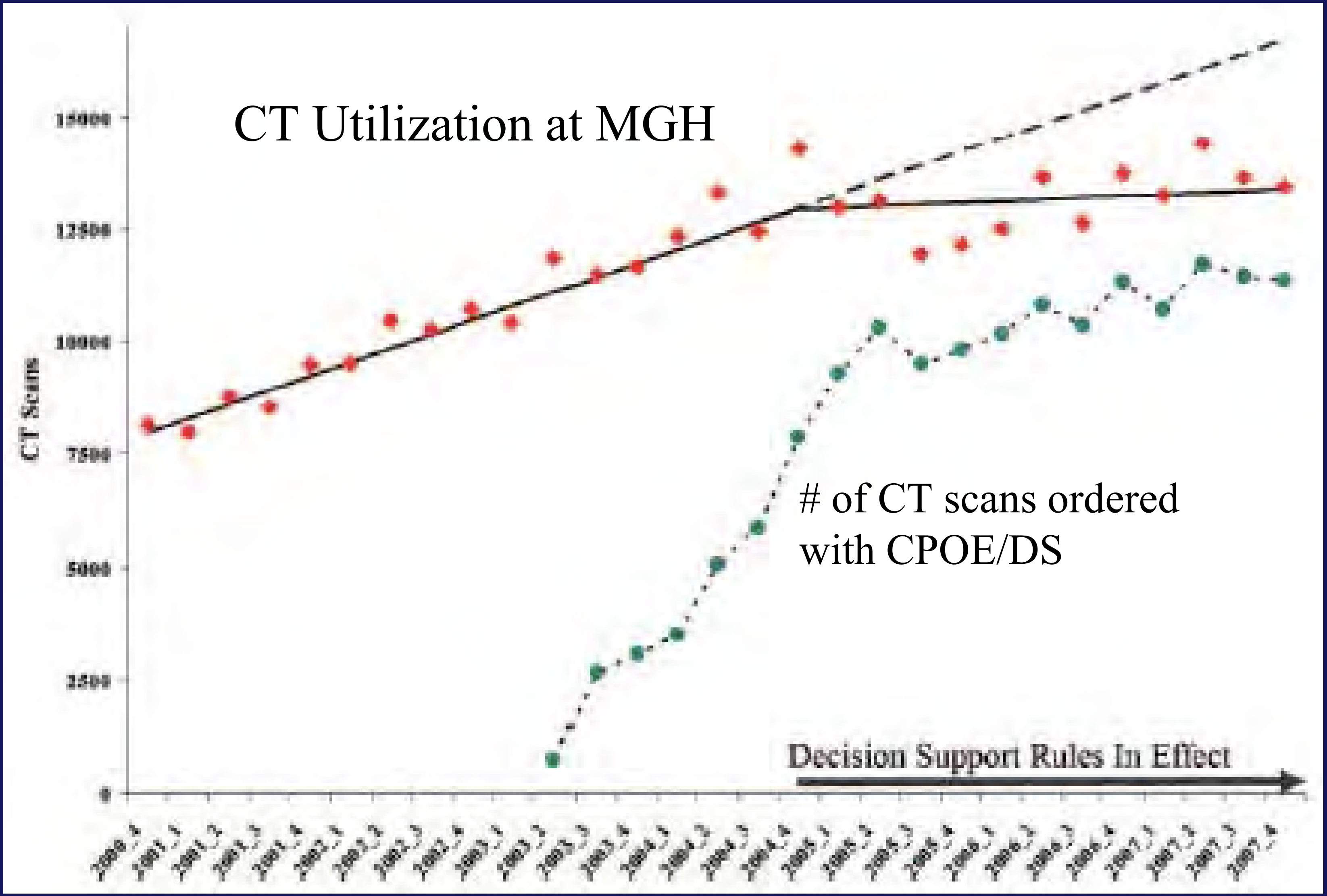
Katz S, Saluja S, Brink JA, Forman HP. *Radiation dose associated with unenhanced CT for suspected renal colic: impact of repetitive studies.* AJR 186, 1120-1124 (2006)

176 Pts (4%) had 3 or more Flank Pain CTs



Estimated Effective Dose





Radiology 251, 147-155 (2009)

Dose Tracking and Rational Exam Selection

- Purpose in tracking
  - Benefit vs. risk (preferably organ vs. whole body)
- Where to track, anticipated outcomes
  - In EMR, lower use
  - Need recommendations for cumulative dose
- What to track, and for how long?
  - Indefinite, to enable long-term follow-up
  - Need to consider body habitus, age, life expectancy
- Decision support system
  - Based on appropriateness criteria, algorithms
  - Will reduce error in use of radiation, contrast media

Second Malignant Neoplasms and Cardiovascular Disease After Radiotherapy

Report of the NCRP SC-17 Committee

Lois B. Travis, M.D., Sc.D.
Director, Rubin Center for Cancer Survivorship
Professor, Department of Radiation Oncology
University of Rochester Medical Center
Rochester, New York

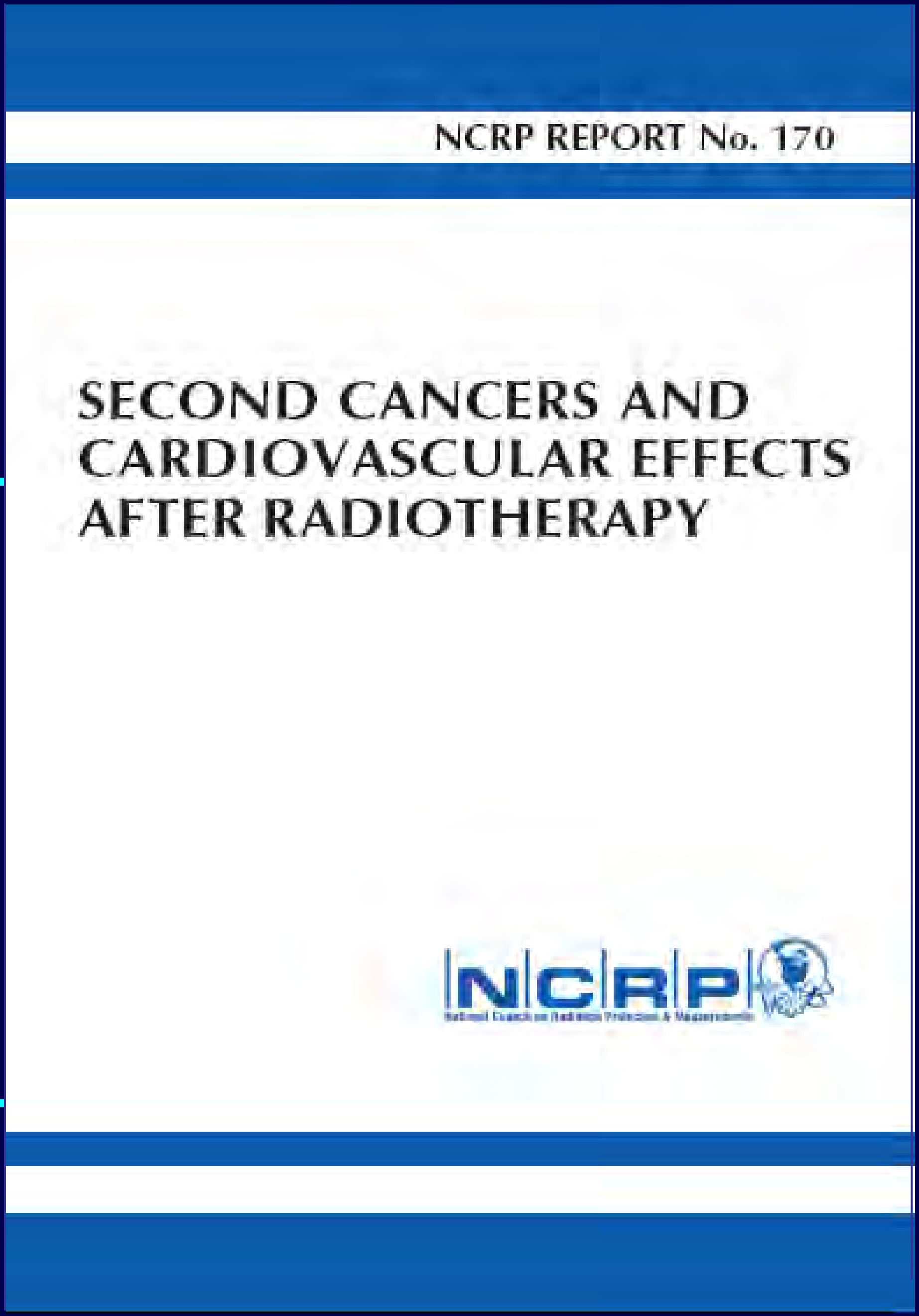
NCRP Meeting
March 11, 2013

National Council on Radiation Protection and Measurements

Report 170

- 440 pages (May 2012)
- Work: 2006 - 2011
- 12 Committee members
- Countless reviewers
- http://www.NCRPonline.org

Travis LB, Ng AK, Allan JM,…Boice JD Jr. Second malignant neoplasms and cardiovascular disease after radiotherapy. JNCI 104, 357-370 (2012)



NCRP REPORT No. 170

SECOND CANCERS AND
CARDIOVASCULAR EFFECTS
AFTER RADIOTHERAPY

Chapters – NCRP Report No. 170

1-2. Executive Summary; Introduction
3. Radiobiology and Cancer Biology
4. Epidemiologic Methods
5. Modern Radiation Therapy
    Conformal, IMRT, Protons, C-14, Neutrons
6. Dosimetry Relevant to 2nd Cancers
7. Genetic Susceptibility
8. 2nd Cancer Risks
9. 2nd Cancer Dose Response
10. Cardiovascular Disease
11. Recommendations

Outline of Presentation
SMN and CVD

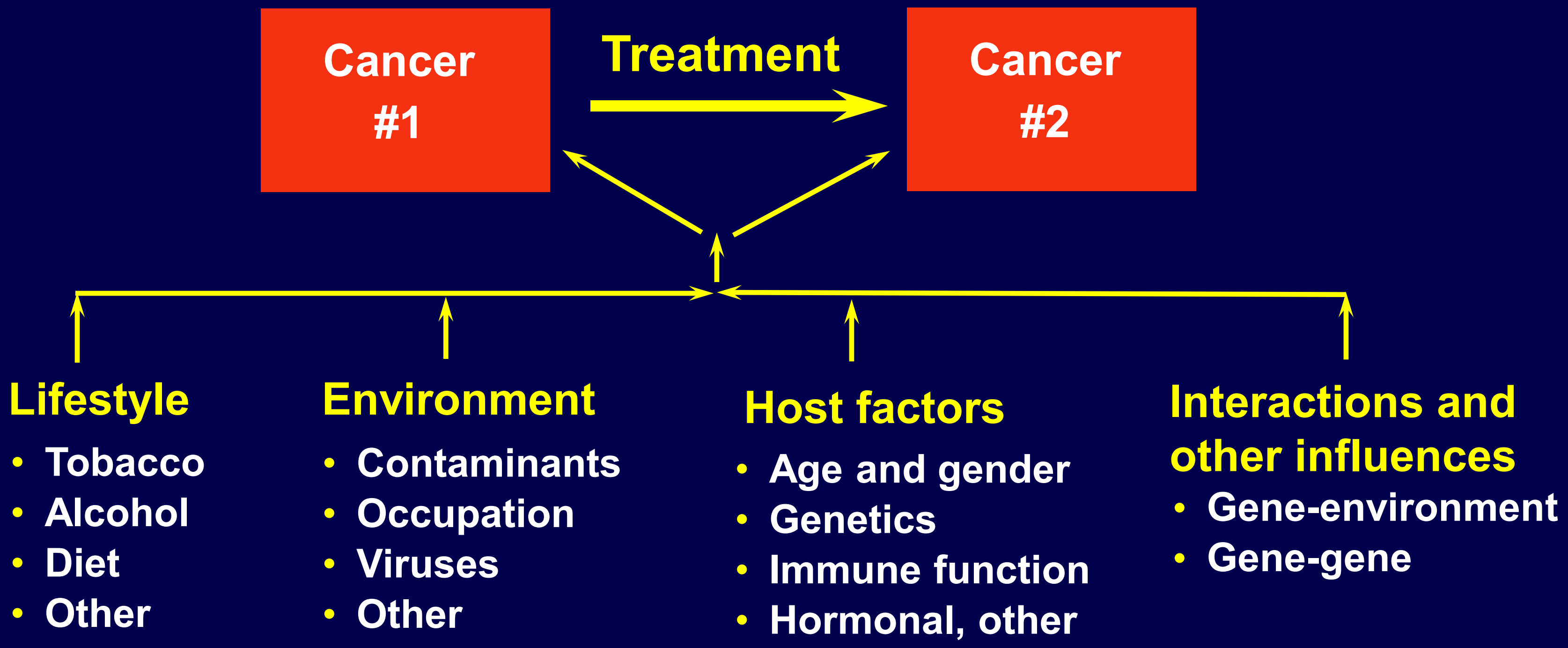
- Context: cancer survivorship
- Overview of SMN
  - Etiologies, epidemiology
- Radiotherapy-related SMN
- Heart disease after radiotherapy
- NCRP recommendations

Cancer Survivorship: 2012

- U.S.: 13.7 million cancer survivors
  - 4% of population
  - 18 million by 2022
- Increases in cancer survival
  - Earlier diagnosis (screening)
  - More effective treatment
- Late effects of cancer and its therapy
  - Second malignant neoplasms
  - Cardiovascular disease

Siegel R, et al. Cancer treatment and survivorship statistics, 2012. Ca Cancer J Clin, 62, 220-241 (2012)

Multiple Primary Cancers
Etiologic Factors



Cancer #1

Treatment

Cancer #2

Lifestyle

- Tobacco
- Alcohol
- Diet
- Other

Environment

- Contaminants
- Occupation
- Viruses
- Other

Host factors

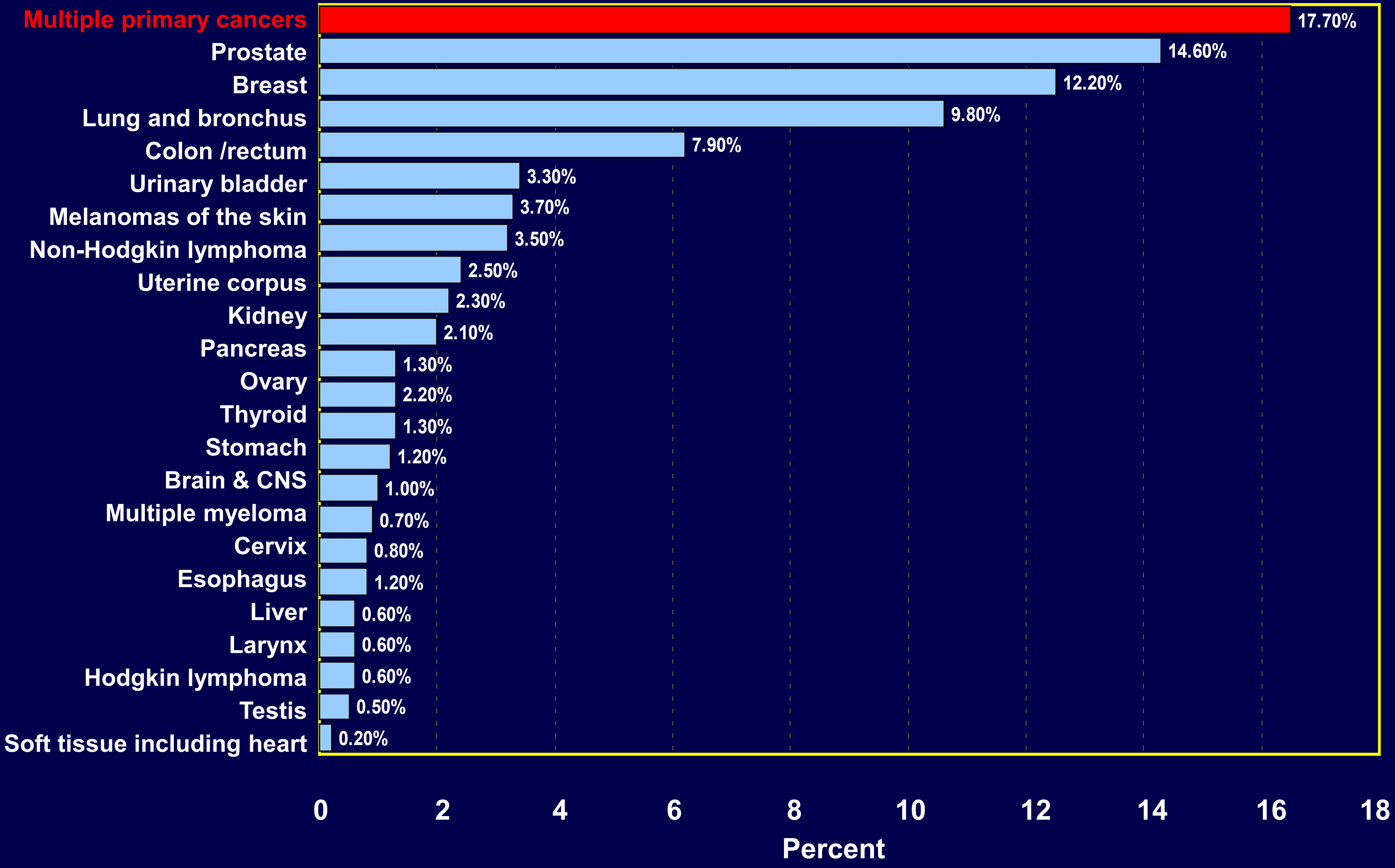
- Age and gender
- Genetics
- Immune function
- Hormonal, other

Interactions and other influences

- Gene-environment
- Gene-gene

Modified from Travis LB. Acta Oncol 323-333 (2002)

Cancer Incidence – Distribution by Site
SEER Program, 2008

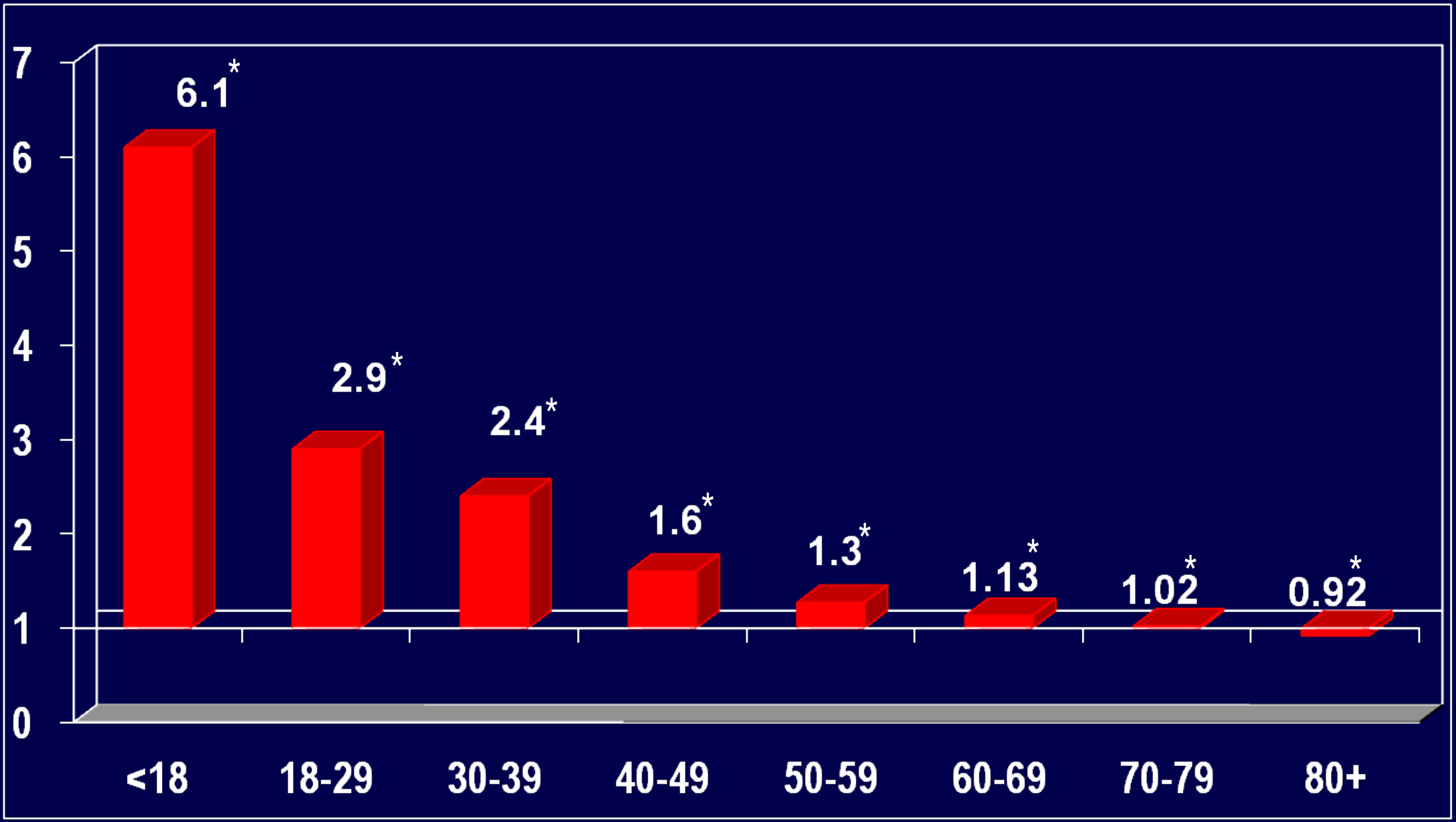


SEER Program Monograph

- Comprehensive risk of developing new primary malignancies
- 9 SEER cancer registries
  - Population-based (10% of U.S.)
  - High quality
- Largest analysis to date
  - 2 million cancer survivors
  - Nearly 30 y period (1973 - 2000)
  - 185,000 subsequent cancers

Curtis RE, et al. (editors). New Malignancies Among Cancer Survivors: SEER Cancer Registries, 1973-2000, NIH Publ. No. 05-5302, Bethesda, MD, 2006.

Risk (O/E) of Subsequent Cancer
By Age at Diagnosis



* P < 0.05

Age at 1st Cancer Diagnosis

Treatment-Related Subsequent Cancers

- Overall SEER results
  - Children and young adults especially prone to late effects of radiation and chemotherapy
  - Therapy not a major cause of new malignancies among older adults

Radiation-Related SMN NCRP Report

- Major populations/cohorts
  - Young patients: Hodgkin lymphoma, childhood cancer
  - Cervical cancer

    -- Many site-specific SMN evaluations
- Radiosensitive sites
  - Breast, thyroid, bone marrow

Travis LB, Ng AK, Allan JM, et al. Second malignant neoplasms and cardiovascular disease after radiotherapy. JNCI 104, 357-370 (2012). NCRP Report No. 170 (2012)

SMN Sites
Radiotherapy Dose-Response*

- Risk increases with increasing dose
  - Breast cancer
  - Lung cancer
  - CNS tumors
- Risk increases then decreases
  - Thyroid cancer
  - Leukemia

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*Travis LB, Ng AK, Allan JM, et al. Second malignant neoplasms and cardiovascular disease after radiotherapy. JNCI 104, 357-370 (2012); NCRP Report No. 170 (2012)

Breast Cancer after HL by Radiation Dose: International Study

Radiation dose (Gy) to location in breast †	Cases/ Controls	RR	(95% CI)
0-	15/76	1.0	(Reference)
4.0-	13/30	1.8	(0.7-4.5)
7.0-	16/30	4.1	(1.4-12.3)
23.3-	9/30	2.0	(0.7-5.9)
28.0-	20/31	6.8	(2.3-22.3)
37.2-	12/31	4.0	(1.3-13.4)
40.5-	**17/29**	**8.0**	**(2.6-26.4)**

† Adjusted for no. of AA cycles and radiation dose to ovaries. P trend < 0.001

Travis LB, Hill DA, Dores GM, et al. JAMA 290, 465-475 (2003)

Underlying cohort: 3,800 women treated for HL at age 30 y or younger.

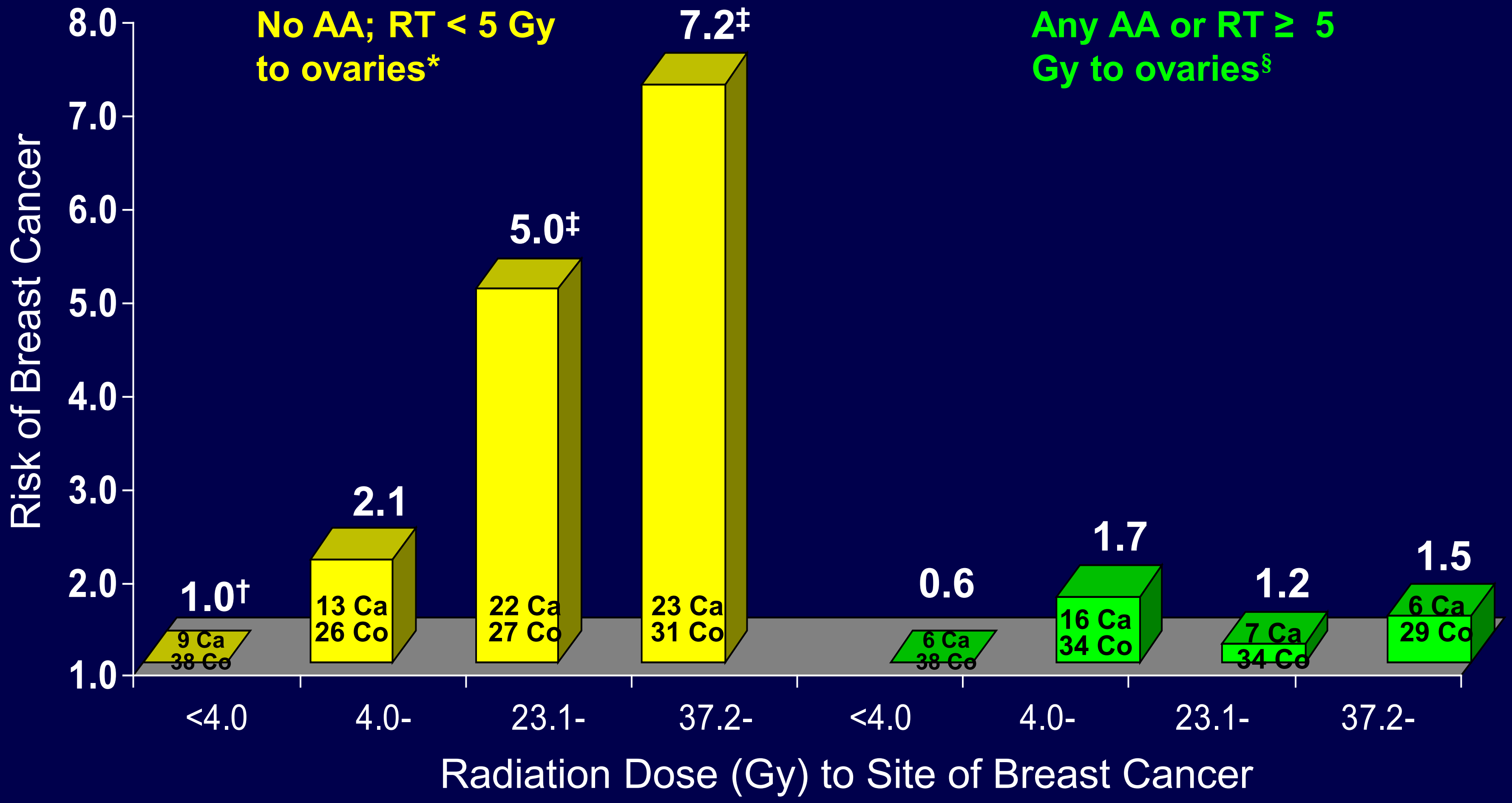
Risk of Breast Cancer by No. of Cycles and Type of Alkylating Agent (AA)

	Cases/Controls	RR	(95% CI)
No. of cycles with AA chemotherapy[†‡]			
0	68/132	1.0	(Reference)
1 - 4	10/20	0.7	(0.3-1.7)
5 - 8	17/55	0.6	(0.3-1.1)
≥9	4/29	0.2*	(0.1-0.7)
Alkylating agent[†]			
Mechlorethamine-based	31/107	0.5*	(0.3-0.9)
Other alkylating agent	6/27	0.3*	(0.1-0.9)

* P < 0.05 [†] Adjusted for radiation dose to breast and ovaries. [‡] P trend = 0.003

Travis LB, Hill DA, Dores GM, et al. JAMA 290, 465-475 (2003).

Breast Cancer Risk According to Radiation Dose to Breast and Ovaries, and Alkylating Agent (AA) Therapy



* P trend < 0.001 ‡ P < 0.05 § P trend = 0.09

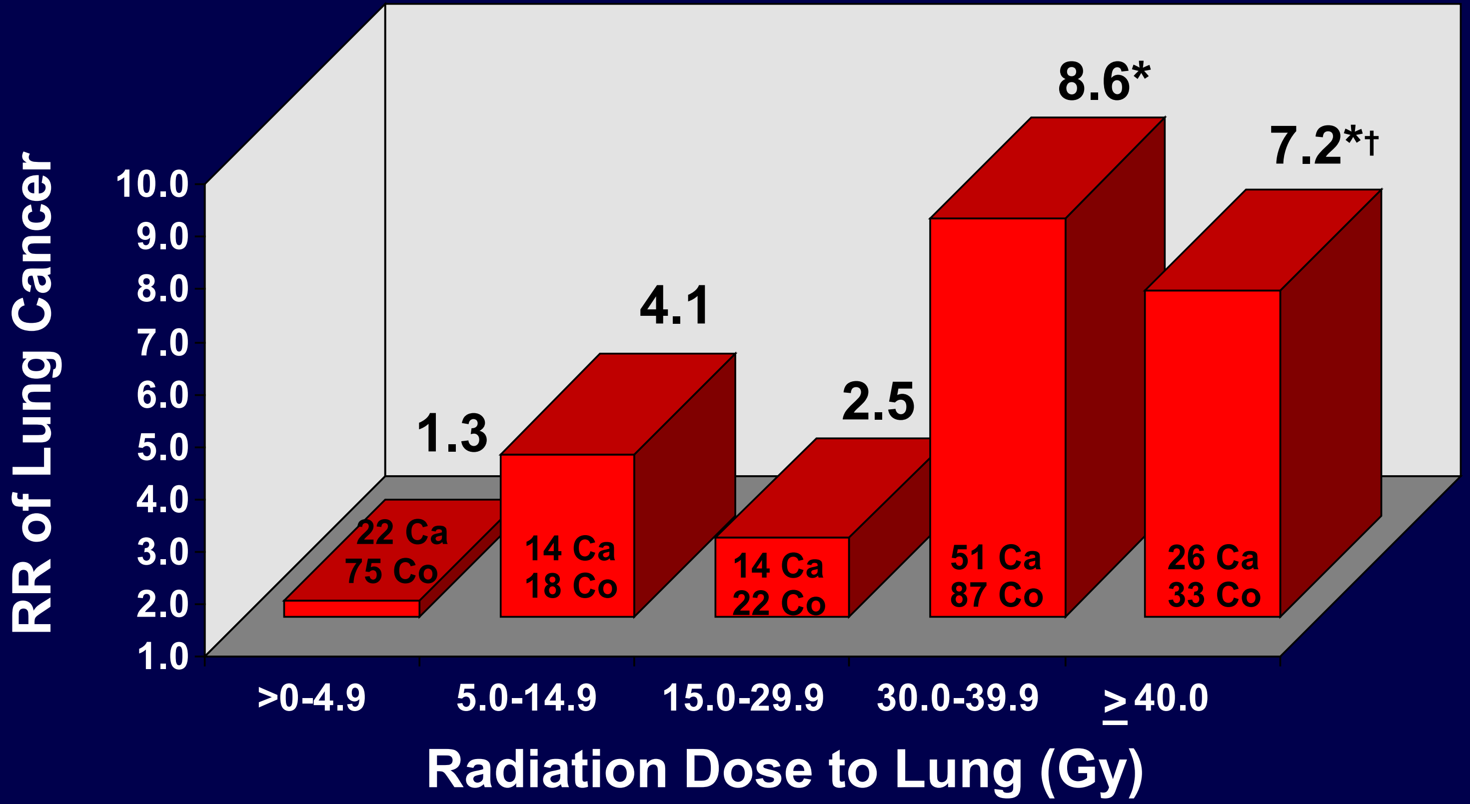
Breast Cancer Following Lymphoma

Summary

- Dose-response relation: no evidence of decline at largest doses
  - Confirmed in childhood cancer survivors (Inskip P. et al. JCO 2009)
  - Continue reductions in exposure to breast

- Reduced risk associated with ovarian damage
  - Hormonal stimulation important for radiation-induced breast cancer

Lung Cancer after HL by Radiation Dose International Study



* P < 0.001 † P trend < 0.001 (All RR were adjusted for tobacco use and alkylating agents.)

Travis LB, Gospodarowicz M, Curtis RE, et al. Lung cancer following chemotherapy and radiotherapy for Hodgkin's disease. JNCI 94(3), 182-192 (2002)

Lung Cancer After Hodgkin Lymphoma

Other Findings*

- Alkylating agents (4.2-fold risk)
  - Strong dose-response
  - Mechlorethamine and procarbazine (P trend $\leq$ 0.001)
  - Temporal trend differed from radiotherapy
    - Early excesses, which diminished with time
- Additive relation: radiation and alkylating agents

Travis LB, Gospodarowicz M, Curtis RE, et al. Lung cancer following chemotherapy and radiotherapy for Hodgkin's disease. JNCI 94(3), 182-192 (2002)

Lung Cancer Following Hodgkin Lymphoma Treatment and Smoking

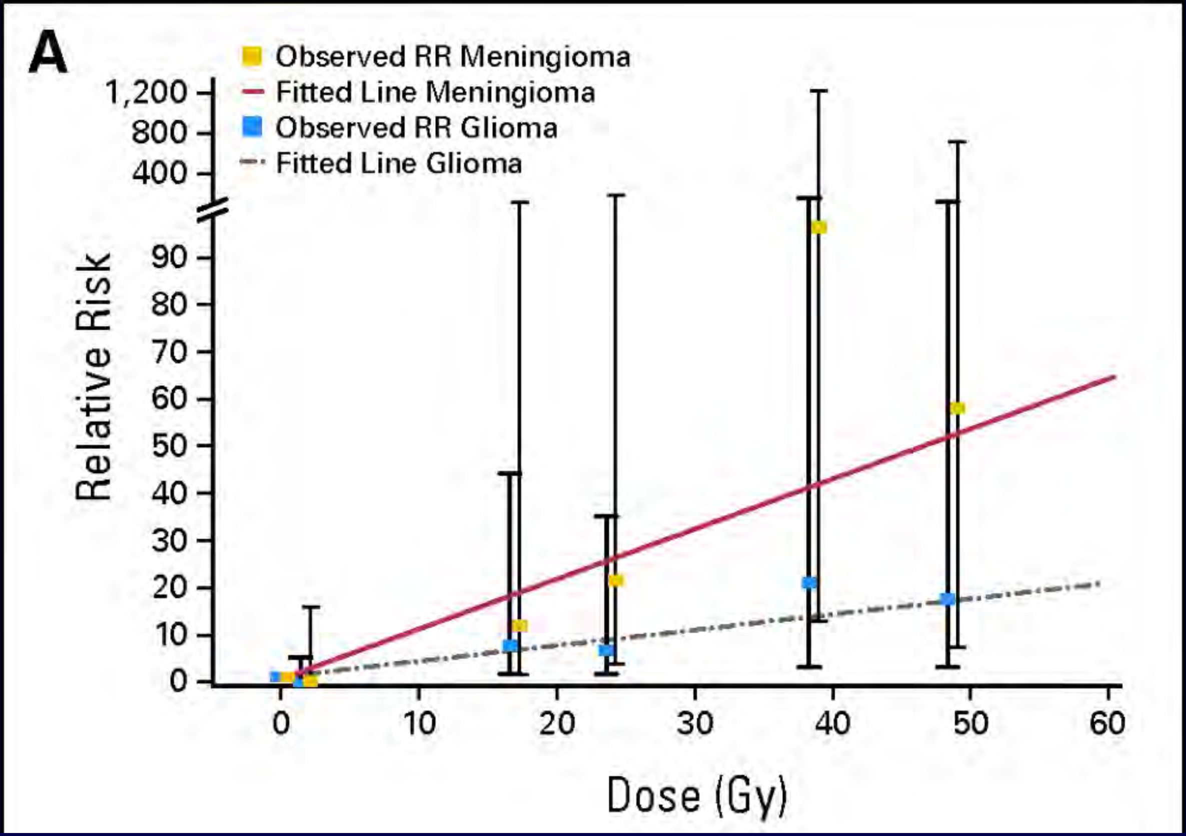
- Tobacco multiplied treatment-associated risks
    - Radiotherapy
    - Alkylating agents
- Tobacco use + radiotherapy: combined risk
    - Moderate-heavy smoker: 20-fold risk
    - Non-smoker/light: 7-fold risk

Travis LB, Gospodarowicz M, Curtis RE, et al. Lung cancer following chemotherapy and radiotherapy for Hodgkin's disease. JNCI 94(3), 182-192 (2002)

Childhood Cancer Survivor Study (CCSS)

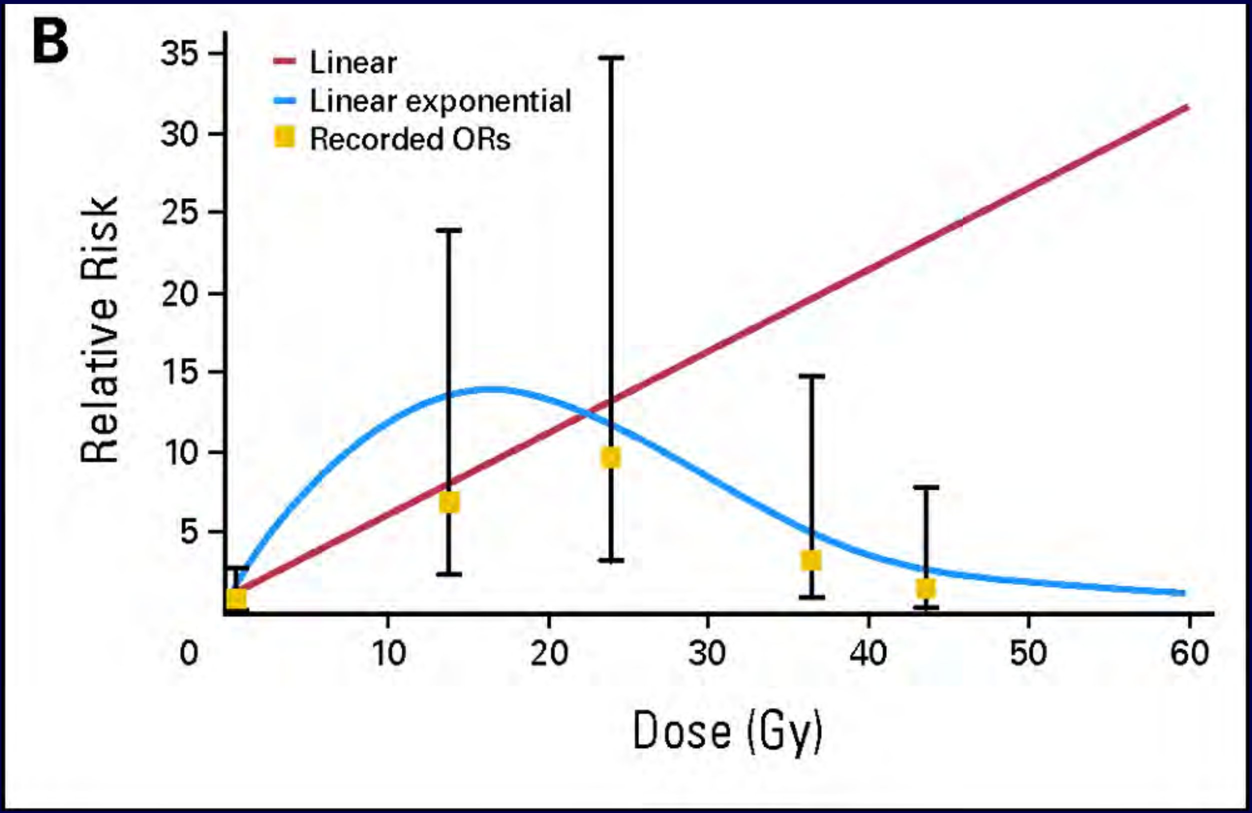
- Retrospective cohort study
- 14,359 5 y survivors
- Diagnosed 1970 - 1986
- 26 institutions: U.S. and Canada
- 325,119 person-y of follow-up
- Studied for multiple outcomes

Relative Risk of CNS Tumors
Radiation Dose; Histologic Variation



Neglia JP, Robison LL, Stovall M, et al. New primary neoplasms of the central nervous system in survivors of childhood cancer: a report from the Childhood Cancer Survivor Study. JNCI 98(21), 1528-1537 (2006)

Thyroid Cancer Risk
Radiation Dose



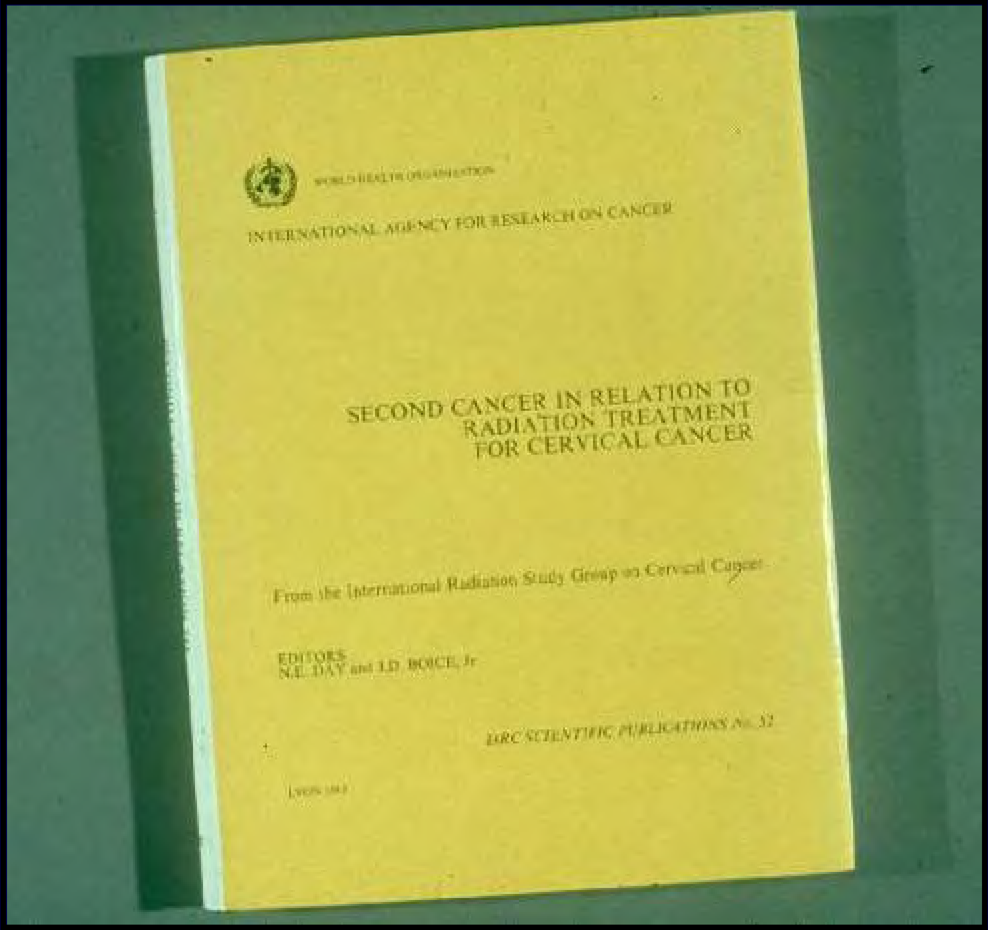
Sigurdson AJ, Ronckers, CM, Mertens AC, et al. Primary thyroid cancer after a first tumour in childhood (Childhood Cancer Survivor Study): a nested case-control study. Lancet 365, 2014-2023 (2005)

Chemotherapy and Thyroid Cancer Risk: CCSS

- Alkylating agents may increase thyroid cancer risk at radiation doses <20 Gy
    - No radiation dose, RR = 2.8 (0.7 – 13.2)
    - Radiation dose <20 Gy, RR = 2.4 (1.2 – 4.5)
    - Radiation dose >20 Gy, RR = 0.9 (0.5 – 1.6)
- Hypothesis: cell-killing at higher RT doses

Velga LH, Bhatti P, et al. Ca Epi Biomark Prev (2012)

International Cervical Cancer Study
Boice et al.



