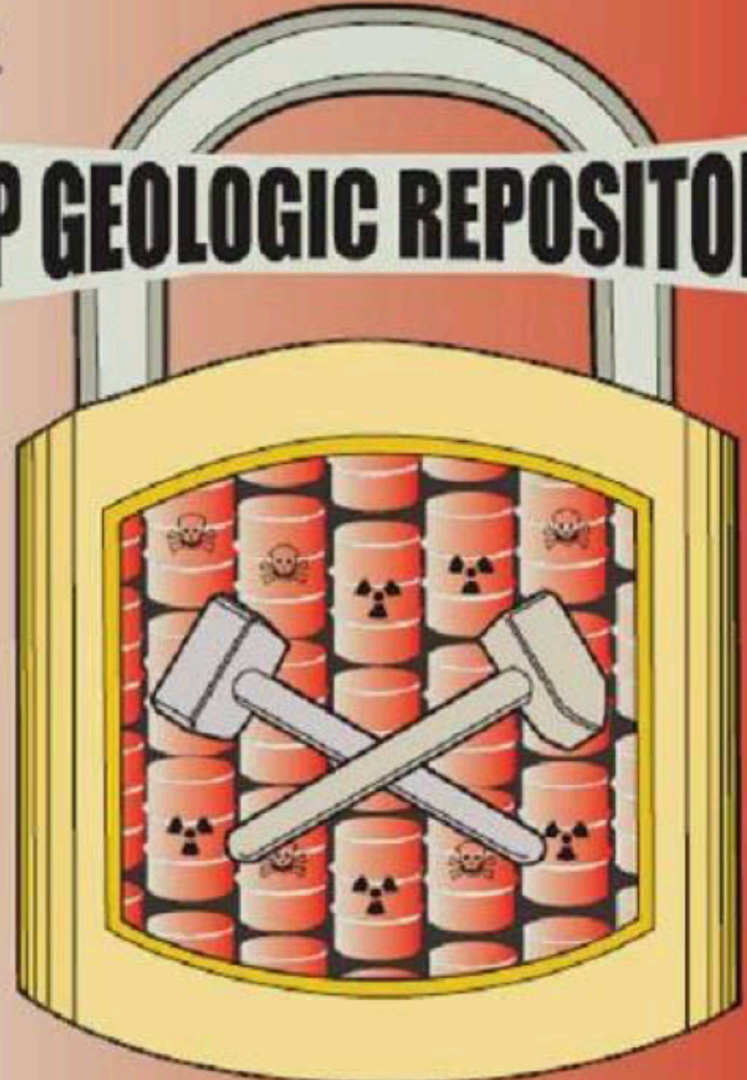
Geologic Repositories and Radioactivity: Consequences for (Earth) Science Education

Norbert T. Rempe, Carlsbad, NM, rempent@yahoo.com

Reviews in Engineering Geology XIX

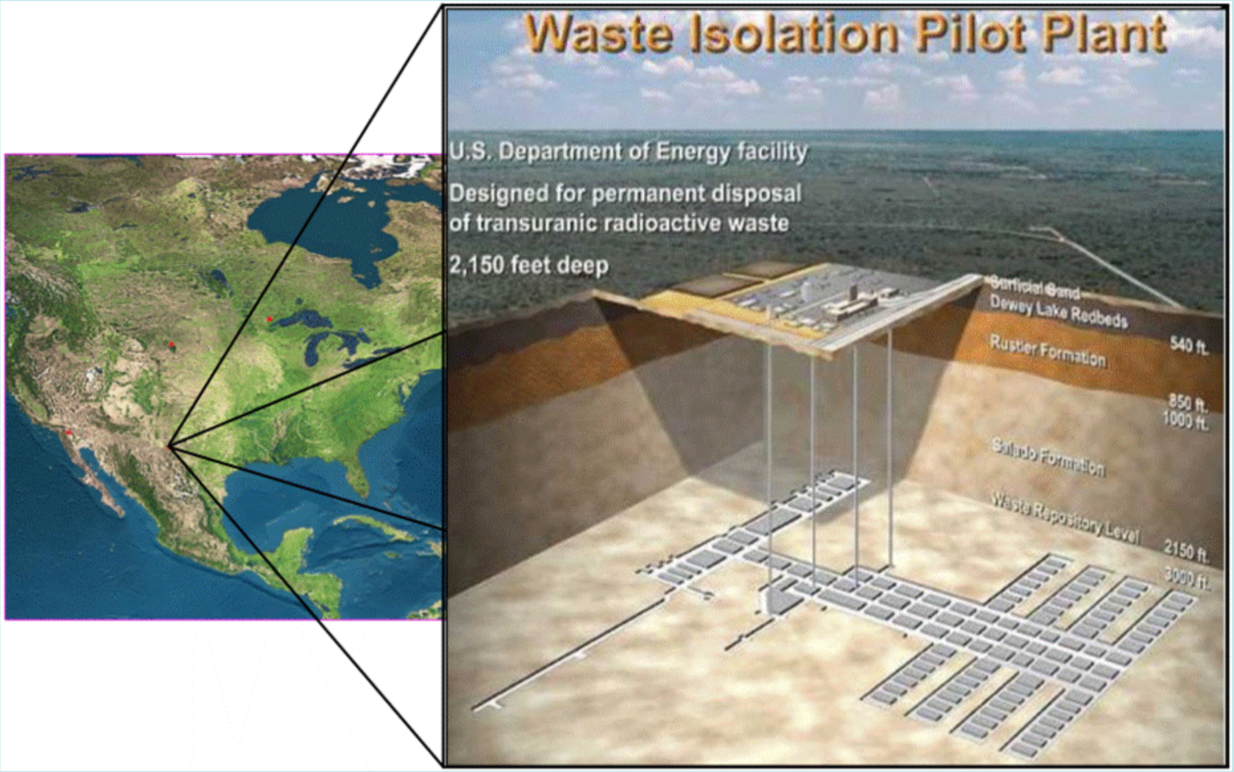
THE GEOLOGICAL SOCIETY OF AMERICA®

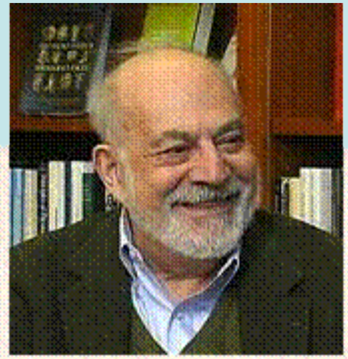
DEEP GEOLOGIC REPOSITORIES



edited by Norbert T. Rempe

WIPP


Waste Isolation Pilot Plant
U.S. Department of Energy facility
Designed for permanent disposal
of transuranic radioactive waste
2,150 feet deep
Surficial Sand
Dewey Lake Redbeds
Rustler Formation
540 ft.
850 ft.
1000 ft.
Salado Formation
Waste Repository Level
2150 ft.
3000 ft.



ON BULLSHIT

Harry G. Frankfurt

PRINCETON UNIVERSITY PRESS

PRINCETON AND OXFORD

First published 1986

Avner Vengosh, Duke University

Rooting Out Radioactive Groundwater (Geotimes, May 2006)

When the **Chernobyl** nuclear power plant exploded in 1986… The accident demonstrated the **fragility of any nuclear facility** and raised the level of awareness over the health **threats that radiation poses** to people and the environment.
…the general population is still **at risk from** a different source: **Naturally occurring radioactive particles** exist in many groundwater systems worldwide…
The global **community must aggressively address these challenges, to ensure a safe water supply**.

Laurence A. Coogan & Jay T. Cullen, University of Victoria

Did natural reactors form as a consequence of the emergence of oxygenic photosynthesis during the Archean? (GSA Today, October 2009)

Natural reactors act as point sources of…**toxic byproducts**.
Natural fission reactors would clearly be **environmentally detrimental**.
…whether the formation of these natural reactors had any significant **biocidal impacts…**

Natural Uranium in Groundwater

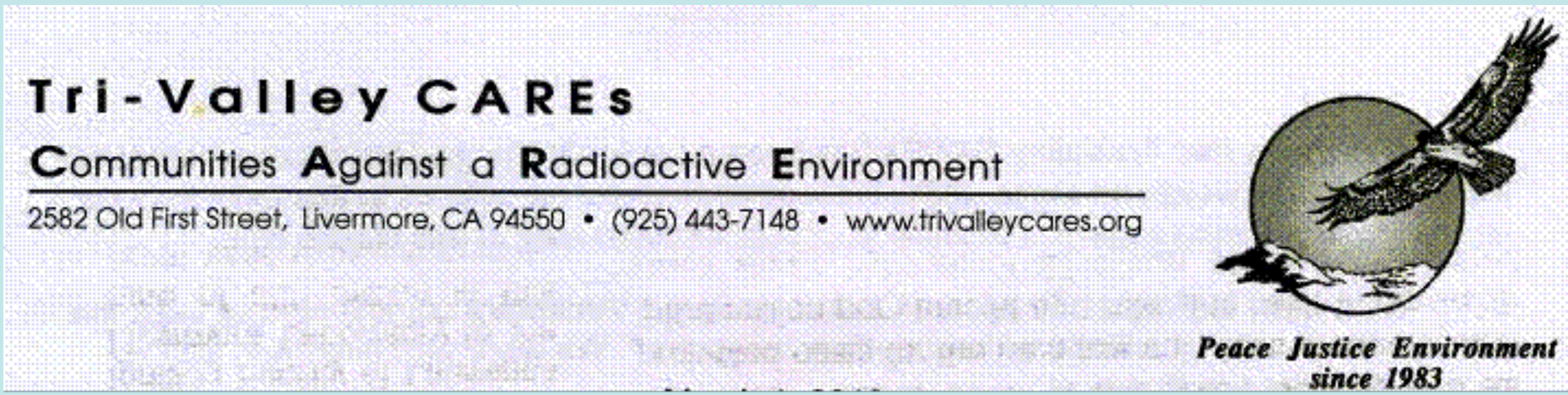
- Can vary considerably from place to place depending on local mineralization, hydrology and geochemistry
- Although typically a few micrograms / liter (a few pCi / liter), U has been measured in public drinking water sources 10 -100 + greater than this
- No permanent health effects have been observed in populations drinking water for generations with these high natural levels

Sources:(1) *Assessing Potential Risks from Exposure to Natural Uranium in Well Water.* Hakonson-Hayes A.C, P.R. Fresqueza,, F.W. Whicker, Journal of Environmental Radioactivity, 59 (2002)
(2) *Public Health Goal for Uranium in Drinking Water.* Office of Environmental Health Hazard Assessment California Environmental Protection Agency, 1997 (3) U.S. Dept. of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Uranium. 1999.*

SENES Consultants

SHB, Inc.

http://www.nma.org/pdf/urw/brown.pdf


Tri-Valley CAREs
Communities Against a Radioactive Environment
2582 Old First Street, Livermore, CA 94550 • (925) 443-7148 • www.trivalleycares.org
Peace Justice Environment
since 1983

Letterhead of anti-nuclear group on the fringe of Lawrence Livermore National Laboratory