WORLD HEALTH ORGANIZATION

INTERNATIONAL AGENCY FOR RESEARCH ON CANCER

SECOND CANCER IN RELATION TO
RADIATION TREATMENT
FOR CERVICAL CANCER

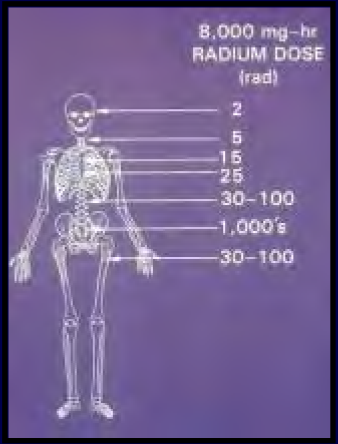
From the International Radiation Study Group on Cervical Cancer

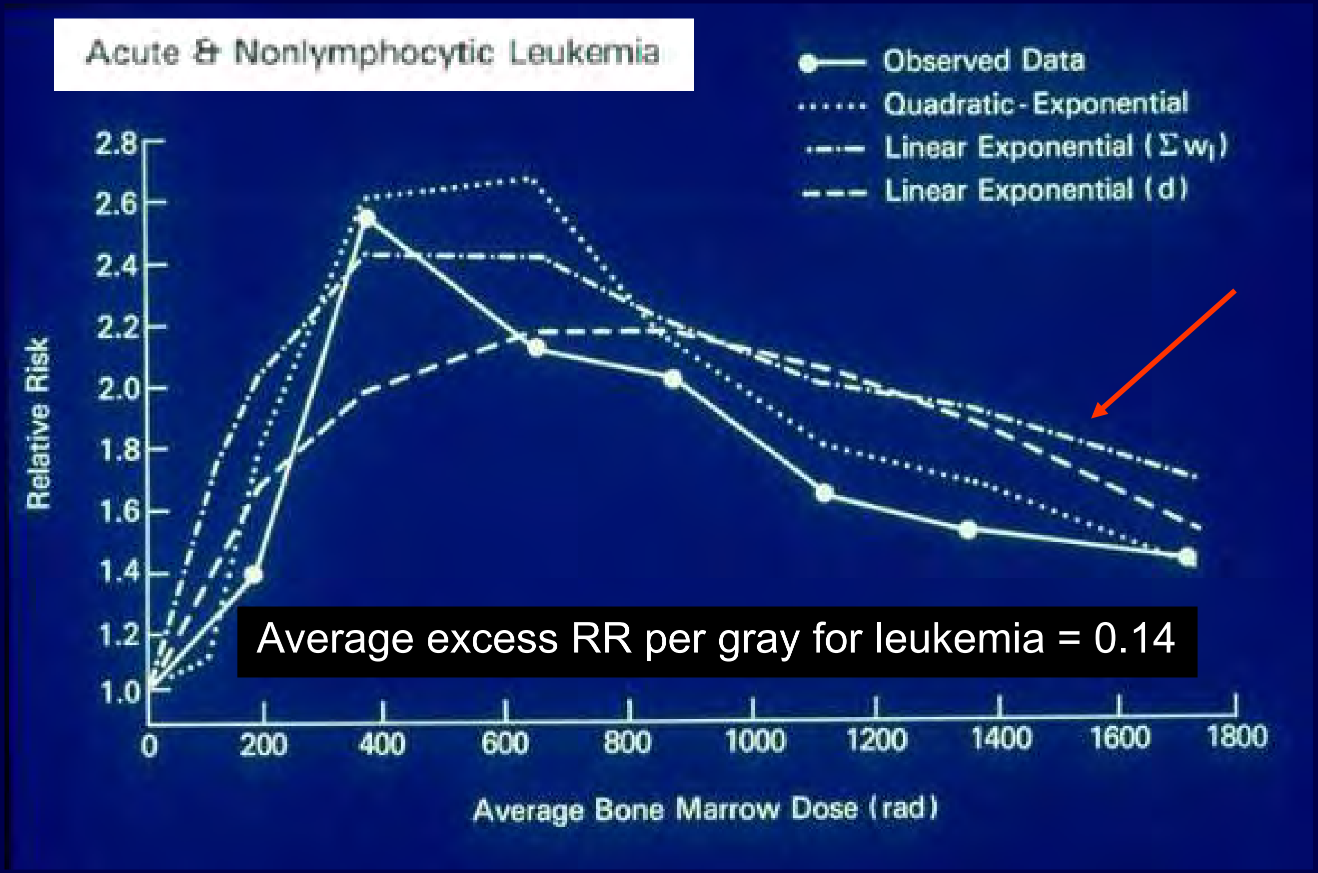
EDITORS
N.E. DAY and J.D. BOICE, Jr

IARC SCIENTIFIC PUBLICATIONS No. 52

- 200,000 women
- 16 RT centers, 17 cancer registries
- 14 countries
- 16 cancer sites

Bone Marrow Dosimetry: Downturn in Risk at High Doses





Average excess RR per gray for leukemia = 0.14

Boice, et al. JNCI (1987): Slide courtesy of Dr. John Boice

Radiation-Induced Leukemia for Various Exposure Types

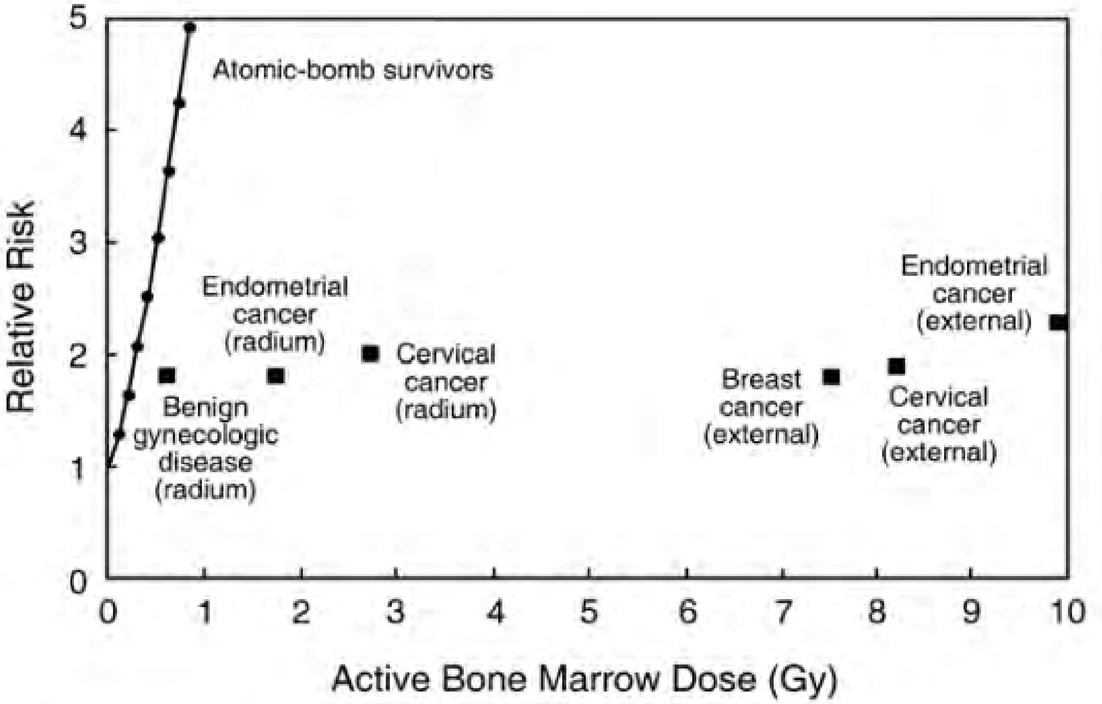
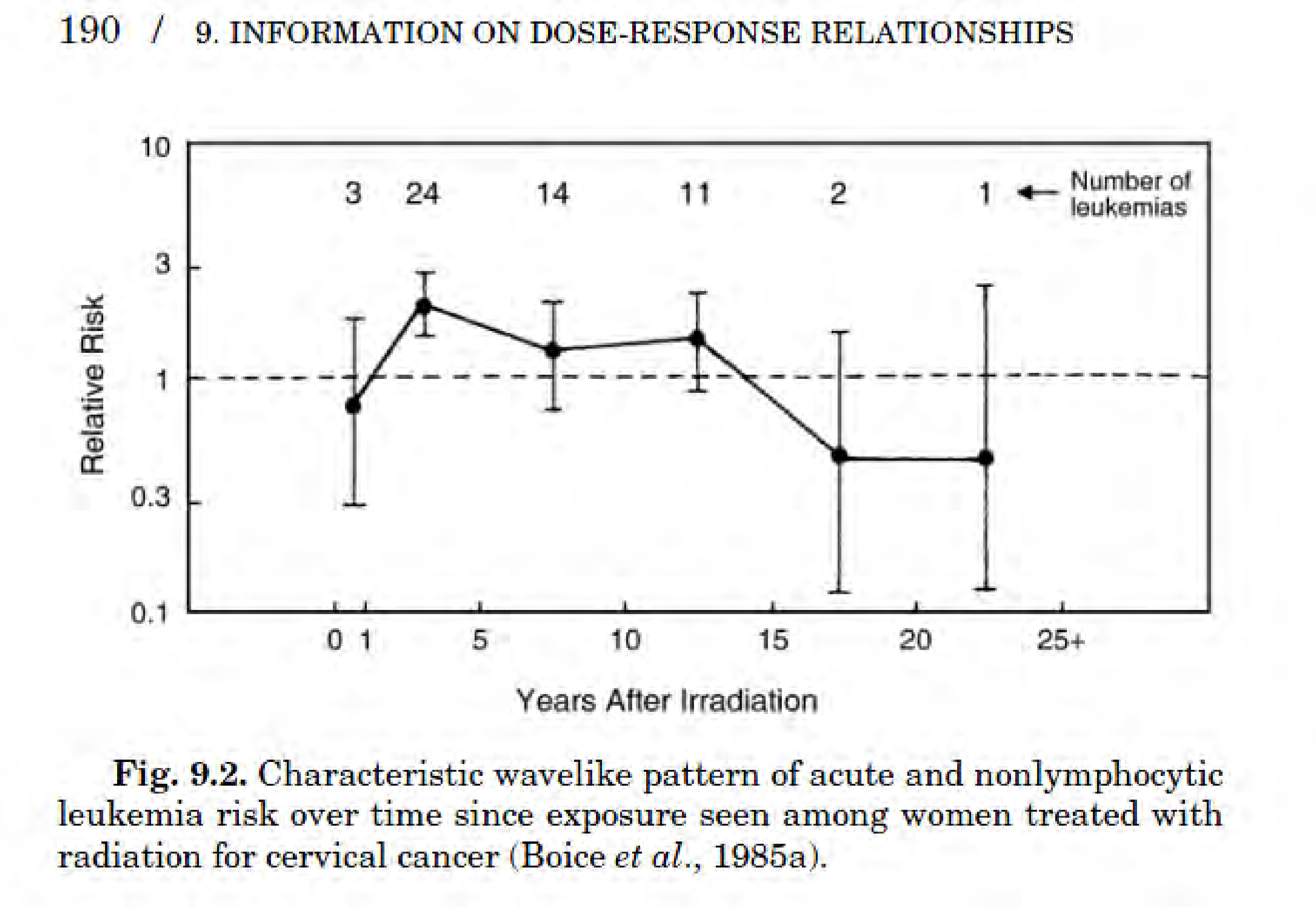


Fig. 9.1. Risk for leukemia in several studies of medically-irradiated populations compared with Japanese atomic-bomb survivors according to dose to active bone marrow (mean value for the study) (Boice, 2002; Boice *et al*. 1987; Curtis *et al*., 1992; 1994; Inskip *et al*., 1994; NA/NRC, 1990).

NCRP Report No. 170 (2012)

Leukemia: Wave-like Pattern Over Time
Cervical Cancer Study

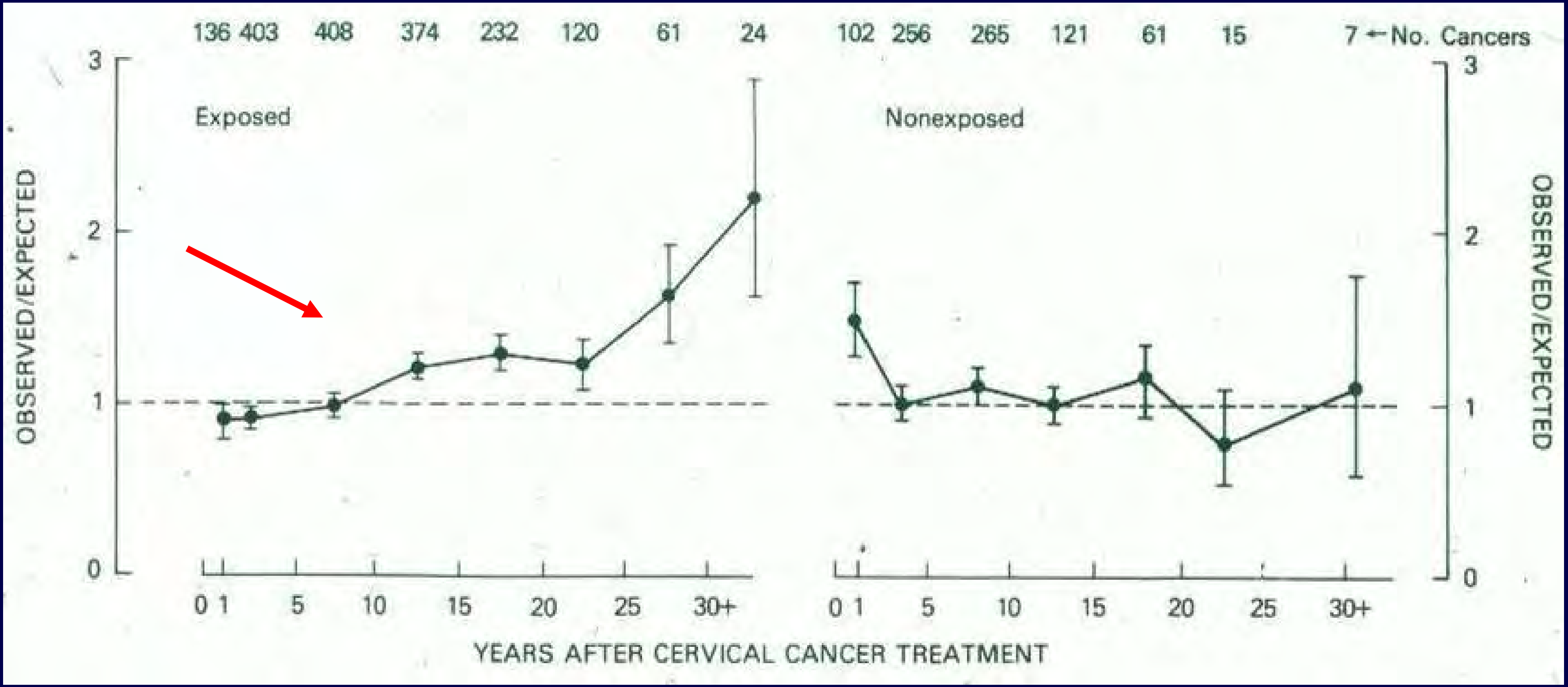


190 / 9. INFORMATION ON DOSE-RESPONSE RELATIONSHIPS

Fig. 9.2. Characteristic wavelike pattern of acute and nonlymphocytic leukemia risk over time since exposure seen among women treated with radiation for cervical cancer (Boice *et al.*, 1985a).

NCRP Report No. 170 (2012)

Solid Cancer: Pattern Over Time
Cervical Cancer Study



Boice et al, JNCI 74, 955 (1985)

Late Effects of Treatment
The Promise of Genomics[1]

- We now have tools
- 2000: LOH in 6q more common in breast cancer after RT for HL vs. de novo breast cancer ($P = 0.03$)[2]
- 2011: variants at 6q21 implicate *PRDM1* in SMN after HL (59 breast cancers)[3]
- Important for all late complications
  - Platinum → neurotoxicity (NCI R01)

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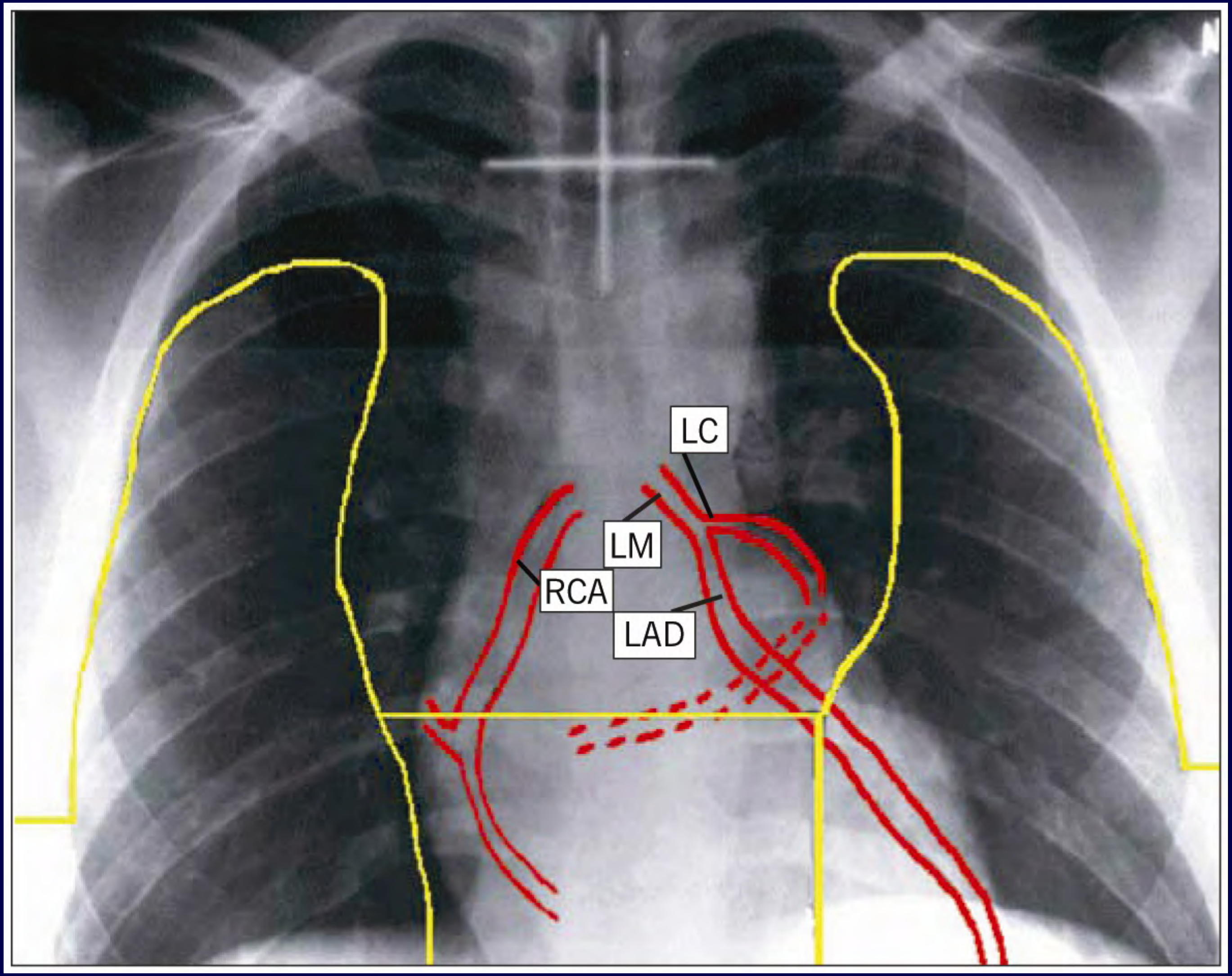
[1] Travis LB. et al. Cancer survivorship—genetic susceptibility and second primary cancers: research strategies and recommendations. JNCI 98, 15-25 (2006).[2] Behren C. et al. CEBP 9, 1027-1035 (2000). [3] Best T. et al. Nature Med 17, 941-943 (2011)

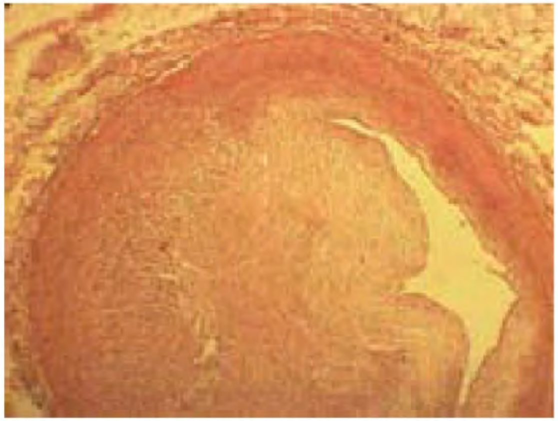
NCRP Report
Radiation and Heart Disease

- Cardiac toxicity of high dose radiotherapy known for some time
- Injury and replacement of cells by myofibroblasts; platelet deposition
  - Later atherosclerosis, CAD
- Dr. Vera Peters, 1950s: Mantle RT for Hodgkin lymphoma

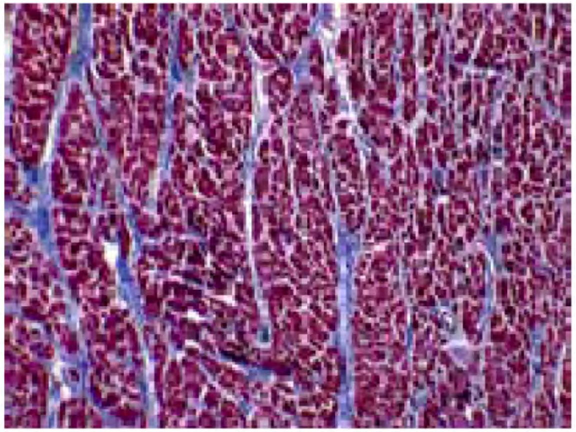
Typical Mantle Radiation Field for Hodgkin Lymphoma



Radiation and Heart Disease
Hodgkin Lymphoma



Coronary artery, 16 yr boy, after 40Gy, Mantle RT



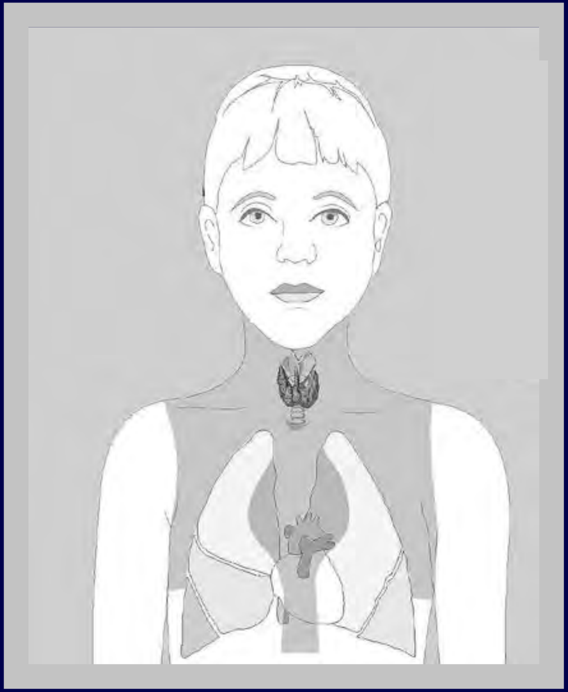
Fatal diffuse myocardial fibrosis after RT for HL

Courtesy of Dr. John Boice from Dr Kiyo Mabuchi, NCI, REB

Radiation Cardiac Injury: Overview

Manifestations

- Premature CAD
- Myocardial infarction
- Valvular disease
- Autonomic dysfunction
- Conduction defects
- Restrictive cardiomyopathy



Mantle Field

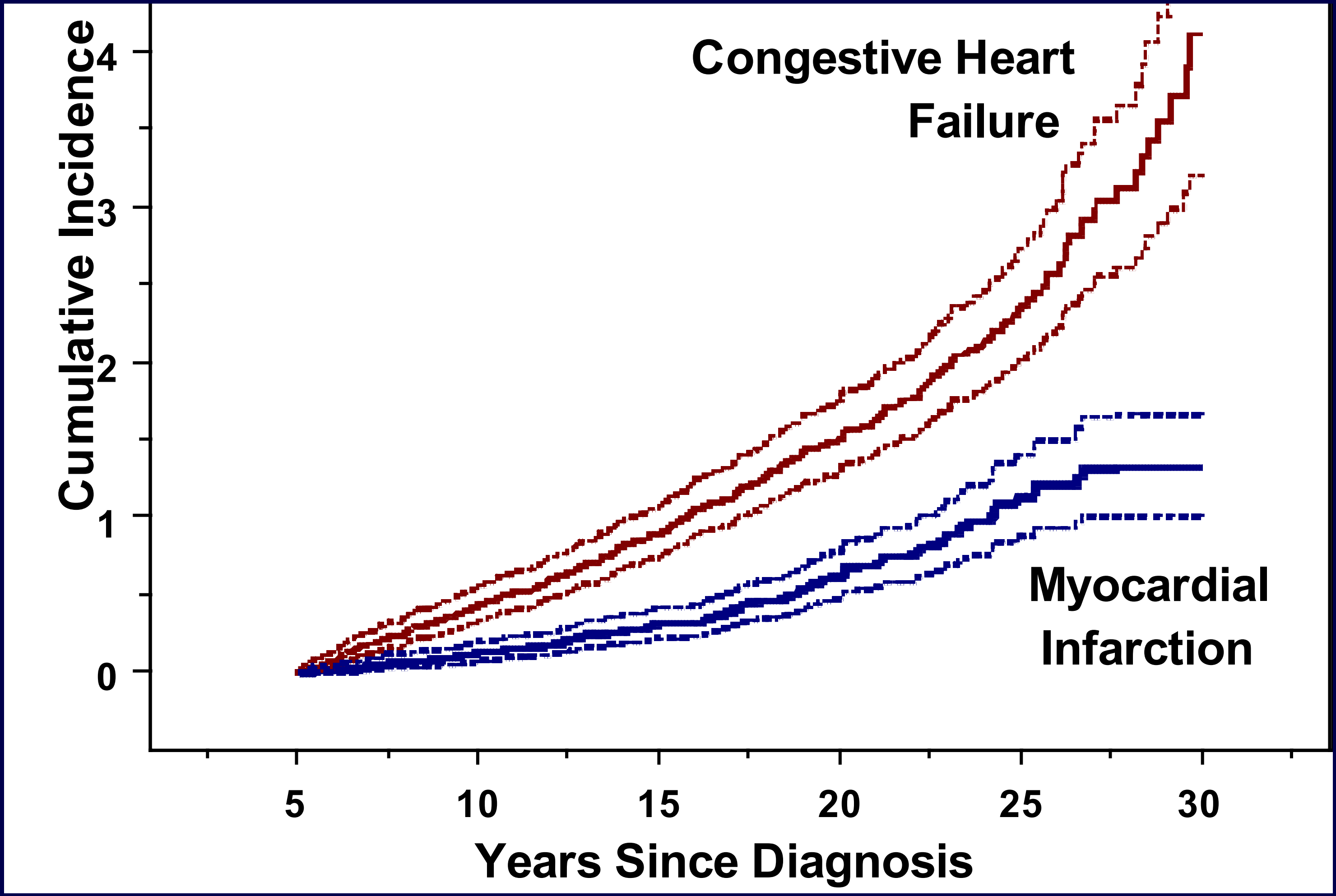
Risk Factors

- Younger age (<5 y)
- Higher dose (>35 Gy)
- Higher daily fraction (≥2 Gy)
- Larger volume of heart in field
- Anteriorly weighted field
- Longer time from RT
- Use of cardiotoxic chemotherapy

Childhood Cancer Survivor Study
Mulrooney et al. BMJ (2009)

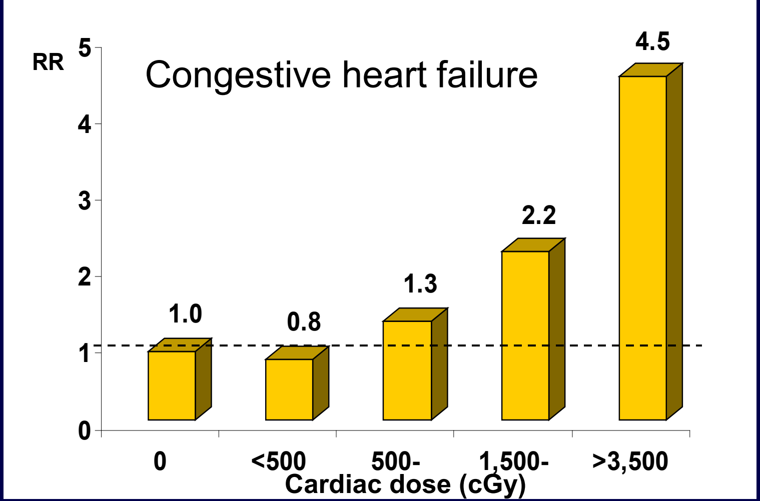
- >14,000 5 y survivors
- Cardiac outcomes
  - Congestive heart failure – 248
  - Myocardial infarction – 101
  - Pericardial disease – 181
  - Valvular abnormalities - 238

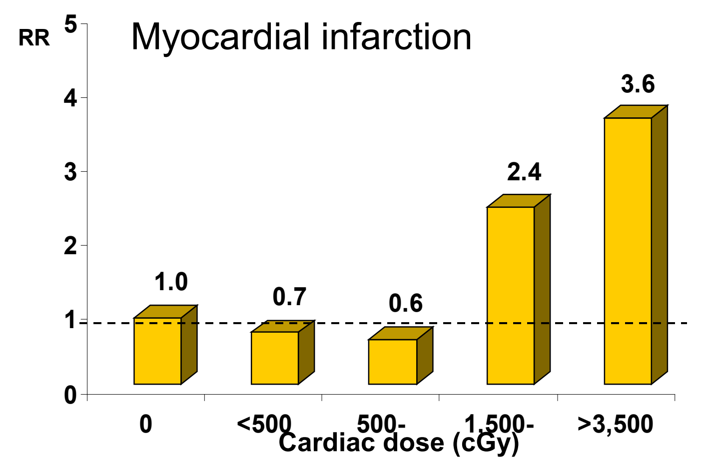
Cumulative Incidence: CHF and MI

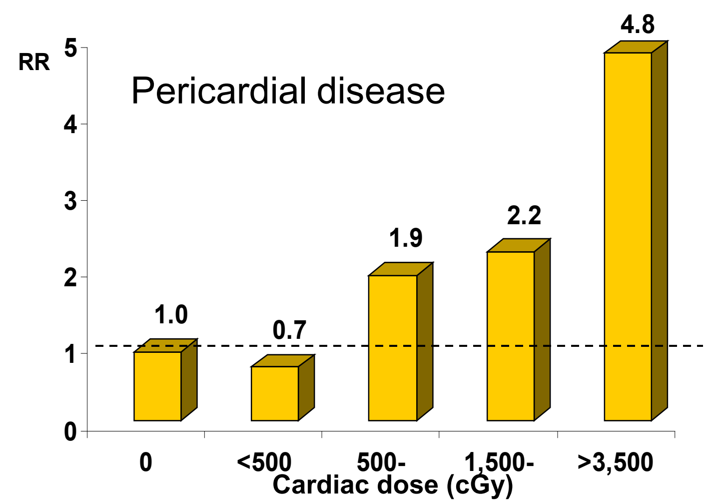


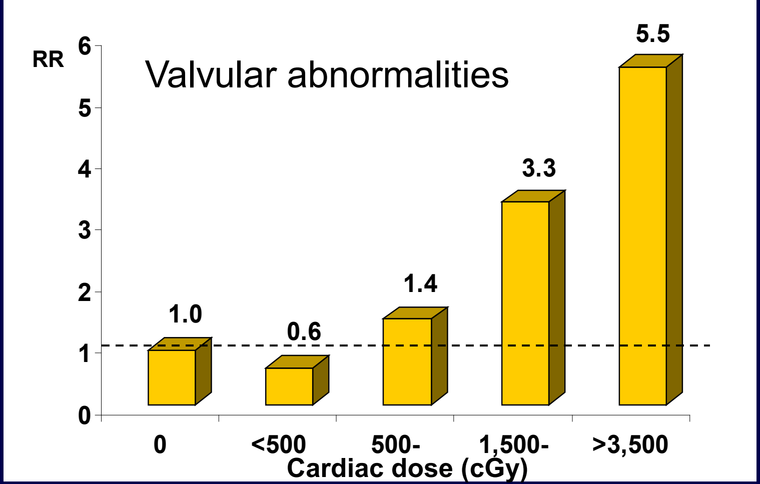
Mulrooney et al. BMJ (2009)

Dose Response – Heart Disease (CCSS)


Congestive heart failure

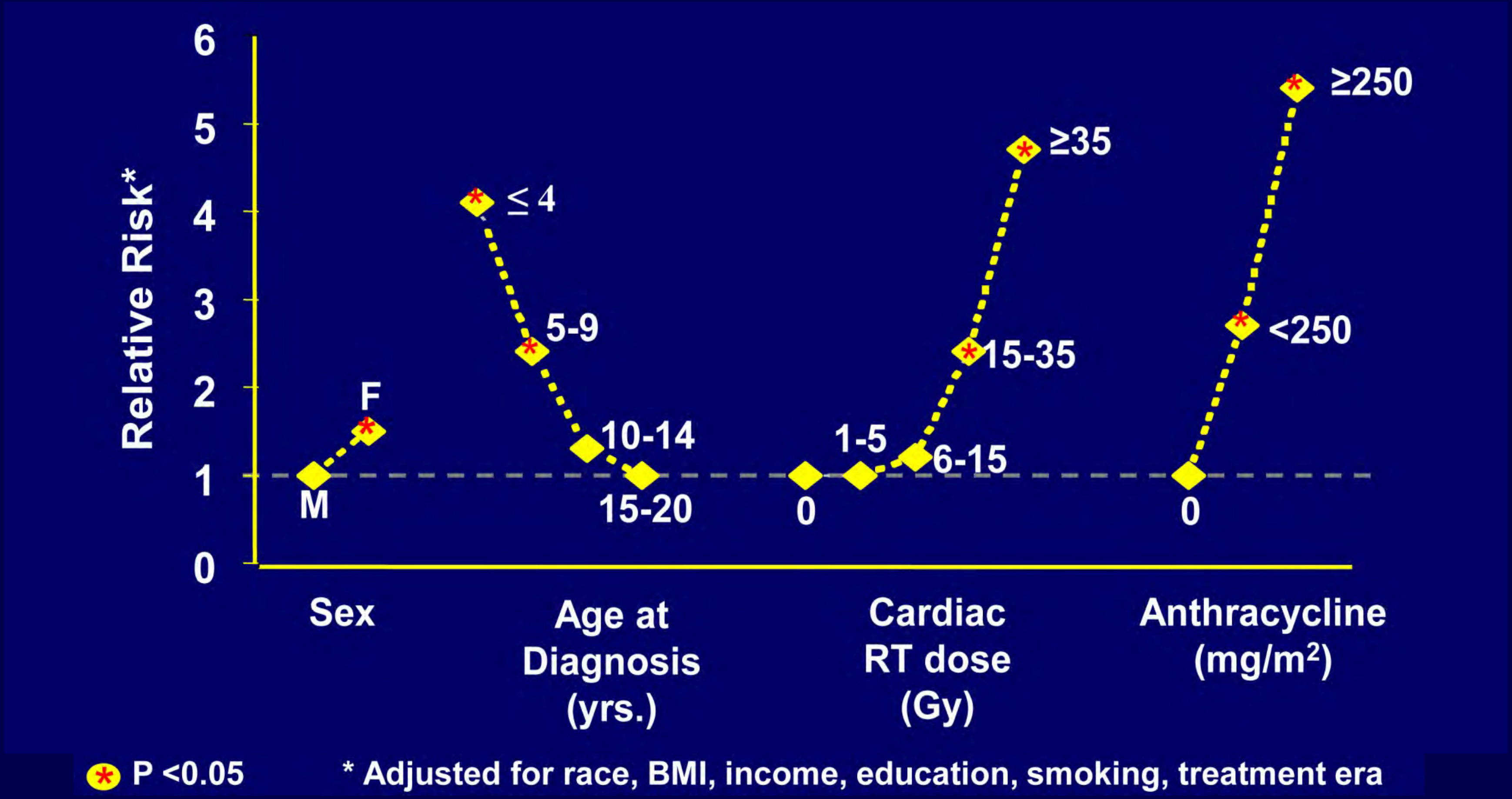

Myocardial infarction


Pericardial disease


Valvular abnormalities

Mulrooney et al. BMJ (2009)