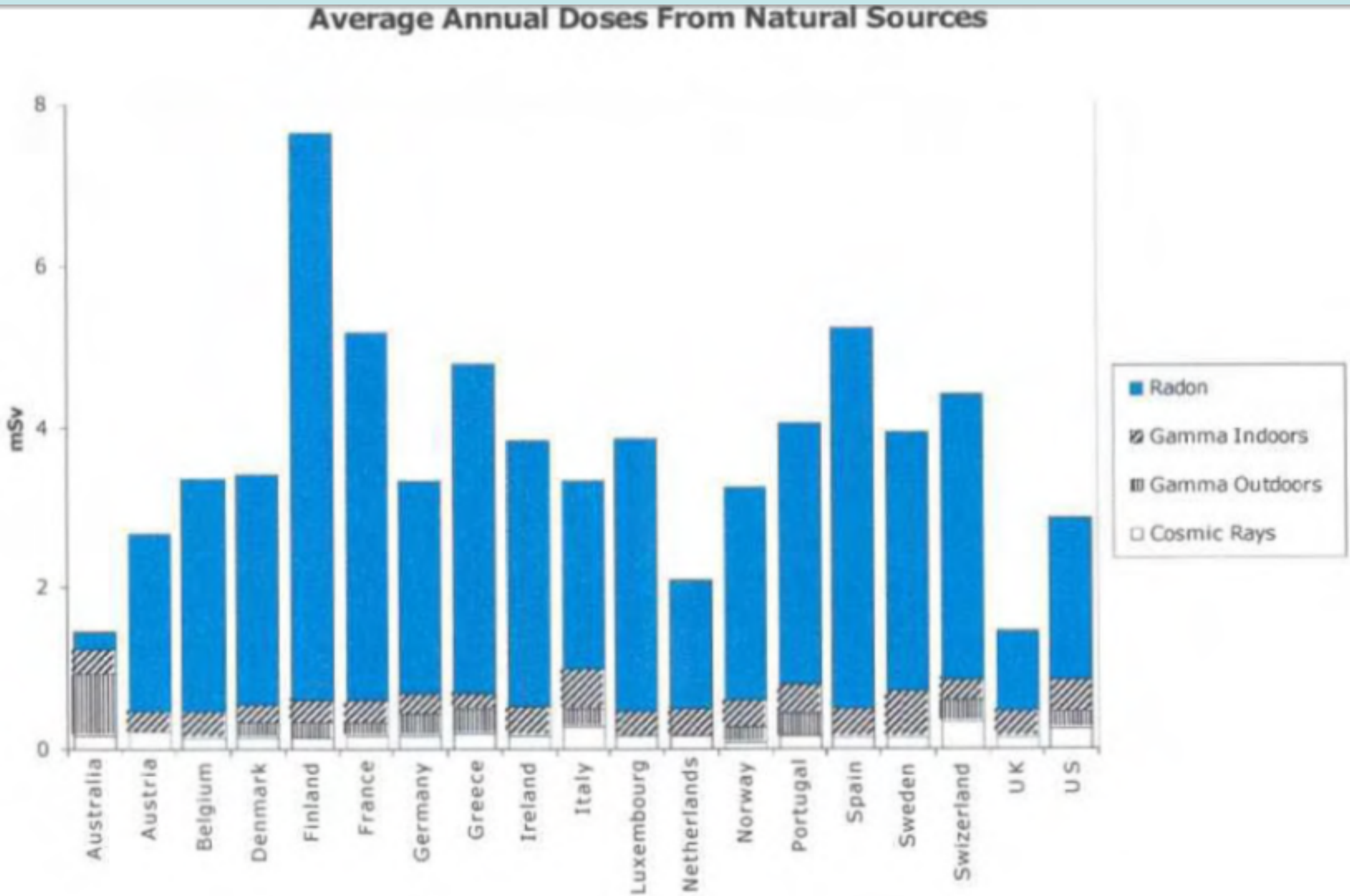


Figure 2-1. A bar graph showing average annual natural radiation doses worldwide. The radiation is measured in mSv and shows the approximate distribution of natural radiation doses from radon, indoor gamma, outdoor gamma and cosmic rays (http://www.uic.com.au/ral.htm).

http://www.clarku.edu/mtafund/prodlib/clark/round6/Ionizing_Radiation.pdf

“Normal” or average v. highest known natural background radiation on Earth

“normal”	Ramsar
Radium in groundwater (Bq/l)	
<10	~500
Radium in soil, rock, food (Bq/g)	
<0.5	~350
Radon inside homes (Bq/l)	
<0.5	>4
Population dose (mSv/yr)	
2-3	20-250

“no consistent detrimental effect has been detected so far”

http://www.ecolo.org/documents/documents_in_english/RamsarHLNRAPaper.doc

Source:
The Very High Background Radiation Areas of Ramsar, Iran: Geology, Radiobiology, and Policy
Andrew Karam, Ph.D., CHP
University of Rochester
Presented to NO CHPS, Radiation Safety Without Borders
November 12, 2002

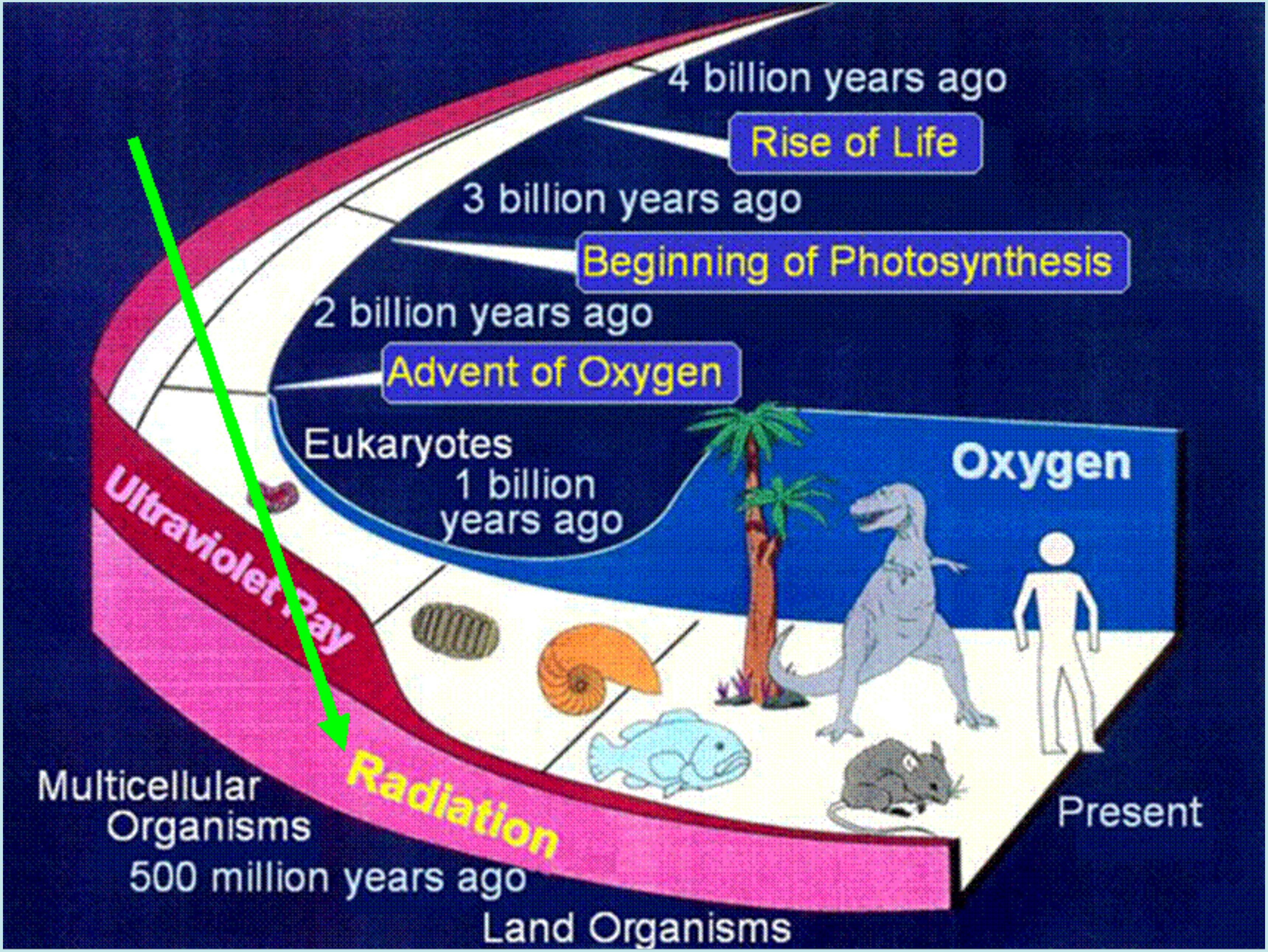
Half lives calculated back into the past result in double lives for radioactive elements,
and an incremental terrestrial background level back into geologic history many times higher than today's levels.

Life evolved under background levels of ionizing radiation much higher than the current range.

Paraphrased from: Gerald L. Looney, 2003 "Radiation Hormesis and the Radiological Imperative"
(http://ecolo.org/documents/documents_in_english/radiation_Looney_03.htm)

When life commenced on Earth around three and a half billion years ago, the natural level of radiation was up to five times higher than today.

Peter A. Parsons, Dose Response. 2006; 4(3): 191–200.
Published online at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2477689/



T.D. LUCKEY, 1982

Decrease in the activity of the earth's crust due do the decay of long-lived radioactive isotopes

Million years ago	Relative decrease in radioactivity			
	U-238	**U-235**	**Th-232**	**K-40**
5000	2.14	128	1.29	14.3
2000	1.35	7.05	1.08	2.82
present	~1	~1	~1	~1

Simplified from L.A. Pertsov, The Natural Radioactivity of the Biosphere, Israel Program for Scientific Translations, Jerusalem, 1967

Passing through the spiral arms of the Milky Way, our Solar System moves periodically through areas of intensive star creation.

In these regions, the intensity of galactic cosmic radiation reaching the Earth is 10 to 100 times* higher than average.

*David S. Smith, Seth Redfield, and John Scalo,
3rd Astrobiology Science Conference, Ames Research Center, 2004 (poster)

Background Radiation and EPA and NRC Regulations

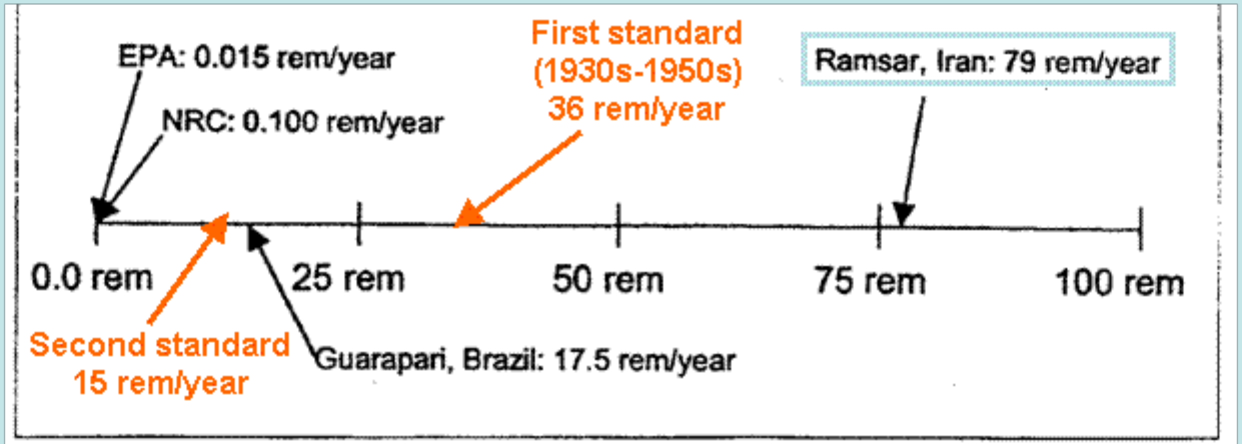


Fig. 2. Scale comparing EPA and NRC regulatory limits to natural background radiation environments (100 rem = 1 sievert; 100 rad = 1 gray)

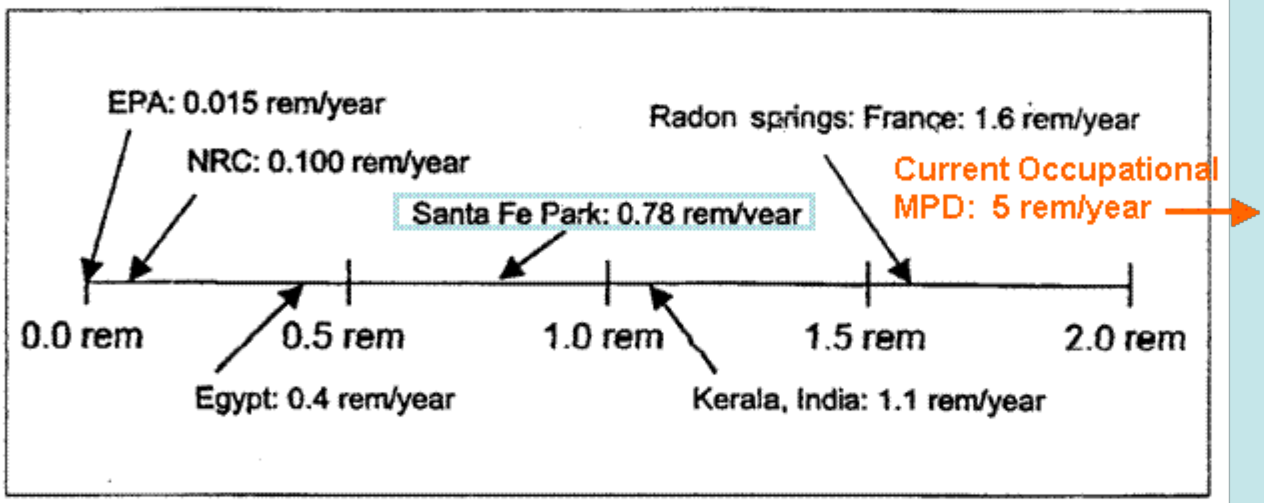
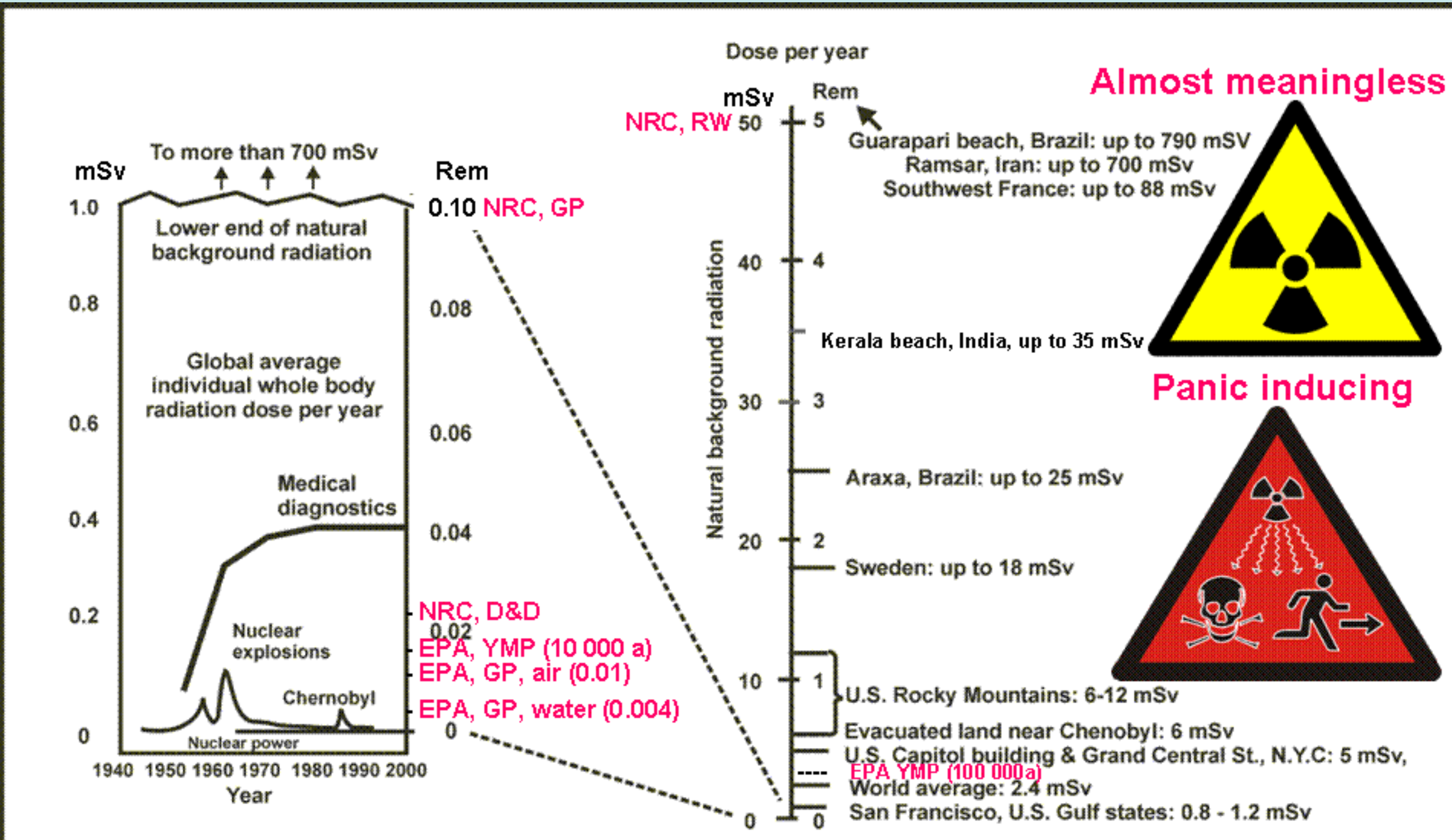


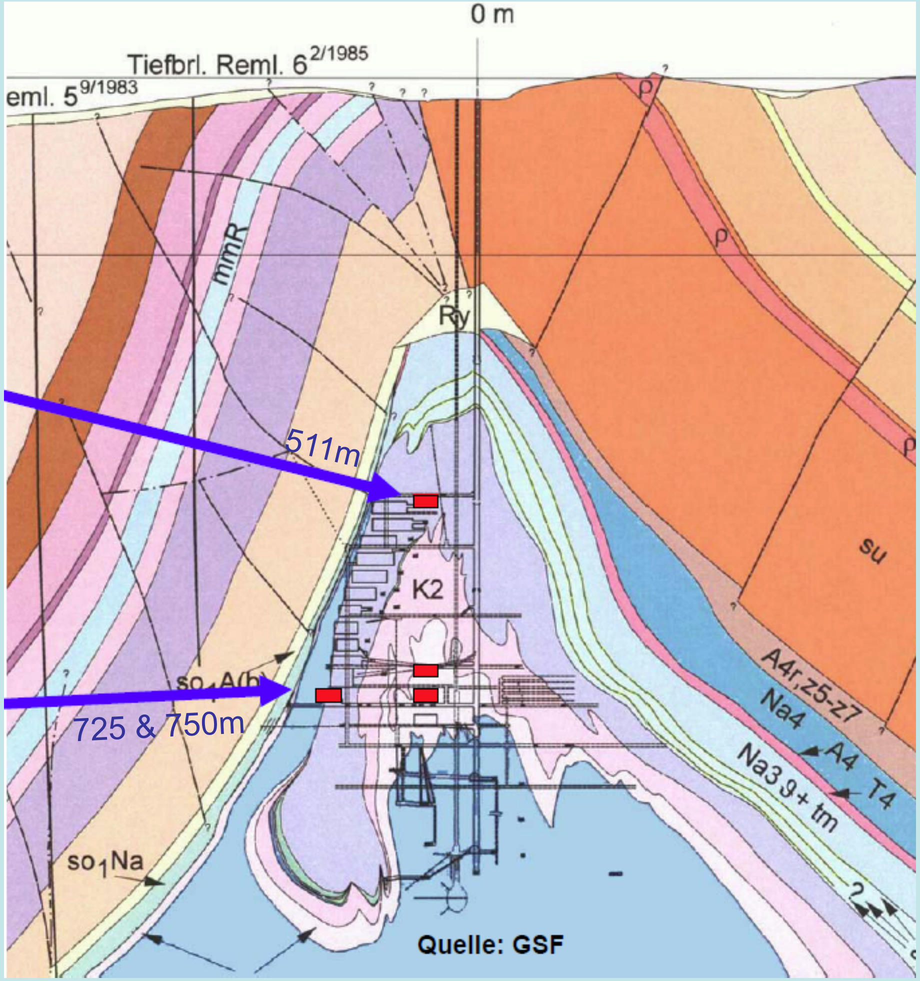
Fig. 3. Expanded scale comparing EPA and NRC regulatory limits to natural background radiation environments (100 rem = 1 sievert; 100 rad = 1 gray)

From Mark M. Hart, "Disabling the terror of radiological dispersal," *Nuclear News* July 2003

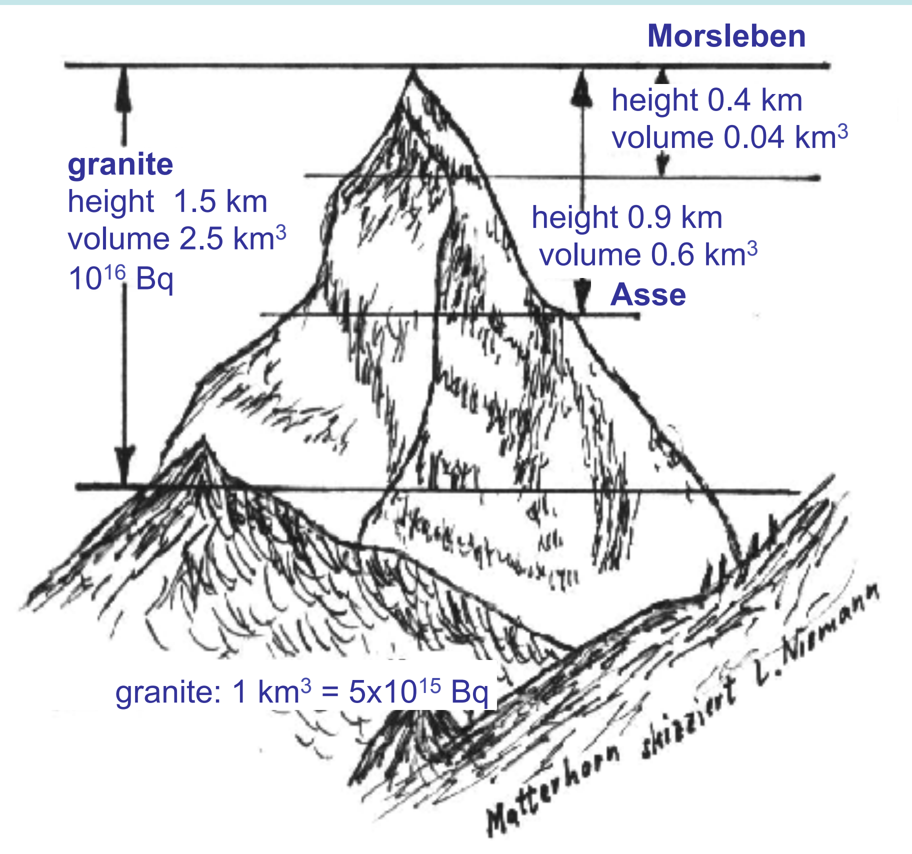


Modified from a
Figure prepared by Ted Rockwell from data found in "Radiation Risk and Ethics", Z. Jaworoski, published in Physics Today, American Institute of Physics, September, 1999 and "Ionizing Radiation and Radioactivity in the 20th Century", Z. Jaworoski, presented at the International Conference on Radiation and its Role in Diagnosis and Treatment", Tehran, Iran October, 2000.

http://www.cns-snc.ca/media/uploads/branch_data/branches/Toronto/radiation/natural_and_human_radiation.html
http://hps.org/publicinformation/ate/faqs/regdoselimits.html
http://dspace.mit.edu/bitstream/handle/1721.1/41588/213482682.pdf?sequence=1



Matterhorn



Asse

If not us, who?

If not now, when?

Mente

et

Malleo

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2. Data, ideas, and conclusions that are extracted may be in error outside the original context or intent.
3. The presenter or provider of this material is not liable for inappropriate or erroneous use of the material or its consequences.
4. None of the material should be assumed to be be original.

Special Note

Norbert T. Rempe prepared this presentation as a private individual, not for profit. This work was *NOT* sponsored by any private organization or government agency.

GEOLOGIC REPOSITORIES AND RADIOACTIVITY: CONSEQUENCES FOR EARTH SCIENCE EDUCATION

Norbert T. Rempe, Carlsbad, NM

Geologic repositories for radioactive waste in rock salt in two countries (Germany and the U.S.) are in trouble. Aside from reasons of purely political expediency and largely unexamined trust in regulatory rationality, their difficulties stem from poor understanding and appreciation of basic scientific data and their interdisciplinary implications.

Most natural sciences address and teach nuclear and radioactive subjects at their margins -if at all- because published, including much academic, opinion presents them as controversial and associated with unique risk. As congenitally multidisciplinary scientists and educators, earth scientists are quite well suited to elevate nuclear and radioactive matters to their proper position as the fundamental and integrative cement between the earth and related natural sciences.