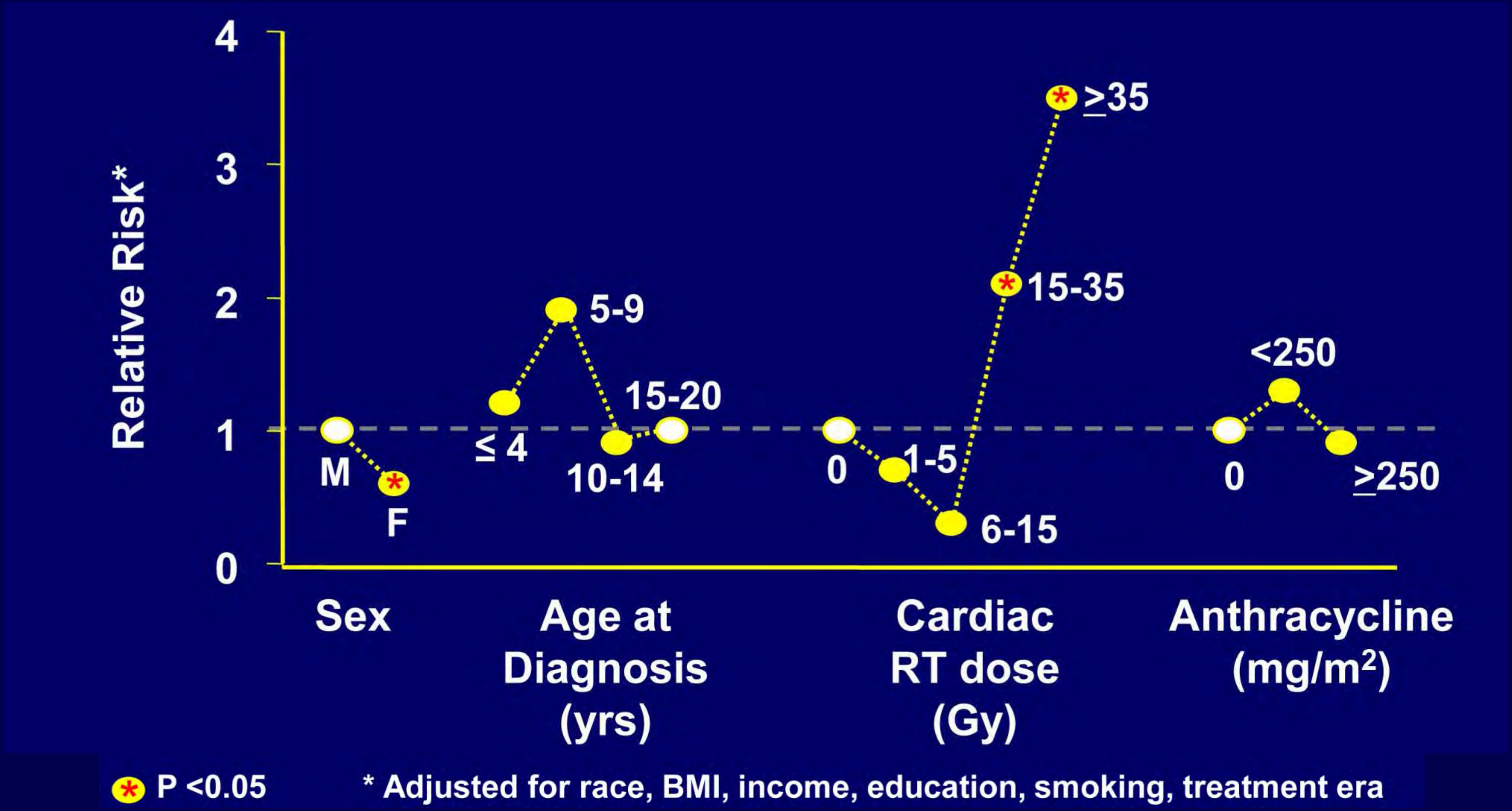
Risk of Congestive Heart Failure: Multivariate Analysis



* Adjusted for race, BMI, income, education, smoking, treatment era

Mulrooney et al. BMJ (2009)

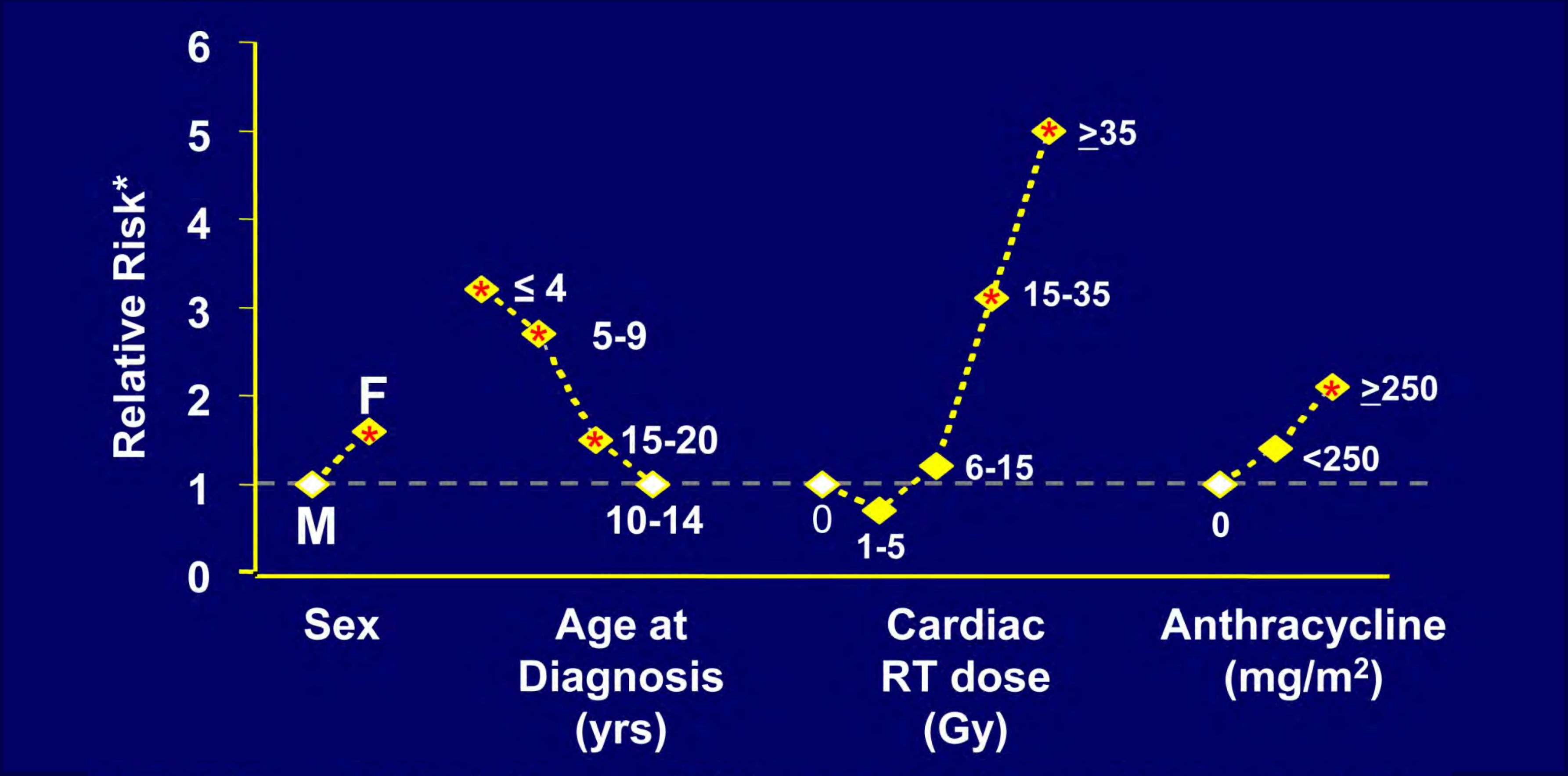
Risk of Myocardial Infarction: Multivariate Analysis



● P <0.05 * Adjusted for race, BMI, income, education, smoking, treatment era

Mulrooney et al. BMJ (2009)

Risk of Valvular Disease: Multivariate Analysis



● P <0.05

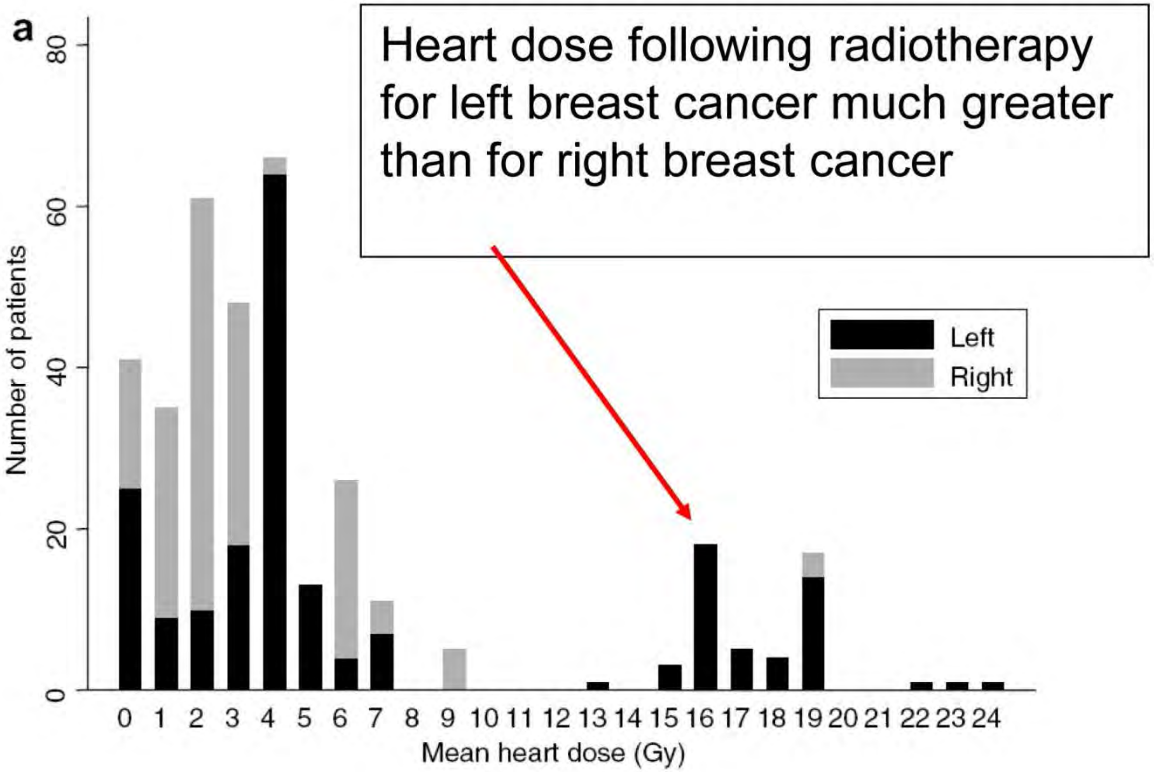
* Adjusted for race, BMI, income, education, smoking, treatment era

Mulrooney et al. BMJ (2009)

Heart Dose from Breast Cancer Radiotherapy

(a) Standard tangential pair

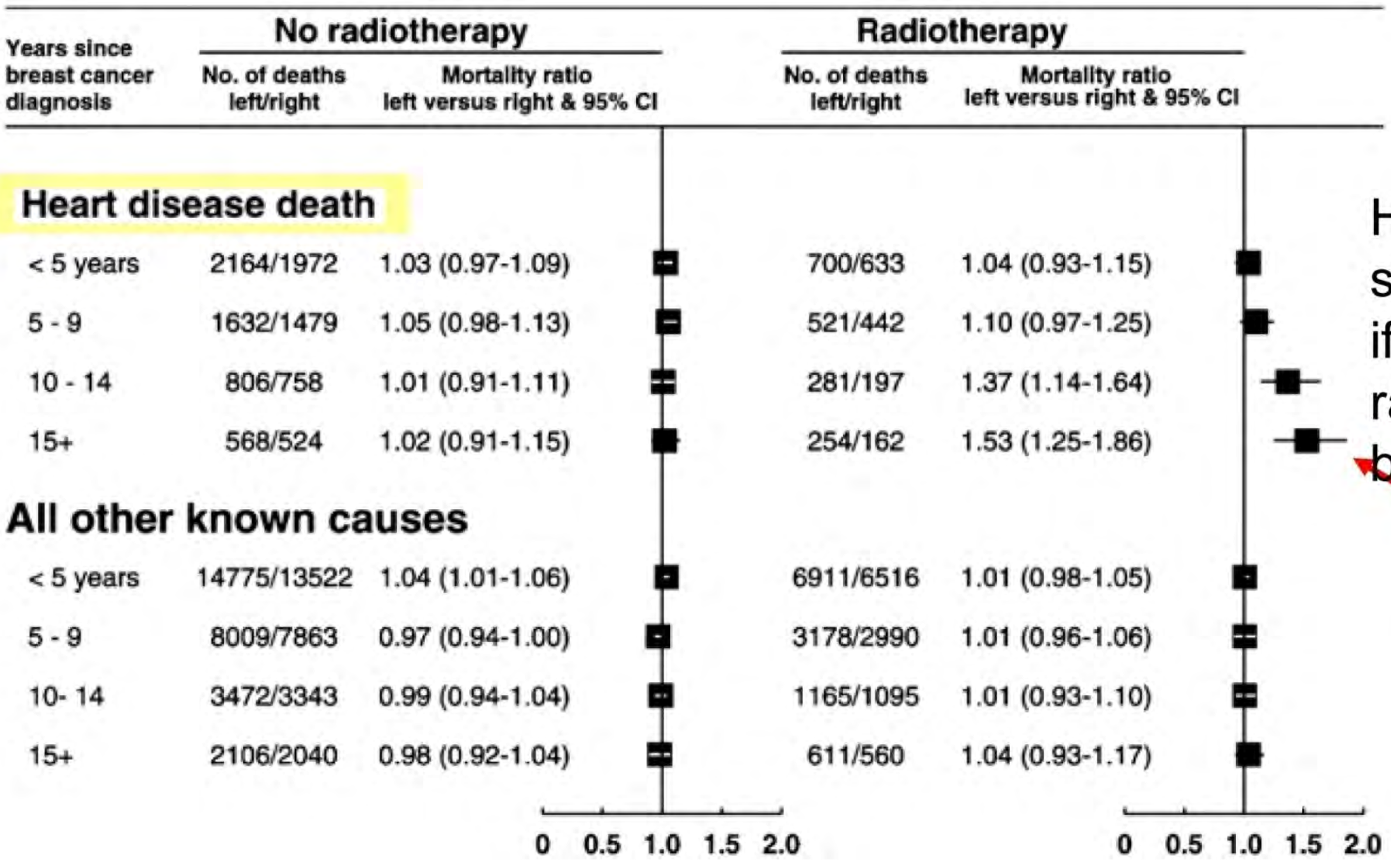
(b) Four orthovoltage fields



Heart dose following radiotherapy for left breast cancer much greater than for right breast cancer

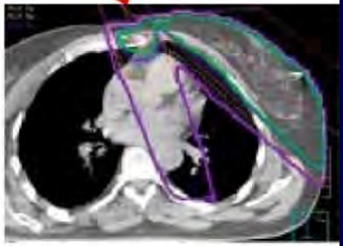
Taylor et al. Radiother Oncol (2009). Slide courtesy of Dr. John Boice.

Heart Disease Comparing Left-Sided vs. Right-Sided Breast Cancer by Radiotherapy



Years since breast cancer diagnosis	No radiotherapy		Radiotherapy	
	No. of deaths left/right	Mortality ratio left versus right & 95% CI	No. of deaths left/right	Mortality ratio left versus right & 95% CI
Heart disease death				
< 5 years	2164/1972	1.03 (0.97-1.09)	700/633	1.04 (0.93-1.15)
5 - 9	1632/1479	1.05 (0.98-1.13)	521/442	1.10 (0.97-1.25)
10 - 14	806/758	1.01 (0.91-1.11)	281/197	1.37 (1.14-1.64)
15+	568/524	1.02 (0.91-1.15)	254/162	1.53 (1.25-1.86)
All other known causes				
< 5 years	14775/13522	1.04 (1.01-1.06)	6911/6516	1.01 (0.98-1.05)
5 - 9	8009/7863	0.97 (0.94-1.00)	3178/2990	1.01 (0.96-1.06)
10- 14	3472/3343	0.99 (0.94-1.04)	1165/1095	1.01 (0.93-1.10)
15+	2106/2040	0.98 (0.92-1.04)	611/560	1.04 (0.93-1.17)

Heart disease significantly high if treated with radiation for left breast cancer



Darby S et al. Lancet Oncol (2005). Slide courtesy of Dr. John Boice.

Other Risk Factors: CVD

- CAD or history of MI
- Hypertension
- Diabetes
- Alcoholism
- Cardiotoxic drugs
- Inherited cardiomyopathies
- Valvular heart disease
- Congenital heart defects

- Other:
-- Obesity
-- Age
-- Tobacco use
-- Family history
-- Lack of physical activity
-- Diet

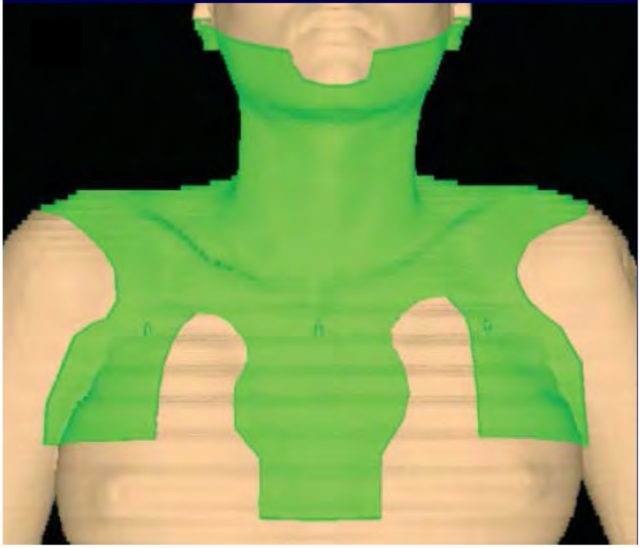
Overarching Recommendations NCRP Report 170

- Long-term and large-scale follow-up of existing cancer survivors
  - Characterize risks of SMN and CVD
  - Evaluate role of co-morbidities, effect modifiers
- Prospective cohorts
  - Newer treatments (*e.g.*, proton therapy)
  - Sites with reductions in RT field and dose
  - Cancer sites not treated with RT
    - Baseline risks and natural history
  - Collect biologic samples

Reductions in Field Size and Dose: HL

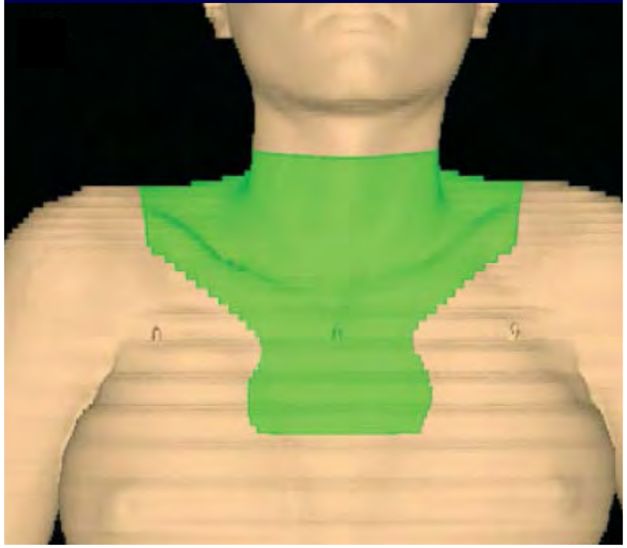
Full Mantle

Dose: 36 - 44 Gy



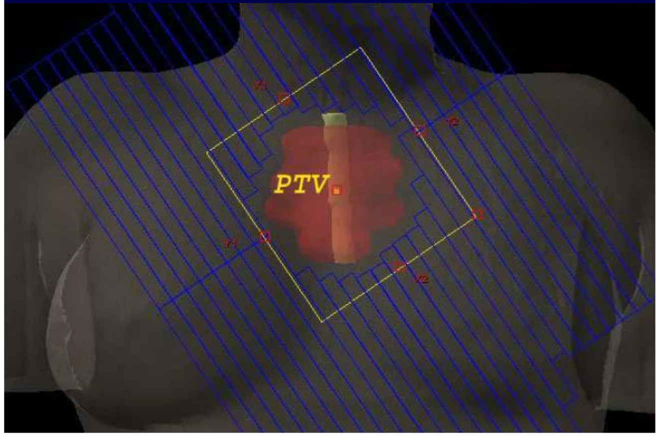
IFRT

Dose: 30 - 36 Gy



INRT

Dose: 20 - 30 Gy



Overarching Recommendations
NCRP Report *(2012)*

- Specific recommendations
  - Site-specific dose-response relationships
  - Risks after different RT modalities
  - Interactions between RT and other risk factors
  - Adolescents and young adults
  - Molecular and genetic underpinnings
  - Risk prediction models

Travis LB, Ng A, Allan JM, et al. JNCI 104, 357-370 (2012); NCRP Report No. 170 (2012).

Worker Exposures

Christopher H. Clement, *Chair*

Characterization of Exposures to Workers Covered Under the U.S. Energy Employees Compensation Act
James W. Neton
National Institute for Occupational Safety & Health

Increased Occupational Exposures: Nuclear Industry Workers
Andre Bouville
National Cancer Institute

Radiation Exposure of U.S. Military Individuals
Paul K. Blake
Defense Threat Reduction Agency

Characterization of Exposures to Workers Covered Under the U.S. Energy Employees Compensation Act

James W. Neton, Ph.D., CHP
Associate Director for Science
National Institute for Occupational Safety and Health
Division of Compensation Analysis and Support

March 11, 2013
Bethesda, MD

The Energy Employees Occupational Illness Compensation Program Act

- Created by Congress in October 2000
- Provides compensation for adverse health effects due to work involved in the production of nuclear weapons
  - Covers work performed for DOE (or its predecessor agencies)
  - Part B provides monetary benefits for workers who contracted cancer
- Probability of causation used to establish eligibility for an award under Part B

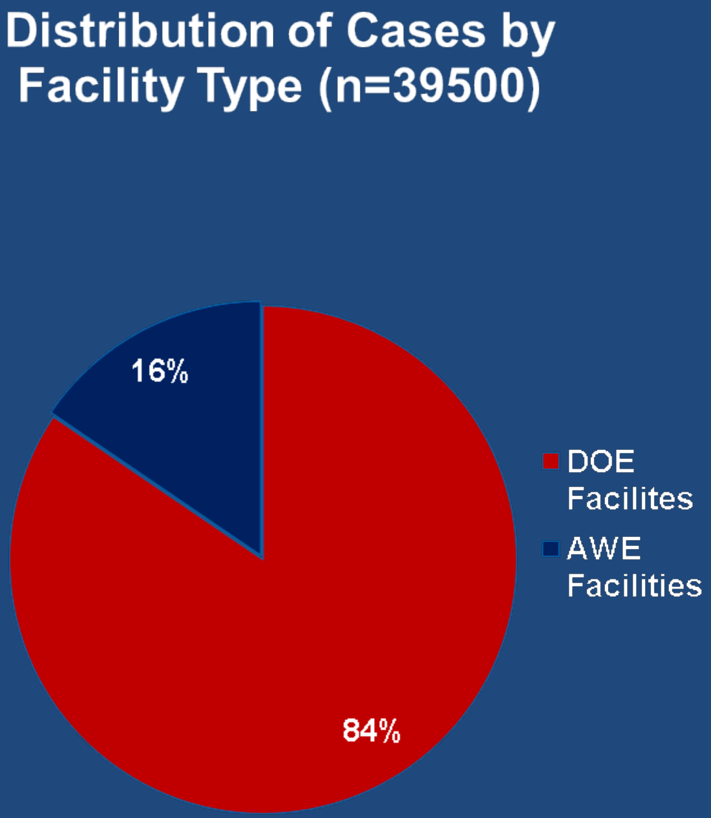
The Energy Employees Occupational Illness Compensation Program Act —cont.

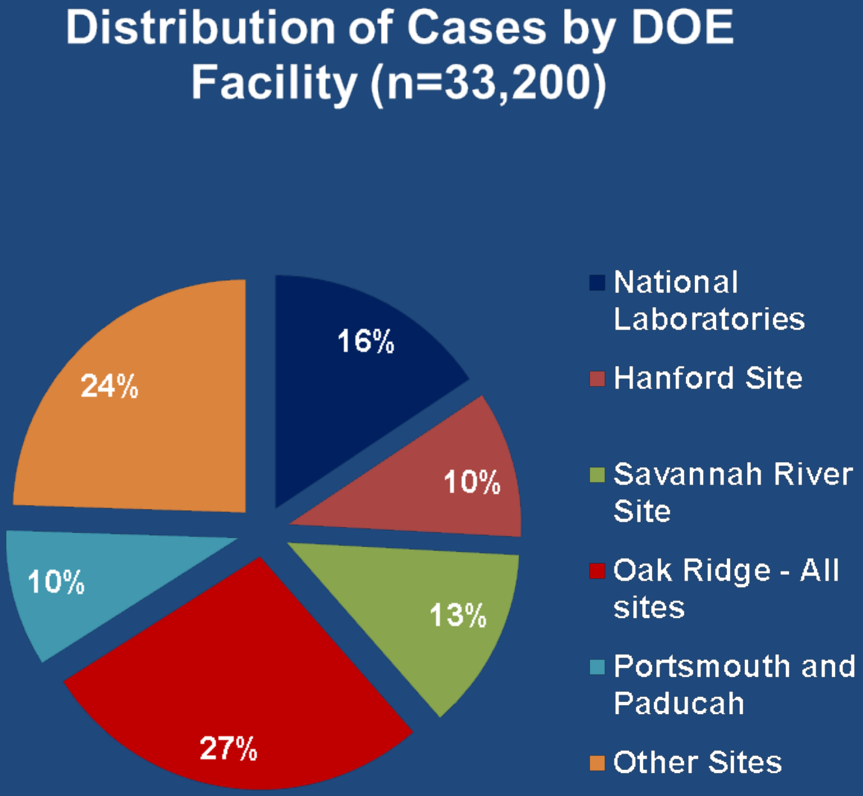
- U.S. Department of Labor (DOL) receives claims and makes probability of causation determination
- DOL forwards claims with covered exposure to NIOSH for dose reconstruction
  - Dose reconstruction used by DOL to determine if a workers cancer was “as least as likely as not” caused by exposure to radiation in the workplace (i.e. a probability of causation of ≥50%
- NIOSH has received more than 39,000 cases for dose reconstruction

Description of Cases Received for Dose Reconstruction

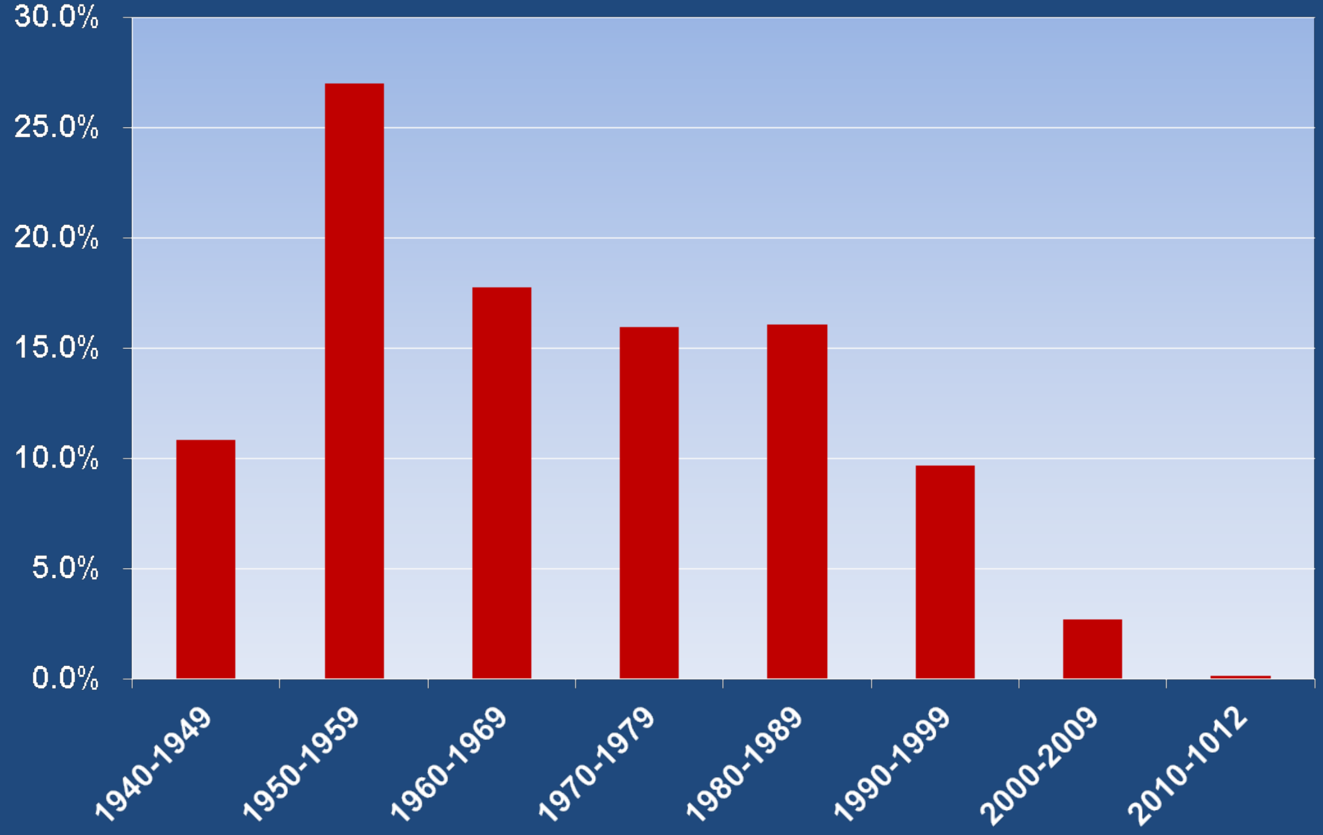
- Cases from workers or survivors at either Department of Energy (DOE) or Atomic Weapons Employer (AWE) facilities
  - DOE facilities are those in which the government had a proprietary interest (estimated population of approximately 650,000 workers)
  - AWE facilities are privately owned commercial operations that performed work under an AEC/DOE contract (estimated population of up to 100,000 workers)
- Cases received have employment histories at 125 different covered facilities

Case Distribution by Facility





Case Distribution by Employment Start Date



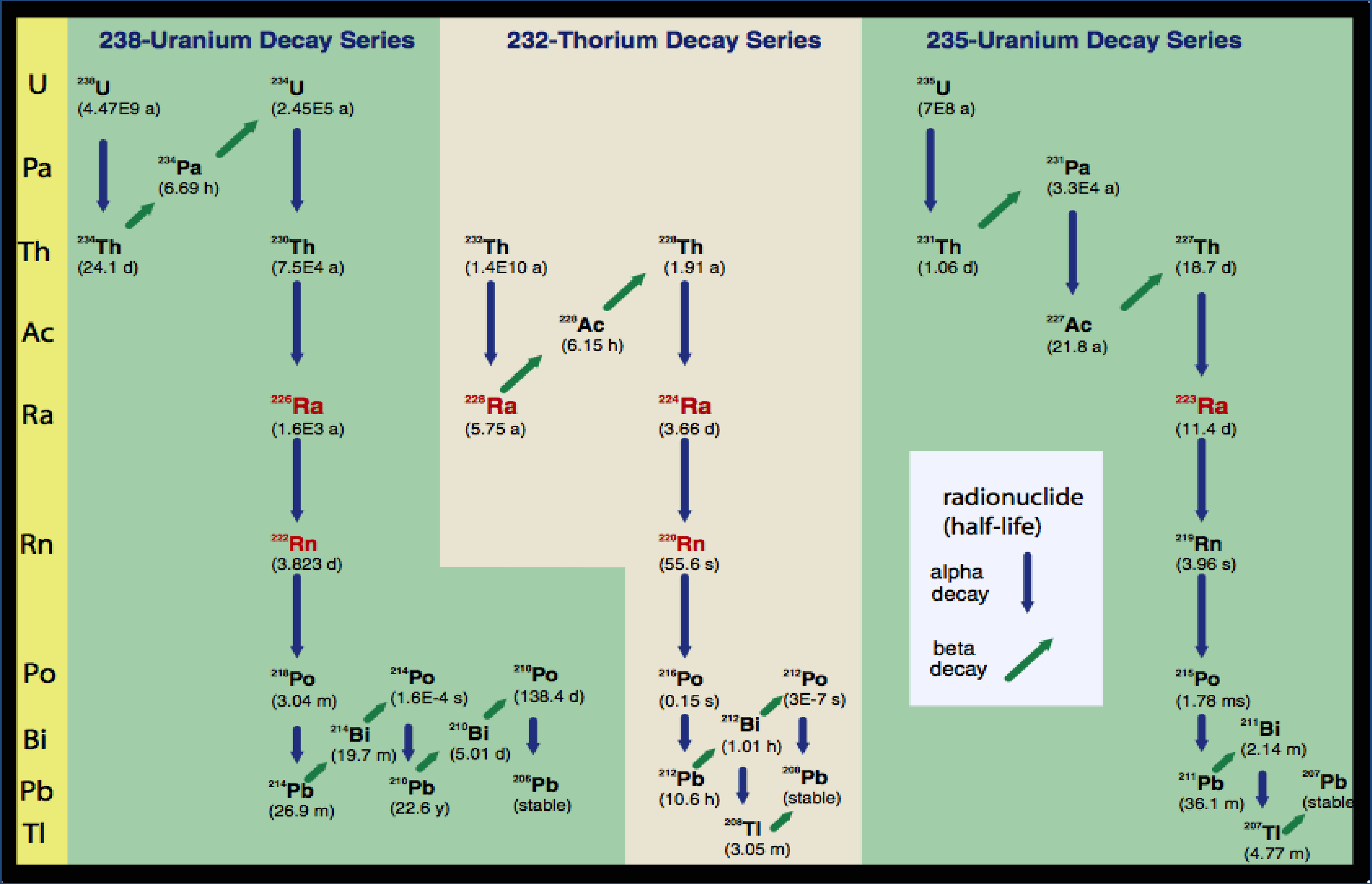
Weapons Production Activities that Created an Exposure Potential

- Uranium Milling and Refining
- Isotope Enrichment
- Fuel and Target Fabrication
- Reactor Operations
- Chemical Separations
- Weapons Component Fabrication
- Weapons Operations
- Research, Development, and Testing

Main Types of Exposure

- External
  - Gamma
  - Beta
  - Neutron
  - Medical x-rays
- Internal
  - Uranium (depleted, natural, and enriched)
  - Thorium
  - Uranium and thorium progeny
  - Plutonium
  - Other actinides (*e.g.*, Am and Cm)
  - Fission and activation products

U and Th Decay Series



U
Pa
Th
Ac
Ra
Rn
Po
Bi
Pb
Tl

238-Uranium Decay Series

^{238}U (4.47E9 a)
^{234}Pa (6.69 h)
^{234}U (2.45E5 a)
^{234}Th (24.1 d)
^{230}Th (7.5E4 a)
^{226}Ra (1.6E3 a)
^{222}Rn (3.823 d)
^{218}Po (3.04 m)
^{214}Po (1.6E-4 s)
^{210}Po (138.4 d)
^{214}Bi (19.7 m)
^{210}Bi (5.01 d)
^{214}Pb (26.9 m)
^{210}Pb (22.6 y)
^{206}Pb (stable)

232-Thorium Decay Series

^{232}Th (1.4E10 a)
^{228}Th (1.91 a)
^{228}Ac (6.15 h)
^{228}Ra (5.75 a)
^{224}Ra (3.66 d)
^{220}Rn (55.6 s)
^{216}Po (0.15 s)
^{212}Po (3E-7 s)
^{212}Bi (1.01 h)
^{212}Pb (10.6 h)
^{208}Pb (stable)
^{208}Tl (3.05 m)

235-Uranium Decay Series

^{235}U (7E8 a)
^{231}Pa (3.3E4 a)
^{231}Th (1.06 d)
^{227}Th (18.7 d)
^{227}Ac (21.8 a)
^{223}Ra (11.4 d)
^{219}Rn (3.96 s)
^{215}Po (1.78 ms)
^{211}Bi (2.14 m)
^{211}Pb (36.1 m)
^{207}Pb (stable
^{207}Tl (4.77 m)

radionuclide
(half-life)

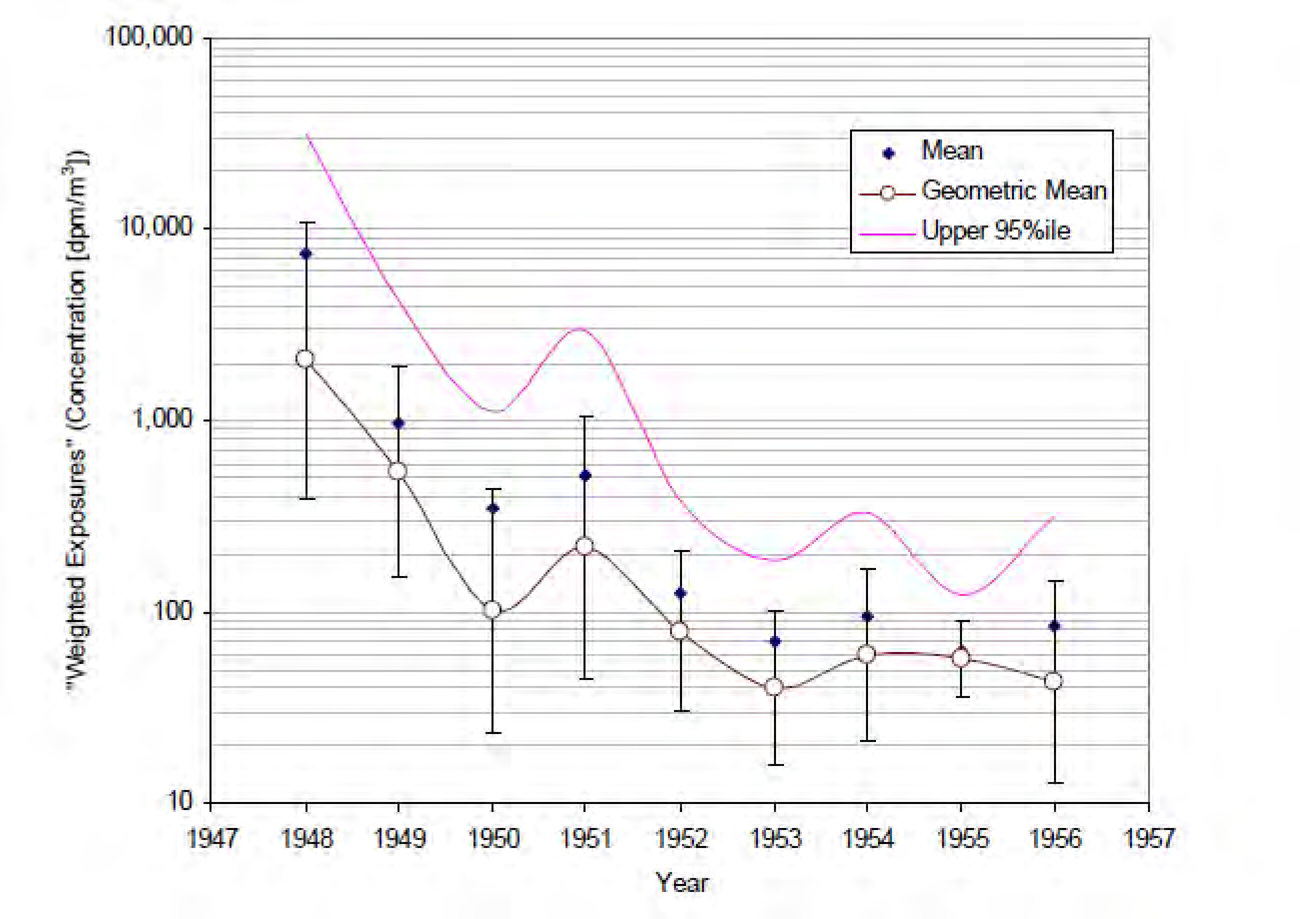
alpha decay

beta decay

The Early Years – Uranium Processing (1940s – 1950s)

- AEC needed large quantities of uranium
  - Chemical processing, metal production, and fabrication
- Much early work conducted by private companies under contract with AEC (*i.e.*, AWEs)
- Early work involved uranium ore in equilibrium with progeny (*e.g.*, Th-230, Ra-226, Rn-220)
- As administrative and engineering controls implemented, exposures reduced dramatically
- Example sites:
  - Ames Laboratory
  - Linde
  - Mallinckrodt
  - Electromet
  - Simonds Saw

Time-Weighted Average Air Concentration Data – Uranium Refining



From: Strom, DJ. (2006). *Default Assumptions and Methods for Atomic Weapons Employer Dose Reconstructions*. Battelle-TIB-5000 PNWD-3741 Rev. 0 (Battelle, Pacific Northwest Division, Richland WA)

Range of Radon Levels - Mallinckrodt 1949-1957

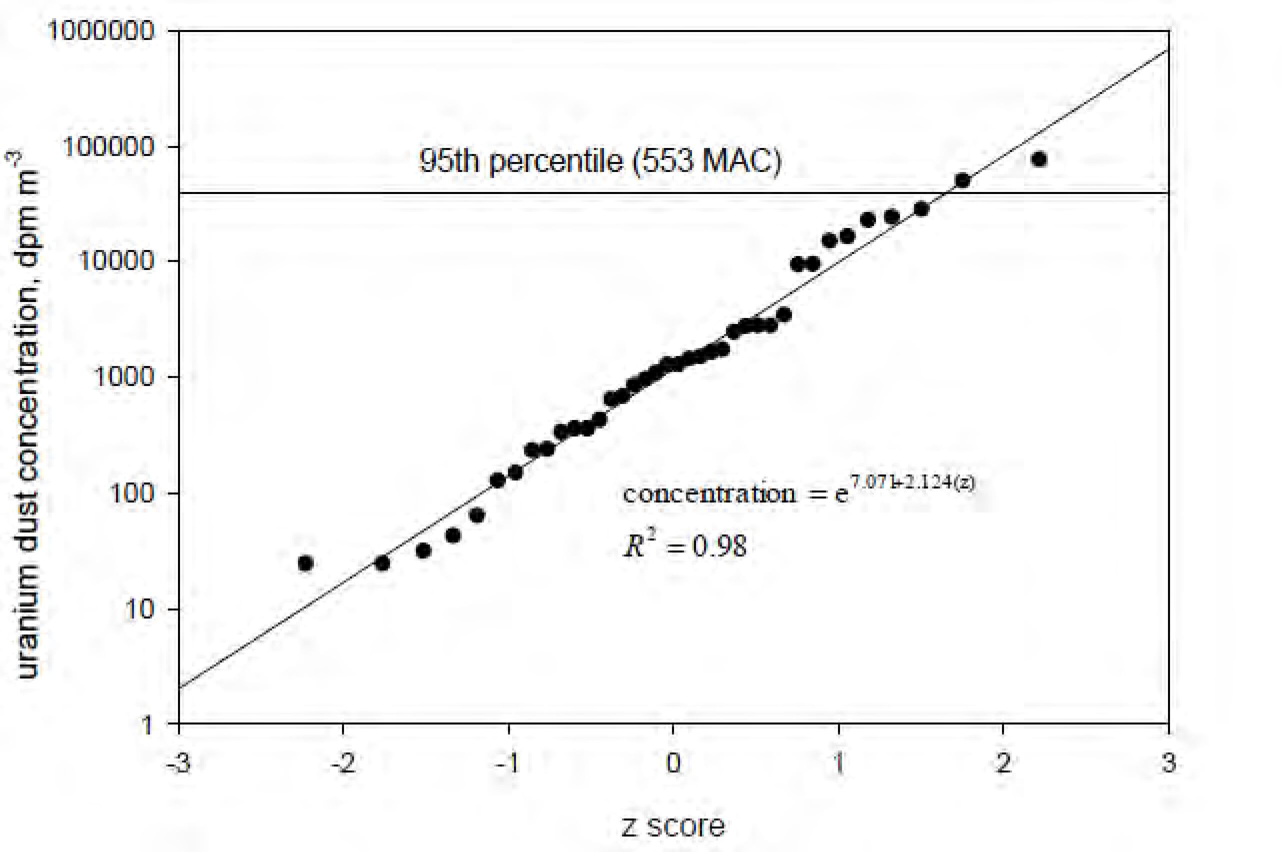
Location	Median (pCi/L)	GSD	95th Percentile (pCi/L)
Plant 6	3 – 19	3 – 7	59 – 244
Ore Filtration Areas	4 – 35	2 – 10	33 – 1012
K-65 Centrifuge	3 – 13	2 – 8	24 – 192
Ore Storage	1 – 26	4 – 22	41 – 590
Scale house	1 – 59	3 – 8	10 – 680

Gamma Exposures - Mallinckrodt

Year	Annual Exposure (R)		
	Min	Avg	Max
1947	14.4	16.1	23.5
1948	14.9	17.0	20.3
1949	7.7	9.0	13.3
1950	4.5	5.4	7.1
1954	5.0	5.9	7.1
1952	5.1	5.9	6.6
1953	4.0	4.6	5.7
1954	3.9	4.4	5.1
1955	3.9	4.4	5.1
1956	1.1	1.4	1.9

From: Oak Ridge Associated Universities. Radiation Exposure Data, Mallinckrodt Uranium Division Operations, January 1947 through June 1956. Report, no author or data listed (circa 1980).

Uranium Rolling
Simonds Saw and Steel (1948)



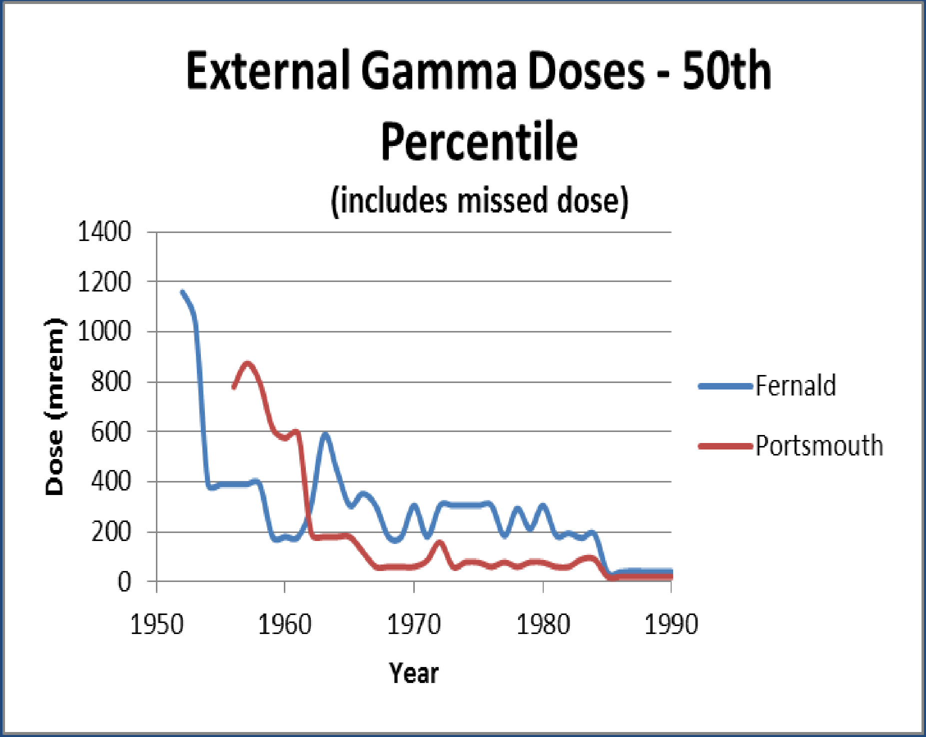
DOE Production and Processing Facilities

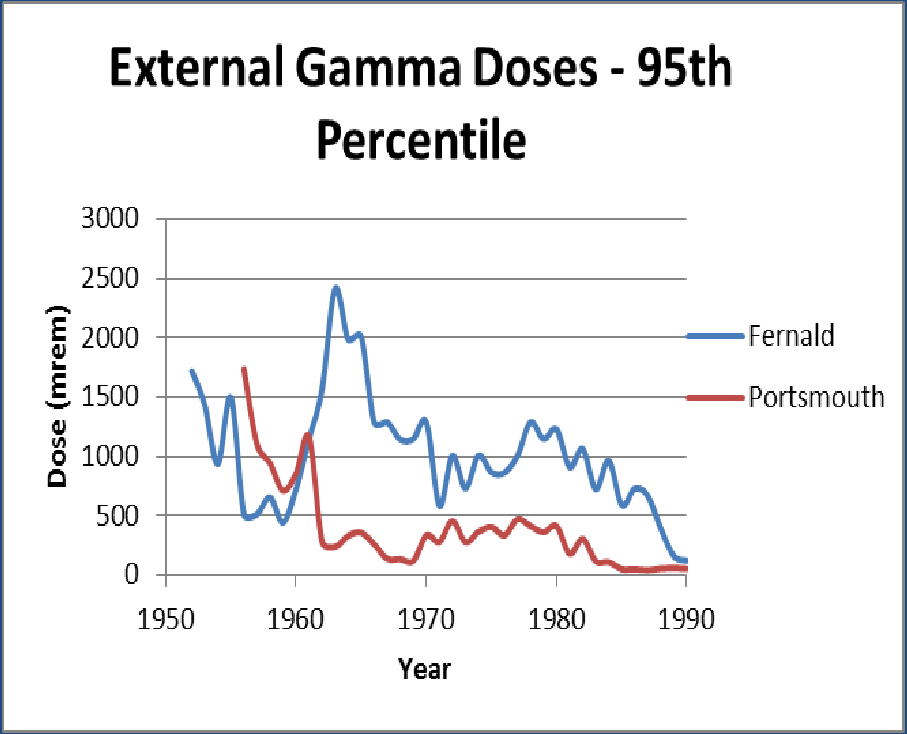
- DOE facilities grew to accommodate demand for production and processing of materials required for weapons production
- Exposures at DOE facilities reduced over those at early commercial facilities
  - Workplace controls continued to improve
  - Exposure guidelines and standards implemented
- Increased variety of source terms due to construction of reactors and chemical processing facilities
  - Introduction of potential for Pu exposure
  - Creates challenges for worker exposure monitoring
  - Insoluble forms of Pu and U lead to large missed doses

DOE Production and Processing Facilities -cont.

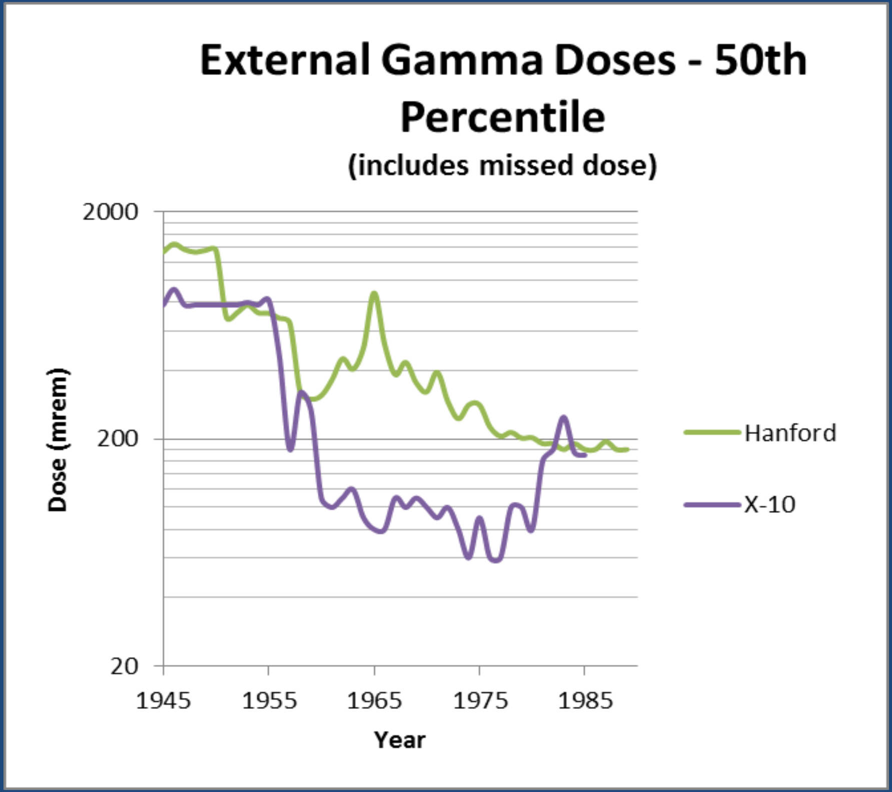
- Routine personnel monitoring programs put in place
- NIOSH has obtained and/or developed databases of external and internal monitoring data
- For a given time period, data found to be well represented by log-normal distributions
    - Where possible, annual geometric means and standard deviations are estabished
- Time-dependent internal and external exposure models have been developed for 11 major DOE sites
- Models are used to reconstruct doses for unmonitored workers (*i.e.*, co-workers)

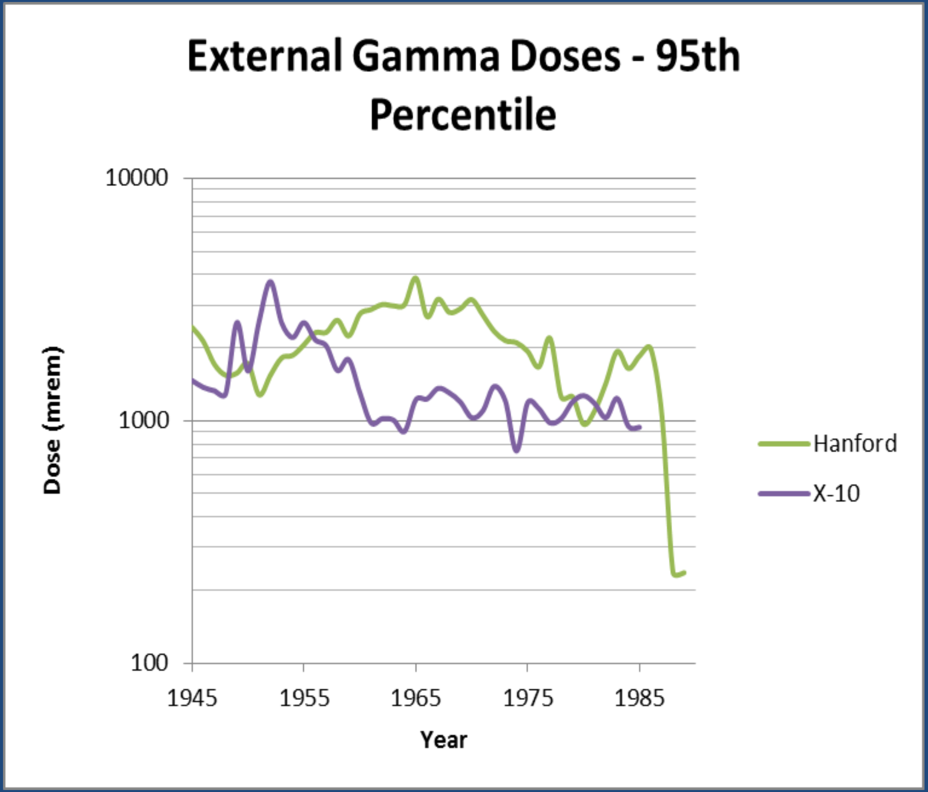
Example External Exposure Models



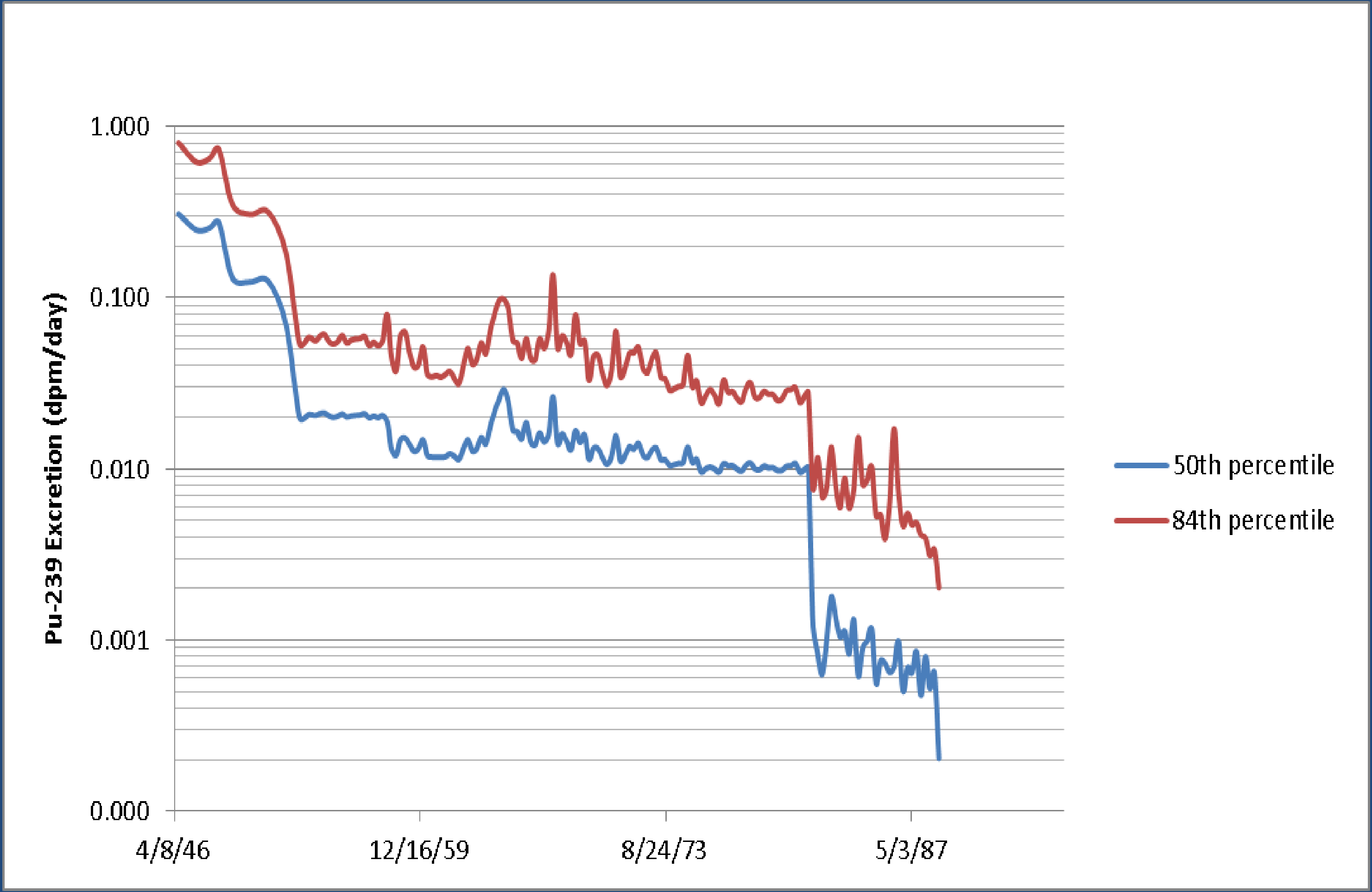


Example External Exposure Models -cont.

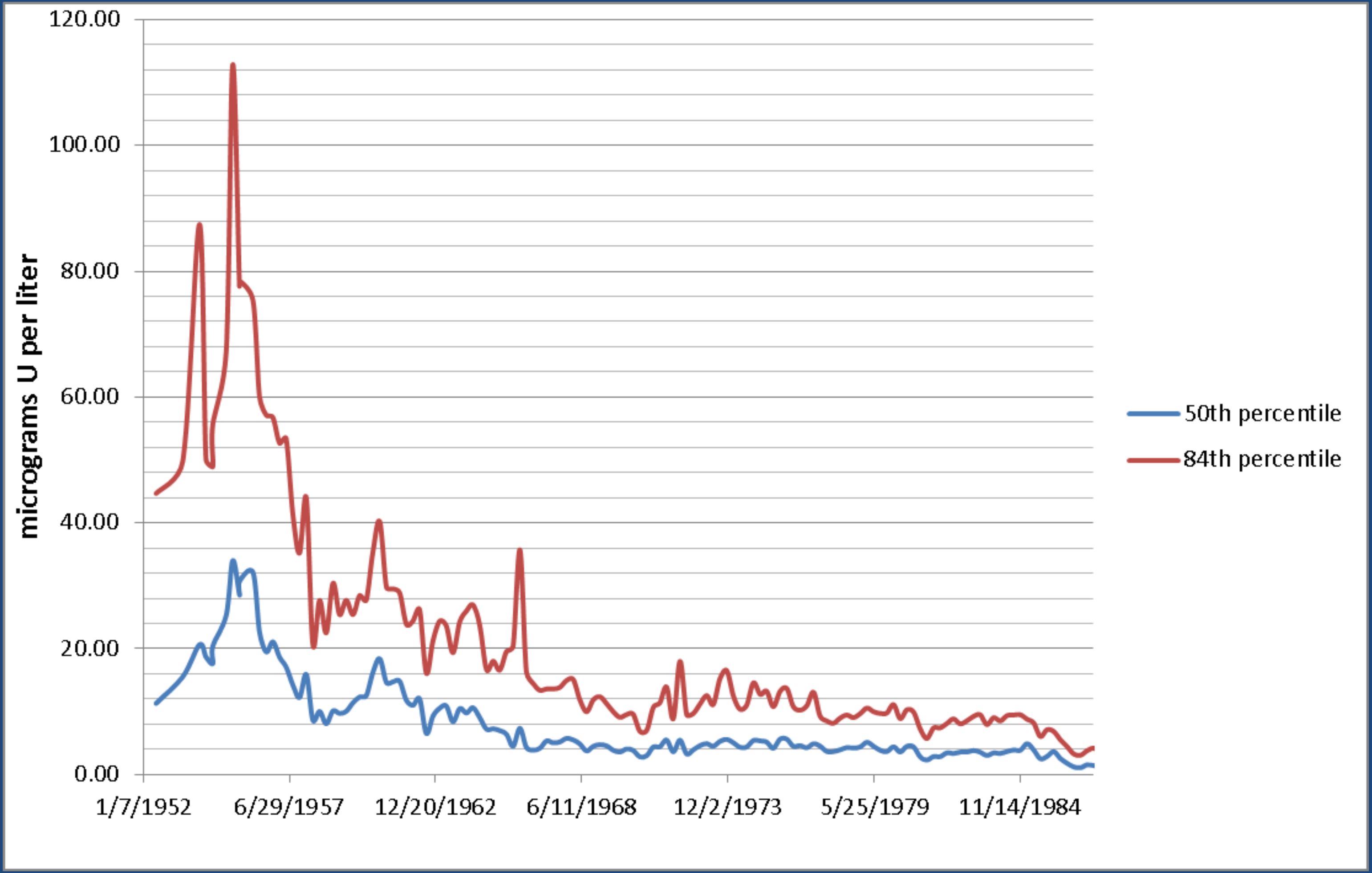




^{239}Pu Excretion Model – Hanford



Uranium Excretion Model - Fernald



Compensation Rates for Cancer Claims
General Observations

- Lung, prostate, and skin cancer make up more than 50% of the cases with a single reported cancer
- Missed dose for inhalation of insoluble actinides produces ≥50% POC for many lung cancer cases
- Unless case has high external dose, cancers of organs which don't uptake radionuclides (*e.g.*, prostate or brain) have low compensation rates
- Cancers with high excess relative risk per Sievert (*e.g.*, leukemias) compensated with relatively low doses

Missed Dose Considerations

- Insoluble inhalation intakes of actinides (*e.g.*, U, Th, and Pu) have low urinary excretion rates
- Bioassay programs incapable of detecting fairly large intakes
- Results in potential for substantial undetected lung exposures (*i.e.*, missed dose), even though exposure potential was reduced over time
- Doses are sufficiently high to produce a probabaility of causation (POC) ≥50%

COMPENSATION RESULTS BY NIOSH-IREP CANCER MODEL
BASED ON CLAIMS WITH DR APPROVED AND SUBMITTED TO DOL THROUGH Sep. 21, 2012 (31,467 CLAIMS)

Rank by Compensation Rate	NIOSH-IREP CANCER MODEL (ICD-9 Code)	Compensated (PC ≥ 50%)		Not Compensated (PC < 50%)		Total Claims	
	Claims With a Single Primary Cancer	**N**	**%**	**N**	**%**	**N**	**%**
1	Lung (162)	2940	65	1581	35	4521	20.335
2	Chronic Myeloid Leukemia (205.1)	48	53.3	42	46.7	90	0.405
3	Non-melanoma skin-Basal Cell (173)	947	52.8	846	47.2	1793	8.065
4	Acute Lymphocytic Leukemia (204.0)	41	50	41	50	82	0.369
5	Liver (155.0)	75	43.1	99	56.9	174	0.783
6	Acute Myeloid Leukemia (205.0)	73	37.4	122	62.6	195	0.877
7	Lymphoma & multiple myeloma (200-203)	626	36.9	1071	63.1	1697	7.633
8	Malignant melanoma (172)	226	35.4	412	64.6	638	2.87
9	Other respiratory (160,161,163-165)	186	30.4	426	69.6	612	2.753
10	Leukemia, excl. CLL (204-208,excl. 204.1)	42	30.2	97	69.8	139	0.625
11	Oral Cavity and Pharynx (140-149)	98	22.1	346	77.9	444	1.997
12	Bone (170)	41	18.3	183	81.7	224	1.008
13	Thyroid (193)	52	16.5	264	83.5	316	1.421
14	Gallbladder (155.1,156)	17	15.2	95	84.8	112	0.504
15	Eye (190)	5	9.8	46	90.2	51	0.229
16	Stomach (151)	49	9.3	479	90.7	528	2.375
17	Colon (153)	91	7.5	1116	92.5	1207	5.429
18	Urinary organs, excluding bladder (189)	41	6.8	559	93.2	600	2.699
19	Bladder (188)	41	6.7	570	93.3	611	2.748
20	Other endocrine glands (194)	1	3.7	26	96.3	27	0.121
21	All Male Genitalia (185-187)	136	3.2	4177	96.8	4313	19.399
22	Esophagus (150)	4	2.9	136	97.1	140	0.63
23	Connective tissue (171)	4	2.8	137	97.2	141	0.634
24	All digestive (150-159)	3	2.7	108	97.3	111	0.499
25	Other and ill-defined sites (195)	1	1.9	51	98.1	52	0.234
26	Breast (174-175)	16	1.8	897	98.2	913	4.107
27	Non-melanoma skin-Squamous Cell (173)	11	1.7	622	98.3	633	2.847
28	Pancreas (157)	5	0.9	575	99.1	580	2.609
29	Rectum (154)	3	0.6	516	99.4	519	2.334
30	Nervous system (191-192)	1	0.2	414	99.8	415	1.867
31	Female Genitalia, excl. ovary (179-	0	0	242	100	242	1.088
32	Ovary (183)	0	0	113	100	113	0.508
Subtotal for Claims with a Single Primary Cancer		5824	26.2	16409	73.8	22233	70.7
Subtotal for Claims with Multiple Primary Cancers		3248	35.2	5986	64.8	9234	29.3
GRAND TOTAL (ALL CLAIMS)		9072	28.8	22395	71.2	31467	100.0

Summary

- Early operations at uranium processing facilities produced high internal and external exposures
  - Lack of enginnering controls
  - Processing of high-grade U ores
- Over time, DOE facilities reduced exposures due to inprovements in adminstrative and engineering controls
- At the same time, introduction of reactors and chemical processing increased the variety of the exposure source term

Summary – cont.

- For facilities with established monitoring programs, co-worker exposure models can be used to characterize exposure to unmonitored workers
- By including missed dose and using other favorable assumptions, almost 30% of all claims have dose reconstructions that result in a POC ≥50%
- Incorporation of missed dose into lung cancer cases results in a compensation rate of more than two times that of the average

Additional Information

- Visit the NIOSH/DCAS website at: http://www.cdc.gov/niosh/dcas
- Also see: Health Phys. 95, No 1, July (2008). This issue is entirely devoted to the NIOSH Dose Reconstruction Program

The findings and conclusions in this presentation are those of the author and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

Increased Occupational Exposures: Nuclear Industry Workers

Andre Bouville
National Cancer Institute (retired)

NCRP meeting, 11 March 2013

Outline

- Introduction
- Routine operation: early years
- Reactor accidents
- Summary

Introduction

- Nuclear fuel cycle:
    - Uranium mining
    - Uranium milling
    - Fuel enrichment
    - Fuel fabrication
    - Reactor operation
    - Fuel reprocessing
- “Effective” doses used for comparison purposes

Workers and annual effective doses

	Monitored workers (10^3)		Average annual E (mSv)	
	1975-1979	2000-2002	1975-1979	2000-2002
Mining	240	12	5.5	1.9
Milling	12	3	10	1.1
Enrichment	11	18	0.5	0.1
Fabrication	20	20	1.8	1.6
Reactor	150	437	4.1	1.0
Reproc.	78	76	7.1	0.9

Source: UNSCEAR 2008 Report

Presentation

- Nuclear fuel cycle:
    - Uranium mining: **NO**
    - Uranium milling: **NO**
    - Fuel enrichment: **NO**
    - Fuel fabrication: **NO**
    - **Reactors: accidents + early operation**
    - **Fuel reprocessing: early operation**
- Doses presented in chronological order

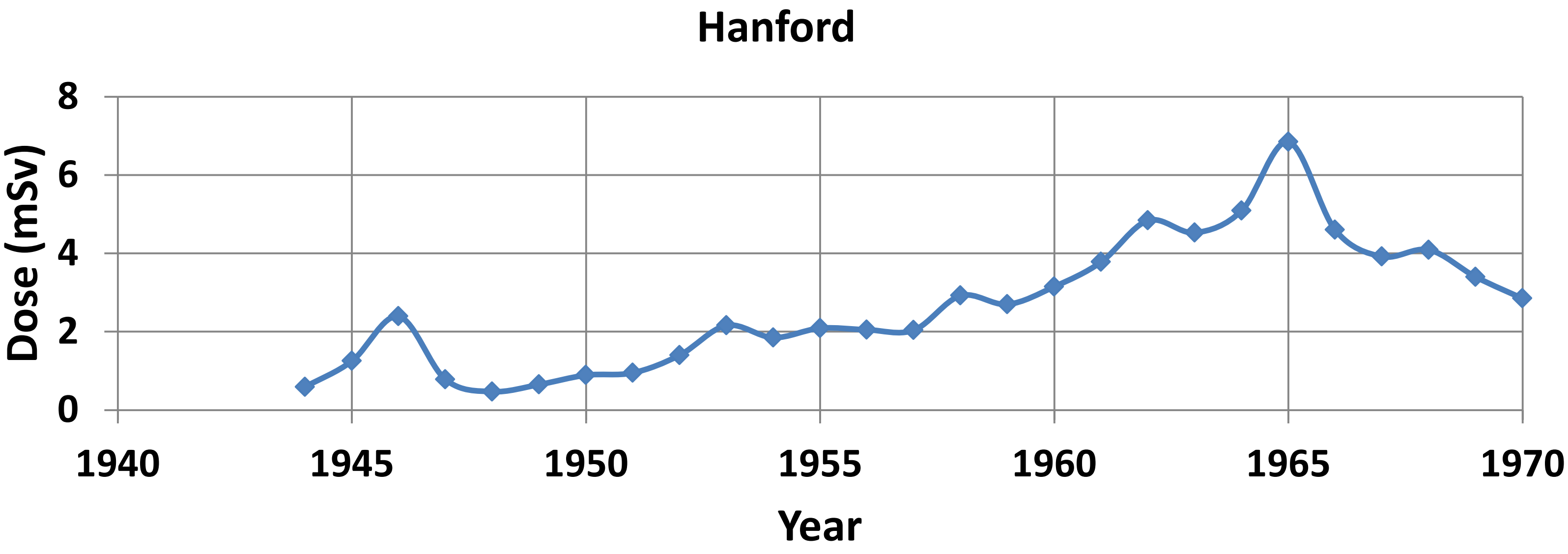
Routine operation: early years

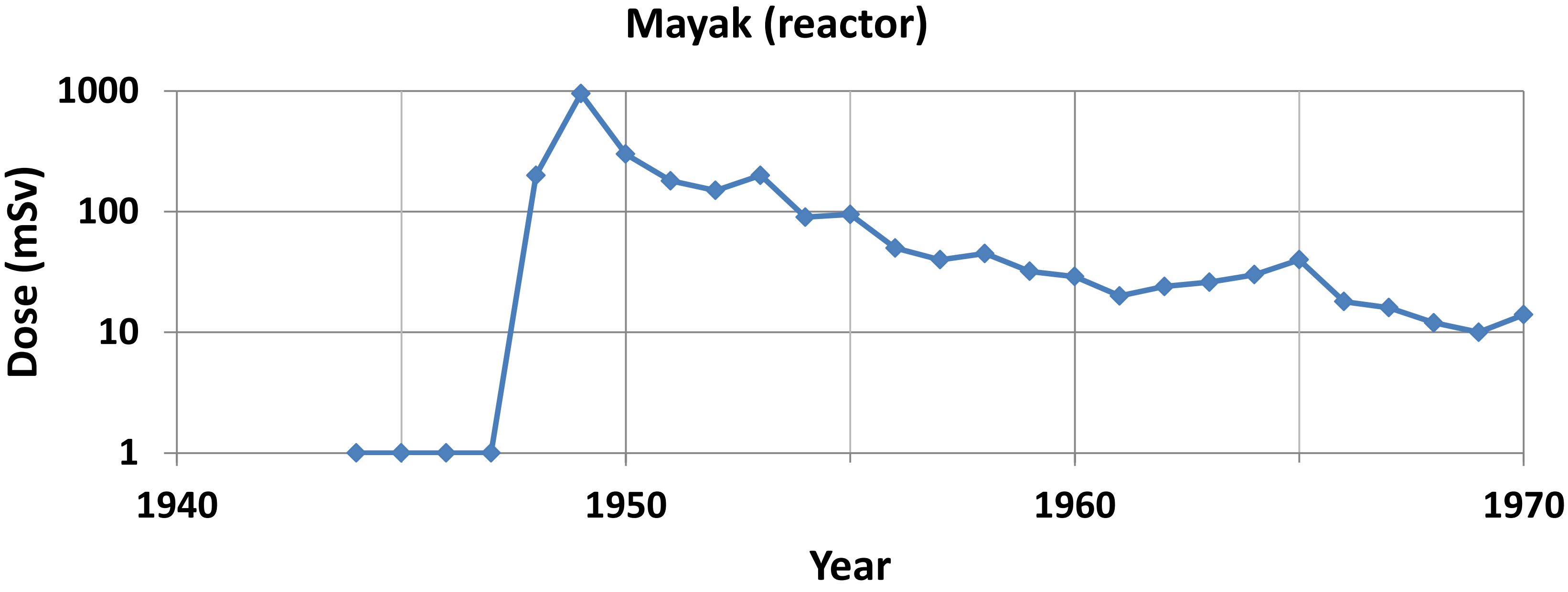
Facilities producing plutonium for military uses:

- Hanford Works, USA (1944+):
    - 9 nuclear reactors
    - 5 Pu processing plants
- Mayak PA, Russia (1948+):
    - 5 nuclear reactors
    - 1 radiochemical plant

Average doses from external irradiation (mSv)

Year	**Hanford**	**Mayak**	
		Reactor	Radiochemical
1944	0.59	-	-
1948	0.47	200	-
1949	0.65	950	400
1950	0.89	300	950
1955	2.09	95	210
1960	3.15	29	170
1965	6.85	40	20
1970	2.85	14	16


Hanford
Dose (mSv)
8
6
4
2
0
1940
1945
1950
1955
1960
1965
1970
Year


Mayak (reactor)
Dose (mSv)
1000
100
10
1
1940
1950
1960
1970
Year

Reactor accidents

- Windscale (1957)
- Three Mile Island (1979)
- Chernobyl (1986)
- Fukushima (2011)

Windscale (U.K.)

- Type: U metal, graphite-moderated, air-cooled reactor (pile)
- Purpose: production of Pu for the U.K. atomic weapons program
- Cause of accident: fire
- Date: 10 October 1957

Windscale: doses

- 471 workers involved in fire activities
- Doses recorded for October 1957:
    - Highest: 44 mSv
    - Median: 4.5 mSv
    - 95th percentile: 16 mSv
- Doses over a 3-month period:
    - Highest: 47 mSv
    - 14 greater than 30 mSv

Three Mile Island (U.S.)

- Type: pressurized-water reactor
- Purpose: production of electricity for commercial purposes
- Cause of accident: equipment failure
- Date: 28 March 1979

TMI: workers with measurable dose

Year	Number of	Highest dose	Average dose
	workers	mSv	mSv
1979	3975	45	3.5
1980	2328	21	1.7
1983	1592	27	7.3
1984	1079	-	6.4
1985	1890	-	4.5
1986	1497	-	6.1
1990	484	-	2.8
1995	191	-	0.1

Chernobyl Accident – 26 April 1986

The most severe accident that ever occurred in the nuclear power industry.