Progress in energy and mineral production, as well as in safe and environmentally sound waste treatment and management depends on such comprehensive and rational approach.

modified from Bjorn Lomborg's book title

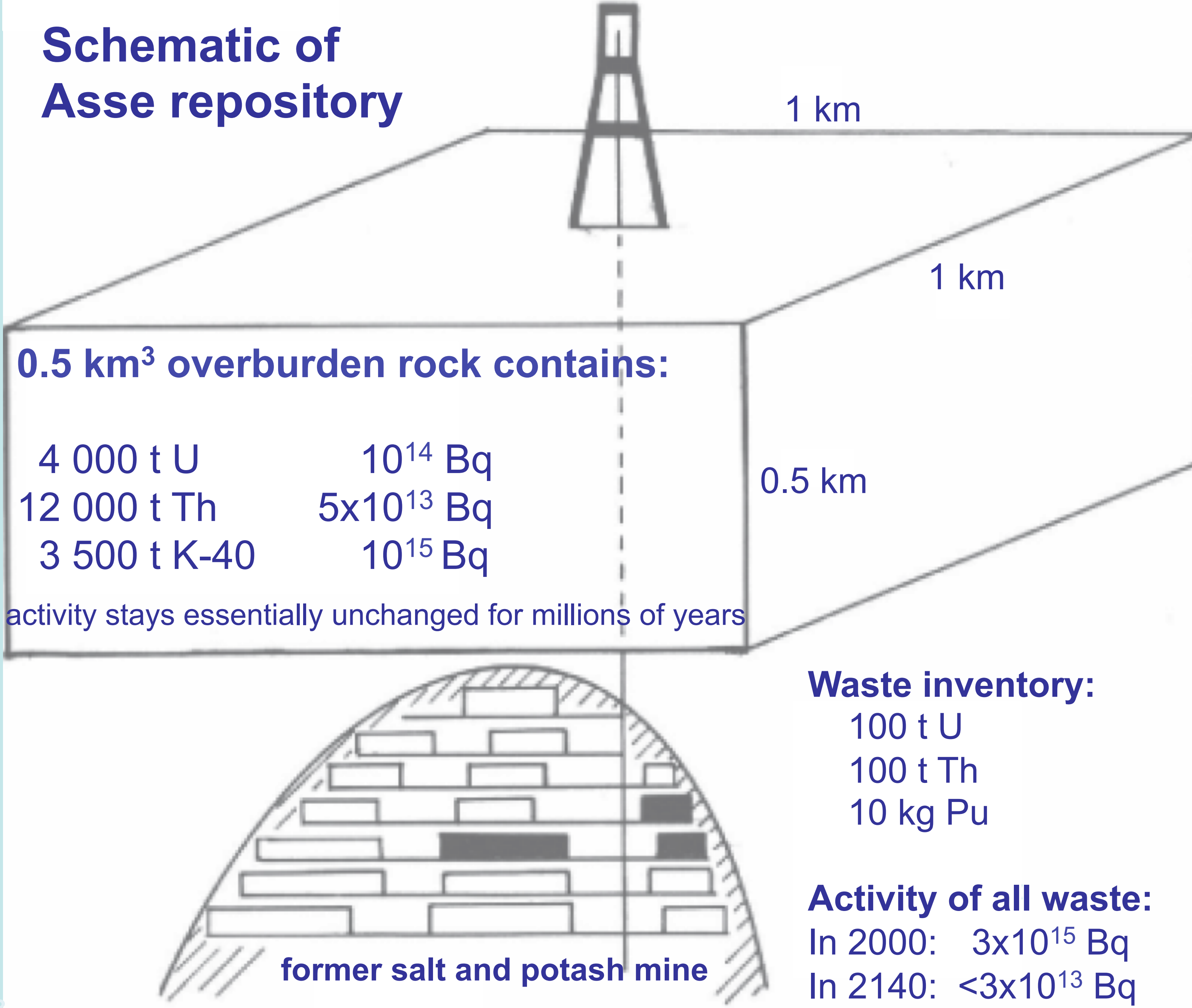
Sacred Cow #1

Ionizing radiation is mostly unnatural and unusual, and always dangerous

Geology isn't a real science

Sheldon Cooper, Ph.D. (fictional theoretical physicist in TV series "The Big Bang Theory")

Schematic of Asse repository



Waste inventory:

100 t U
100 t Th
10 kg Pu

Activity of all waste:

In 2000: 3×10^{15} Bq
In 2140: $<3 \times 10^{13}$ Bq

translated from: http://www.novo-argumente.com/artikel/99/novo9943.pdf

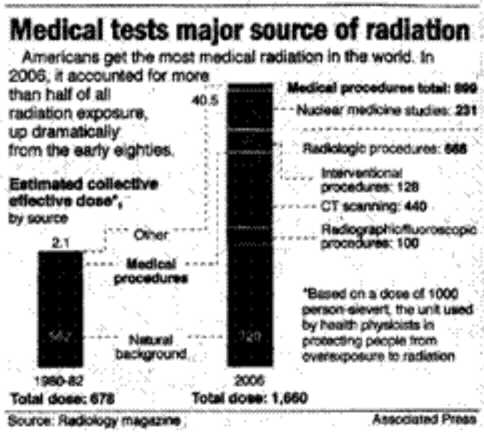
Americans get most radiation in the world

By Marilynn Marchione
ASSOCIATED PRESS

We fret about airport scanners, power lines, cell phones and even microwaves. It's true that we get too much radiation. But it's not from those sources — it's from too many medical tests.

Americans get the most medical radiation in the world, even more than folks in other rich countries. The U.S. accounts for half of the most advanced procedures that use radiation, and the average American's dose has grown sixfold over the last couple of decades.

Too much radiation raises the risk of cancer. That risk is growing because people in everyday



...diation dose could be cut by two-thirds with no loss of quality.

What should patients do?

"You should question everything — what's the dose, why am I getting it? You should be an informed consumer," said Dr. Fred Mettler, radiology chief in the New Mexico Veterans Administration health care system. He led a study of health effects after the Chernobyl accident and is a U.S. representative to the United Nations on radiation safety.

He advised challenging "big ticket" tests like CT scans that deliver a lot of radiation to the chest and abdomen — places where cancer is likely to develop. "You shouldn't get too excited about feet and knee X-rays," Mettler said.

HEALTH & WELLNESS

Medical Radiation Is a Growing Concern

Associated Press

0.005 for a dental X-ray. Natural

MARKET TUMULT

The Euro Turns Radioactive

Trading-Firm Breakdowns Accompanied

2005

ISBN 0-930073-35-5

UNDER-EXPOSED

What If Radiation Is Actually GOOD for You?

by Ed Hiserodt

Laissez Faire Books
a division of the Center for Libertarian Thought, Inc.
LITTLE ROCK, ARKANSAS

Radiation-driven Ecosystems

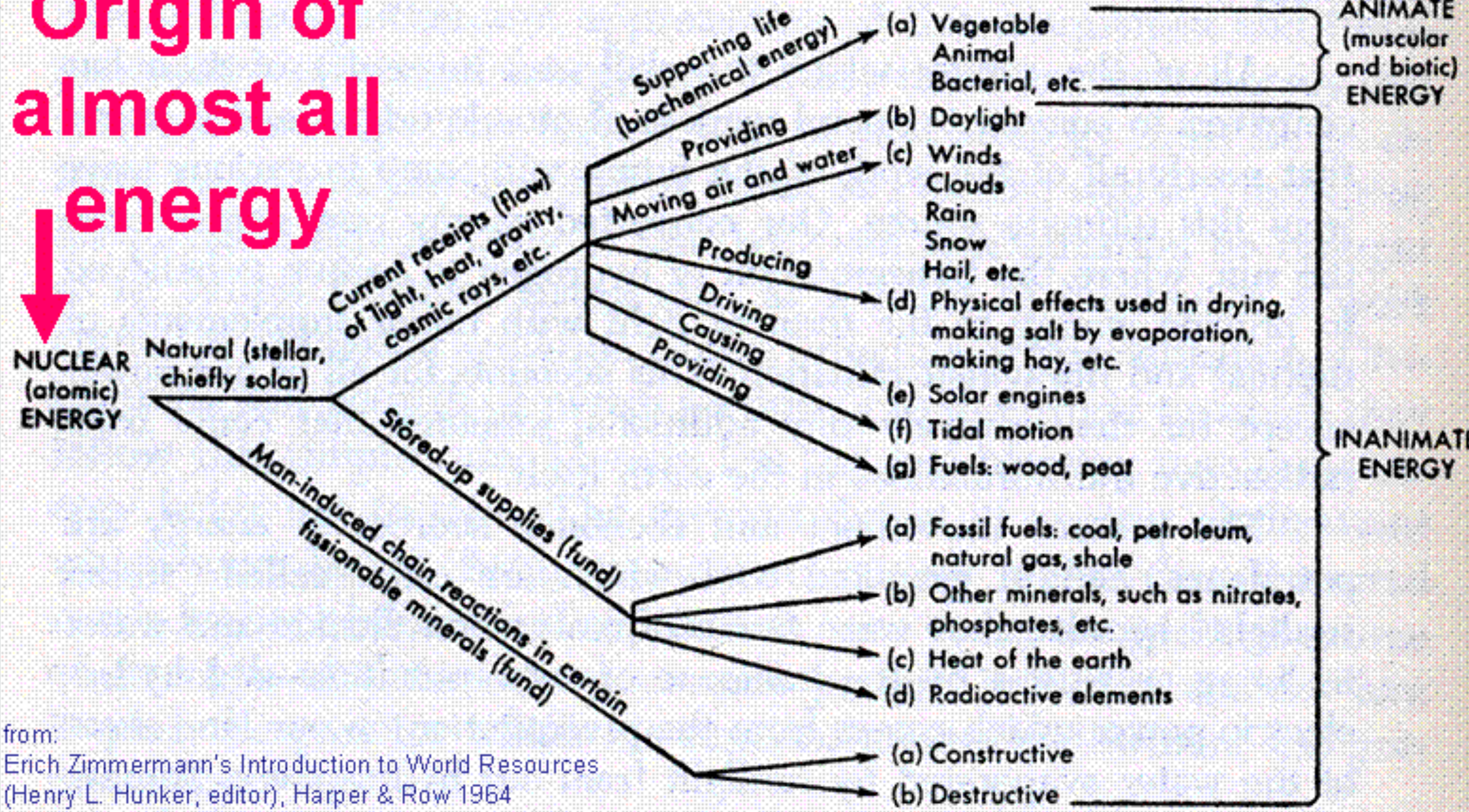
Fusion is the process that takes place in stars like our Sun. Whenever we feel the warmth of the Sun and see by its light, we are observing the products of fusion. We know that all life on Earth exists because the light generated by the Sun produces food and warms our planet. Therefore, we can say that **fusion is the basis for our life**

http://www.lbl.gov/abc/Basic.html

…virtually all of the energy we use originates in the power of the atom. Nuclear reactions energize stars, including our Sun. **The energy we capture for use on Earth comes largely from the Sun or from nuclear forces local to our own planet**.

http://needtoknow.nas.edu/energy/energy-sources/the-sun.php

Origin of almost all energy



from:
Erich Zimmermann's Introduction to World Resources
(Henry L. Hunker, editor), Harper & Row 1964

Natural Radioactivity by the Square Mile, 1 Foot Deep

Total volume: 7.894 x 10^5 m^3. Activity levels vary greatly depending on soil type, mineral make-up, and density (~1.58 g/cm^3 is the basis of this calculation).

Nuclide	Activity used in calculation	Nuclide mass	Activity found in soil volume
U	0.7 pCi/g (25 Bq/kg)	2,200 kg	0.8 curies (31 GBq)
Th	1.1 pCi/g (40 Bq/kg)	12,000 kg	1.4 curies (52 GBq)
K 40	11 pCi/g (400 Bq/kg)	2000 kg	13 curies (500 GBq)
Ra	1.3 pCi/g (48 Bq/kg)	1.7 g	1.7 curies (63 GBq)
Rn	0.17 pCi/g (10 kBq/m^3) soil	11 µg	0.2 curies (7.4 GBq)
		Total:	>17 curies (>653 GBq)

http://www.physics.isu.edu/radinf/natural.htm

Romantics might like to think of themselves as being composed of stardust.

Cynics might prefer to think of themselves as nuclear waste.