Chernobyl (Ukraine)

- Type: graphite-moderated, water-cooled reactor
- Purpose: production of electricity for commercial purposes
- Cause of accident: human errors
- Date: 26 April 1986

Emergency workers

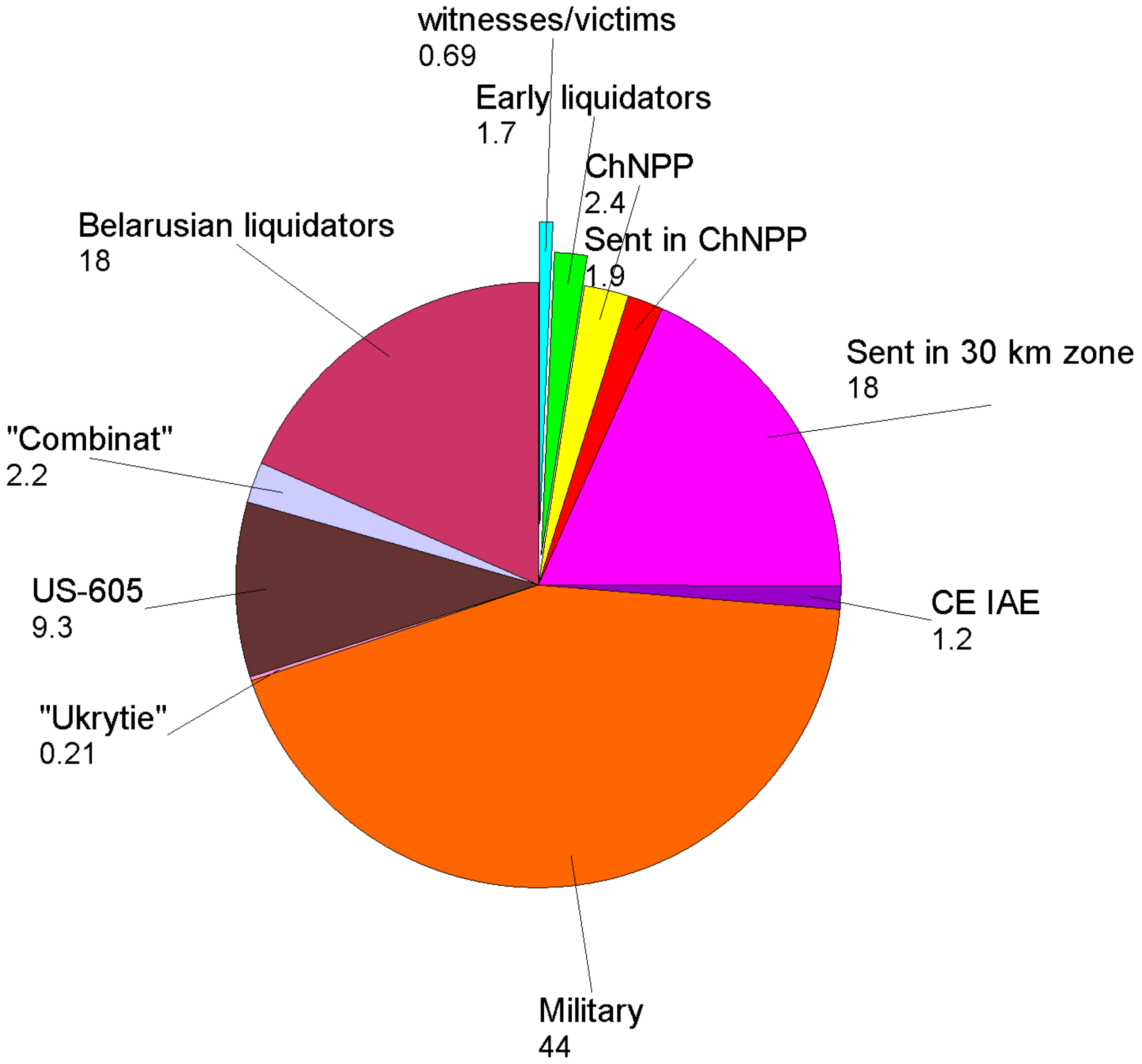
- **REACTOR STAFF: 374**
- **FIREMEN: 69**
- **GUARDS: 113**
- **MEDICAL: 10**

Emergency workers with acute radiation sickness

	Number	Deaths
Mild (0.8 - 2.1 Gy)	41	0
Moderate (2.2 - 4.1 Gy)	50	1
Severe (4.2 - 6.4 Gy)	22	7
Very severe (6.5 - 16 Gy)	21	20
Total	134	28

Chernobyl: recovery operation workers

Year	Number of workers	% workers with recorded dose	Mean recorded dose (mGy)
1986	305,826	35	146
1987	138,173	64	96
1988	51,278	71	43
1989	24,128	69	41
1990	5,766	66	47
1986-1990	526,245	48	117



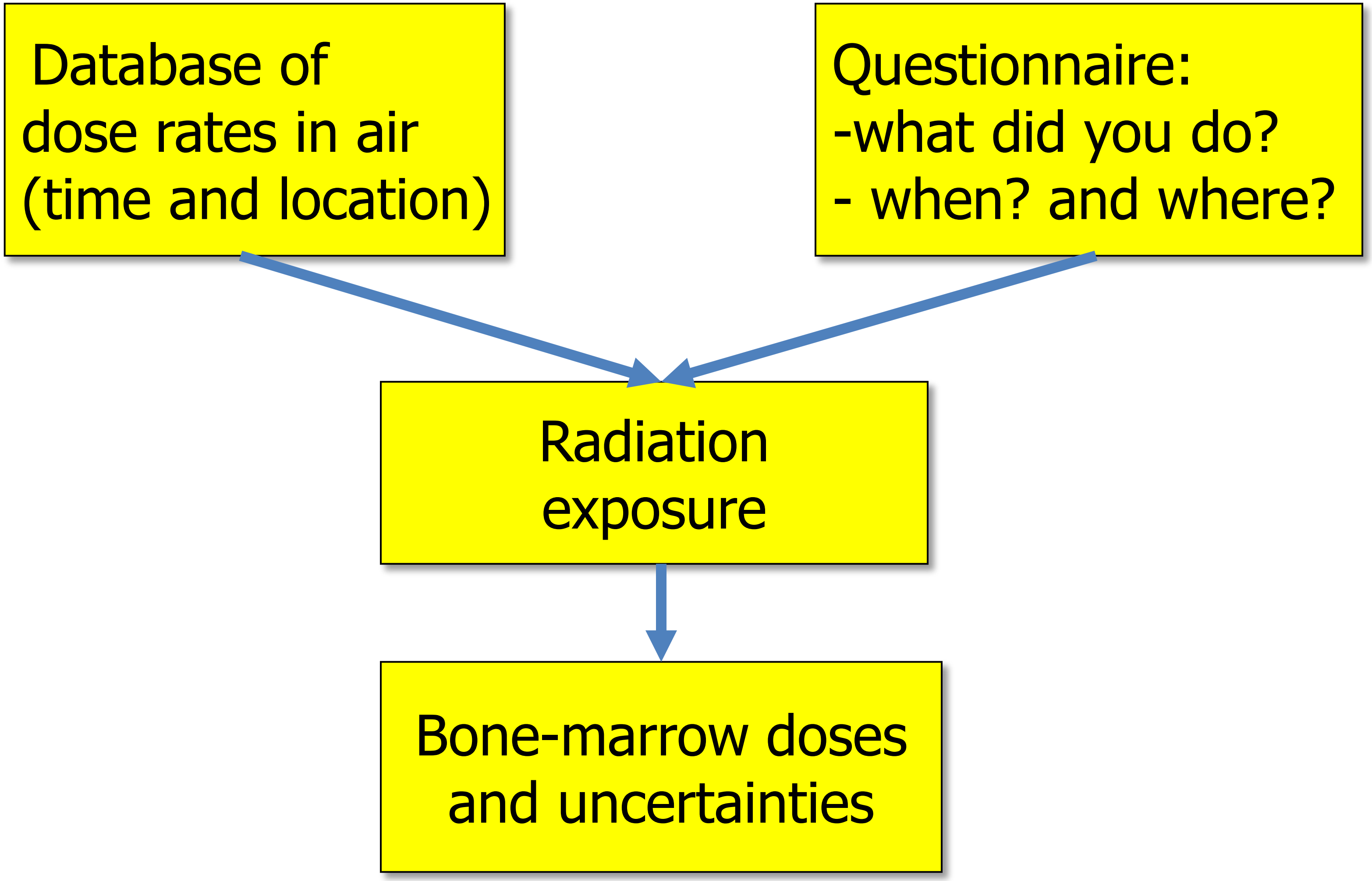
Categories of recovery operation workers (%)

NCI Study of leukemia among Ukrainian clean-up workers*

- Case-control study: 71 cases and 501 controls.
- Dosimetry records not available for half of the subjects, and also inadequate.
- Dose estimates based on RADRUE.

*Romanenko et al. Radiat. Res. 170, 691-697 (2008)

RADRUE: time-and-motion method



Database of
dose rates in air
(time and location)

Questionnaire:
-what did you do?
- when? and where?

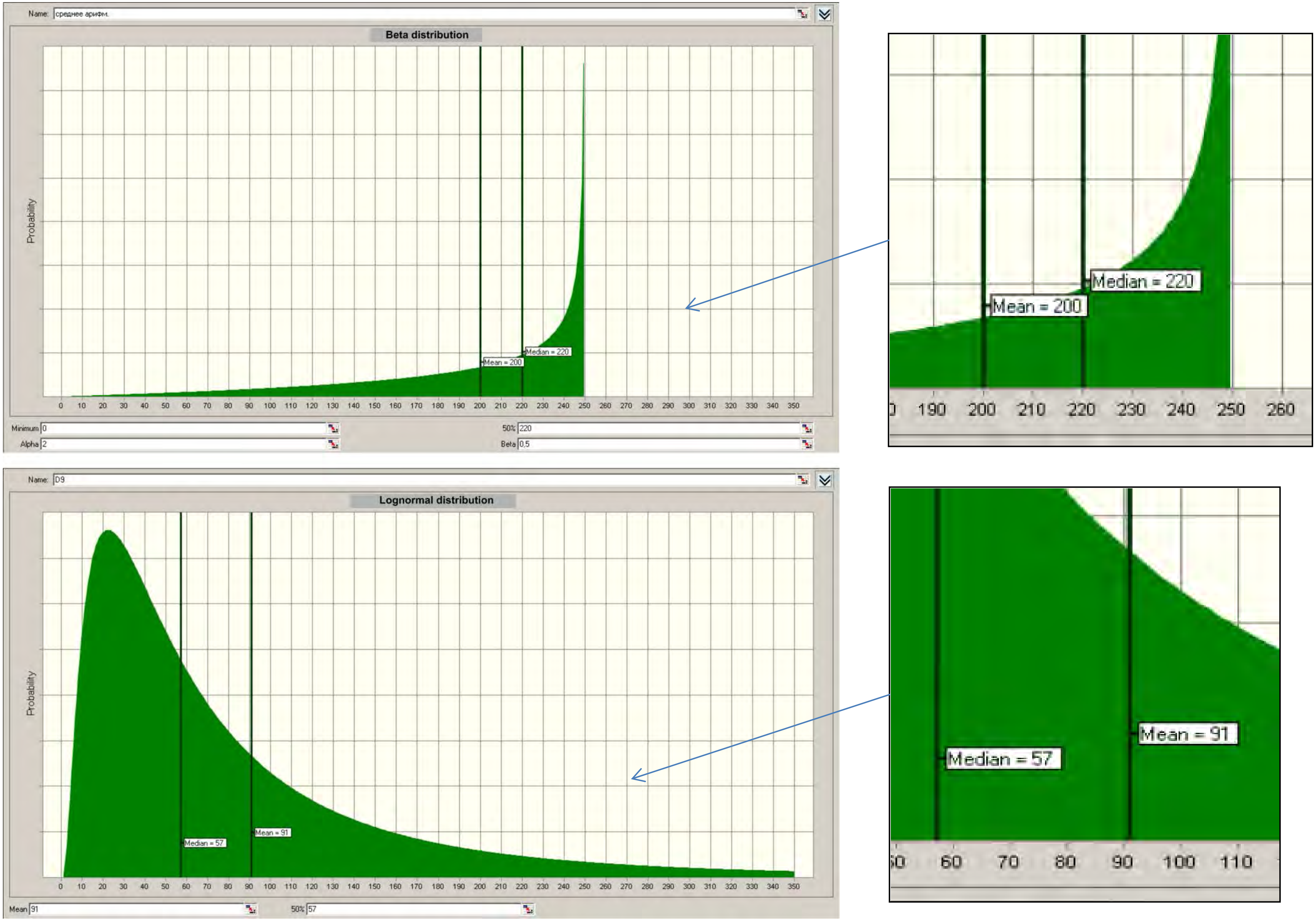
Radiation
exposure

Bone-marrow doses
and uncertainties

Individual mean dose estimates (mGy)

	Number of workers	**Average dose**	**Min. dose**	**Max. dose**	**Average GSD**
Accident victims	2	2880	2580	3170	3.4
Early liquidators	66	97	0.5	1010	2.0
Reactor ersonnel	9	234	23	966	1.7
Military	220	71	0.01	554	2.1
Sent on mission	181	30	<0.01	694	2.0
ALL	572	87	<0.01	3260	2.0

Source: Chumak, 2008



Name: среднее арифм.

Minimum 0

50% 220

Alpha 2

Beta 0,5

Name: D9

Mean 91

50% 57

Distribution of “official” doses (above) and RADRUE- calculated doses (below).

Fukushima: the worst accident after Chernobyl

Fukushima (Japan)

- Type: boiling water reactor
- Purpose: production of electricity for commercial purposes
- Cause of accident: tsunami
- Date: 11 March 2011

Doses to workers: March 2011 to December 2012

Range (mSv)	TEPCO	Contractors	Total
>250	6	0	6
100-250	140	21	161
50-100	585	661	806
20-50	599	3032	3631
10-20	708	3316	4024
1-10	987	8735	9722
<1	661	6163	6824
Total	3628	21770	25398
Maximum (mSv)	678	238	678
Average (mSv)	25	10	12

Doses greater than 250 mSv

- 7 workers may have received doses > 250 mSv
- The most important component of those doses is due to inhalation intake of I-131
- The dose estimates are being refined:
  - Determination of the best intake scenario
  - Role of KI administered following the intake
  - Additional dose due to other radionuclides (I-133, Cs-137, etc.)

Internal Exposure and External Exposure in Highly Exposed Plant Workers

WORKER	**Total (mSv)**		**External (mSv)**	**Internal (mSv)**
A	678		88 (13%)	590 (87%)
B	643		103 (16%)	540 (84%)

Summary

- Among the examples chosen, early deaths due to radiation exposure were only observed after the Chernobyl accident.
- Doses greater than 0.5 Sv were observed:
  - after the Chernobyl accident,
  - after the Fukushima accident,
  - during the early operation of Mayak PA.

Radiation Exposure of U.S. Military Individuals

Brief for: Annual NCRP Meeting
Bethesda, MD
March 11, 2013

Briefer: Paul K. Blake

DEFENSE THREAT REDUCTION AGENCY • UNITED STATES OF AMERICA

USSTRATCOM CENTER FOR COMBATING WMD

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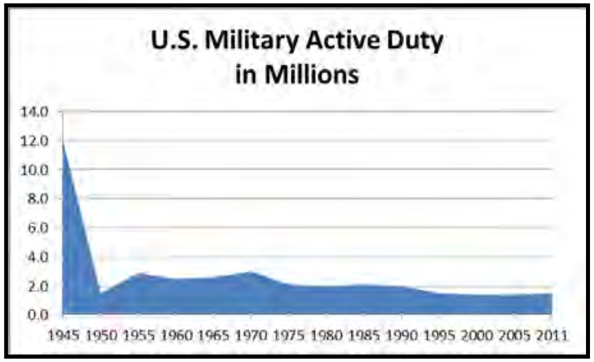
Outline

- Introduction
- The Formative Years
- Military Ionizing Radiation Exposure
- Radiation Dosimetry
- Data Repositories
- Radiogenic Disease Compensation Programs

The U.S. Military

- The U.S. Armed Forces consist of the Army, Navy, Marine Corps, Air Force, and Coast Guard.
- It is the world's 2nd largest military, after China's People's Liberation Army.
- The U.S. military (as of Sep 2012)[1]:
  - 1.4M Active military
  - 1.3M Guard & Reserve military
  - 0.7M Civilian employees
- All of these cohorts have the potential for radiation exposure.
- Annual occupational monitoring: 70k (2%)



1: http://siadapp.dmdc.osd.mil/personnel/MILITARY/miltop.htm accessed 05 Feb 2013.

The U.S. Military

- The U.S. military employs or encounters numerous ionizing and non-ionizing radiation sources.
- Radiation exposure may occur during peacetime, during warfare, and on occasion, in operations other than war.
- Military planners are concerned about radiation effects on people, equipment, and structures, to include effects in space, on land, and the sea.
- The U.S. military employs numerous military, civilian, and contract personnel to address these concerns.
- My presentation today will focus on ionizing radiation exposure of U.S. military-affiliated individuals.

The Formative Years

The U.S. military was an early adopter of ionizing radiation:

- CPT Borden, USA published, "The use of the Roentgen Ray by the Medical Department of the U.S. Army in the War with Spain (1898)" – only 3 years after Roengten's discovery of the X-ray.
- When the U.S. entered WWI, almost 20 years later, X-ray technology was still in its infancy.
- By WWII, tremendous strides had occurred in radiology.
- COL Stafford Warren, USA, a radiologist, was appointed Medical Director, Manhattan Project.
  - Directed radiation safety operations at the Trinity and Operation Crossroads nuclear test detonations.

The Manhattan Project

- The Manhattan Project (involving up to 130,000 people), coordinated by the Army Corps of Engineers, resulted in development of standardized radiation detection and safety equipment.
- Since that time, U.S. military individuals have experienced many new and varied radiation exposure situations, and this plethora of varied exposures continues through today.

Exposure Cohorts

- The U.S. military maintains occupational radiation exposure records from 1945-present:

Cohort[1]	Unique Individuals (x1000)
Army	700
Navy-Marine Corps (including Naval Reactors)	800
Air Force	150
Coast Guard	3
Op. Tomodachi Registry	70
DTRA-Atmospheric Detonation Participants	493
DTRA-Underground Test Participants	50
DTRA-Pacific Atoll Cleanup Participants	7
	2,273

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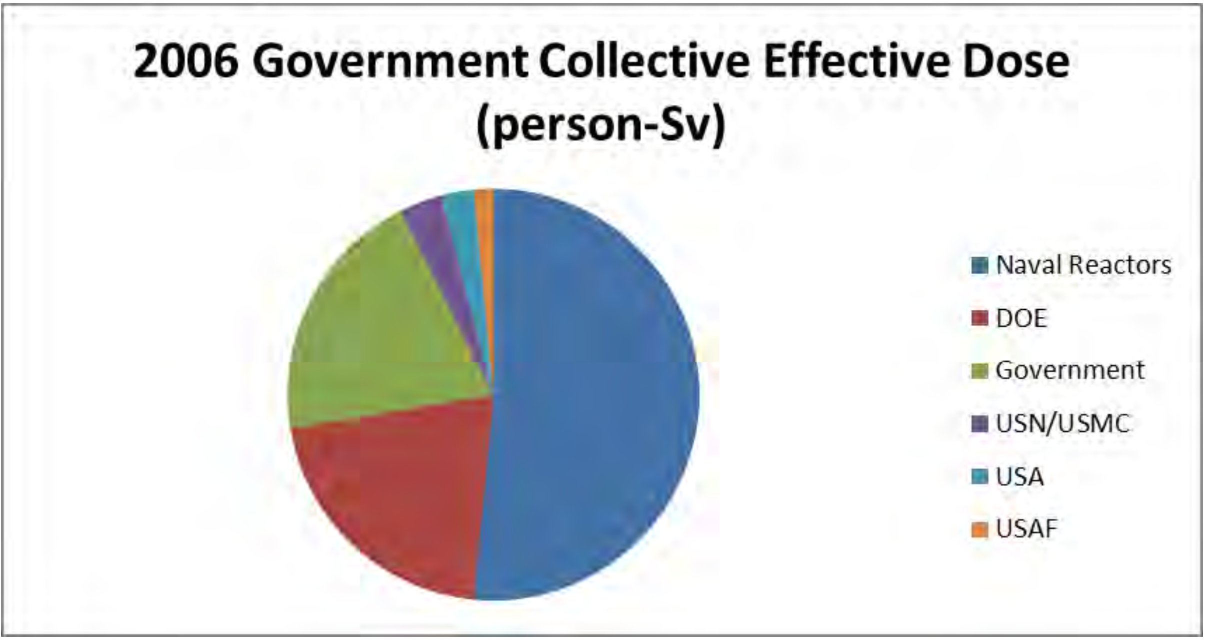
[1] Data as of CY2012

Collective Effective Dose



Cohort	Individuals	person-Sv
Naval Reactors	45,964	20.0
DOE	91,280	8.1
Government	122,367	7.8
USN/USMC	5,965	1.3
USA	12,018	1.0
USAF	6,598	0.6
	284,192	38.8

Reference: NCRP Report 160, Chap.7, “Ionizing Radiation Exposure of the Population of the United States”

Radioepidemiology Studies

- Atomic vets: numerous National Academy of Sciences (NAS) & Department of Veterans Affairs (VA) studies
- Shipyard personnel (nuclear powered ship work)
  - NIOSH studies of Portsmouth Naval Shipyard workers
  - Johns Hopkins study of 70,000 workers at six shipyards
- Submariners
  - VA (2000) - WWII sub sailors nasopharyngeal radium irradiation
  - NYU (2001) – update of Yale study (85,500 nuclear sub sailors)
- Gulf war depleted uranium cohort
  - Unique in fragment surveillance
- Results - little or no evidence of radiation dose response.

DoD Guidance

- JP 3-11 Operations in CBRN Environments
- DoDI 6055.08 Occupational Rad. Protection
  - Implements EPA, NRC, OSHA guidance
  - Does not apply to:
    - Diagnostic/therapeutic exposure
    - Nuclear warfare exposure
    - NATO exposure
    - Aircrew cosmic radiation exposure
    - Naval Reactors exposure

Regulated 10 CFR 20 Exposure

- The Navy/Marine Corps and Air Force each maintain Master Material Licenses with the Nuclear Regulatory Commission (NRC).
- The Army, DTRA, and Defense Logistics Agency have individual NRC Licenses.
- All of the military personnel exposed to these NRC regulated sources must comply with 10 CFR 20, …

Regulated 91b Exposure

- Military Application of Atomic Energy (91b) – as per 42 USC 2121 authority.
  - Includes special nuclear material, byproduct and source material.
    - > For example, exposure from Naval Reactor sources or exposure from nuclear weapon warheads
  - The U.S. military maintains rigorous radiological controls programs for these radiation sources. Personnel exposure limits are similar to 10 CFR 20, or more restrictive.

Regulated X-Ray Exposure

- Clinical sources - 59 military hospitals, 360 health clinics:
  - Numerous diagnostic and therapeutic sources
  - Fluoroscopic (cardiology) – are often highest annual occupational individual dose.
- Industrial sources:
  - Radiography
  - Accelerators
  - Analytical sources, …

Coast Guard

- Guidance: COMDINST M6000.1
- Limited occupational exposure. Primarily, from x-ray unit operation at 30 medical clinics or possibly vessel boarding ops.
- Possible historical x-ray exposure from high voltage electrical cabinets at LORAN stations between 1942-2010.

Naval Reactors

- The U.S. Navy has 104 operational reactors (including 71 submarines & 11 aircraft carriers), and has successfully steamed over 151 million miles on nuclear power. The responsible organization, Naval Reactors, is consistently recognized for its record of excellence[1].
- These reactors have unique design aspects:
  - Nimitz Class carriers operate for 20 y without refueling, with an expected service life of 50 y.
  - Virginia Class submarines have life-of-ship reactor cores that will last 33 y.
- The USS Enterprise (CVN-65), inactivated at the end of 2012, had a 51 y lifetime.

---

[1] Naval Proceedings, Sep 2012, pg. 83.

Naval Reactors

- Naval Reactors[1] has accumulated over 6500 reactor-years of safe operation involving 526 nuclear reactor cores, without a single reactor accident, over a period of more than 50 years.
- No individual in the Naval Reactors Program has exceeded the federal annual limit in effect at the time.
  - In recent years, the average annual radiation exposure for vessel operators has dropped to about one-tenth of the average annual exposure a member of the American public receives from natural background radiation and medical sources.
- The majority of radiation exposure occurs at four Navy shipyards that maintain nuclear powered vessels.

1: http://nnsa.energy.gov/ourmission/poweringnavy accessed 05 Feb 2013.

Atomic Veterans

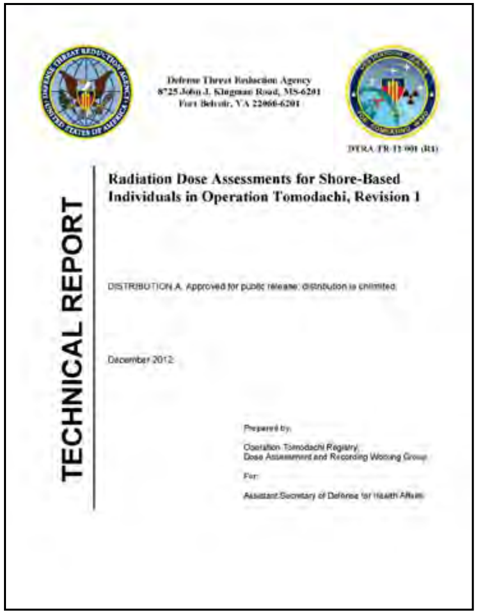
- Atomic Veterans are a unique US military exposure cohort, as defined by 38 CFR 3.309 and 3.311:
  - The US conducted about 200 atmospheric nuclear weapon tests from 1945 to 1962. The testing was principally conducted in Nevada and the Pacific. About 230,000 US military and civilians, took part in the tests. Largest doses were approx. 0.9 Sv.
  - In 1988, approx. 230,000 additional veterans were added to this cohort. These were Japanese-held POWs or occupation force members located in proximity to Hiroshima and Nagasaki during the period Sep 1945 through 30 Jun 1946. Largest occupational force doses were approx. 0.01 Sv.

Operation Tomodachi

- On March 11, 2011, an earthquake/tsunmai devasted Japan, and resulted in radiological releases from the Fukushima Daiichi Nuclear Power Station.
- In support of Japan, DoD launched Operation Tomodachi, involving 24,000 U.S. service members, 189 aircraft, 24 naval ships, and costing $90 million.
- The radiological release potentially impacted 53,000 DoD-affiliated individuals on shore, and 17,000 individuals on ships.
- DoD instituted extensive environmental monitoring, and both external and internal monitoring of individuals.

Operation Tomodachi

- DoD issued over 3,000 personnel dosimeters
  - that measured 0.25 mSv or less per individual
- Extensive distribution of KI
  - Minimal directed consumption (based on DoD guidance)
- Internally monitored (portable & fixed scanning) over 8,000 individuals
  - Phase I: Individuals with potential for high exposure
  - Phase II: Voluntary open availability (includes military dependents)
  - 946 monitored in US, 7,434 monitored in Japan
  - Only 236 (2.8%) greater than MDA
  - Maximum estimated effective dose: 0.3 mSv
  - Maximum estimated thyroid dose: 4.7 mSv



Defense Threat Reduction Agency
8725 John J. Kingman Road, MS-6201
Fort Belvoir, VA 22060-6201

DTRA-TR-12-001 (R1)

TECHNICAL REPORT

Radiation Dose Assessments for Shore-Based Individuals in Operation Tomodachi, Revision 1

DISTRIBUTION A. Approved for public release: distribution is unlimited.

December 2012

Prepared by:

Operation Tomodachi Registry
Dose Assessment and Recording Working Group

For:

Assistant Secretary of Defense for Health Affairs

Operation Tomodachi

- At the request of the Chair, Senate Veterans Affairs Committee, DoD created an Operation Tomodachi Registry, which includes a public website:

  http://registry.csd.disa.mil/otr

  - About 70,000 names and associated demographics
  - Individual daily location data
  - Location-based, conservative, estimated radiation doses:

Group	Effective Dose (mSv)	Thyroid Dose (mSv)
Children (<17 y)	0.01 to 1.6	0.03 to 27
Adults (≥17 y)	0.01 to 1.2	0.07 to 12

Dosimetry – External

- The Army, Naval, and Air Force Dosimetry Centers, and various Naval Reactor sites comprise greater than 50% of NVLAP accredited radiation dosimeter processors.
- They process whole body and extremity dosimetry, to include solid state (TL, OSL) and electronic pocket dosimeters.

Dosimetry – Internal

- Similarly, Army, Naval, Air Force, and Naval Reactors sites offer a variety of internal monitoring:
  - In Vivo (external counting)
  - In Vitro (urine bioassays)

Data Repositories

- DoD has five repositories of radiation exposure that maintain records from 1945-present:
  - Operation Tomodachi Registry
    - includes dependents
  - Army Dosimetry Center
  - Naval Dosimetry Center
  - Air Force Dosimetry Center
  - DTRA’s Nuclear Test Personnel Review
    - includes atomic vets, underground test participants, and pacific atoll cleanup participants

Radiogenic Disease Compensation

- Federal radiogenic disease compensation:
  - Department of Veterans Affairs (VA) 38 CFR 3.309/3.311
    - Veteran compensation based on percent disability; includes presumptive and non-presumptive compensation.
    - Approx. 1,000 veteran claims/y (mostly atomic vets.)
      - Service-connected, non-presumptive atomic vet participants: ~**29%**
  - Department of Justice (DOJ) – 28 CFR 79
    - Lump sum presumptive compensation
    - Over 500 (onsite nuclear detonation participant) veteran claims in FY12
  - Department of Labor (DOL) – 20 CFR 10
    - Lump sum non-presumptive compensation for DoD civilian workers
    - A few claims/y

Public Exposures

David J. Pawel, *Chair*

Impact on the Japanese Atomic-Bomb Survivors of Radiation Received from the Bombs
Harry M. Cullings
Radiation Effects Research Foundation

Joint U.S./Russian Studies of Population Exposures Resulting from Nuclear Production Activities in the Southern Urals
Bruce A. Napier
Pacific Northwest National Laboratory

Populations Living Near Nuclear Power Plants
Daniel O. Stram
University of Southern California

Nuclear Reactor Accidents: Exposures and Health Effects Among Members of the Public
Maureen Hatch
National Cancer Institute

The Impact on the Japanese Atomic Bomb Survivors of Radiation Received from the Bombs

Harry M. Cullings
Radiation Effects Research Foundation
Hiroshima and Nagasaki, Japan

National Council on Radiation Protection and Measurements
Bethesda, MD March 11-12, 2013

Outline

- Affected population
- Doses received
- Acute somatic effects
- Quantification of risk for late effects
  - Population
  - Individual

Outline

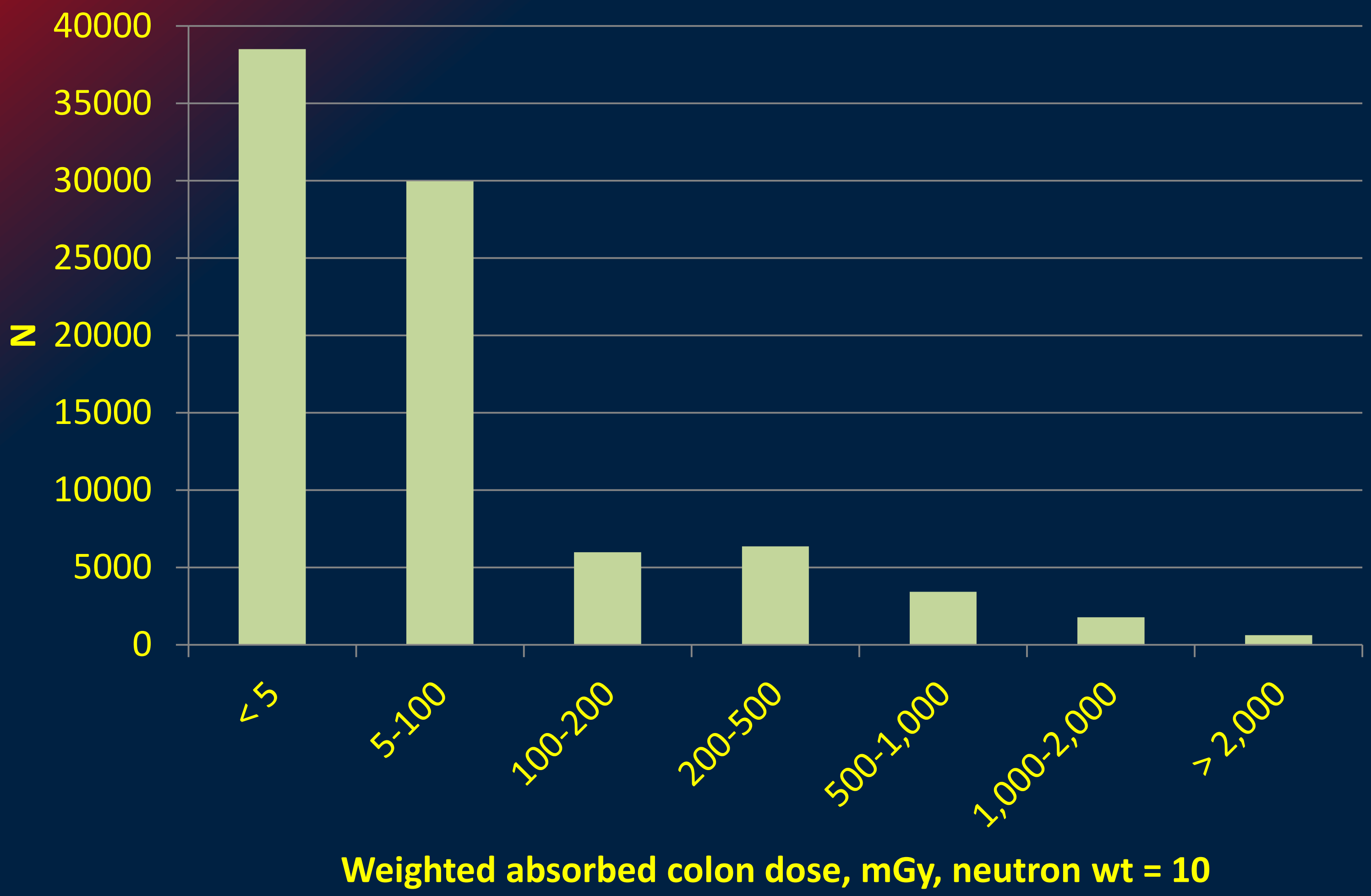
- Late somatic effects
  - Cancer, noncancer
  - Others
- *in utero* exposure
- Genetic effects
- Psychosocial effects
- Research

Affected Population

- Life Span Study (LSS) in-city (<10 km from bomb) survivors selected from 1950 national census
  - 61,984 in Hiroshima
  - 31,757 in Nagasaki
- Contribution of radiation to acute mortality almost impossible to assess due to combined injury (thermal, blast)
- LSS is fairly exhaustive re those <2 km from hypocenter at time of bombing
  - Probably contains ~ ½ of survivors at <2 km
  - There were other affected survivors at >2 km
    - Effects at related doses are small
      - Average colon dose at 2 km ≈ 16 mGy (H), 27 mGy (N)

Doses Received

- 86,671 in-city members of LSS with known doses



Acute Effects

- Acute signs have not been a major focus of RERF studies – scientific interest is more on lower doses and late effects
- RERF studies of acute effects have tended to use most restrictive (radiation-specific) clinical signs to minimize misclassification
  - Not designed or very useful to evaluate full impact on survivors
  - *e.g.*, Stram and Mizuno (Radiat. Res. 1989)
- If 500 mGy DS02 colon dose is taken as a rough threshold for the most sensitive symptoms (*e.g.*, nausea, etc.)
  - ~8,400 members of LSS exceeded this

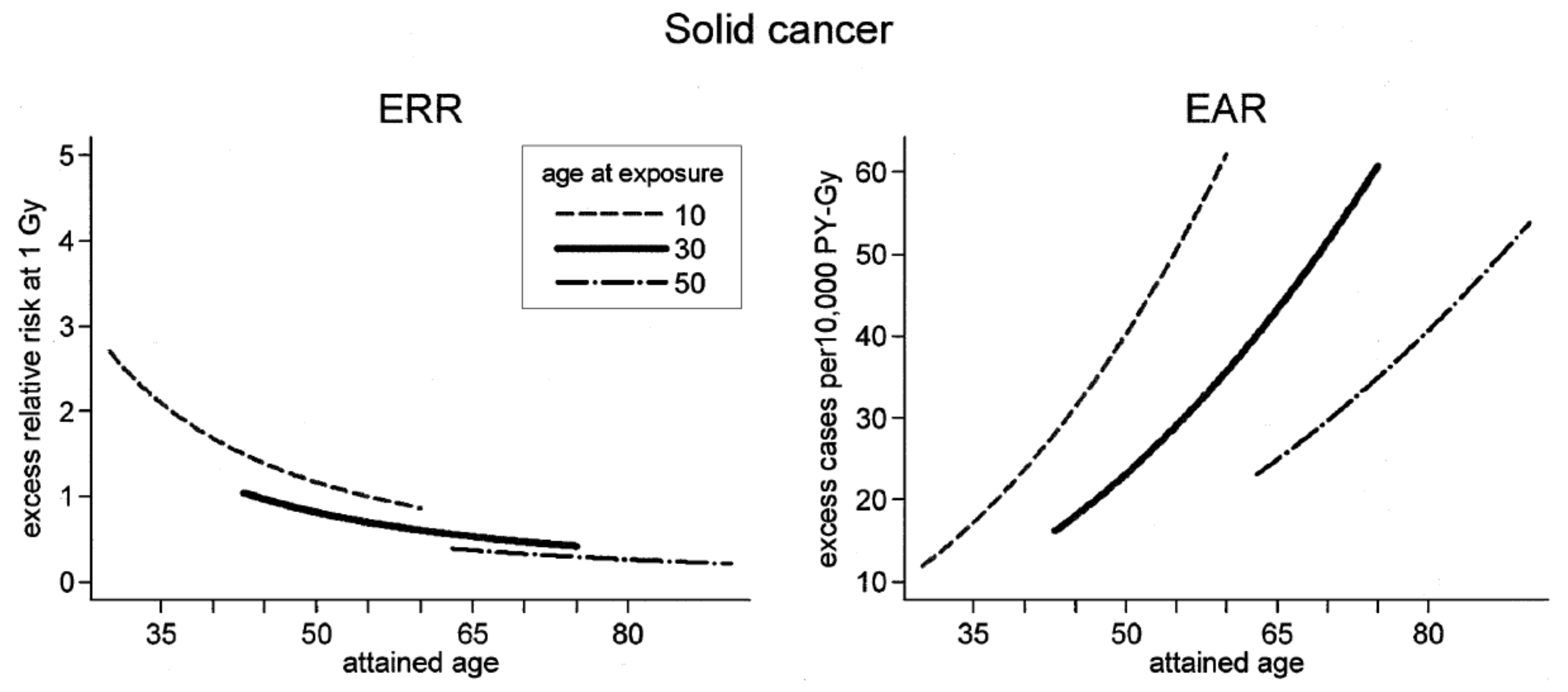
Age-Time Patterns of Risk for Late Effects – Solid Cancer

- Dependence on age at exposure
  - For many effects, younger exposure → greater effect (especially EAR, less so for ERR)
  - Somewhat expected from radiation biology
  - Uncertain due to confounding by effect of birth cohort on baseline rates

Age-Time Patterns of Risk for Late Effects – Solid Cancer

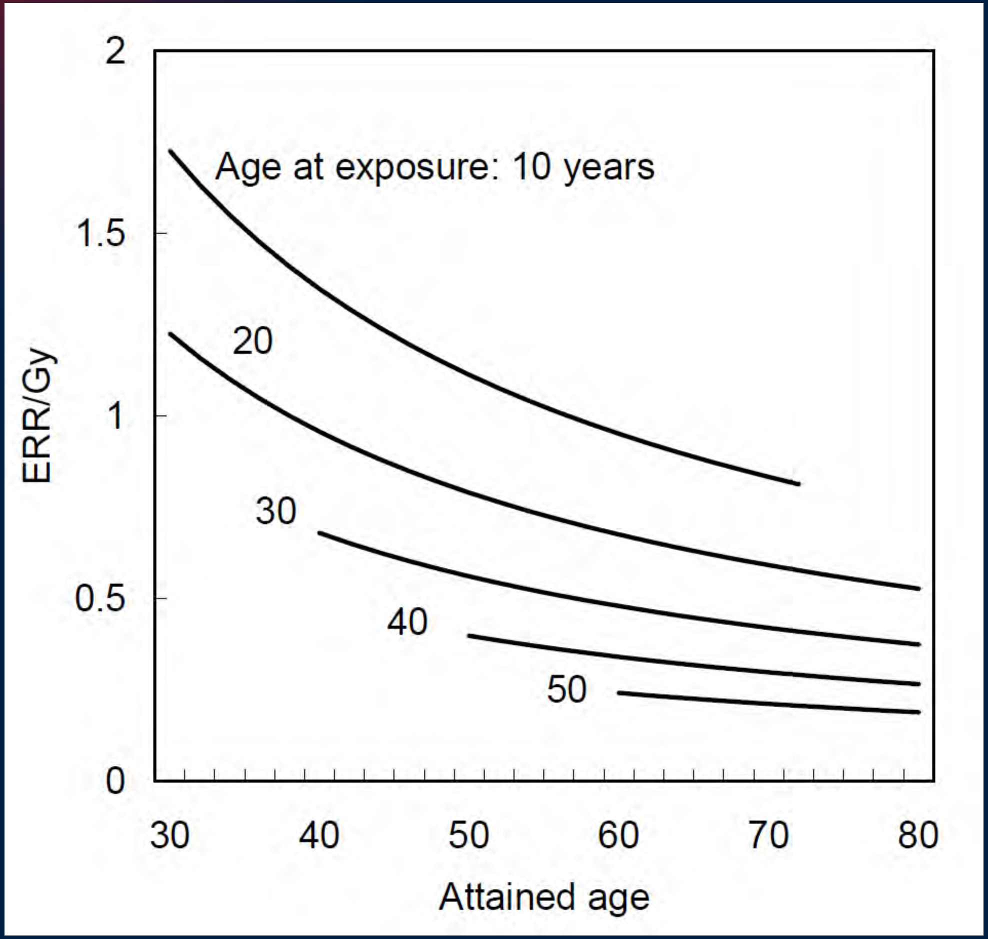
- Dependence on attained age or time since exposure
  - For many effects, *relative* risk decreases with age
  - Although excess absolute rates increase with age
  - These patterns are consistent with some very basic mechanistic considerations re accumulation of irreversible damage (*e.g.*, mutations)

Age-Time Patterns of Risk for Late Effects – Solid Cancer Incidence



*Preston *et al.* Radiat. Res. 2007

Quantification of Risk for Late Effects – Solid Cancer Mortality



Modification of the excess relative risk (ERR) for all solid cancer by age at exposure and attained age. Ozasa *et al*. LSS Report 14, Radiat. Res. 2012.