Simon Singh, Big Bang: The Origin of the Universe, p. 389 (Fourth Estate 2004)

83% of present surface heat flow is due to radioactive decay of U, Th, and K

http://www.und.edu/org/ihfc/Gosnold_AAPG07.ppt#316,18,Global Heat Flow

Geothermal energy is the ethical energy source for the future

http://www.heatflow.und.edu/Gosnold2Geothermal.ppt#263,1,Geothermal Energy is the Ethical Energy Source for the Future

Paul K. Kuroda, 1917-2001

Paul Kazuo Kuroda
1917-2001

- Was inspired by Francis W. Aston lecture
  on mass spectra and isotopes 1936
  and Niels Bohr's lectures at Tokyo University 1937

- Emigrated from Japan 1949; became US citizen 1955

- Taught chemistry, U. of AR 1952-1987

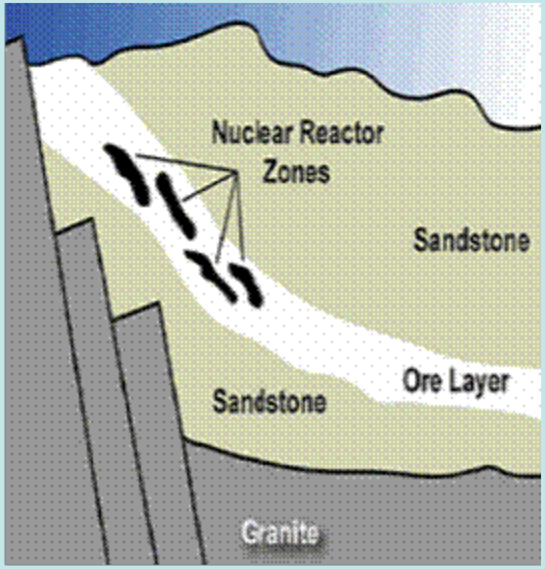
- Published theory of Pre-Fermi natural reactor in
  Journal of Chemical Physics, v. 25. p. 781 (1956)
  (Oklo discovery 1972)

*"99 out of 100 graduate students are neither smart enough
nor truly motivated to become good scientists.
I clearly belonged to that group."*

Nigeria
CAMEROON
Gulf of Guinea
EQUITORIAL GUINEA
LIBREVILLE
Gabon
CONGO
Lambaréné
Oklo
ATLANTIC OCEAN
ANGOLA

Oklo Nuclear Geysers (16 individual reactors)

- Operated 1.8 billion years ago,
  - for >150 000 years,
  - in 30-min pulses with 2.5 hr dormant periods,
  - consuming >5t U.
- **Prove nuclear fission is natural.**
- **Suggest other natural reactors waiting to be found.**



Established 1845 **SCIENTIFIC AMERICAN** July 1976 Volume 235 Number 1

ARTICLES

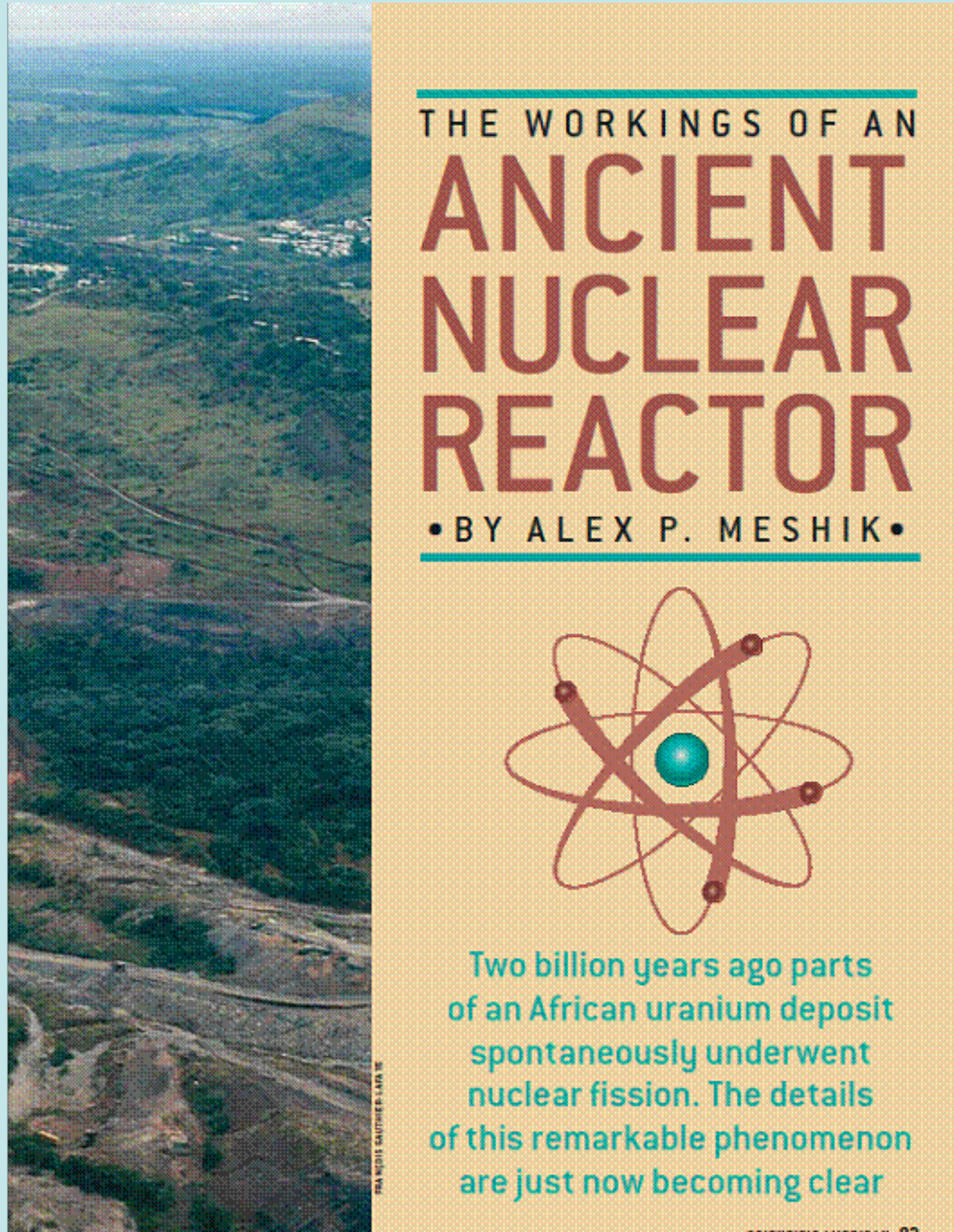
GEORGE A. COWAN ("A Natural Fission Reactor") heads the nuclear-chemistry division of the Los Alamos Scientific Laboratory. He writes: "I became involved with

based on the study of nuclear explosions. I am just now greatly intrigued by the information that can be obtained from a fossil reactor, particularly by the possibility that the Oklo investigation will demonstrate an acceptably safe pattern for the permanent disposal of plutonium."

"In the design of fission reactors man was not an innovator but an unwitting imitator of nature"

"I (first) thought it was a phony" (Los Alamos Monitor, July 14, 2002)

November 2005



THE WORKINGS OF AN

ANCIENT NUCLEAR REACTOR

• BY ALEX P. MESHIK •

Two billion years ago parts of an African uranium deposit spontaneously underwent nuclear fission. The details of this remarkable phenomenon are just now becoming clear

earliest known repository for radioactive waste

pre-Fermi (*natural*) reactors

Oklo

Gabon

- Oklo is a worst-case analogue:
  - Rocks were jointed and fractured
  - Permeabilities waxed and waned
  - The ore went critical, enduring fission and high temperatures
  - Confinement remained effective without engineered barriers or carefully designed waste forms
  - Fission products were available for migration for billions of years
- Conclusion: geologic repositories did, do, and will confine radionuclides

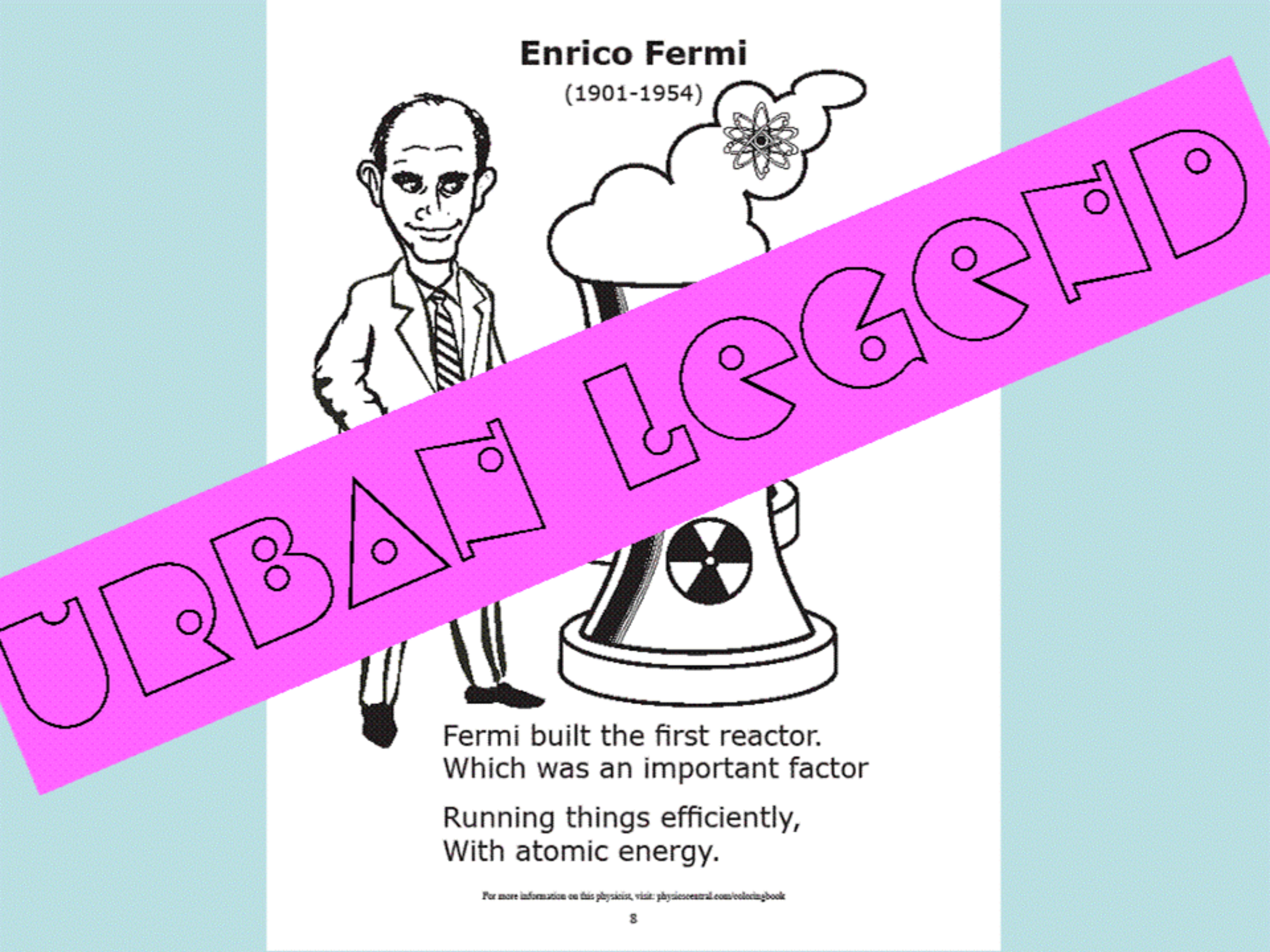
(even without human assistance or Yankee ingenuity)

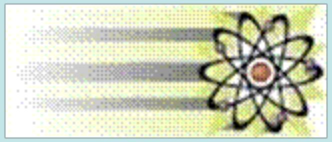
Nature solved the radioactive waste "problem" 2 billion years ago.

Any state is a "nuclear" state.

An educated "anti-nuclear" person is an oxymoron.

William C. Clark, 1980: "Neither the witch hunting hysterics nor the mindlessly rigid regulations characterizing so much of our present chapter in the history of risk management say much for our ability to learn from the past"


Enrico Fermi
(1901-1954)
URBAN LEGEND
Fermi built the first reactor.
Which was an important factor
Running things efficiently,
With atomic energy.
For more information on this physicist, visit: physicscentral.com/coloringbook
8



Radiation and Life

- Life evolved in a radiation field (“vitamin-R”) that was much more intense than today:
  - Higher Concentration of Radioactive Elements
  - Natural Reactors
- Natural background radiation levels on Earth vary by at least two orders of magnitude.

after S. M. J. Mortazavi, 2006, at:
http://www.ecolo.org/documents/documents_in_english/ramsarMORTAZAVI-HLR-06.ppt

Background Radiation Exposure

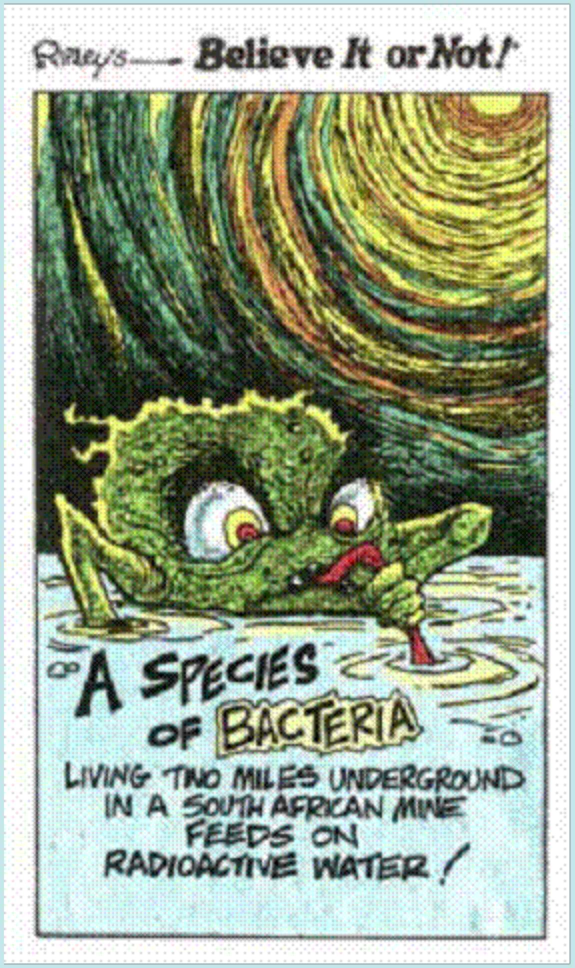
- US average: 3.6 mSv y^{-1}
  Worldwide average: 2.4 mSv y^{-1}
- Recommended max. dose for radiation workers: 20 mSv y^{-1}
  Goal for members of the public: <1 mSv y^{-1}
- Inhabitants of Ramsar, Iran: 240 mSv y^{-1}
- Exposure of people in Ramsar is >200 times the recommended maximum goal

The lack of ill effects from receiving this dose cannot be reconciled with current radiation protection standards

Modified from: http://www.ecolo.org/documents/documents_in_english/ramsar-Monfared-HLR-06.ppt#257,2,Introduction

“Microbes from Hell’s Zip Code”

S. African gold mine & Nevada Test Site



Water plus rock plus radiation can sustain life for millennia

Radiation may keep life going, thriving, and evolving

Tullis Onstott, Princeton

(Hometown: Carlsbad, NM)

http://www.cemp.dri.edu/cemp/workshop2009/presentations/Moser-Deep_Earth_Life.pdf

Current clean-up cost for US/DOE facilities is estimated at $350 billion for EPA standard of 15 mrem above background

(15 mrem is <5% of average natural background in USA)

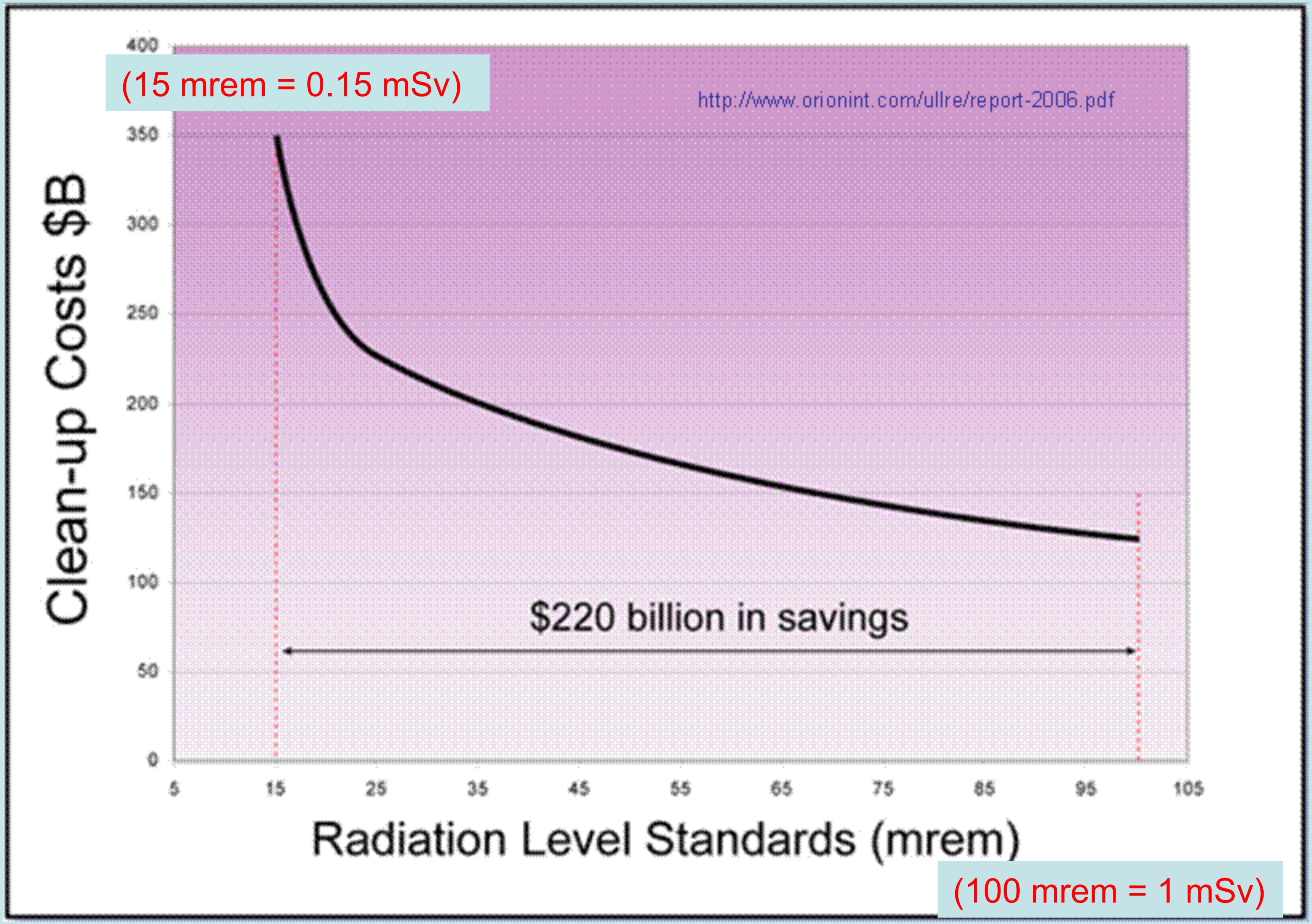
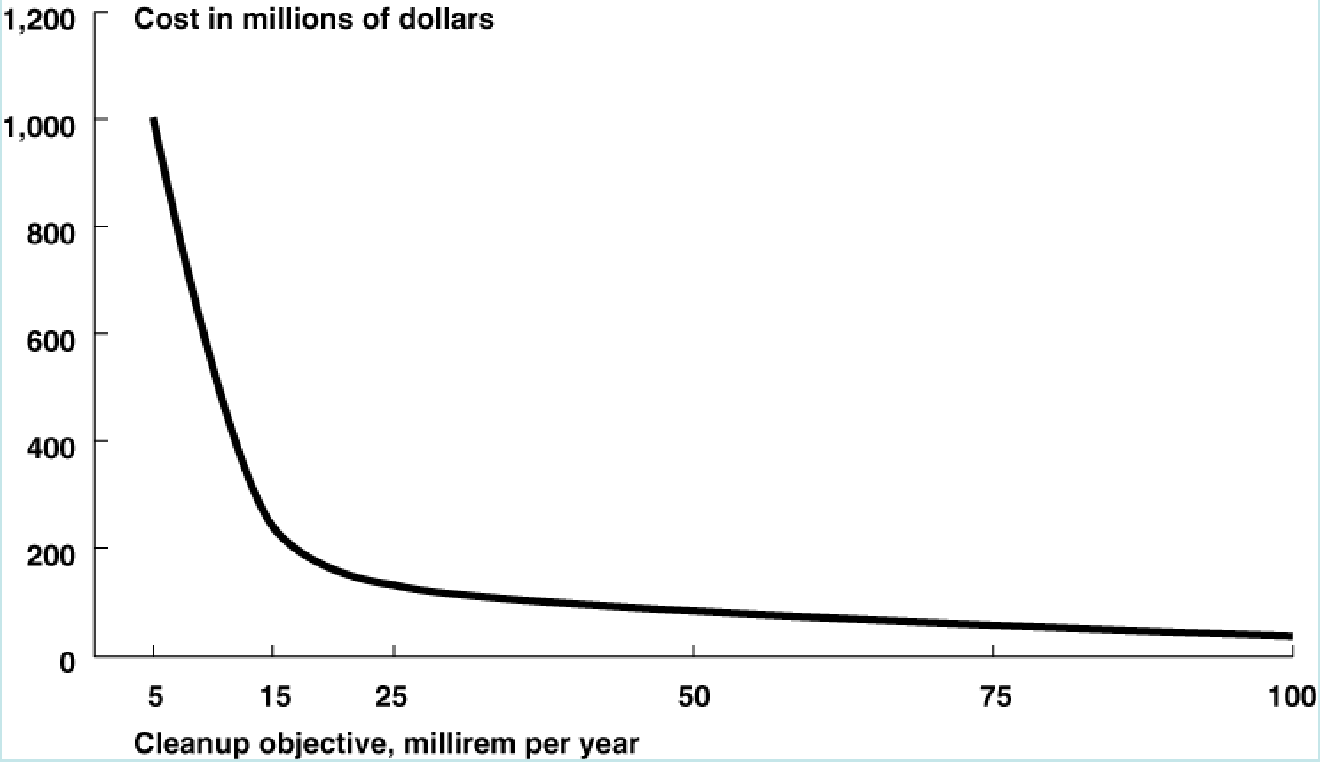


Figure 1: Cleanup Costs As A Function of Cleanup Levels—Nevada Test Site Analysis, 1995



GAO/T-RCED-00-252

http://www.philrutherford.com/Radiation_Risk/GAO_252_testimony.pdf

In radiation protection one ounce of gray matter outweighs one ton of lead

(F. Wachsmann, 1969)

http://www.manmed.de/seiten/themen/veranstaltungen/kongresse/hannover/Strahlenschutz%20-%20Sinn%20und%20Unsinn-Roth.pdf

Death by Regulation: The Need for a Scientific Standard

Society for

Humane

Abolition of

Regulations that

Kill

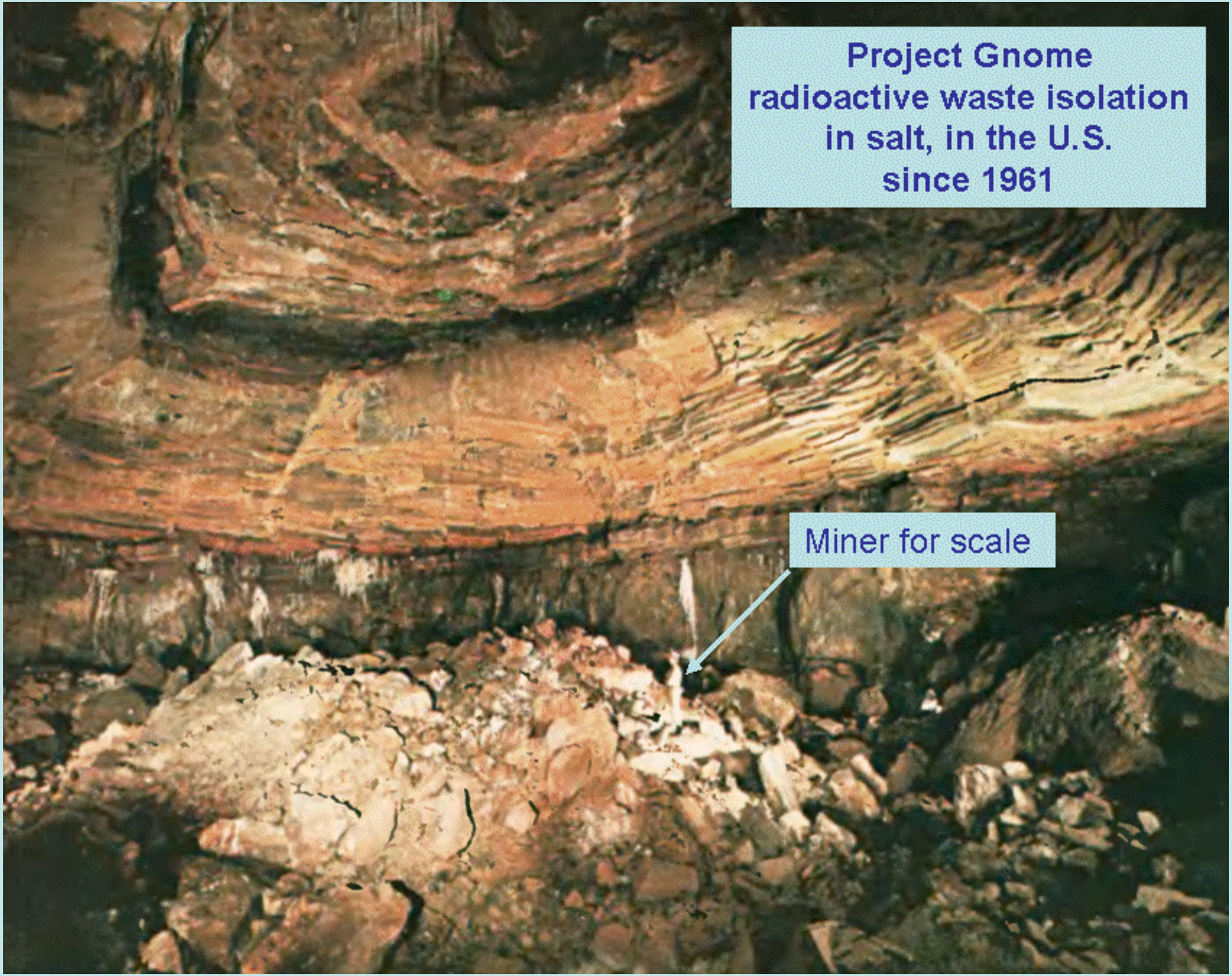
Jay H. Lehr, Science Director, The Heartland Institute, 2002

20th Annual Meeting of Doctors for Disaster Preparedness, Colorado Springs, CO

Insistence on, and
cadaverous compliance with,
regulations without continuously
questioning and justifying
their factual and rational basis

is the last refuge of
the lazy, incompetent, and
malevolent

ng(o)3


Project Gnome
radioactive waste isolation
in salt, in the U.S.
since 1961
Miner for scale

Natural background radiation: 3 mSv/y. (range: 1-10 mSv/y.)