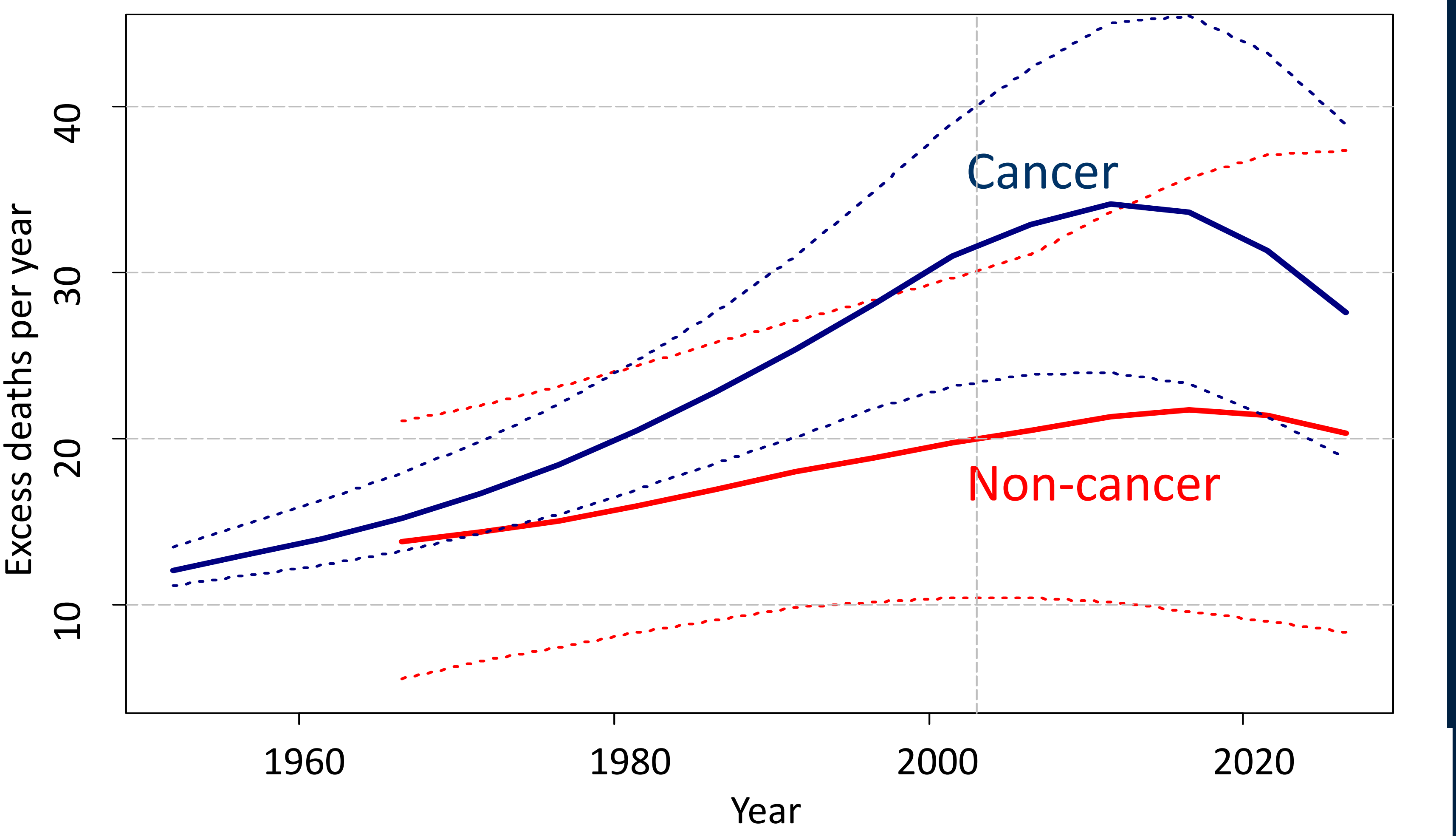
Quantification of Risk for Late Effects

- Population (cohort, *i.e.*, LSS)
  - Fitted excess # of cases to date
  - Projected excess # of cases
  - Summarizes detriment to those affected by the atomic bombs
- Individual (given age at exposure)
  - Risk at specific future age
  - Integrated measures of risk
    - Lifetime excess risk / risk of exposure-induced death (REID)
    - **Loss of life expectancy**

Cohort Excess Cases for Major Outcomes

- Mortality or incidence (as noted) to date:
  - Solid cancer: 527 (of 10,929 deaths)
  - Leukemia (non-CLL, non-ATL): 94 (of 312 cases)
  - Non-cancer: 353 (of 35,685 deaths)
- Much more detail is available
  - Cancer incidence
  - Site-specific cancer
  - Specific non-cancer outcomes such as stroke, heart disease
  - Circulatory, respiratory, and digestive disease mortality classifications have statistically significant ERR in the range 0.11 to 0.23

Projected Excess Deaths per Year in LSS



*K. Furukawa, RERF, unpublished; dotted lines are 95% credible intervals

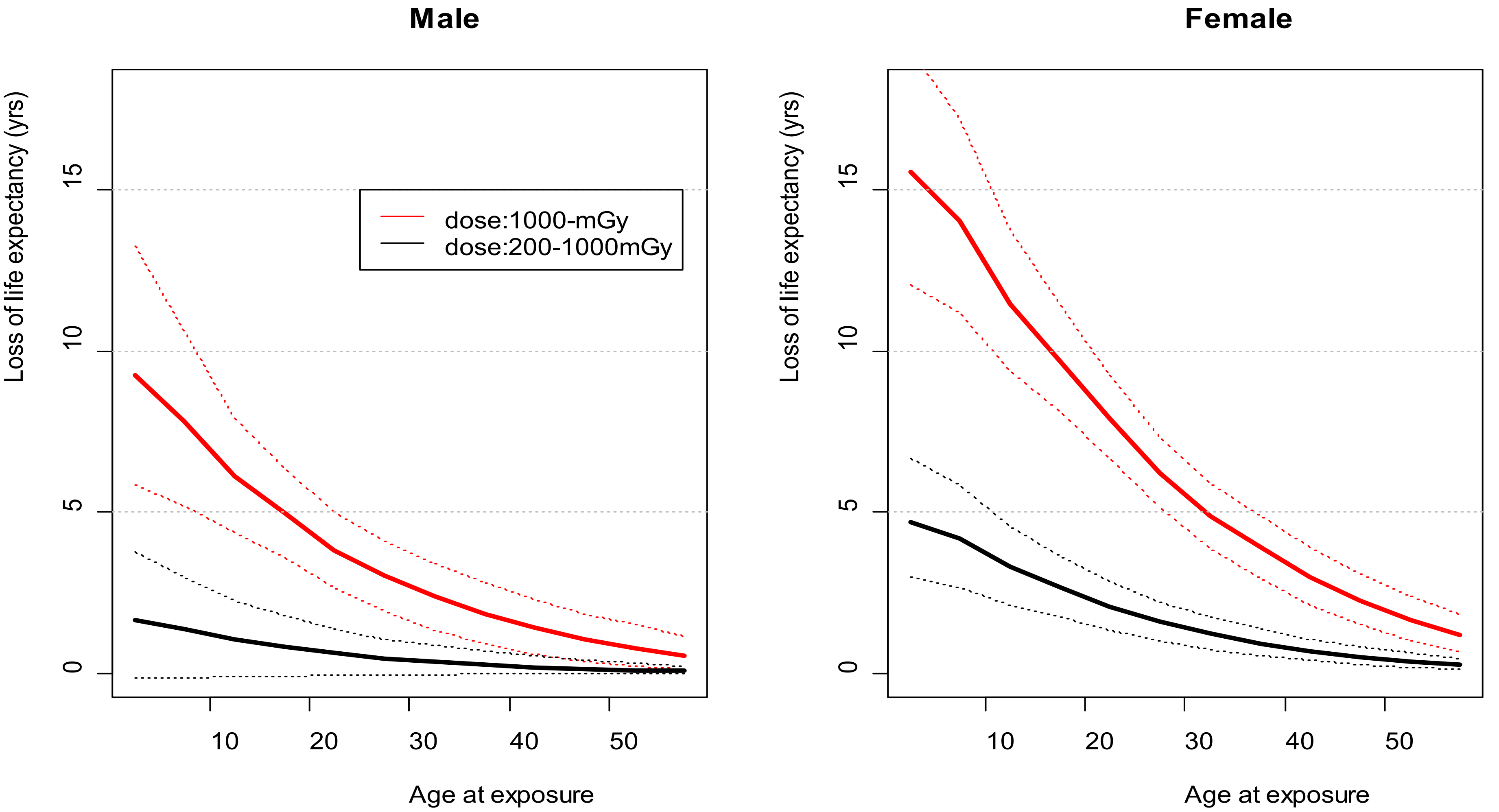
Individual Risk for Major Outcomes

- Solid cancer
  - Mortality risk: ERR = 0.42 (sex-averaged) at age 70 y for exposure to 1 Gy at age 30 y
  - Lifetime excess risk: ~30% for those exposed to 1 Gy or more at age <5 y, declining for higher ages at exposure
- Leukemia
  - Incidence risk: ERR = 1.74 at age 70 y for exposure to 1 Gy at age 30 y

Individual Risk for Major Outcomes

- Noncancer disease
  - Mortality risk: ERR = 0.13 (sex-averaged) at age 70 y for exposure to 1 Gy at age 30 y
  - Lifetime excess risk: ~10% for women, 5% for men, for those exposed to 1 Gy for most ages at exposure
- Combined cancer and noncancer
  - Loss of life expectancy: ~15 y for women and 10 y for men for those exposed to 1 Gy or more at age <5 y

Projected Loss of Life Expectancy



K. Furukawa, RERF, unpublished; dotted lines are 95% credible intervals

National Council on Radiation Protection and Measurements
Bethesda, MD March 11-12, 2013

Other Health Effects

- Cataract: surgery incidence: ERR = 0.32 at age 70 y for exposure to 1 Gy at age 20 y
  - Threshold estimate = 0.5 Gy
- Myelodysplastic Syndrome
- Thyroid: benign nodules and cysts
- Uterine myoma (fibrosis)
- Accelerated menopause
- Hyperparathyroidism
- Immunological effects

in utero Exposure

- Cohorts: mortality follow-up (N ≈ 3,600), clinical (N ≈ 1,600)
- Developmental disability: 8 - 16 weeks gestation most sensitive, 17 - 25 weeks also of concern
  - Otake & Schull, Intl. J. Radiat. Biol. 1998
- Risk of solid cancer from *in utero* exposure may be < for exposure in early childhood
  - Preston *et al*., J. Natl. Cancer Inst. 2008

Genetic Effects

- Cohorts
  - ~77,000 registered births, 1948 - 1953 (first genetic study)
  - ~11,000 children of survivors (clinical study)
- One of the earliest concerns in studies of atomic-bomb survivors
  - Continues to present day at RERF
  - *No statistically significant results yet…*

Genetic Effects

- Endpoints studied
  - Birth defects/outcomes, sex ratio
  - Chromosomal aberrations
  - Mutations in blood proteins
  - DNA
    - Minisatellites
    - BAC arrays
    - Array CGH with high density probes
    - …Sequencing
  - Cancer mortality and incidence
  - Adult multi-factorial diseases

Psychosocial Effects

- Social stigma and discrimination
  - Especially among young persons of reproductive age
- Uncertainty and confusion about health effects
- Psychoneurological and psychological effects
  - Difficult (impossible?) to separate from effects of other insults and stresses associated with the bombings
  - Some studies show increased patient complaints of various symptoms

Some Current Research Interests

- Effects on
  - Diabetes?
  - Eye, other than cataract?
- Interaction with other risk factors
- Immunological effects, inflammation, aging
- Low-dose effects on well-known outcomes
  - Cancer

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Joint US/Russian Studies of Population Exposures Resulting from Nuclear Production Activities in the Southern Urals

Bruce Napier

Pacific Northwest
NATIONAL LABORATORY

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JCCRER - Joint Coordinating Committee for Radiation Effects Research

- JCCRER is a bilateral Government committee representing agencies from the United States and the Russian Federation
- JCCRER's major role is to coordinate scientific research on the health effects of exposure to ionizing radiation in the Russian Federation from the production of nuclear weapons
- Studies of cohorts of individuals exposed at/by the Mayak Production Association are the primary focus

Some (not all) Contributors

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Russian Federation & FSU

Part of the old Soviet weapons complex

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“Technological Failures” resulted in releases to the environment

- Atmospheric venting of reactors and reprocessing plant
- Inadequate liquid radioactive waste handling
- HLW tank farm accident(s)
- Other events

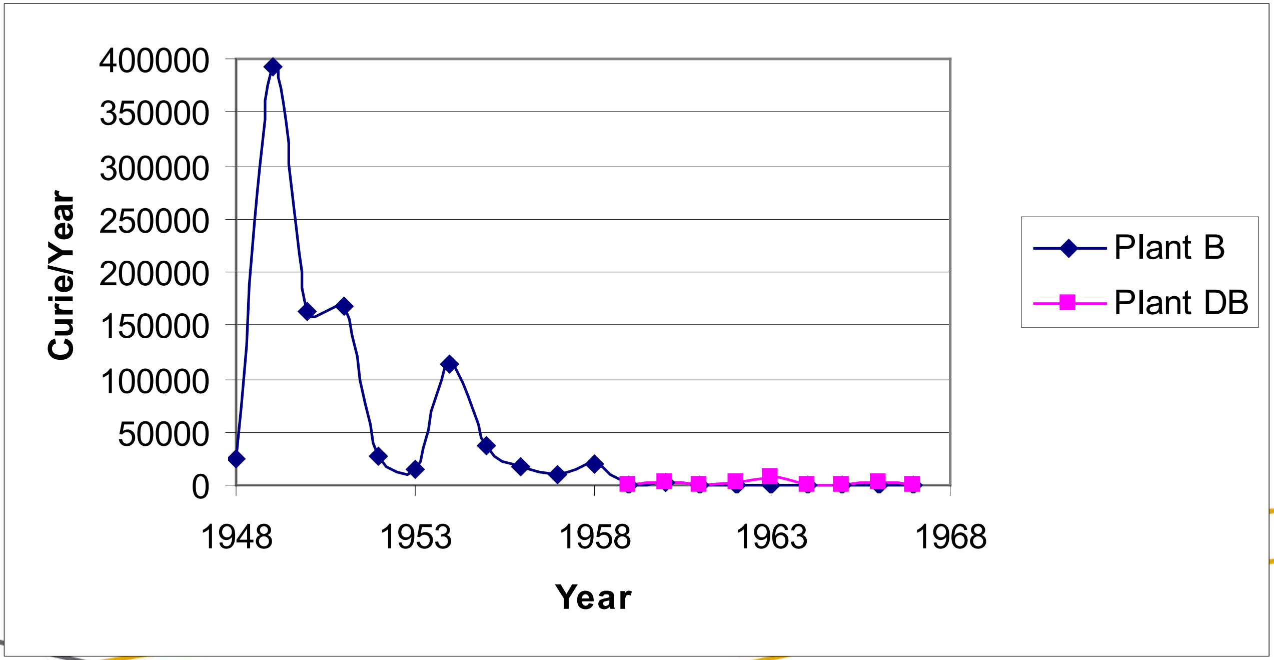
Environmental Releases – Reactors to Atmosphere

- Graphite moderated reactors similar in design to USA Hanford production reactors
  - Air cover gas
  - Release of 74 EBq of 1.8 h ^{41}Ar
- Online refueling/accident remediation
  - Drilled out stuck fuel elements
  - Noble gases $^{83m,85m,87,88,89}Kr$, $^{131m,133m,133,135,138}Xe$ = 85 EBq
- Also smaller iodine releases - 400 TBq

Derived from: Rovny and Mokrov (2006)

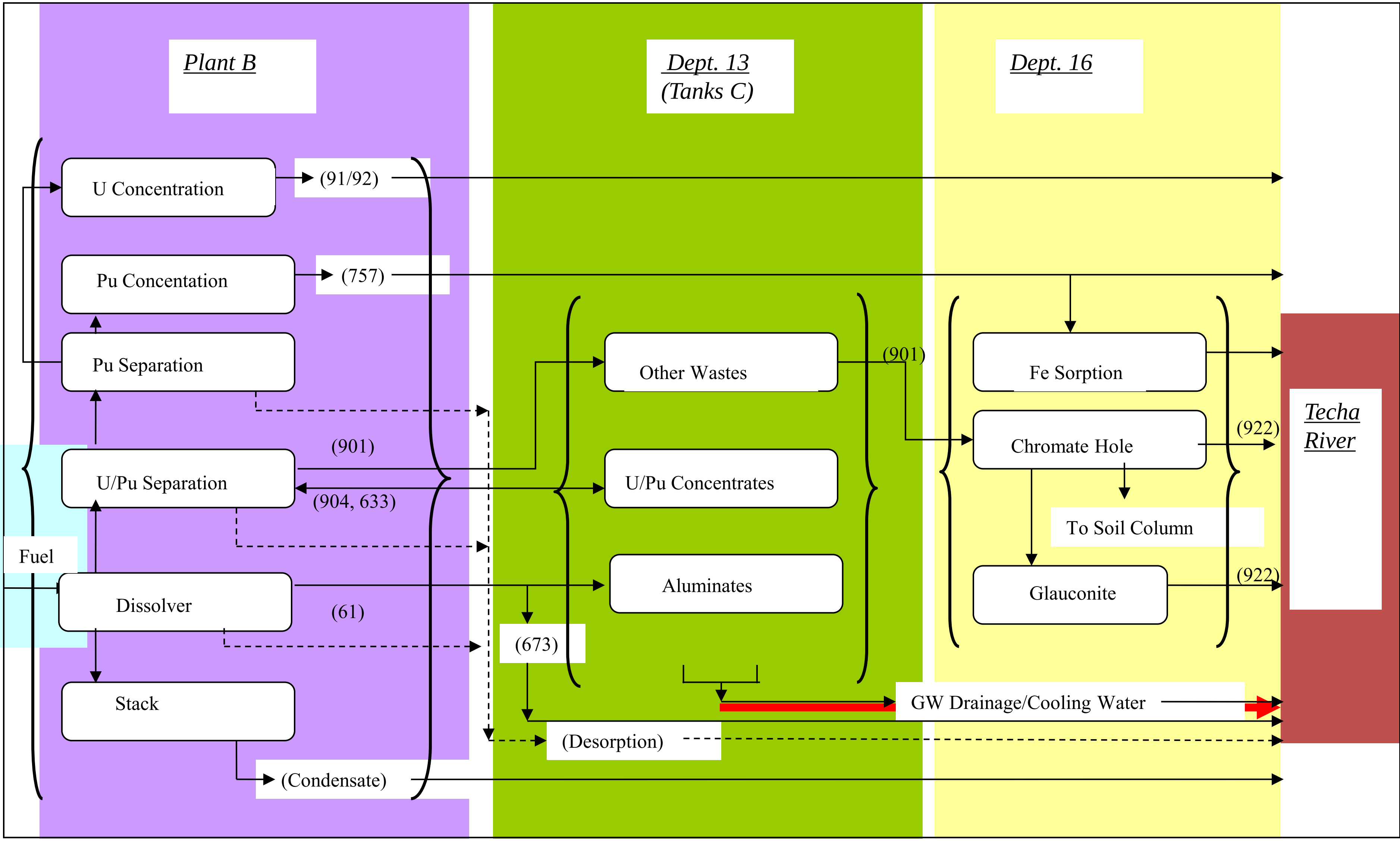
Environmental Releases – Reprocessing to Atmosphere

- Combination of stack monitoring and reactor production/holdup/release modeling
- Total ~50 PBq ^{131}I (1.3 MCi)



Derived from: Mokrov, Lyzhkov, Muzrukov, Pyatin, Rovny, Anspaugh, and Napier (2008)

Radioactive Liquids At Mayak



Plant B

Dept. 13
(Tanks C)

Dept. 16

U Concentration

(91/92)

Pu Concentation

(757)

Pu Separation

Other Wastes

(901)

Fe Sorption

Chromate Hole

(922)

Techa
River

(901)

U/Pu Separation

U/Pu Concentrates

(904, 633)

To Soil Column

Fuel

Dissolver

Aluminates

Glauconite

(922)

(61)

(673)

Stack

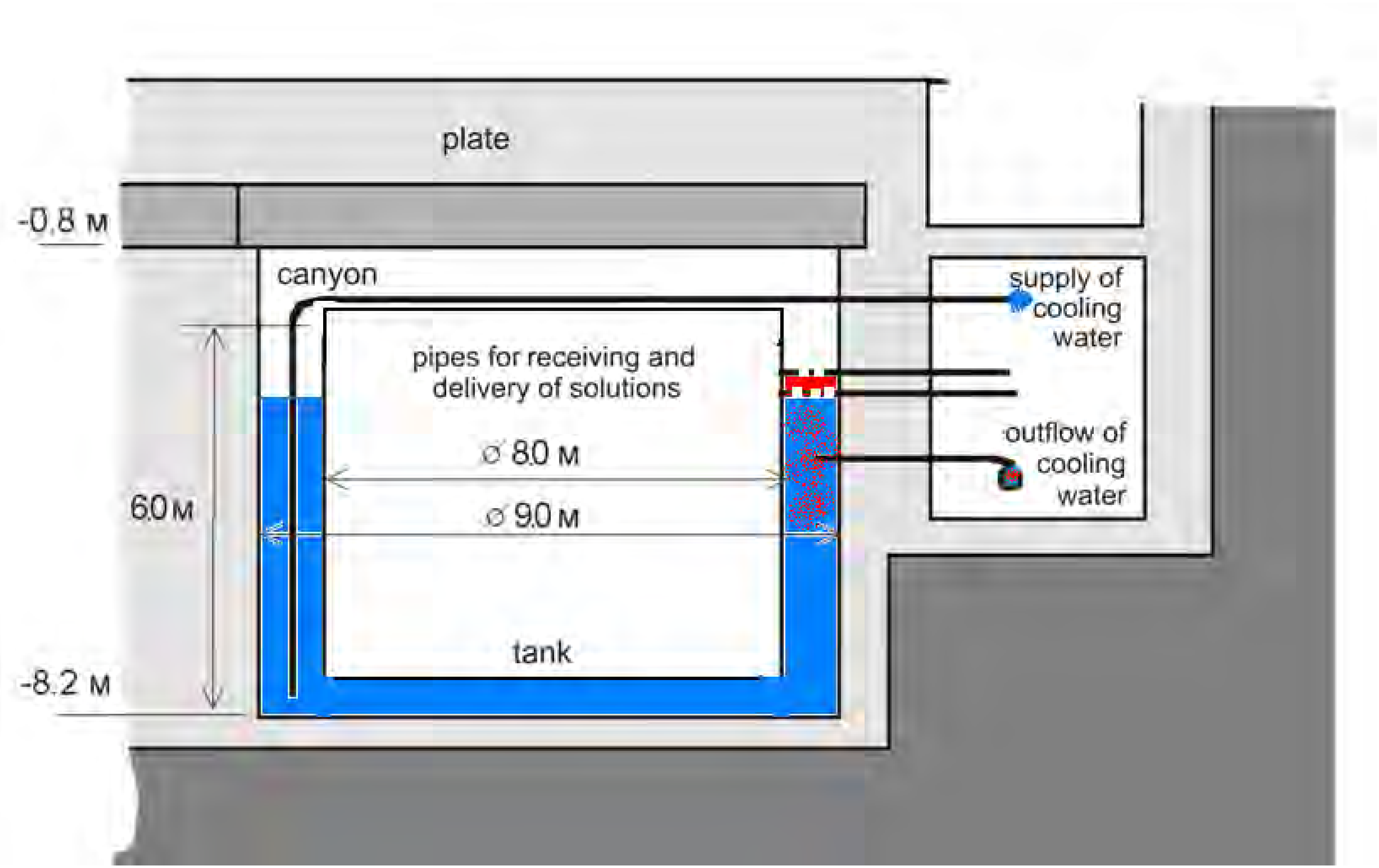
GW Drainage/Cooling Water

(Desorption)

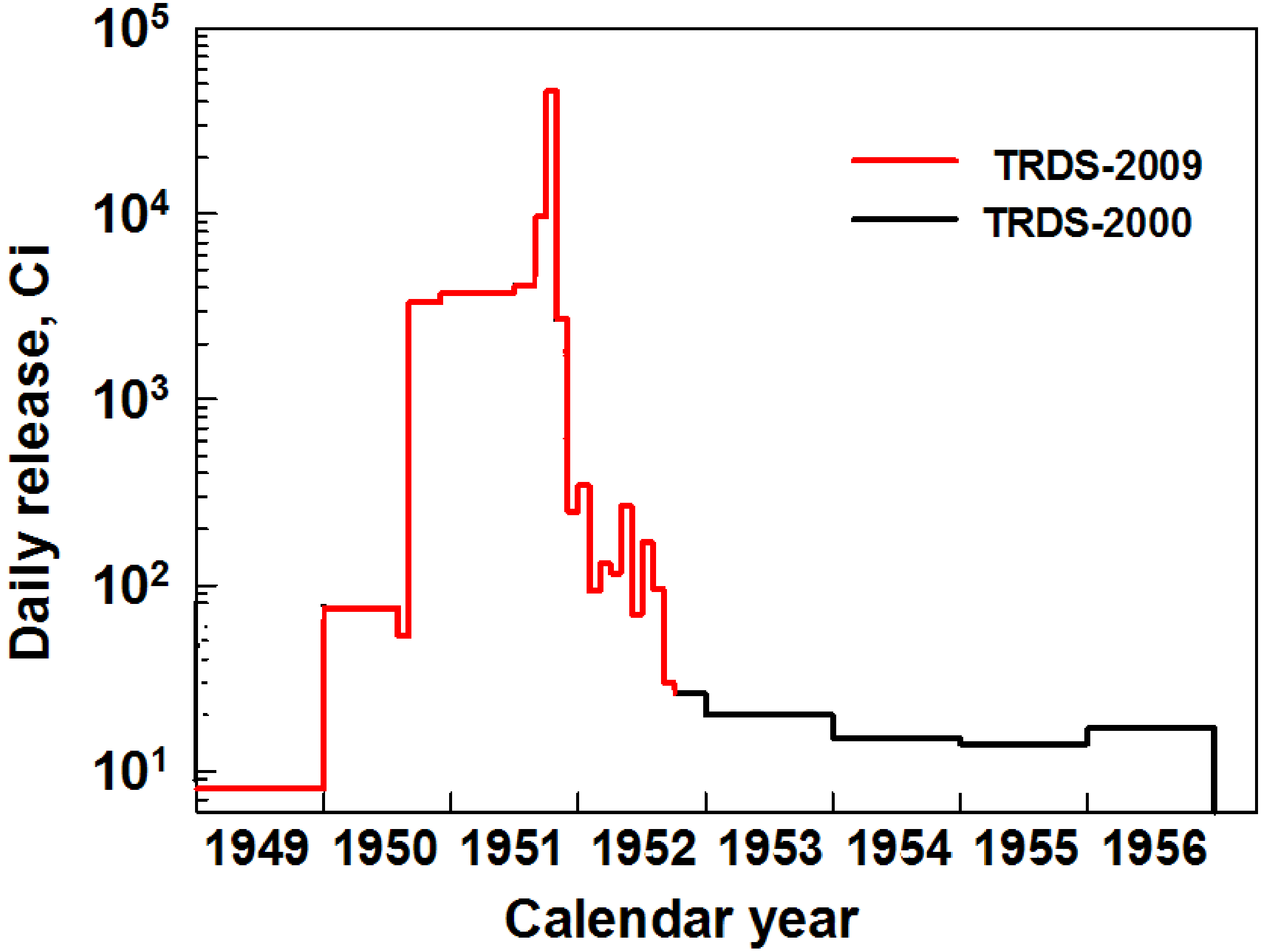
(Condensate)

Derived from: Glagolenko et al. (2008). ISTC Project #2841

Environmental Releases – Tank Farms

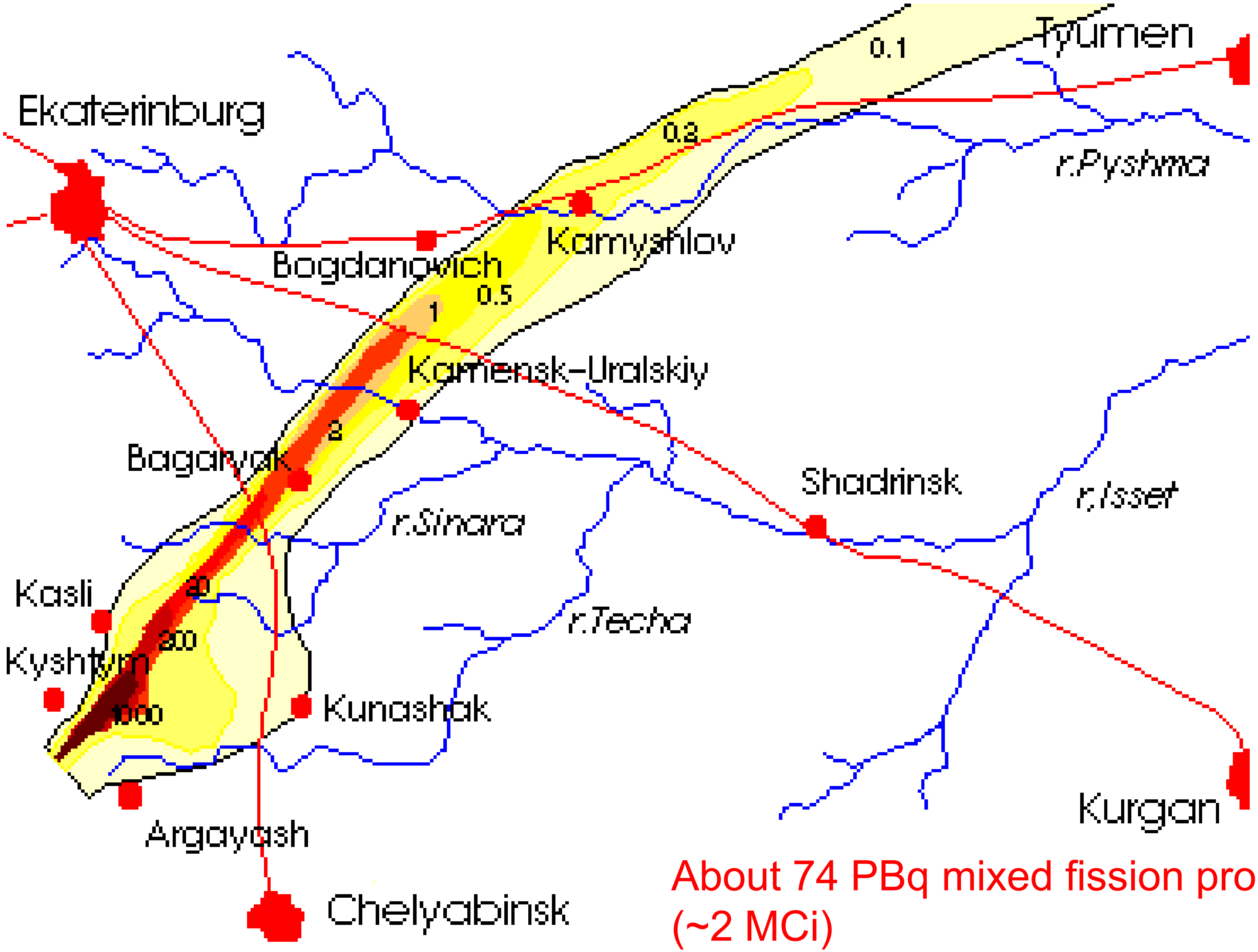


Environmental Releases – Techa River: 52 PBq (1.4 MCi) routine, 63 PBq (1.7 MCi) accidental



From: Degteva, Tolstykh, Vorobiova, Shagina, Anspaugh and Napier (2009)

1957 “Kyshtym Explosion”-Overheated HLW Tank



About 74 PBq mixed fission products (~2 MCi)

Mayak – Public Cohorts of Interest

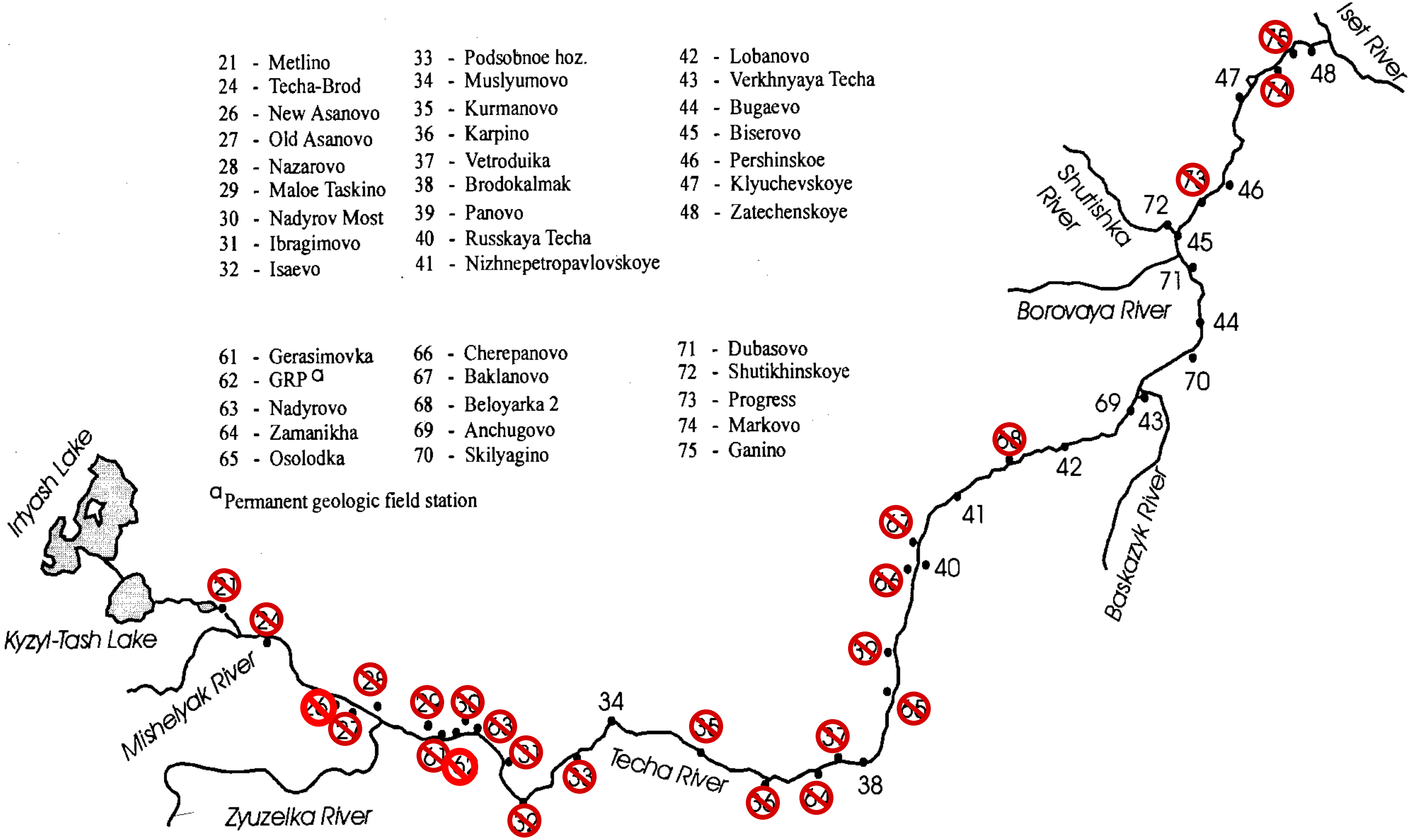
- Ozersk children’s thyroid cohort (not established yet)
- Techa River Cohort (30,000 individuals)
- Techa River Offspring Cohort (31,000 individuals)
- East Urals Radioactive Trace (EURT) Cohort (18,000 evacuated; 8,000 resident)

Ozersk Children's Cohort

- Doses scheduled to be completed soon; some thyroid doses in excess of 2 Gy (2000 mGy) are expected
- Cohort not defined; no explicit risk estimates available
- Initial results indicate that thyroid cancer rates in Ozersk are approximately 1.5 times higher than regional rates

Koshurnikova NA, Kaigorodova LY, Rabinovich EI, Martinenko II, Okatenko PA, Khokhryakov VV, Mosharova EP, Mokrov J, Fomin E, Alekseyev VS, Panteleyev NT, Sannikova LA, Ryzhykh TV. Health Phys. Jul;103(1), 24-27 (2012)

Techa River System



21 - Metlino
24 - Techa-Brod
26 - New Asanovo
27 - Old Asanovo
28 - Nazarovo
29 - Maloe Taskino
30 - Nadyrov Most
31 - Ibragimovo
32 - Isaevo

33 - Podsobnoe hoz.
34 - Muslyumovo
35 - Kurmanovo
36 - Karpino
37 - Vetroduika
38 - Brodokalmak
39 - Panovo
40 - Russkaya Techa
41 - Nizhnepetropavlovskoye

42 - Lobanovo
43 - Verkhnyaya Techa
44 - Bugaevo
45 - Biserovo
46 - Pershinskoe
47 - Klyuchevskoye
48 - Zatechenskoye

61 - Gerasimovka
62 - GRP[a]
63 - Nadyrovo
64 - Zamanikha
65 - Osolodka

66 - Cherepanovo
67 - Baklanovo
68 - Beloyarka 2
69 - Anchugovo
70 - Skilyagino

71 - Dubasovo
72 - Shutikhinskoye
73 - Progress
74 - Markovo
75 - Ganino

[a] Permanent geologic field station

Techa River Cohort

- General population; those exposed on the river 1949 - 1951 born before 1949, plus 5000 “late entrants” who migrated in between 1952 - 1960
- Relatively old – youngest is now 60 y old
- Internal exposures: consumption of water, milk and food contaminated with ^{137}Cs, ^{90}Sr, ^{89}Sr and other radionuclides
- Wide range of doses from river
  - Red bone marrow mean 300 mGy, max 2 Gy
  - Soft tissues mean 30 mGy, max 500 mGy
- Some medical confounding

Techa River Offspring Cohort

- Exposed in utero
- Progeny of exposed parents
- Children of children (12,000)

Techa River: Unique Individual Data Set

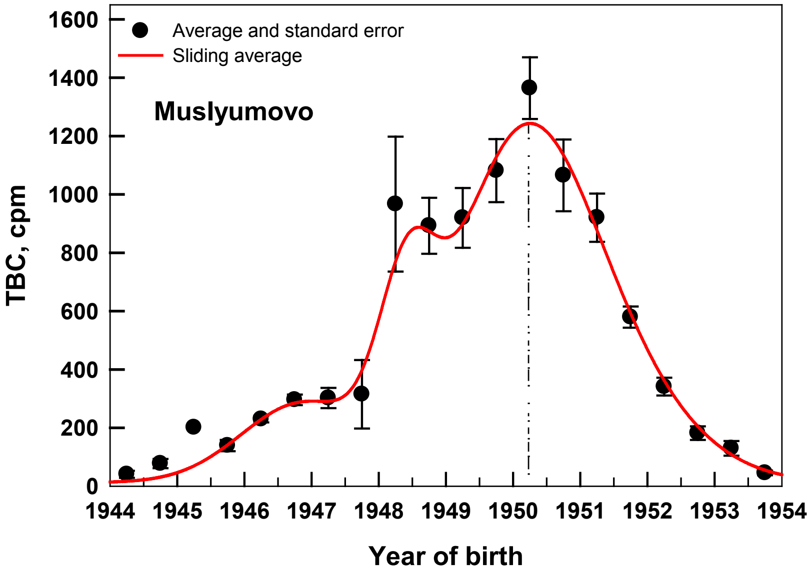
- TRC members followed for decades
  - 10,000 post-mortem bone measurements
  - 17,500 *in vivo* tooth beta measurements
  - 20,500 *in vivo* WBC measurements 1974 - 1997
  - 2,300 *in vivo* WBC measurements 2006 - 2009
  - 4,200 teeth from 2,600 donors for EPR
  - 42,000 x-ray procedures in 9,200 individuals

Techa River: Unique Environmental Data Set

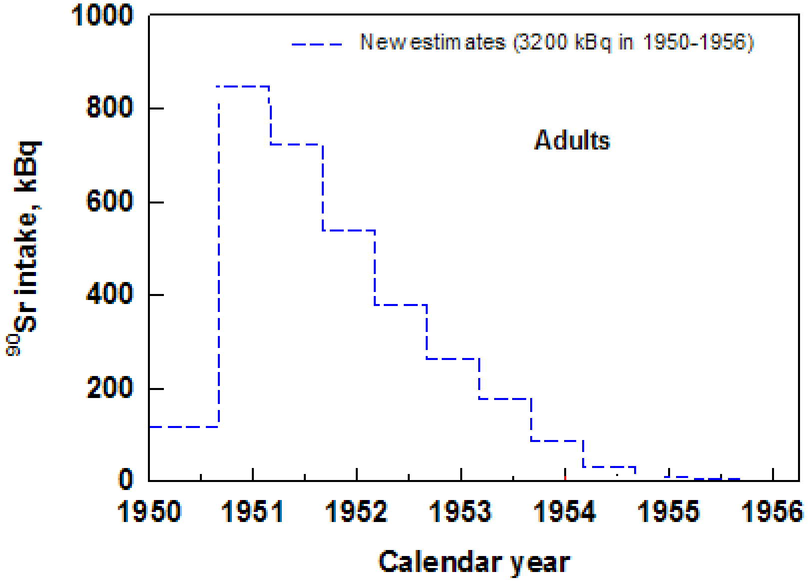
- 10,500 Techa River water samples
- 2,000 river sediment samples
- 4,200 soil samples
- 12,500 milk samples
- 7,900 other food samples
- 7,000 gamma exposure rate measurements

Techa River: Unique Methodology for Uptake Estimation

Tooth beta counts

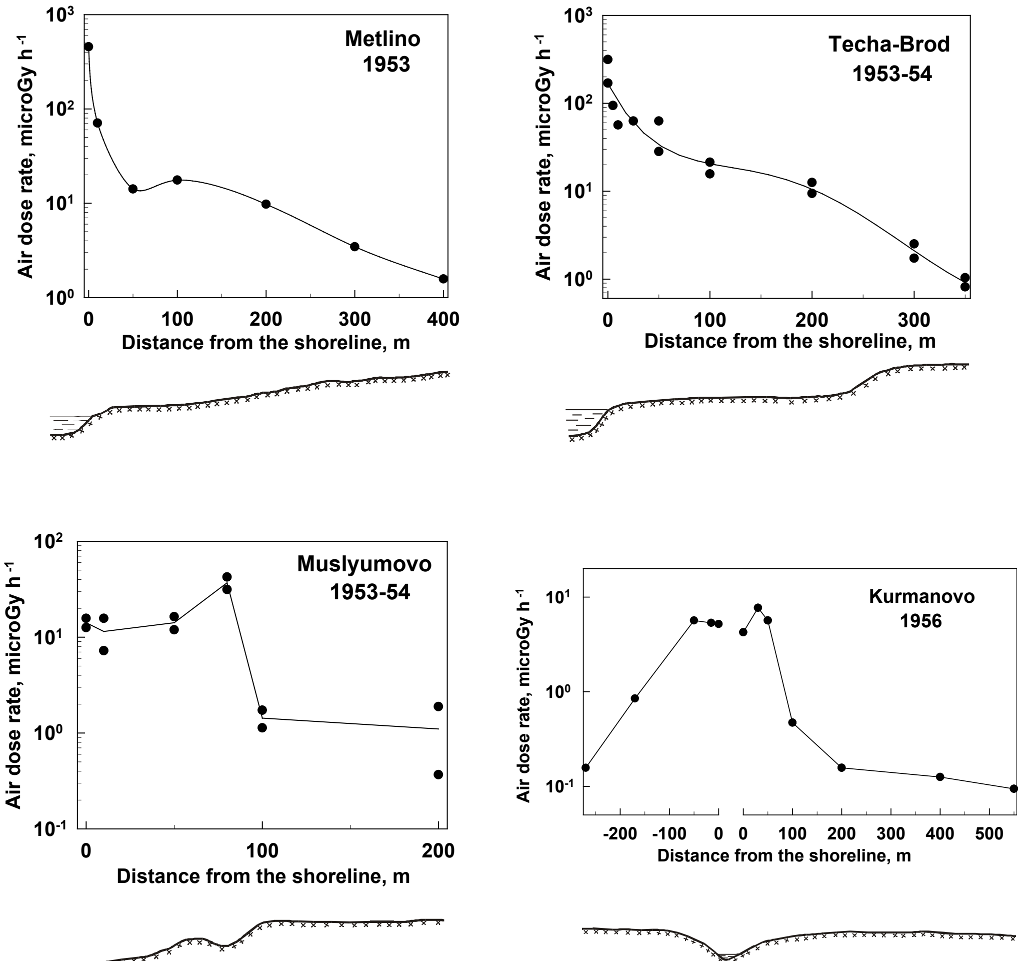


Derived intake function



Tolstykh EI, Degteva MO, Peremyslova LM, Shagina NB, Shishkina EA, Krivoshchapov VA, Anspaugh LR, Napier BA. Health Phys. July;101(1), 28-47 (2011)

Techa River: Powerful Methodology for External Dose Estimation



Degteva MO, Shagina NB, Vorobiova MI, Shishkina EA, Peremyslova LM, Tokareva EE, Anspaugh LR, Napier BA. (2011)

Techa River Cohort: Solid cancer dose response

- **About 928,000 person-y have accumulated in the Techa River mortality cohort and the 2,303 deaths from solid cancers represent an excess of 50 cases.**
- **Krestinina et al., Int. J. Epi. (2007)**
  Strong evidence of significant dose-response for solid cancers incidence
  10% increase at 0.1 Gy *(TRDS-2000, period 1956 -* ***2002, incidence****)*
- **IRPA-13 poster presentation (2012)**
  7.4% increase at 0.1 Gy *(TRDS-2009, period 1956 -* ***2005, incidence****)*
- **Schonfeld et al. Rad. Res. (2012) –** ***in press***
  6.1% increase at 0.1 Gy *(TRDS-2009, period 1956 -* ***2007, mortality****)*
- **Preliminary incidence data (as of September 2012)**
  6% increase at 0.1 Gy *(TRDS-2009, period 1956 -* ***2007, incidence***)

Nuclear Worker Study - 9% increase at 0.1 Gy
Atomic Bomb Survivors - 5% increase at 0.1 Gy

Techa River Cohort: Leukemia Incidence

- Between 1953 and 2005, 93 first primary cases of leukemia, including 23 cases of chronic lymphatic leukemia (CLL), were ascertained among the cohort members.
- A significant linear dose-response relationship was seen for leukemias other than CLL ($P < 0.001$), but not for CLL.
- The estimated excess relative risk per gray is 4.9 (95% confidence interval (CI): 1.6; 14.3) for leukemias other than CLL and less than 0 (95% upper bound 1.4) for CLL.