20 *Int. J. Low Radiation, Vol. 2, Nos. 1/2, 2006*

Cancer incidence in areas with elevated levels of natural radiation[1]

S.M.J. Mortazavi* **Senior author: A. Niroomand-Rad**

National Radiation Protection Department (NRPD),
Iranian Nuclear Regulatory Authority (INRA),
PO Box 14155-4494, Tehran, Iran

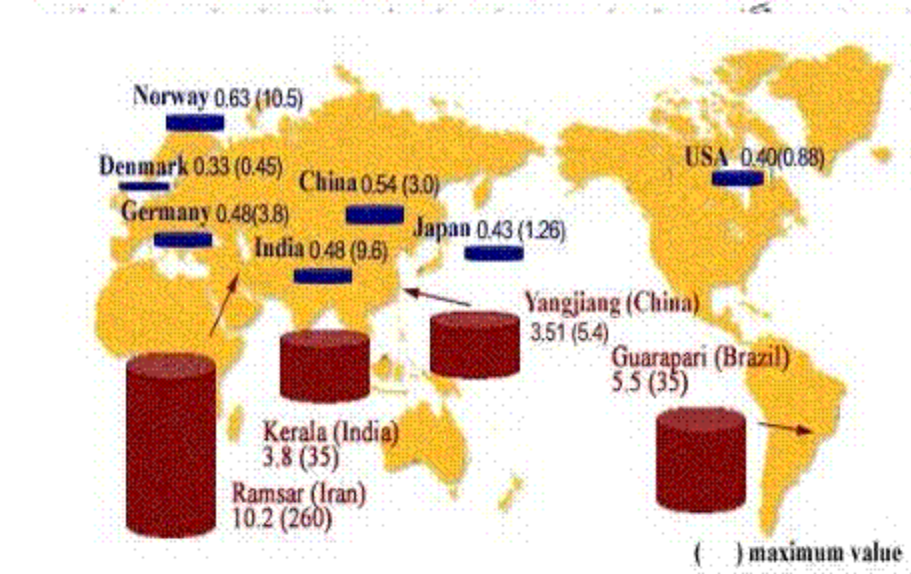
Natural background radiation levels
"… in Ramsar are approximately 55-200 times higher than that of the global average rate." (typ. 260 mSv/y.)
"… no increased level of chromosome aberrations.
… It can be concluded that prolonged exposure … decreases the frequency of chromosome aberration and the cancer incidence rate."

Annual terrestrial radiation doses in the world

http://www.taishitsu.or.jp/radiation/

Area	mean (mGy/year)	maximum (mGy/year)
Ramsar, Iran	10.2	(260)
Guarapari, Brazil	5.5	(35)
Kerala, India	3.8	(35)
Yangjiang, China	3.51	(5.4)
Hong Kong, China	0.67	(1.00)
Norway	0.63	(10.5)
France	0.60	(2.20)
China	0.54	(3.0)
Italy	0.50	(4.38)
World average	0.50	
India	0.48	(9.6)
Germany	0.48	(3.8)
Japan	0.43	(1.26)
USA	0.40	(0.88)
Austria	0.37	(1.34)
Ireland	0.36	(1.58)
Denmark	0.33	(0.45)

Ramsar


Norway 0.63 (10.5)
Denmark 0.33 (0.45)
China 0.54 (3.0)
Germany 0.48(3.8)
Japan 0.43 (1.26)
India 0.48 (9.6)
USA 0.40(0.88)
Yangjiang (China)
3.51 (5.4)
Guarapari (Brazil)
5.5 (35)
Kerala (India)
3.8 (35)
Ramsar (Iran)
10.2 (260)
( ) maximum value

Annual Background Radiation Exposure vs. Annual Public Exposure Limits: U Mines and Mills

- Background Levels (from previous slide)
  - > Colorado average = 400 mrem
  - > Leadville, Colorado = 526 mrem
  - > U.S. average = 310 mrem
- Regulatory Limits
  - > EPA drinking water standard = 4 mrem[1]
  - > EPA limit for all exposure pathways = 25 mrem[2]
  - > NRC Limit with radon = 100 mrem; excluding radon = 25 mrem[3]

[1] U.S. Environmental Protection Agency. Radionuclides in drinking water. Available at: http://www.epa.gov/safewater/radionuclides/index.html.

[2] U.S. Environmental Protection Agency. Environmental radiation protection for nuclear power operations, 40 CFR 190.10; 2006.

[3] U.S. Nuclear Regulatory Commission; Domestic Licensing of Source Material ; 10 CFR 40

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http://www.nma.org/pdf/urw/brown.pdf

Radiation Background in Kerala India

- Unusually high natural radiation background has been known for many years due to natural thorium in the monazite sands of the region
- Annual outdoor exposure levels as high as 7000 mrem have been measured where people live
- Recent epidemiological studies have concluded no excess cancers in over 69,000 residents studied for 10 years[1]

[1] R Naire, B Rajan, et al; Background radiation and cancer incidence in Kerala,India—Karunagappally cohort study; Health Physics, 96,1, January, 2008

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How Common are Uranium and its Daughter Products[1] in Nature?[2]

- Typical concentration in soil and rocks (pCi*/gram):
  - > Uranium = 0.6 – 3.0
  - > Uranium in phosphate rock used for fertilizers = 40 – 80
  - > Radium = 0.4 – 3.6
  - > Thorium = 0.2 – 2.2

[1] Daughter products = those chemical elements that uranium decays into as a result of its radioactive properties. Thorium and radium are also radioactive.

[2] Sources: (1) National Council on Radiation Protection and Measurements. Natural background radiation in the United States. Washington, DC: National Council on Radiation Protection and Measurements; NCRP Report No. 45; 1975. (2) National Council on Radiation Protection and Measurements. Exposure of the population in the United States and Canada from natural background radiation. Bethesda, MD: National Council on Radiation Protection and Measurements; NCRP Report No. 94; 1992 (updates and supersedes NCRP Report No. 45).

*pCi = picocurie, one-trillionth of a curie, the amount of radioactivity where approximately two atoms decay per minute. Picocurie is a measure of the amount of radioactivity.

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Example Conclusions from Studies on Health Impacts on Populations Living Near Uranium Mines and Mills

" The absence of elevated mortality rates of cancer in Montrose County over a period of 51 years suggests that the historical milling and mining operations did not adversely affect the health of Montrose County residents."[1]

"No unusual patterns of cancer mortality could be seen in Karnes County over a period of 50 years suggesting that the uranium mining and milling operation had not increased cancer rates among residents."[2]

[1] *Cancer and Noncancer Mortality in Populations Living Near Uranium and Vanadium Mining and Milling Operations in Montrose County, Colorado, 1950 -2000.* Boice, JD, Mumma, MT et al. Journal of Radiation Research, 167:711-726; 2007

[2] *Mortality in a Texas County with Prior Uranium Mining and Milling Activities, 1950 – 2001.* Boice, JD, Mumma, M et al. Journal of Radiological Protection, 23:247 – 262; 2003

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Some Final Thoughts # 2

The goal of science is the gradual removal of prejudices; which is belief in the absence of evidence

- Niels Bohr

- *Atomic physics and human knowledge*. John Wiley 1958 p 31

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The verbatim quote:

It is, indeed, perhaps the greatest prospect of humanistic studies to contribute through an increasing knowledge of the history of cultural development to that gradual removal of prejudices which is the common aim of all science.

Niels Bohr, *Atomic Physics and Human Knowledge* (1958).

Radioactive Earth History and Its Implications for Current Issues

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Historical and local variations in the radioactivity of geologic materials and in the natural background levels of ionizing radiation in geologic environments are not widely or sufficiently appreciated.

Background radiation levels much higher than today's natural average likely played a role in early organic evolution and may do so again. U-235/U-238 ratios in Precambrian uranium ores were high enough that some fission reactors operated spontaneously long before Hahn, Meitner, Strassmann, und Fermi. Little to no dispersal of fission products from such reactors and from uranium deposits in general demonstrates geologic isolation of radioactive waste to be a reasonable practical solution.

Ignorance and insufficient acknowledgement of the "marriage between geology and radioactivity" (G. Kirsch, 1928) breed irrational fear and opposition to anything nuclear or radioactive. An antinuclear geologist should therefore be an oxymoron.

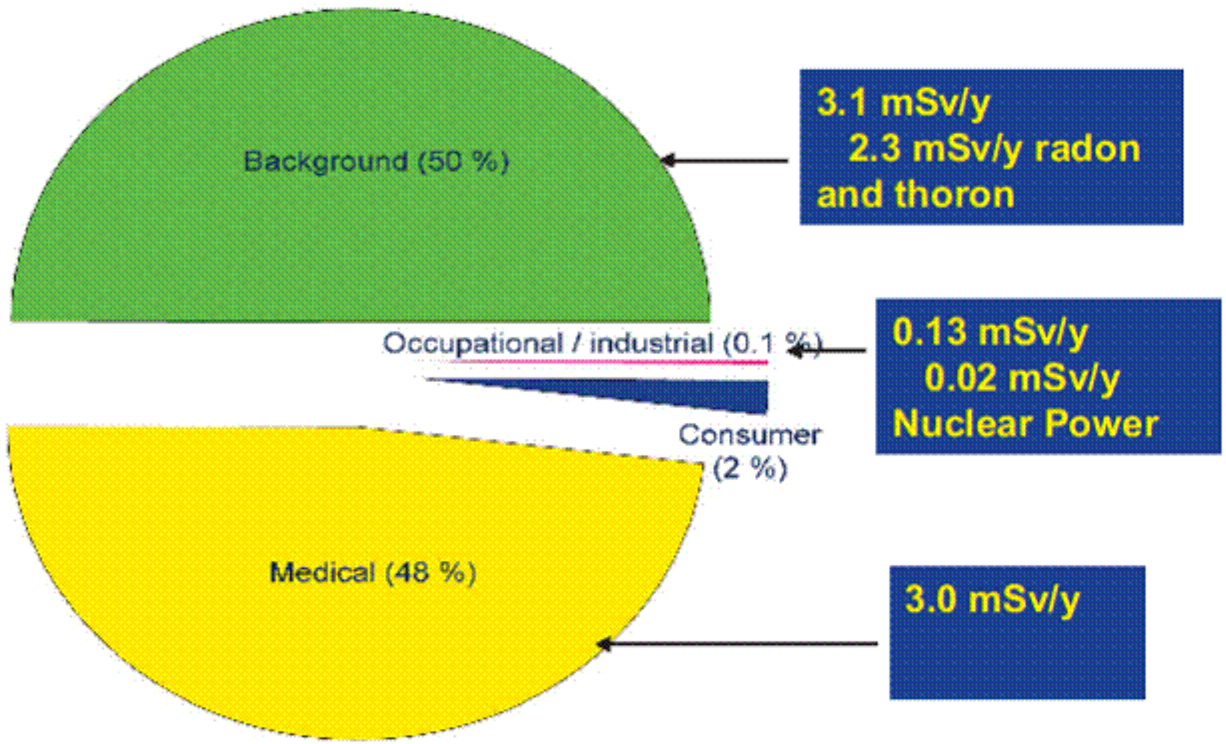
Natural Radioactivity by the Square Mile, 1 Foot Deep

Total volume: 7.894×10^5 m^3. Activity levels vary greatly depending on soil type, mineral make-up, and density (~1.58 g/cm^3 is the basis of this calculation).

Nuclide	Activity used in calculation	Nuclide mass	Activity found in soil volume
U	0.7 pCi/g (25 Bq/kg)	2,200 kg	0.8 curies (31 GBq)
Th	1.1 pCi/g (40 Bq/kg)	12,000 kg	1.4 curies (52 GBq)
K 40	11 pCi/g (400 Bq/kg)	2000 kg	13 curies (500 GBq)
Ra	1.3 pCi/g (48 Bq/kg)	1.7 g	1.7 curies (63 GBq)
Rn	0.17 pCi/g (10 kBq/m^3) soil	11 µg	0.2 curies (7.4 GBq)
		Total:	>17 curies (>653 GBq)

http://www.physics.isu.edu/radinf/natural.htm

2006



NCRP 160 Ionizing Radiation Exposure of the Population of the United States

http://brc.gov/Disposal_SC/docs/Frank%20Parker%20-%20disposal%20subcommittee%20office%20july%207,%202010%20final.pdf

Dose Perspectives

100,000 mrem – Dose leading to ~5% chance of Fatal Cancer (UNSCEAR)

10,000 mrem/yr – IAEA mandatory intervention

5,000 mrem/yr – Worker dose standard

1,000 mrem/yr – IAEA reference level for intervention for cleanup situations

360 mrem/yr – US Average dose all sources (NCRP)

100 mrem/yr – All sources limit (IAEA practices, DOE)

25 mrem/yr – NRC and DOE LLW

15 mrem/yr – EPA Radiation (40 CFR 191)

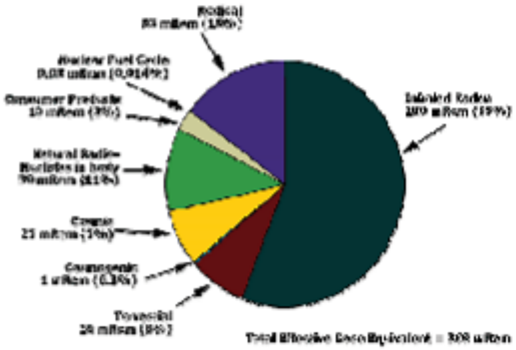
10 mrem/yr – Air (atmospheric) (40 CFR 61)

4 mrem/yr – Drinking Water (40 CFR 141)

1 mrem/yr – IAEA Exemption/Clearance

Note: Air crew average (300 mrem/yr)
From UNSCEAR (2000)

Typical Annual Sources of Public Exposure



Graphics from NCRP Report No. 93

http://www.cresp.org/PACOP/Presentations/Day%201%20July%2013%202009/02_LETOURNEAU_Marty%20slc%20final.pdf

Table 1: Estimated Costs to Achieve Different Soil Cleanup Levels at Selected DOE Sites and Generic NRC-Licensed Sites

Dollars in millions

Agency/site/ analysis date	Cost of 100 millirem a year	Cost of 25 millirem a year	Cost of 15 millirem a year	Cost of less than 10 millirem a year
DOE/Nevada Test Site and test ranges/1995	35	131	240	1,003[a]
DOE/Brookhaven Laboratory waste facility/1998	15.9	24.4	28.2	64.5[b]
NRC-licensed power plant[c] /1997	0.17	0.31	0.41	1.44[d]
NRC-licensed metal extraction facility[c]/1997	5.30	6.21	7.33	13.86[d]

Note: Totals do not represent overall estimates of cleanup costs, which may include costs for activities other than soil cleanup, including the decontamination and removal of equipment and structures, as well as liquid waste treatment.

[a]5 millirem a year.

[b]1 millirem a year. Totals are present values.

[c]Generic site.

[d]3 millirem a year.

Source: GAO's presentation of data from DOE and NRC.

http://www.gao.gov/new.items/rc00152.pdf

Major U.S. Radiation Standards

Standard/agency	Numerical limit
General standards	
General public/NRC (10 C.F.R. 20)	100 millirem/year
Source-specific standards	
Uranium mill tailings/EPA, NRC (40 C.F.R. 192; 10 C.F.R. 40, App. A)	Radium 226, 228: 5 picocuries/gram surface, 15 picocuries/gram subsurface Radon 222: 20 picocuries/square-meter-second[a]
High-level waste operations/NRC (10 C.F.R. 60)	100 millirem/year
Spent fuel, high-level waste, transuranic waste disposal/EPA (10 C.F.R. 191)	All pathway: 15 millirem/year Groundwater 4 millirem/year[b]
Yucca Mountain high-level waste (proposed)/EPA (64 Fed. Reg. 46976)	All pathway: 15 millirem/year Groundwater 4 millirem/year[b]
Yucca Mountain high-level waste (proposed)/NRC (64 Fed. Reg. 8640)	25 millirem/year all pathway
Low-level waste/NRC (10 C.F.R. 61)	25 millirem/year
Drinking water/EPA (40 C.F.R. 141)	Radium: 5 picocuries/liter Gross alpha: 5 picocuries/liter Beta/photon: 4 millirem/year[b]
Uranium fuel cycle/EPA (40 C.F.R. 190)	25 millirem/year
Superfund cleanup/EPA (40 C.F.R. 300)	Risk range goals: 1 in 10,000 to 1 in 1 million[c]
Decommissioning/NRC (10 C.F.R. 20)	25 millirem/year
Occupational standards	
Occupational Safety and Health Administration, NRC, DOE (29 C.F.R. 1910; 10 C.F.R. 20; 10 C.F.R. 835)	5,000 millirem/year

[a] A picocurie is a trillionth of a curie, which is a commonly used unit of measurement of the activity of radiation.

[b] Radioactivity from human-made radionuclides in community drinking water systems.

[c] Lifetime risk of an individual's getting cancer.

http://www.gao.gov/new.items/rc00152.pdf

Potential Range of Cleanup Guidance for a Rad/Nuc Event – Which One Do We Use?

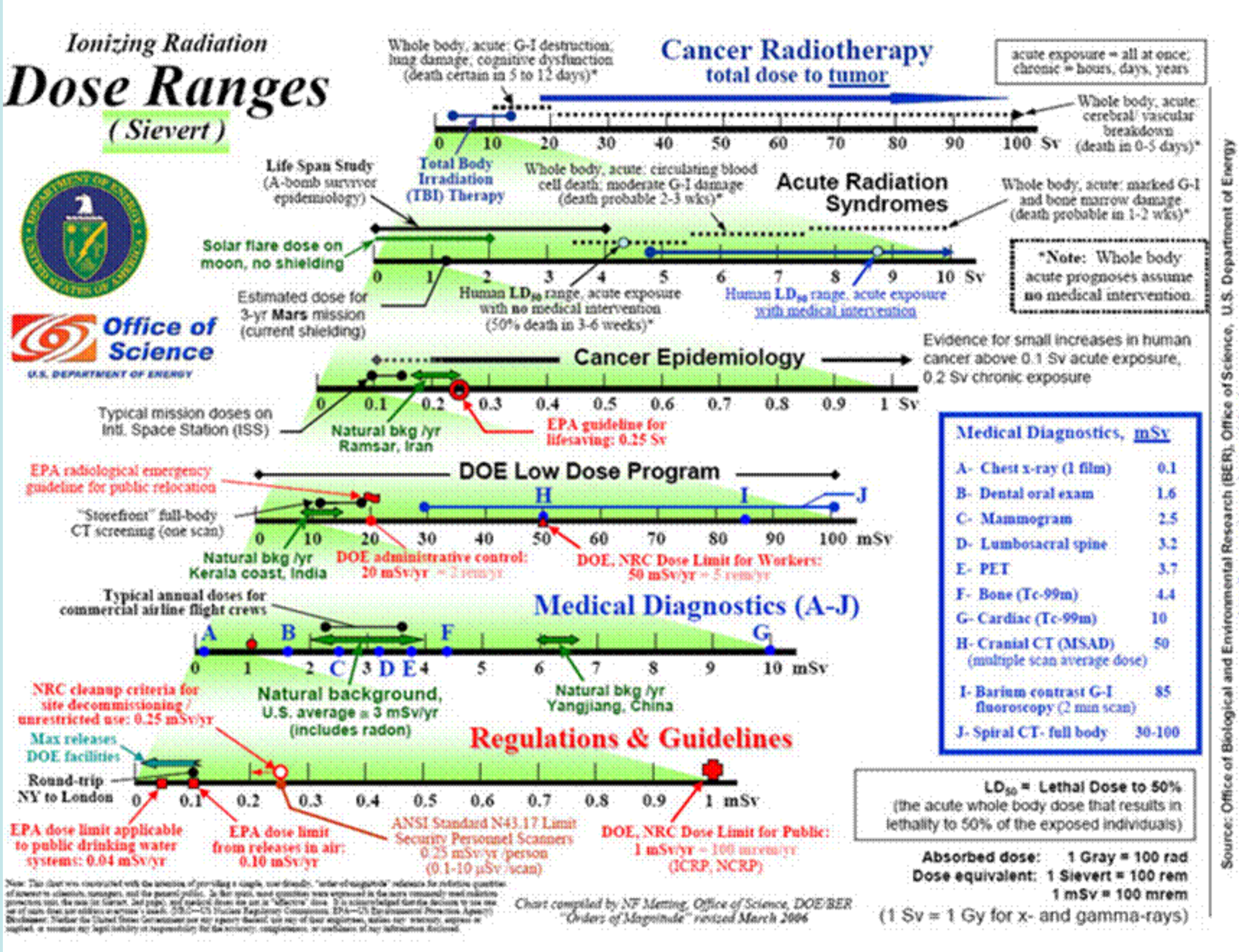
15 mrem/yr	EPA, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination", e.g., Hanford Site
25 mrem/yr	NRC, Final Rule on Radiological Criteria for License Termination (10 CFR Part 20 Subpart E)
100 mrem/yr	Health Physics Society Position Statement "Guidance for Protective Actions Following a Radiological Terrorist Event"
500 mrem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents", 400-R-92-001,…"doses in any single year after the first will not exceed 0.5 rem"
2 rem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents", 400-R-92-001,…"doses in first year will not exceed 2 rem"
5 rem/yr	NRC, "Standards for Protection against Radiation", recommendation and established dose limit for workers (10 CFR 20 Subpart C)

slightly edited from http://nuclearfiles.org/menu/key-issues/nuclear-weapons/issues/effects/PDFs/economic_consequences_slides.pdf

General radiation doses and expected effects (radiation doses are to the entire body).

- 0-5 rem received in a short period or over a long period is safe—we don't expect observable health effects.
- 5-10 rem received in a short time or over a long period is safe—we don't expect observable health effects. At this level, an effect is either nonexistent or too small to observe.
- 10-50 rem received in a short time or over a long period—we don't expect observable health effects, although at above 10 rem your chances of getting cancer are slightly increased. We may also see short-term blood cell decreases for doses of about 50 rem received in a matter of minutes.
- 50-100 rem received in a short time will likely cause some observable health effects and received over a long period will increase your chances of getting cancer. Above 50 rem we may see some changes in blood cells, but the blood system quickly recovers.
- 100-200 rem received in a short time will cause nausea and fatigue. 100-200 rem received over a long period will increase your chances of getting cancer.
- 200-300 rem received in a short time will cause nausea and vomiting within 24-48 hours. Medical attention should be sought.
- 300-500 rem received in a short time will cause nausea, vomiting, and diarrhea within hours. Loss of hair and appetite occurs within a week. Medical attention must be sought for survival; half of the people exposed to radiation at this high level will die if they receive no medical attention.
- 500-1,200 rem in a short time will likely lead to death within a few days.
- >10,000 rem in a short time will lead to death within a few hours.

http://hps.org/physicians/documents/Radiation_Benefit_and_Risk_Assessment.pdf



http://www.lowdose.energy.gov/pdf/Dose-Ranges-pdf.pdf