Krestinina L, Preston D, Davis F, Epifanova S, Ostroumova E, Ron E, Akleyev A. Radiation and Environm. Biophys. (2009)

Summary of Mayak and Techa Results

- Radiation effects (cancer and non-cancer) are evident
- Radiation effects are commensurate with the Japanese LSS
- Radiation effects are commensurate with the 15-Country worker study
- Radiation effects appear to be linear with dose to <0.05 Gy
- Internal doses protracted over many years seem to be just as important as instantaneous external doses

Observations

- The ICRP paradigm for radiation protection is correct:
    - Radiation doses from external and internal sources have the same effect, therefore internal and external doses may be added
- Long-term chronic doses have essentially the same effect as instantaneous acute doses
    - DDREF is approximately equal to 1
- Radiation is a weak carcinogen
    - The fraction of cancers in the Mayak and Techa River cohorts attributable to radiation is small
- Events from the 1940s, 1950s, and 1960s still disrupt the lives of regional inhabitants

Analysis of Cancer Risks in Populations Near Nuclear Facilities: Phase I. A Report By the National Academy of Sciences Radiation and Studies Board

Daniel O. Stram

NCRP 2013 Annual Meeting
Bethesda MD

Keck School of
Medicine of **USC**

Background

- 104 operating nuclear power plants (NPPs) in US
    - 65 sites in 31 states
        - 15 percent of population within 50 km (30 miles)
        - 1 million residents within 8 km (5 miles)
- Other USNRC licensed fuel cycle plants (FCPs)
    - 13 FCPs within 10 states
        - Mining, Milling, Conversion, Enrichment, Fabrication
- *Applications for 24 additional reactors under active review at time of study*

Background

- NCI report (Jablon et al. 1990; 1991) is main source of information about cancer risk near NPPs
- USNRC uses the 1990 report as primary source of information about cancer risks near NPPs
- USNRC requested study to update the 1990 report
    - Phase 1, scoping study
    - Phase 2, implementation

Statement of Task

- Identify scientifically sound approaches for "carrying out the cancer epidemiology study that has been requested by the USNRC"
  - Methodological approaches for assessing off-site dose (pathways, record availability, variability and uncertainty)
  - Methodological approaches for assessing cancer epidemiology (study populations, geographical areas, cancer types, availability of outcome data, different designs, power, clustering, confounding, characterizing & communicating uncertainty)

Reasons for the Request

- *Priority of Public Concerns Relative to Other Priorities of the NRC*
  - ***New NPPs are anticipated to open in the future***
- Relying on 1990 NCI report may be inappropriate because
  - Facility inventory has changed
  - Populations have changed
  - Improvements in methodology may be possible today
- NRC initially contracted with ORAU which produced reports on updating the NCI analysis
- NRC then asked NAS to look more broadly at methodology

Jablon Report

- Primary Analysis
  - Mortality in “case” and “control” counties
    - Case counties: those with or near NPP as of 1982
    - Control counties: 3 counties matched (on demographic variables)
  - Change in RR between case and control counties before and after startup of nuclear plants
    - “Δ^2 Contrast”
  - Found no tendency for “case vs. control” county relative risks to be greater after the start of operations than before the start of operations ($\Delta^2 = 0$)

Perceived Problems with Jablon Report

- Counties are large
  - Only a small fraction of population of County may live near the plant of interest
    - *e.g.*, San Diego county and San Onofre NPP
  - Most recent studies (*e.g.*, French, German, Swiss, UK) use a distance band approach
  - *Some use geographically based dose estimates taking account of weather patterns etc.*
- Many new facilities have been opened since 1982
- The basic comparison (Δ^2) fails to take account of temporal patterns (*e.g.*, due to accumulation of dose)
  - Some plants had started quite recently, very little time to accumulate dose in the period (1950 - 1984) that Jablon considered
- Mortality analysis not ideal for many cancers
  - Only small amount of incidence data available (5 states) as of 1984

Other Epidemiological Studies

- Seascale Childhood Leukemia Cluster near Sellafield fuel reprocessing plant
  - Urquhart et al., Gardener and Winter, Lancet 1983 (and Yorkshire TV program)
  - COMARE established in 1985
- Studies in at least 11 countries
  - Some indicate increased risks
    - **German KiKK (doubling of rate near to German Facilities)**

      Methods of this study have been criticized
    - **France Geocap study**
      - Excess found in nearby communities (5km)
      - But not related to pattern of releases (dose based geographical coding)
  - Others indicate no increased risk
    - UK (COMARE 2011)
    - Swiss study (Spyker et al., 2011)

Dose Studies

- Pacific Northwest Laboratory Study
  - Developed annual estimates of population exposures around nuclear plants
  - Generally exposures to public from properly operating reactors are extremely low (…)

Structure of NAS Phase I Report

- Chapter 1 Introduction/Background
- Chapter 2 Description of effluent releases
- Chapter 3 Methods to estimate dose from effluent releases and other sources
- Chapter 4 Possible epidemiologic study designs
- Chapter 5 Public engagement process

Quick Summary of Chapter 2

- Effluent release data not always available
  - Carbon 14 is especially problematic (no reporting requirement until recently)
- Meteorology data only adequate for continuous releases
- Even when available records would only support rough estimation of population dose as function of distance and direction
  - Would not supported detailed dose reconstruction for individuals (as in case/control) study

Chapter 2

- Environmental monitoring data not particularly helpful
  - Almost all data below MDL
  - Data above MDL could be used to validate reported effluent releases
- Collecting and computerizing effluent and meteorology data requires **"large and costly effort"**

Quick Summary of Chapter 3

- Absorbed dose to organs of interest most relevant quantity for epidemiologic study
  - MEI dose or total population dose not relevant (ignores variations by wind direction etc)
- Absorbed doses are likely to be very low (at most 10 - 20 mrem/y to the MEI)
  - Mostly well below variations in background level around plants of interest
  - Below medical and diagnostic exposures
  - Below air travel radiation doses for some individuals

Chapter 3

- Absorbed doses will be uncertain but detailed uncertainty analysis is not possible except in special cases or for illustrative purposes
- Computer models have been developed that could be adapted to support an epidemiological study

Chapter 4, Epidemiology

- Even in absence of any confounders, likely doses are far too small for the expected risk increases (under LNT model) to be detectable in any sort of Phase II study
  - If 1million people are exposed to the upper value for the MEI for lifetime this would produce about 800 excess cases (LNT model) from among 400,000 total cases of cancer
  - Using the mean dose (and LNT) would give considerably fewer excess cases (if the increases exist at all)
  - Population mobility would spread these out among even wider population numbers

What Then Could Justify A Phase II Study?

1. Hypothesis *(or conspiracy theory)* that releases are very much larger than reported
   A. Continuous understatement of releases
   B. Sporadic large or uncontrolled releases
2. Or that individuals near facilities are much more sensitive to effects than anticipated
3. *Or that some other exposure other than radiation causes cancer risk to increase near NPP/FCPs*

Why do a study?

None of 1-3 seem particularly likely scientifically, but *may have public credence*

Analysis could be aimed at "ruling out" such scenarios.

Define a detectable level of risk (even if higher than can be reasonably attributable to effects of radiation)

Then see if the epidemiological data can exclude such effects

Given that a Phase II Study is justified What are the Possible Designs?

- Update of Jablon et al
  - County level data in pre-post Δ^2 test
    - More post-period data exists for plants that were in operation in 1982
      - Assumption of immediate change in risk when plants opened could be relaxed (allow for dose accumulation)
    - Much more incidence data available
      - But generally for the post period only
    - Additional plants could be considered (~20 opened after 1982)
      - Many at same location as earlier plants

More Comprehensive Ecological Study

- Smaller geographic regions
  - Only county-level mortality data is available from NCHS
    - Obtaining finer detail means contacting state vital statistics agencies and may require geocoding of addresses
      - May not be possible for early time periods
    - Data likely to be available at approximately the census tract level (1500 people on average)

Ecological Study

- Incidence as well as mortality
  - Tumor registries available in (nearly) all states
  - However obtaining access to all registry data is complex
    - Few studies have attempted this (7th Day Adventist Study)
      - Data should be available at census tract level
    - A NAACCR committee is working on this issue
- Focus on many or all cancers but concentrating on the most "radiogenic"

Modeling of Ecologic Data

- Create complex cross classified table of estimated person years and number of events
  - Stratify on age, calendar time, gender socio-economic status.
  - Compute dose within each cell of the table
- Analyze risk using quasi-Poisson models
    - Test for associations between risk and distances or dose estimates
    - Test for temporal changes (pre-post startup) in exposed versus unexposed regions
    - Allow for trends (*e.g.*, as if due to exposure accumulation) in analysis of temporal changes
  - Overdispersion is expected
  - Multiple comparisons always a concern

Dose surrogates

- Modeling of response to dose or dose surrogates (distance) can be accommodated and may be important
  - Distance or distance/direction is a time-invariant dose surrogate
  - Reconstructed dose (for geographical region) is time dependent, accumulates in time after start of facility, etc.
    - May also vary by age within the same calendar periods
  - If relationship between risk and distance is detected, examination of whether the temporal pattern of risk is consistent with dose aggregation is a reality check on results

Drawbacks to Ecologic Study

- Specificity of “exposure” estimates and surrogates
  - Assume that individuals remain within same census tract for all time?
  - Incorporate population mobility into dose calculation?

Retrospective Cohort Design

- Focus on childhood cancer
  - More “radio-sensitive”
  - Shorter latency
  - Less mobility
  - Heightened public concerns

Study Outline

- Define birth cohort of children where data on birth address available
  - All children born between 1992 and 2009
  - In or near states with NPPs or FCPs
  - Geo-code addresses (keep those individuals born within 50 km of NPP/FCP, about 14 million births)
  - Obtain birth certificate information
  - Link addresses to census information etc

Design

- Define follow-up time for capture of cancer incidence data where incidence data available throughout the US
  - All leukemia for children aged 0 - 14 y occurring between 2006 - 2009 (approximately)
- Link all birth records to all registries and to estimated dose
- Assume all children remain in place of birth for dose calculation purposes
- Use event hazard regression as analysis tool

Drawbacks of Retrospective Cohort Design

- Focus on children born recently (1992+) necessary because of inadequacy of tumor registry records for earlier cohorts
- However dose is expected to be higher for earlier time periods
- Enormous data request and huge linking problem (14 million birth records)

Reducing the Workload with a Case/Control Design?

- Start with birth records of cases both occurring within 50 km of NPP/FCP and born within same region
- Identify controls (*e.g.*, randomly sample from among children born that day within the 50 km region)
- Only link cases and controls to census data, etc.
  - Has drawback that cases are selected to be less mobile than controls
  - If probability of moving versus staying is inhomogeneous with respect to dose this will lead to bias away from the null
  - Other studies are doing same kinds of analyses, could/should collaborate with them

Power

- With the retrospective cohort 4 y of “accrual” (years 2006 - 2009) would yield roughly 80% power to detect a 40% excess number of leukemia cases within 8 km of the NPPs/FCPs
- *This is outrageously large compared to what reported releases would indicate*
- *If such increases are not detected then will the study have ruled out enough of an increase so that public concerns are dissipated?*

Committee Findings

- A large multisite study with many years of data required to study cancer risks near NPP/FCPs
- Cancer incidence and mortality data that can be geocoded to census track only available for recent periods

Findings

- Contact of individuals in case/control or cohort design not feasible or reliable; record linkage based study is more practical
- Studies of pediatric cancers could take advantage of existing linkages in 6 large states

Recommendations

- Additional pilot work required before launching full phase 2 study
  - 7 facilities in 6 states recommended to be included
- Test feasibility
  - Retrieving cancer incidence and mortality data within 50 km to test feasibility of ecologic study
  - Confer with investigators already performing pediatric cancer linkages to birth records
  - Perform linkages to additional birth registration and cancer incidence data
  - Obtain and link to census data

Is this Effort Worthwhile?

- The statement of task does not ask for our assessment of the value of the Phase II "study requested by the NRC" only for methods to implement such a study

Costs/Benefit

- *Expected costs are extremely significant*
  - *Assembling effluent and meteorology data required for dose calculations by year for each possible geographic unit described as "large and costly effort"*
  - *Obtaining all cancer mortality and incidence data for a large fraction of the population over extended periods of time, and geocoding these to census level requires a level of effort that is unprecedented in any similar study I am aware of.*

Costs

- *A retrospective-study involving all birth records for a large portion of the US over an extended period is also unprecedented and likely to be extremely costly*
  - *Nested case/control design may reduce some of these costs, but introduces additional concerns*

Benefits?

- If public concerns about safety outweigh other NRC priorities then the study is worth doing
  - *Results would play important role in public discussion about Benefits/Costs of nuclear power*

Benefits?

- *Some unexpected and not easily explained results are almost guaranteed, especially for the ecologic study where many outcomes can be examined*
- Effective communication of multiple comparisons problem when reporting results is essential

There may be side benefits

- This could serve as a model study for increasing the coordination of existing tumor registries
- Linkages of birth records, cancer records and mortality records , may be useful for other studies
  - Other investigators already involved in doing this on large scale

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National Cancer Institute

U.S. DEPARTMENT
OF HEALTH AND
HUMAN SERVICES

National Institutes
of Health

Nuclear Reactor Accidents:
Exposures and Health Effects Among Members of the Public

Maureen Hatch, Ph.D.

Radiation Epidemiology Branch,
Division of Cancer Epidemiology and Genetics

NCRP, April 12, 2013

(Reactor) Accidents Happen…

- Windscale, UK 1957
- Three Mile Island, USA 1979
- Chernobyl, USSR 1986
- Fukushima, Japan 2011

Each is unique, but there are commonalities:

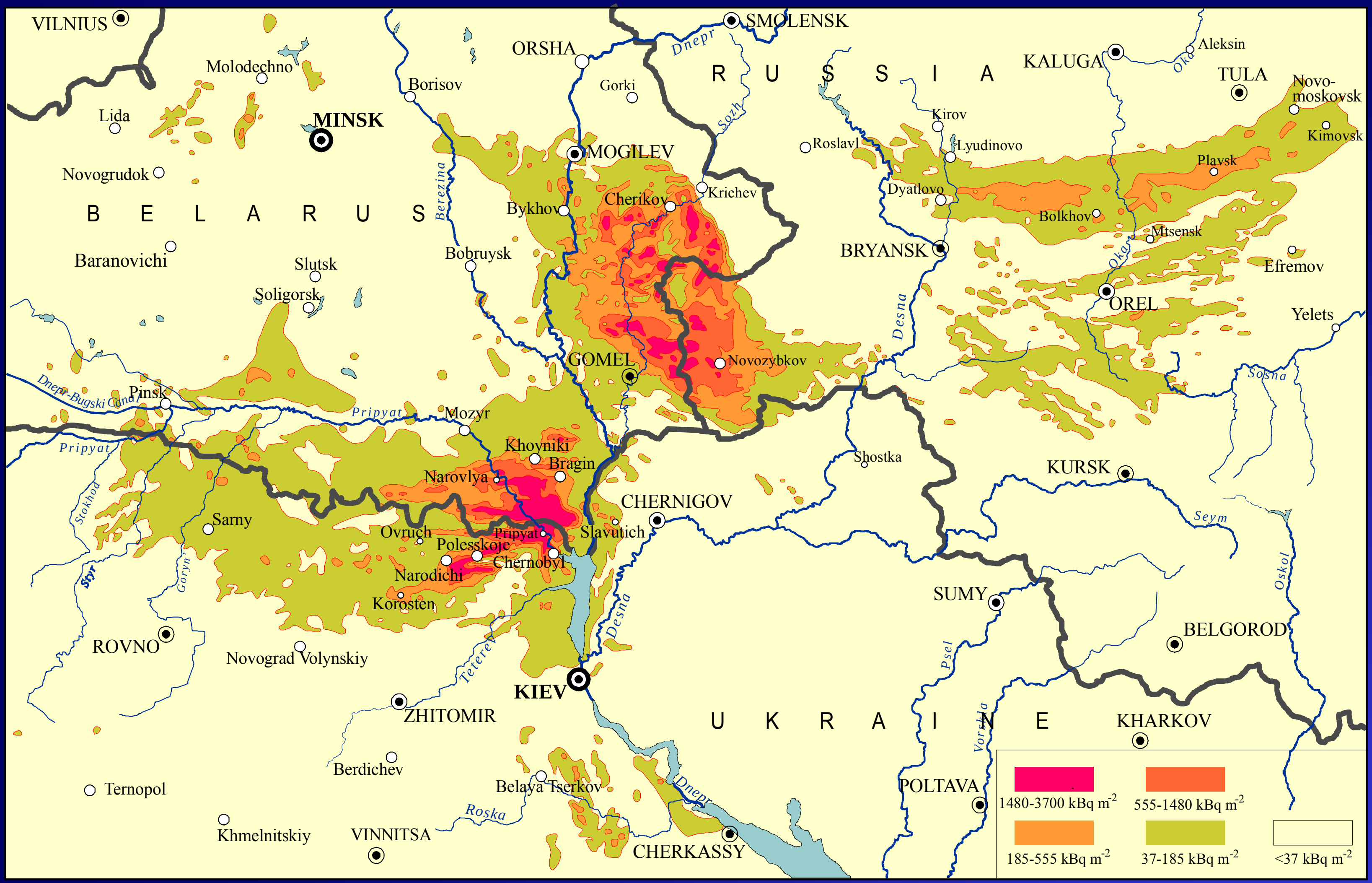
- Circumscribed in time and place
- Similar type of radiation release
- Large numbers of people affected
- Both short- and long-term health consequences
- Sources of new knowledge

Doses at Three Mile Island far, far lower

than Chernobyl fallout but risk perception high

> “Don’t want to land on no three mile island
> Don’t want to see my skin aglow (no no no)”
>
> \- Jimmy Buffett

Chernobyl Accident Fallout



Exposure to Radioactive Iodine from Chernobyl

- ^{131}I concentrates in the thyroid
- Contaminated milk the principal source of exposure
- Children received the highest doses

Iodine Deficiency in Contaminated Areas

- Possible risk factor for thyroid cancer
- Increases uptake of radioiodines
- May stimulate thyroid cell proliferation
- May increase effect of radioiodines

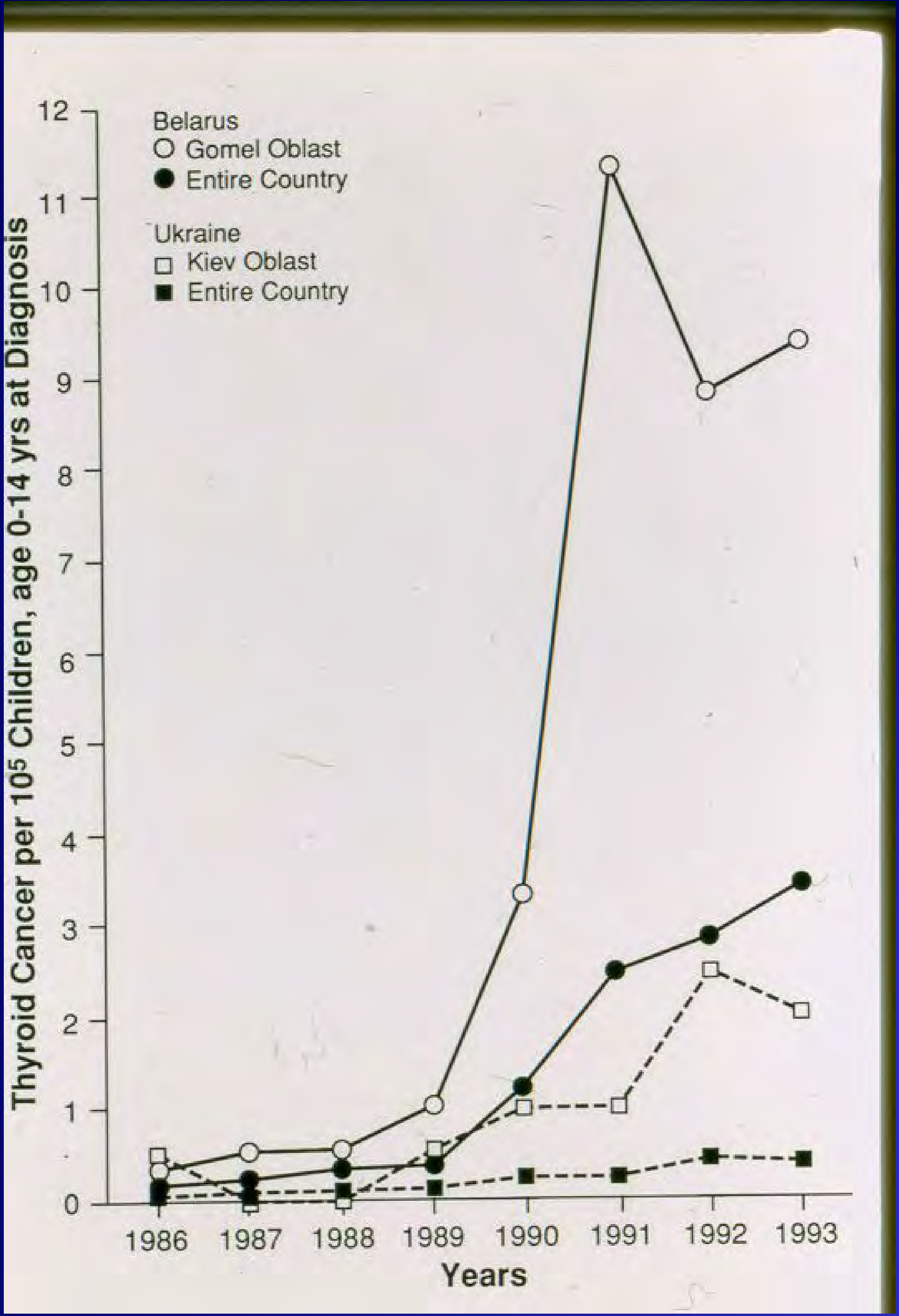
Radiation and Thyroid Cancer: What was Known before Chernobyl

- Atomic bomb
  - Biggest increase in children
- X-ray exposures: medical uses
  - Increase following exposure in childhood
- ^{131}I: dx and tx
  - No obvious increase in adults but data sparse in children

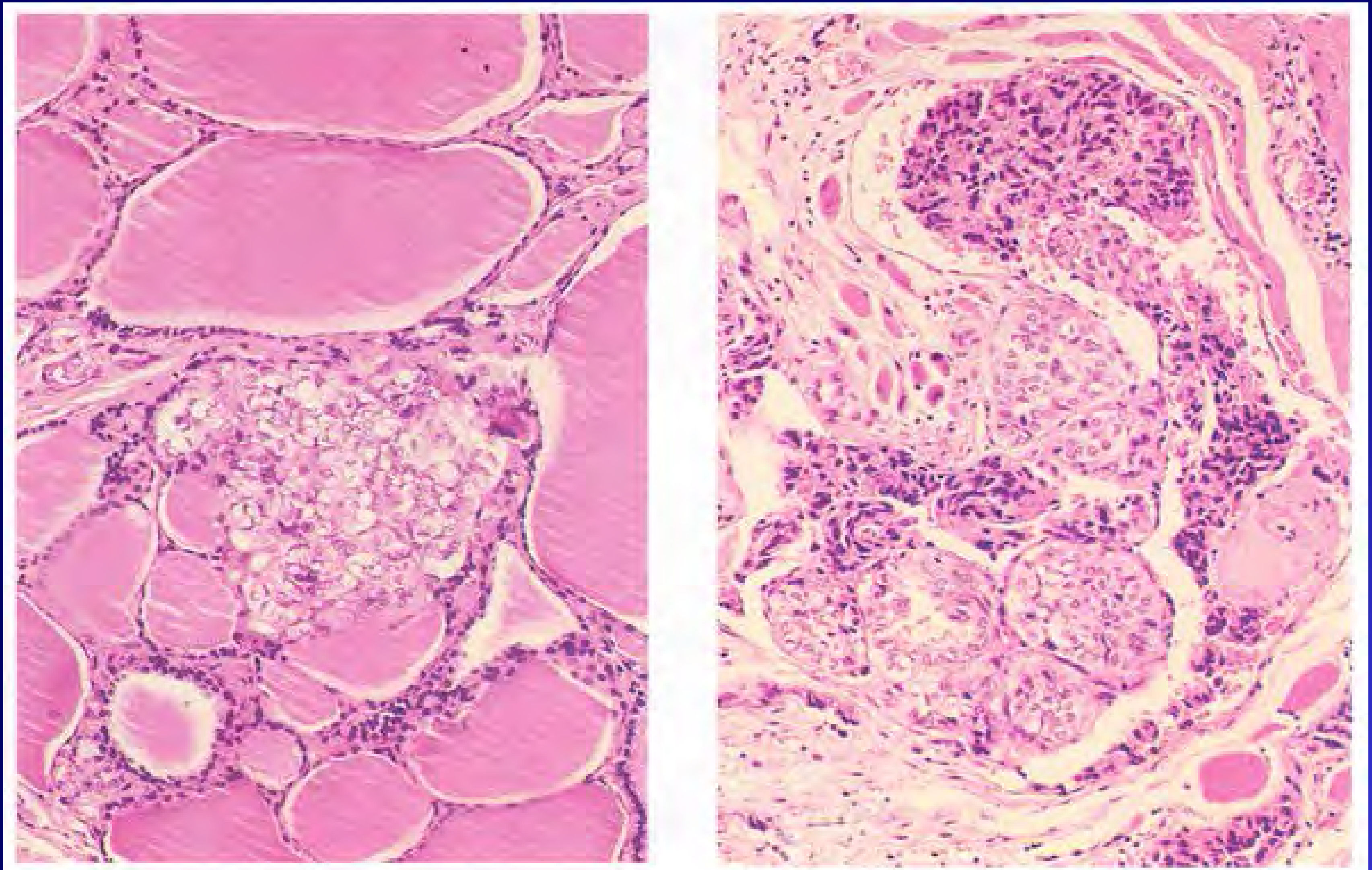
Thyroid Cancer in Contaminated Areas of Ukraine, 1981 - 1990

Year	Thyroid Cancer (No.)
1981	0
1982	0
1983	0
1984	0
1985	0
1986	0
1987	0
1988	0
1989	0
1990	3

Prisyazhiuk A. et al., The Lancet (1991)


Belarus
○ Gomel Oblast
● Entire Country
Ukraine
□ Kiev Oblast
■ Entire Country
Thyroid Cancer per 10⁵ Children, age 0-14 yrs at Diagnosis
12
11
10
9
8
7
6
5
4
3
2
1
0
1986
1987
1988
1989
1990
1991
1992
1993
Years

Papillary cancer, solid subtype



Case-Control Study in Belarus

Dose (Gy)	Cases	Controls	OR (95% CI)
<0.3	64	88	1.00
0.3 - 0.9	26	15	2.38 (1.2, 4.9)
1+	17	4	5.84 (2.0, 17.3)

Astakhova L. et al. Radiat. Res. (1998)

Radiation Dose and Iodine Status:
Belarus and Russian Federation, 1992- 1998

- Population-based case-control study (<15)
- 276 cases, 1300 matched controls
- Stable iodine status based on settlement soil levels
- Consumption of potassium iodide from interview

Cardis E. et al., JNCI (2005)

Radiation Dose and Iodine Status: Belarus and Russian Federation, 1992- 1998

OR at 1 Gy (95% CI)

Potassium iodide	Highest two tertiles of soil iodine	Lowest tertiles of soil iodine
No	3.5 (1.8, 7.0)	10.8 (5.6, 20.8)
Yes	1.1 (0.3, 3.6)	3.3 (1.9, 10.6)

Cardis E. et al., JNCI (2005)

Iodine Levels and Radiation Dose: Bryansk region, Russian Federation, 1996

Urinary Iodine Excretion (µg/dl)	ERR per Gy Estimate	95% CI
<5.0	24.1	(1.7, 78.31)
5.0 – 7.49	18.3	(10.7, 28.6)
7.5 – 9.99	16.2	(0.8, 49.3)
≥10	13.0	(-11.0, 71.2)

Shakhtarin V. et al., IJE (2003)

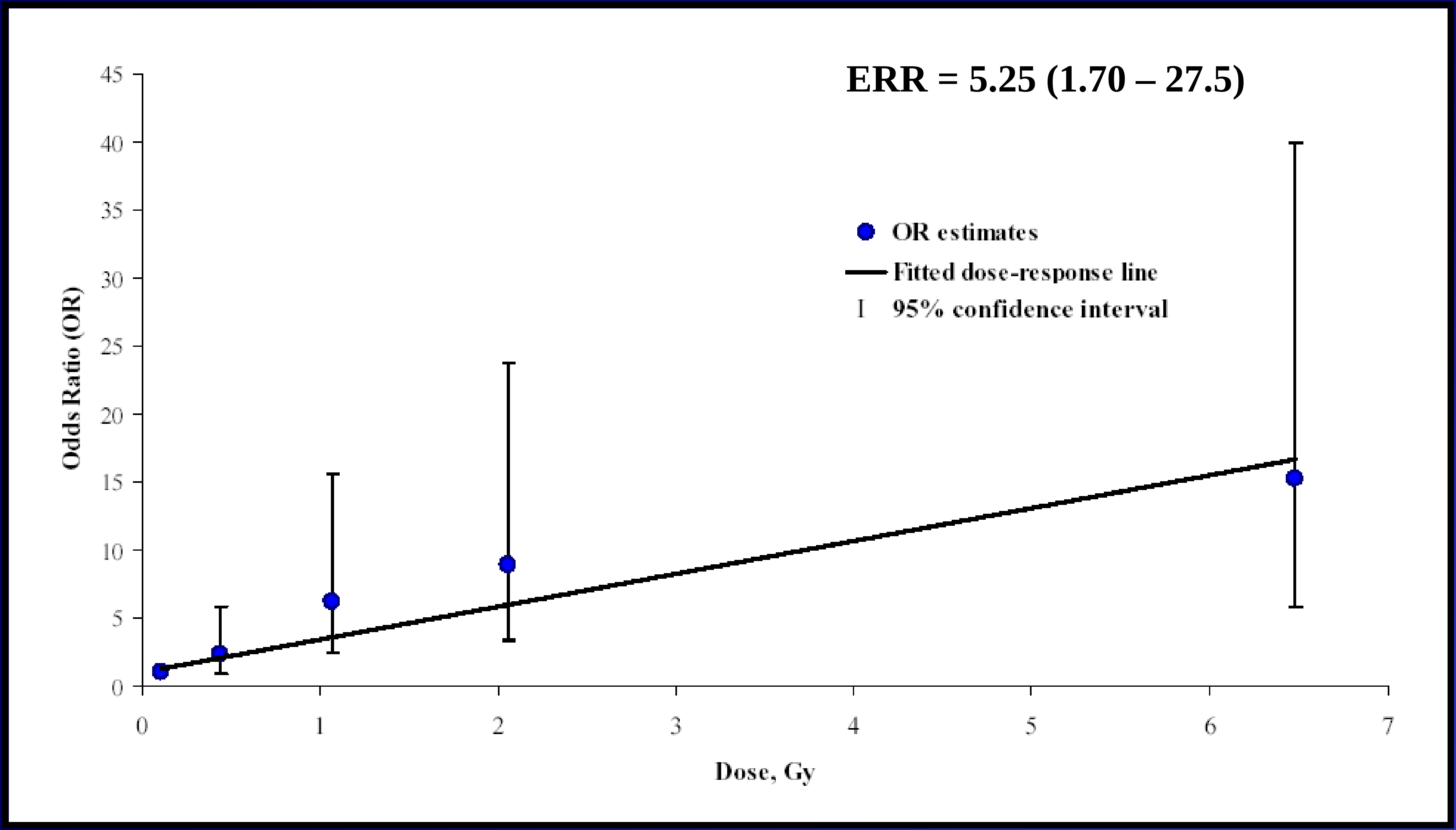
Cohort Studies of Exposed Children in Ukraine and Belarus

- - 13,000 in Ukraine (mean dose 0. 65 Gy)
  - 12,000 in Belarus (mean dose 0.56 Gy)

- Screened serially for thyroid disease using palpation and ultrasound

Tronko et al. (2006), Zablotska et al. (2010)

Analysis of Thyroid Cancer Prevalence: Ukraine



Incidence Analysis Shows Elevated Risk in Ukraine Decades post-Accident

- ERR/GY = 1.91 (0.43, 6.35) (n = 65)
- No detectable decrease in risk during follow-up

Brenner et al. 2011

Conclusions from Analytic Studies of Exposure in Childhood/Adolescence

- Consistent results from analytic studies (2 – 5-fold excess overall)
- Strong, linear dose response
- Magnitude of risk similar to external radiation exposure in childhood

Questions Still Remain About....

- Age and gender as modifiers of thyroid cancer risk in children
- Pattern over time (increase likely to continue for years)
- Role of iodine deficiency
- Risk of thyroid cancer in those exposed in utero…

Exposure to the Embryo/Fetus

- I-131 readily crosses the placenta
- ~10 - 12 weeks of gestation, fetal thyroid becomes fully active and rapidly accumulates iodine from the maternal circulation
- Late in gestation, levels of iodine in fetal thyroid many-fold higher than those in maternal thyroid

Potential Radiosensitivity

- **Small thyroid mass**
- **High levels of cellular proliferation**

Prior Epidemiologic Evidence

- Utah Fallout:
  - Thirty-year follow-up of 400 “downwinders” exposed to I-131 in utero found no cases of thyroid disease, benign or malignant. Small sample, low doses.

    (Lloyd et al., Health Phys. 1996)
- Chernobyl Fallout in Belarus:
  - Ultrasound screening study in 2000 of schoolchildren living within 150 km of the CNPP (2,409 exposed prenatally, 9,720 exposed before age 3 y). Thyroid cancer rates higher in postnatal group (0.32%, n = 31 cases versus 0.09%, n = 1 case). Pre/post-accident comparison; no individual dose estimates.

    (Shibata et al., Lancet 2001)

NCI In Utero-Ukraine Study

- 2,682 mother-child pairs
- Mean fetal thyroid I-131 dose = 72 mGy (0 - 3,240)
- Screened for thyroid cancer, 2003 - 2006:
  - 7 thyroid carcinomas, 1 hurthle cell neoplasm

EOR/GY = 11.7 (P = 0.12)

Hatch et al. (2009), Likhtarev et al. (2011)

Other Uncertainties (1)…

- Effect of exposure in adults

  - ecologic post-Chernobyl studies report increased incidence with lev3els of ground contamination

  - IARC study of clean-up workers with median thyroid dose = 70 mGY finds an ERR/Gy = 3.8 ($p < 0.05$) Kesminiene et al., 2012

Other Uncertainties (2)…

- Effects of uncertainty in dose estimates
- Specific molecular features
- Changes in tumor characteristics

Genomics of Thyroid Cancer After Radiation Exposure

- Survey of genetic changes in
  - Germline
  - Tumor DNA
- Assess relationship of radiation exposure and somatic genetic events

What We Have Learned

- I-131 at young ages increases risk of PTC
- Excess risk, modifying factors compatible with external radiation
- No detectable decrease in risk two decades after exposure

Thyroid Cancer Morbidity and Mortality Due to Chernobyl

- ~ 5,000 cases of thyroid cancer through 2002
- 15 thyroid cancer deaths

Thyroid Cancer Morbidity and Mortality Due to Chernobyl

- Variable estimates of lifetime excess
  - 4,000 – 9,000 deaths (WHO, 2005)
  - 30,000 – 60,000 cancer deaths (Greens/EFA Party, 2006)
  - 93,000 cancer deaths (Greenpeace, 2006)

Thank You for Your Attention.

No financial conflicts.

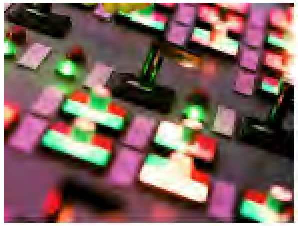
Summary

Paul A. Locke, *Chair*

Implications of Radiation Dose and Exposed Populations on Radiation Protection in the 21st Century

John D. Boice, Jr.

National Council on Radiation Protection & Measurements



Forty-Ninth
Annual Meeting Program

NCRP
Scientific Authority Since 1929

Summary Session

Implications of Radiation Dose and Exposed Populations on Radiation Protection in the 21st Century

John D Boice Jr
National Council on Radiation Protection & Measurements

49th Annual Meeting
Bethesda MD -- March 12, 2013

Some Observations – Common Themes

- There’s more to be done in all aspects of Radiation Protection
- We need to communicate better
- We need more radiation scientists

Implications of Radiation Dose and Exposed Populations on Radiation Protection in the 21st Century

Radiation protection guidance should keep in step with

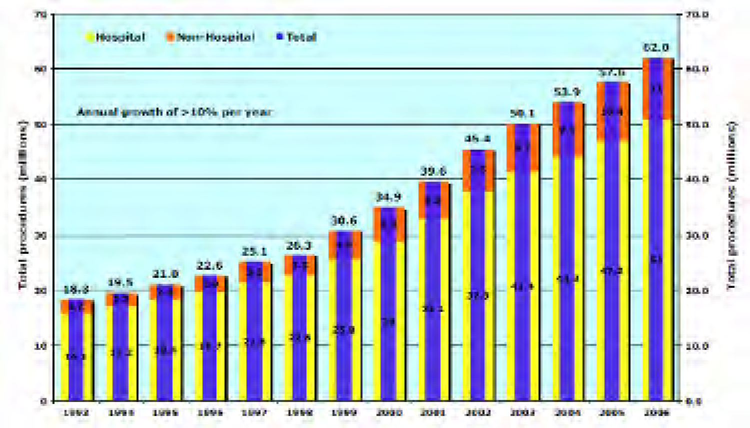
- The increase in population exposures (dose)
- The changes in size of the population exposed,
- The possibility of nuclear incidents (accidents, terrorism).
- The development of new scientific knowledge. New data on the biological effects of ionizing radiation include new information on cataracts, heart disease and non-cancer
- The changes and development of new technologies.

As the needs for radiation protection change in the 21st century there is a need for constant improvements, constant vigilance, continued guidance and more radiation protection scientists.

The Importance of Dose

Willie Sutton robbed banks “because that's where the money is.”

Radiation protection should emphasis medical exposures (patients and workers) “because that’s where the dose is.”



CT over years

Radiation Protection in Medicine

- Guidance on Evaluating and Communicating Radiation Risks for Imaging Studies
- Tissue Injuries from Diagnostic and Interventional Radiological Imaging Procedures
- Radiation Protection in Dentistry

Radiation Protection in Medicine

- Operational Radiation Safety for PET and Multi-Modality (Hybrid) Imaging Systems (*e.g.*, PET/CT. SPECT/CT, and PET/MRI) and Associated Radionuclide Production
- Error Prevention in Radiation Therapy
- Genetic Susceptibility to Radiation-Induced Cancer and Non-cancer Diseases
- Update Medical Doses in NCRP Report No. 160
- Tracking and Reporting Patient Doses for Individuals

The Importance of Perception Stress and Fear of Radiation

The Real and Increasing (and Unappreciated) Health problems at Fukushima (similar to TMI and Chernobyl) are the:

Mental health problems

Are we focusing on the splinter where the log is staring us in the face? How to consider? Communication, education, outreach.

After Fukushima:
families on the edge of meltdown

Two years after the Fukushima nuclear disaster, a new phenomenon is on the rise: atomic divorce. Abigail Haworth reports on the unbearable pressures and prejudices being faced by those caught in the radiation zone. The Observer, Sunday, February 24, 2013

'Each anniversary we will be thinking, "Is this the year one of our daughters will get sick?"' Kenji and Aiko Nomura with Sakura, 3, and 15-month-old Koto. Photograph: Panos Pictures/Eric Rechsteiner

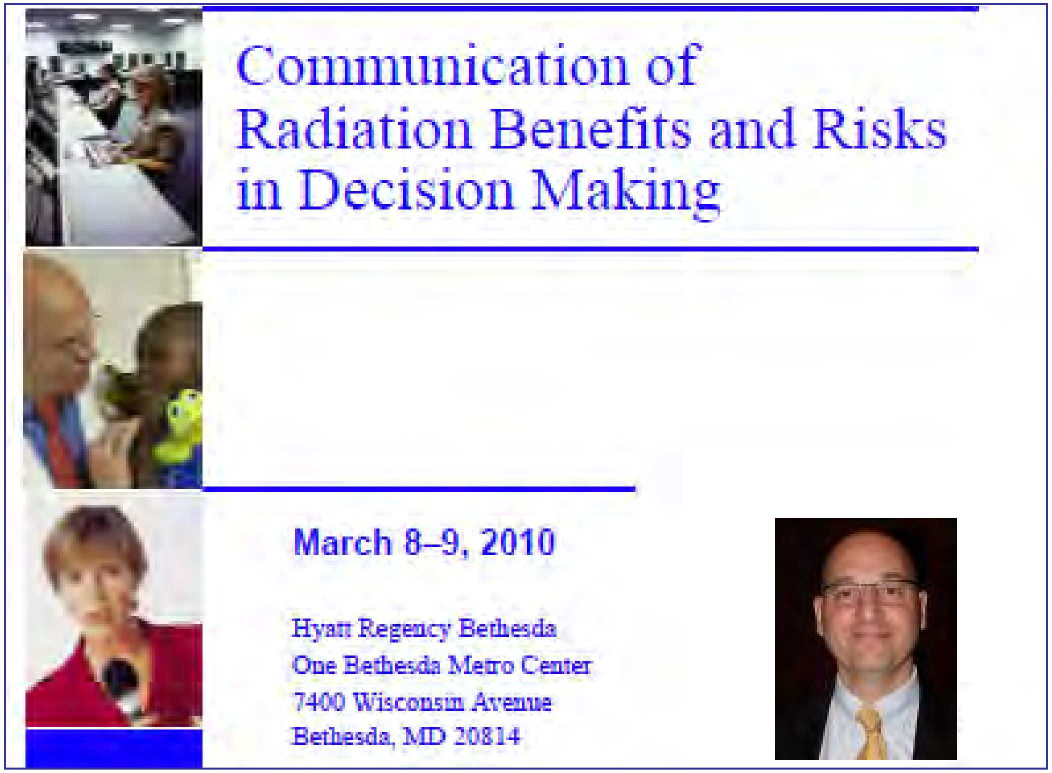
Marital discord has become so widespread that the phenomenon of couples breaking up has a name: *genpatsu rikon* or "atomic divorce".

After Fukushima:
families on the edge of meltdown

Now that what Noriko Kubota (Iwaki Meisei University) calls the "disaster honeymoon period" of people uniting to help each other in the immediate aftermath is over, long-term psychological trauma is setting in.

"We are starting to see more cases of suicide, depression, alcoholism, gambling and domestic violence across the area," says the psychologist. The young are not immune either. In late 2012, Fukushima's children topped Japan's obesity rankings for the first time due to apparent comfort eating and inordinate amounts of time spent indoors avoiding contamination. "From the point of view of mental health, this is a very critical time," says Kubota. (Feb 24 2013, Observer)

Importance of Communications



Communication of Radiation Benefits and Risks in Decision Making

March 8–9, 2010

Hyatt Regency Bethesda
One Bethesda Metro Center
7400 Wisconsin Avenue
Bethesda, MD 20814

Radiation risk communicators must overcome the challenges posed by three basic observations about people under stress:

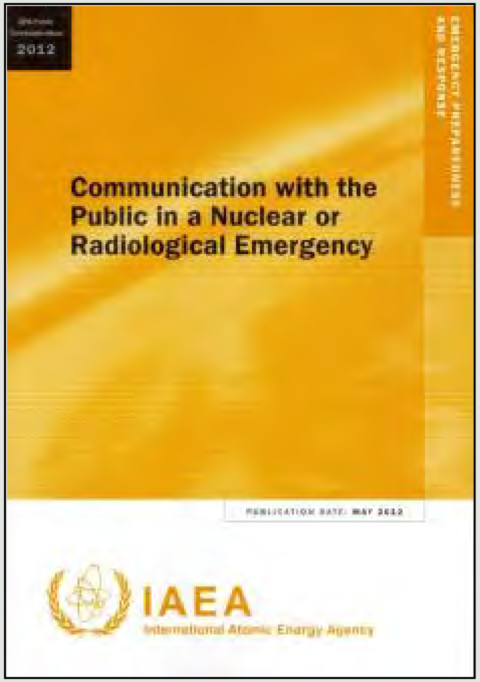
1. **People under stress typically want to know that you care before they care about what you know.**
2. **People under stress typically have difficulty hearing, understanding, and remembering information.**
3. **People under stress typically focus more on negative information than positive information.**

Covello: Health Phys. 2011

The Importance of Communication

- There is a particularly urgent need to develop improved plans and materials for communicating with the public. IAEA initiatives are encouraging. We need to continue to improve.

- Risk-communication strategies that help people place radiation risks in perspective by comparing them with other risks can help reduce fears of radiation.



2012

Communication with the Public in a Nuclear or Radiological Emergency

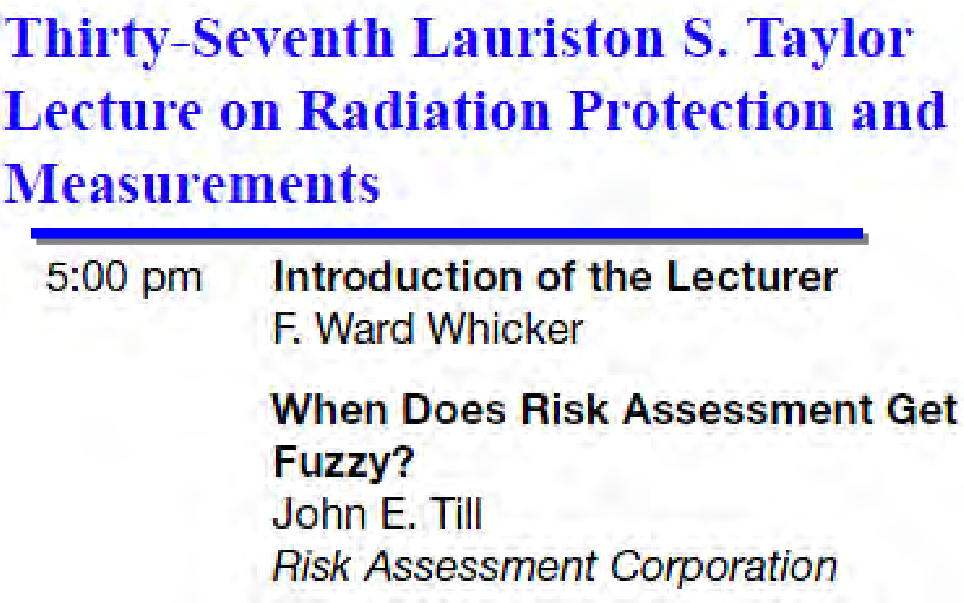
IAEA
International Atomic Energy Agency

Slovic: Bull. Atomic Sci. 2012

Tenth Annual Warren K. Sinclair Keynote Address

Fukushima Nuclear Power Plant Accident and Comprehensive Health Risk Management
Shunichi Yamashita
Fukushima Medical University

- There is a need for improved risk communication and outreach.
- There is a need for improved outreach, stakeholder involvement, community involvement.
- Trust and credibility has to be earned which is difficult once lost.
- Genetic susceptibility, FOXE1, potentially important in radiation risk



Thirty-Seventh Lauriston S. Taylor Lecture on Radiation Protection and Measurements

5:00 pm **Introduction of the Lecturer**
F. Ward Whicker

When Does Risk Assessment Get Fuzzy?
John E. Till
Risk Assessment Corporation

- Wasn't fuzzy, was he?
- Communicate risks in understandable ways and based on best science.
- Stakeholder involvement is critical.
- Trust must be earned.

Risk Communication

- Even when radiation doses are low, risk communication and outreach is essential to convince the public, media, authorities that risks are tiny. (No threshold for fear!)
- Scientists must be willing to communicate their work to other scientists, regulators, media, and the public.
- Be available
- Town meetings
- Focus groups
- Dialogues
- Engage, empower

県民健康調

提言案について真剣な議論を交わす専門家会議の参加者

What is a Stakeholder?

- Not someone who holds a piece of wood!
- Although a “stake” is a pointed piece of wood or post, American settlers would mark their property with stakes, often referred to as “staking their claims.” The property was also called their “stake.”
- ICRP Publication 82
  (58) In the wider decision making process, the role of all interested parties, usually termed stakeholders, should be recognized. This recognition is particularly important in cases of remediation and rehabilitation of land with residues from past activities and events. The extent of stakeholder involvement will vary from one situation to another…. The weight given to these interests could be an important factor in the acceptability of the ultimate decision.

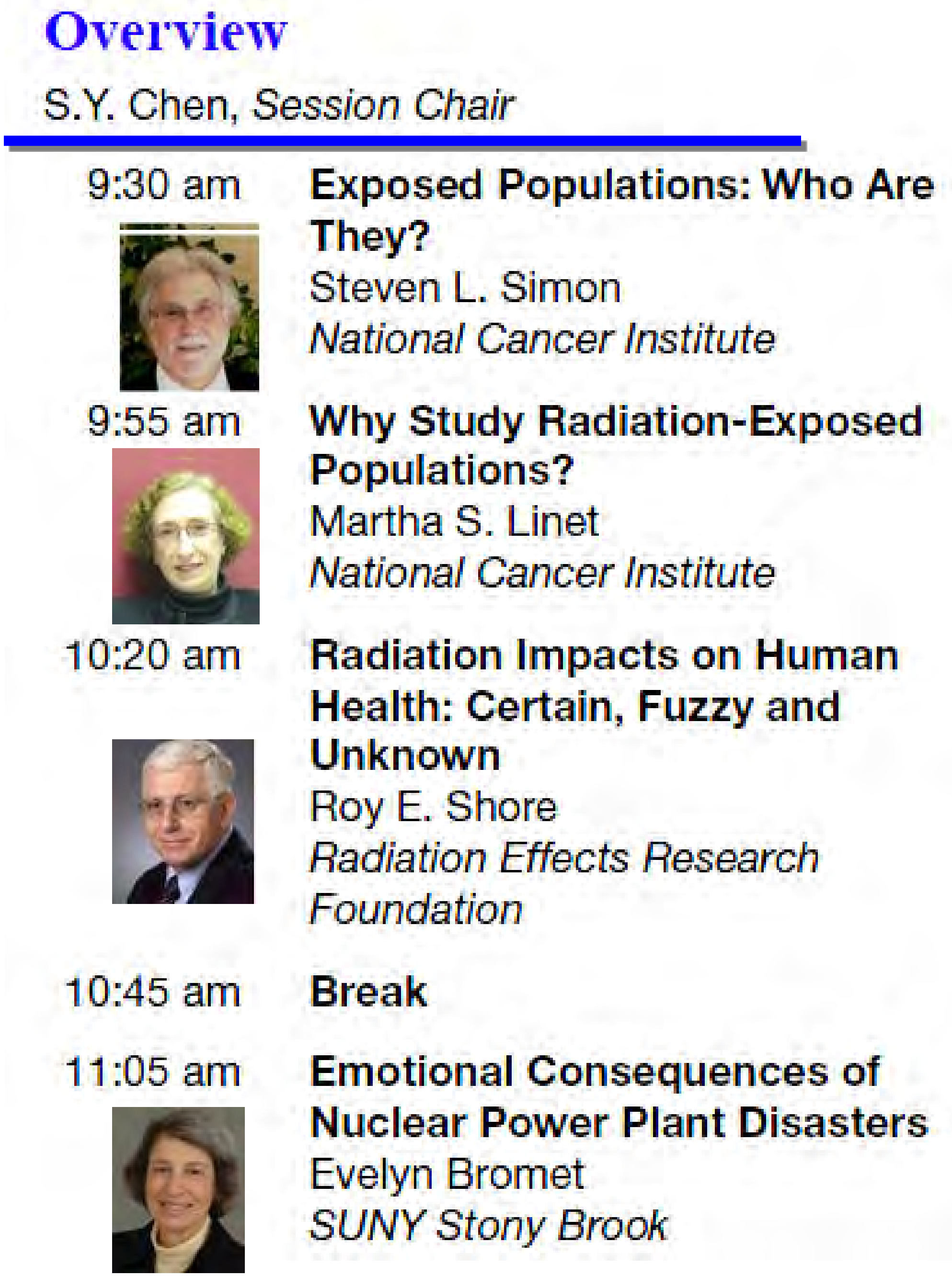
Stakeholders - Trust & Credibility

- This trust and credibility has to be earned by taking measures that go beyond what is expected. Good risk management must include **actively engaging stakeholders** as equal partners (*e.g.*, the citizens).

- It must include **transparency** in the science being applied and the decisions being made so stakeholders believe their voices are being heard.

- Building **credibility and trust** is as important as the science itself

- What does it matter to have the best environmental and population risk assessment and control **if the results are not believed**?



Overview

S.Y. Chen, *Session Chair*

9:30 am **Exposed Populations: Who Are They?**
Steven L. Simon
National Cancer Institute

9:55 am **Why Study Radiation-Exposed Populations?**
Martha S. Linet
National Cancer Institute

10:20 am **Radiation Impacts on Human Health: Certain, Fuzzy and Unknown**
Roy E. Shore
Radiation Effects Research Foundation

10:45 am **Break**

11:05 am **Emotional Consequences of Nuclear Power Plant Disasters**
Evelyn Bromet
SUNY Stony Brook

- The sources and opportunities for exposure seem endless!
- New knowledge on effects necessitates continued assessment of detriment.
- We need to learn about low dose protraction/ fractionation exposures.
- Did you know that mental disorders may be more important than cancer?

- We have met the exposed populations and he is us!

- The importance of patient medical exposures (~100% of the population).

- Don’t forget medical workers and aviation.

New Knowledge - Cataracts

Dose limits for the eye is an important issue raised based on new data on health effects. ICRP Recommendations 103 has generated debate and discussions within the United States.

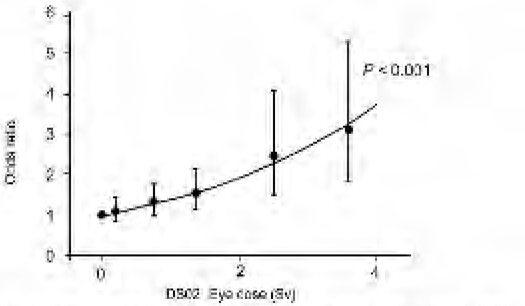
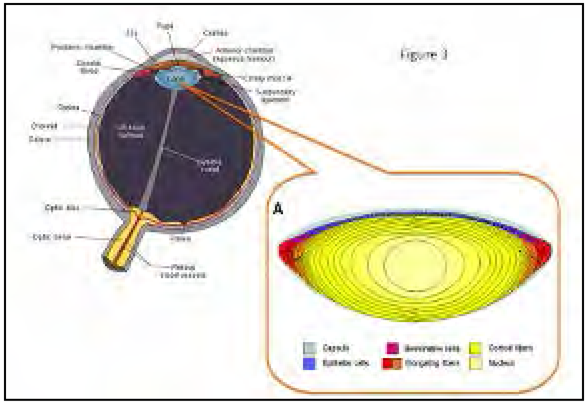


Figure 5. Dose responses for postoperative cataract. Prevalence study in 2000–2002.
(Neriishi K et al. Radiat Res 168:404, 2007)



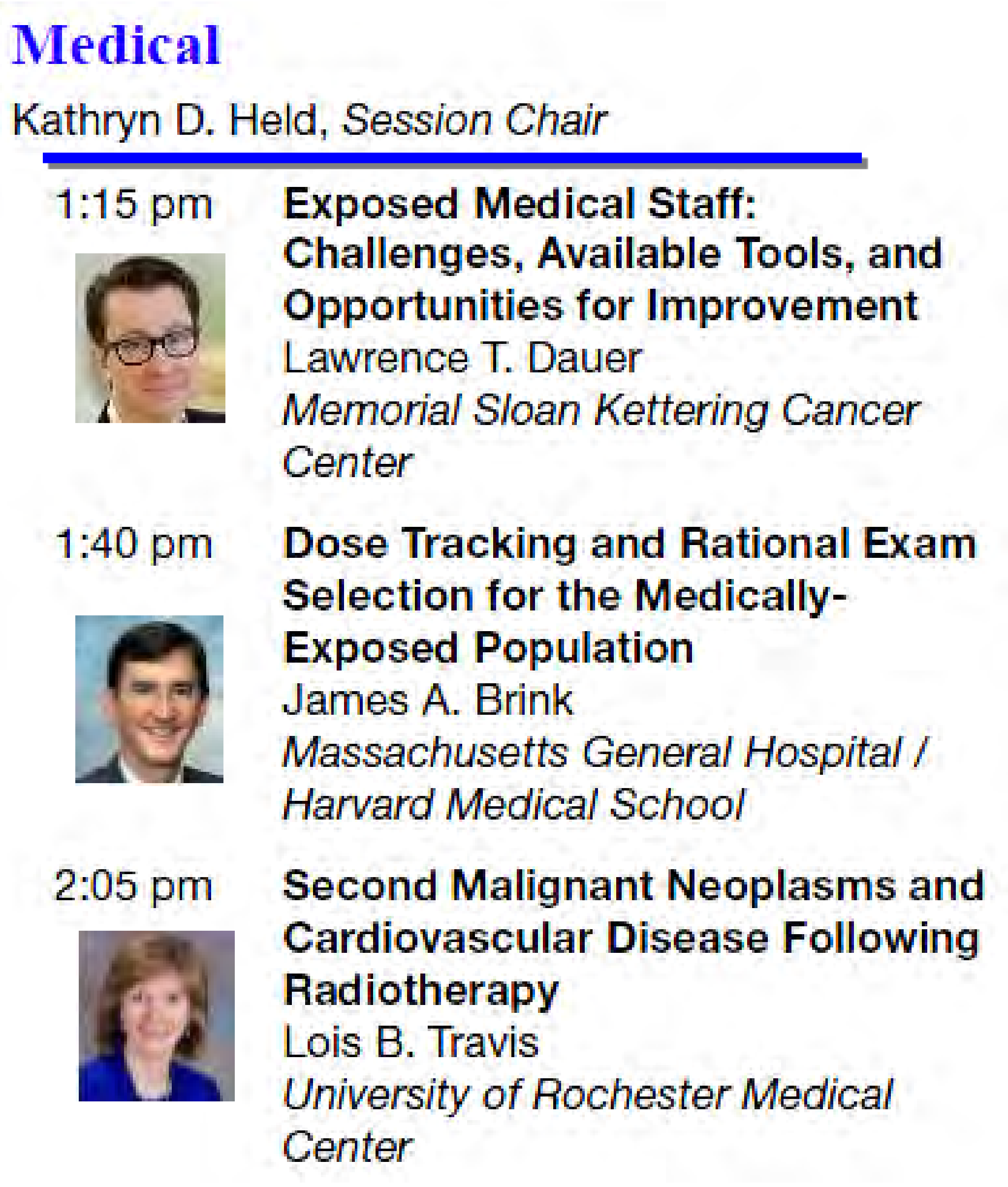
Nuclear Regulatory Commission

Cindy Flannery, CHP
U.S. Nuclear Regulatory Commission

Update on Revisions to the U.S. Nuclear Regulatory Commission's Radiation Protection Regulations (10 CFR Part 20)

- Engage stakeholders on dose limit for lens of the eye
- Explore implications of greater alignment ICRP Publication 103
- Align with the recent methodology and terminology for dose assessment
- Improve individual protection and reduce future exposures to workers at, or near, the current dose limits
- Improve reporting of occupational exposure by NRC and Agreement State materials licensees and some medical occupations into the NRC Radiation Exposure Information and Reporting System (REIRS)

December 2012 (SRM-SECY-12-0064) – Staff Requirements Memorandum



Medical

Kathryn D. Held, *Session Chair*

1:15 pm **Exposed Medical Staff: Challenges, Available Tools, and Opportunities for Improvement**
Lawrence T. Dauer
Memorial Sloan Kettering Cancer Center

1:40 pm **Dose Tracking and Rational Exam Selection for the Medically-Exposed Population**
James A. Brink
Massachusetts General Hospital / Harvard Medical School

2:05 pm **Second Malignant Neoplasms and Cardiovascular Disease Following Radiotherapy**
Lois B. Travis
University of Rochester Medical Center

- Constant vigilance due to increased new and novel uses of radiation. Radiation signature? Posterior subcapsular opacities.
- How can we track medical doses and provide guidance in medicine?
- Heart a major adverse effect of curative treatments. Risk models needed. Susceptibility?

Worker Exposures

Christopher H. Clement, *Session Chair*

3:10 pm **Characterization of Exposures to Workers Covered Under the U.S. Energy Employees Compensation Act**
James W. Neton
National Institute for Occupational Safety & Health

3:35 pm **Increased Occupational Exposures: Nuclear Industry Workers**
Andre Bouville
National Cancer Institute

4:00 pm **Radiation Exposure of U.S. Military Individuals**
Paul K. Blake
Defense Threat Reduction Agency

- NIOSH/Military remarkable in dose reconstruction. Statistical uncertainty modeling. Epidemiology uses.
- Still areas of high occupational doses. Learn from the accidents. Decision making.
- Military record - 104 reactors, no mishaps, low occupational doses, self regulating and effective. Strategies effective.

Risk Predictions of Second Cancers
IMRT (●) vs Protons (○)

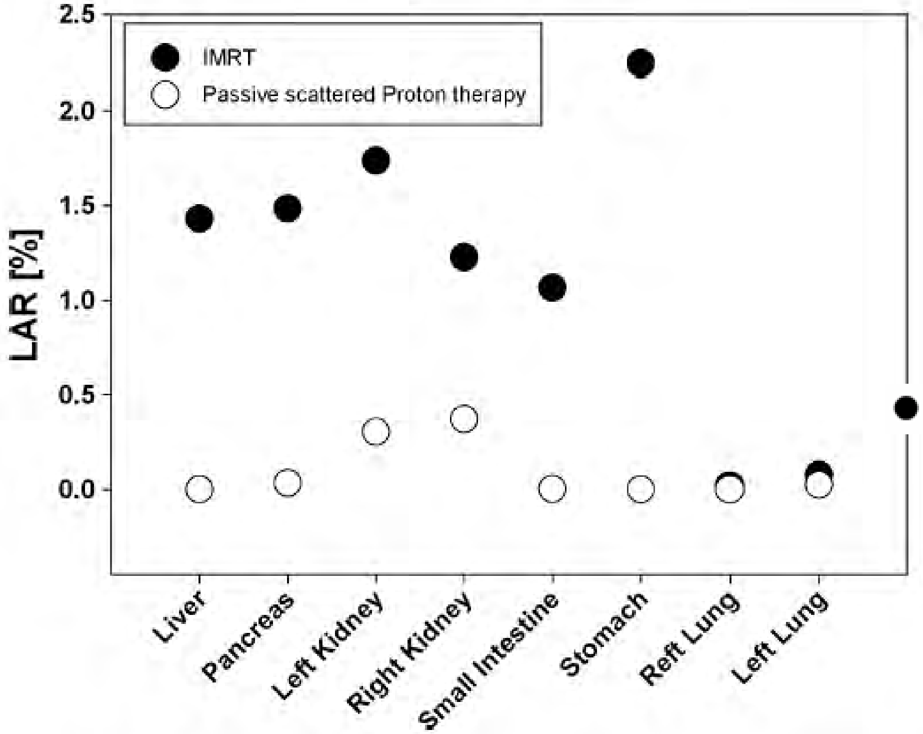


Fig. 3. Lifetime attributable risks (LAR) for a 14-y-old male patient with an attained age of 75 y based on EAR for various organs in the IFV. Treatment area was the spine, close to T12. Risk estimations are based on the model by Schneider (2009) in combination with the EAR low-dose risk formalism by BEIR (2006). Close circles: IMRT delivery; open circles: passive scattered proton delivery.

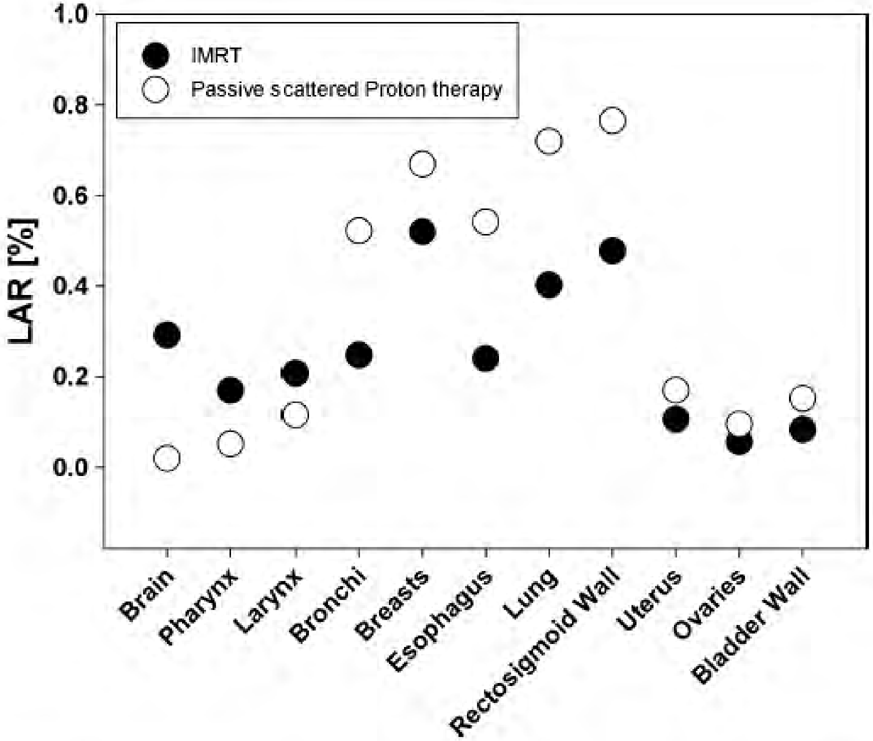


Fig. 2. Lifetime attributable risks (LAR) assuming an 8-y-old female patient with an expected attained age of 75 y based on EAR for various organs in the OFV. The treatment site was next to the spine, close to T12. The data are averaged over six treatment fields with an average diameter of 6 cm. Risk estimations are based on EAR low-dose risk formalism by BEIR (2006). Close circles: IMRT delivery; open circles: passive scattered proton delivery.

Paganetti: Health Phys. 2012

Operation Tomodachi

- Group doses estimated for 70,000
- 8,000 thyroid measurements were made.
- Doses were estimated conservatively:
  1. Breathing rate corresponding to highest level of physical activity
  2. Outdoors all the time

DoD Forward Looking

- Extensive Dose Reconstructions years after exposure are problematic and expensive (*e.g.*, program for Atomic Veterans)
- Methodology will be valuable for any future accident or incident
- Innovative inclusion of families (spouses and children)

Public Exposures

David J. Pawel, *Session Chair*

9:30 am **Impact on the Japanese Atomic-Bomb Survivors of Radiation Received from the Bombs**
Harry M. Cullings
Radiation Effects Research Foundation

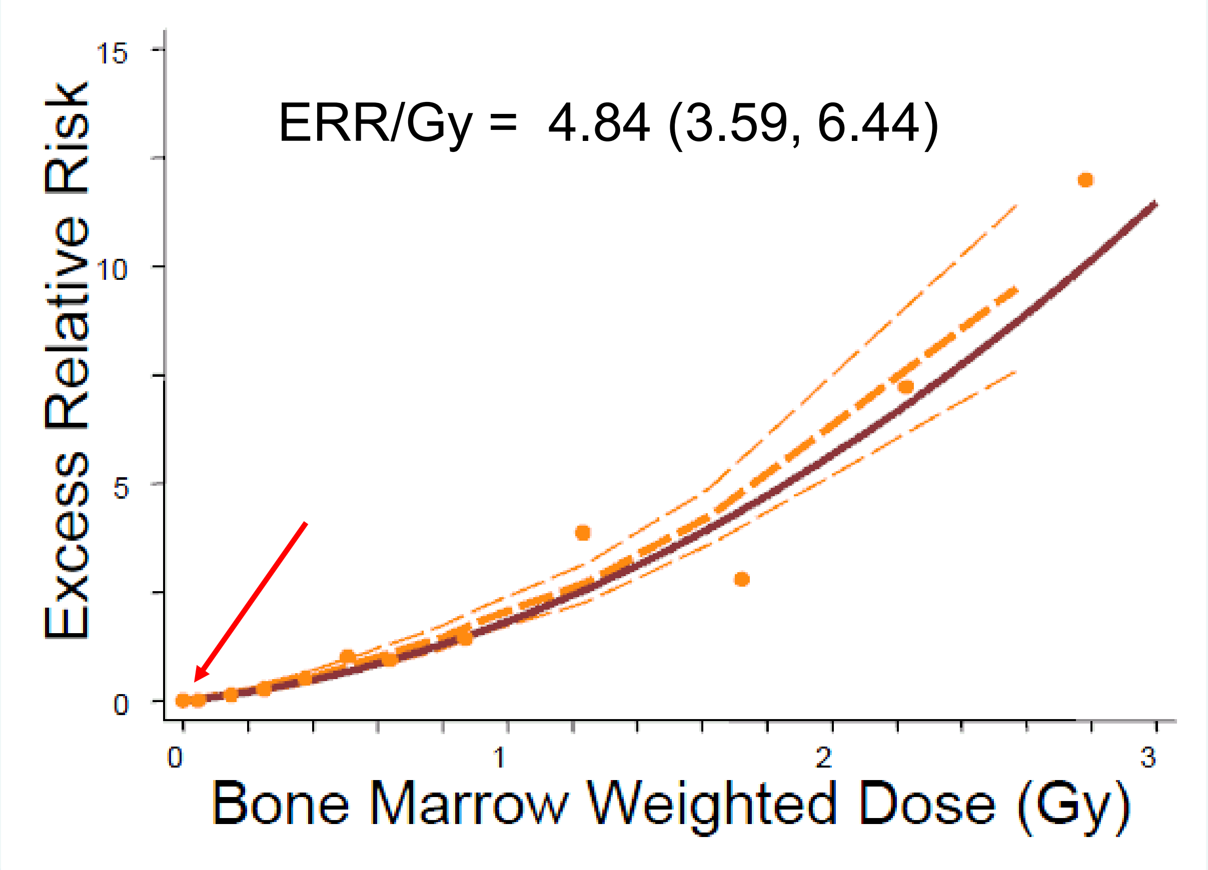
9:55 am **Joint U.S./Russian Studies of Population Exposures Resulting from Nuclear Production Activities in the Southern Urals**
Bruce A. Napier
Pacific Northwest National Laboratory

10:20 am **Populations Living Near Nuclear Power Plants**
Daniel O. Stram
University of Southern California

10:45 am **Nuclear Reactor Accidents: Exposures and Health Effects Among Members of the Public**
Maureen Hatch
National Cancer Institute

- Foundation of protection guidance is based on the best dosimetry possible. Continued new data.
- Are low dose rate effects different from high dose rate effects?
- Need for radioecology.
- Some studies are for societal needs. Out of date. Low power.
- Psychosocial outcomes will likely emerge as most significant health effect. More KI guidance.

LSS Leukemia Dose Response



Linear-quadratic fits better than Linear model.

Leukemia has much higher risk coefficient than solid cancer. Excess occurs early.

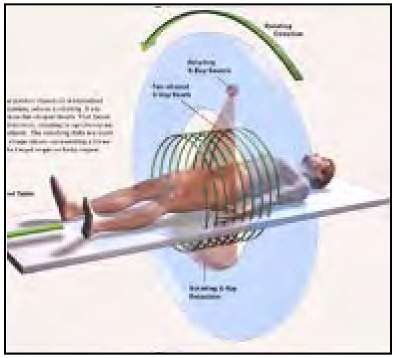
No association multiple myeloma, Hodgkin lymphoma, NHL only males

Hsu et al: Radiat. Res. 2013

A Major Issue in Radiation Epidemiology and Radiation Protection?

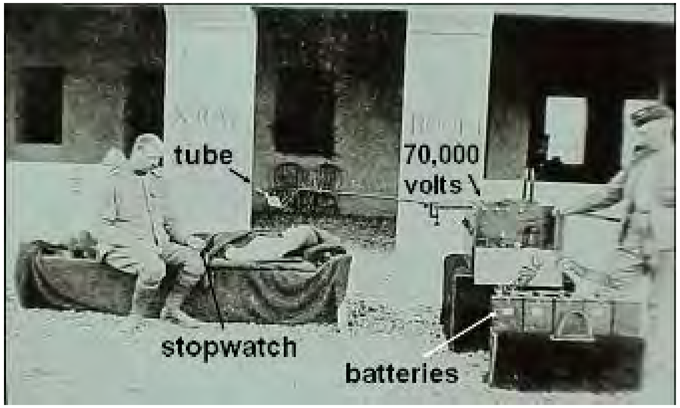
What is the level of risk when exposure received gradually over time and not briefly ?

Medicine



Accidents

Occupation



Environment

NCRP - One Million U.S. Radiation Workers and Veterans

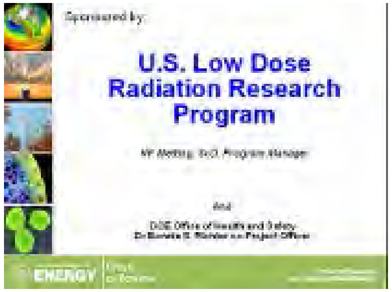
- Manhattan Project Workers
- Atomic veterans
- Nuclear utility workers
- Medical and other occupational
- Possible – other military

DEFENSE THREAT REDUCTION AGENCY • UNITED STATES OF AMERICA

Vanderbilt-Ingram Cancer Center

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

NATIONAL CANCER INSTITUTE



Sponsored by:

U.S. Low Dose Radiation Research Program

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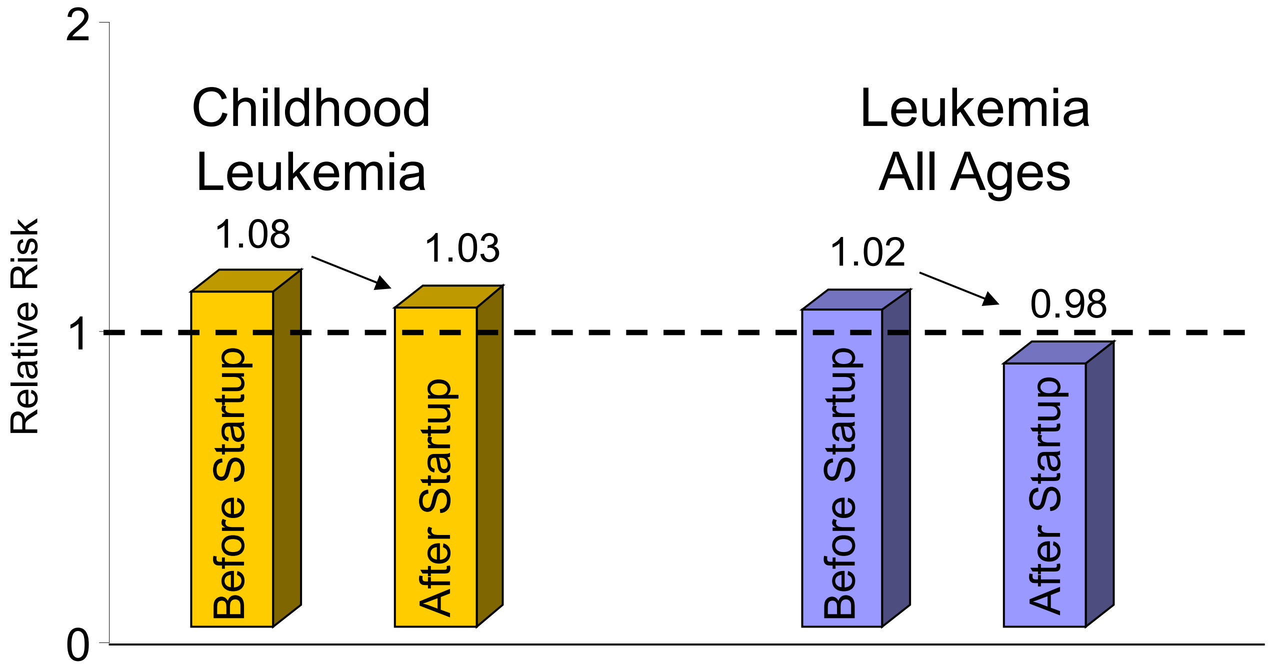
NASA

Overall Relative Risk of Leukemia Before and After Nuclear Facility Startup



Risk higher before than after facilities began operating

Jablon et al: JAMA 265,1403-1408, 1991

Be cautious in conducting "studies" of very low statistical power (ICRP 99)

Concluding Comment

- Fukushima, CT exams, nuclear terrorism are in the public consciousness and also support need for protection guidance
- We need to Educate – Public, Scientists, Medics, Health Care Providers
- We need to Communicate – be transparent and effective
- We need to Involve stakeholders (citizens) – continually
- We need to Reassess Protection guidance as new science arises.
- Mental health, tip of the iceberg? – focus on real not perceived problem
- Patients, medical workers, aviation? – dose

We Need Scientists for Future - A Clarion Call

- A National Effort is Needed.
- Government, Universities, Private Sector, Military, Clinical – Everyone.