

# TEACHING VARIABILITY OF RADIATION AND RADIOACTIVITY IN GEOLOGICAL TIME AND SPACE

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**Ionizing** natural background **radiation** on Earth **varies** spatially by up to **two orders of magnitude** at present, and its average intensity decreased –for probably most of the time– since before the beginning of biological evolution. Backward extrapolation of the half-life concept indicated the potential for **spontaneous fission reactions during the Precambrian** even before their reality was proven by the discovery of the **Oklo** natural uranium reactors. Claims of hazard, damage, or **risk** to organisms exposed to the upper limits of the **natural background** range remain **unsupported by** observable **evidence**. Radioactivity and radiation (beyond the technical aspects of radiometric dating) must be **understood and integrated** into the teaching of geoscience in the interest of **scientific literacy and integrity**. Appreciation of their variability through time and space **reduces** irrational **fears** and advances comparative and **realistic assessment of real hazards and risks**.

## General Caution

1. Presentations are open to misinterpretation without (or likely even with) the presenter's interaction with his audience.
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 original.

## Special Note

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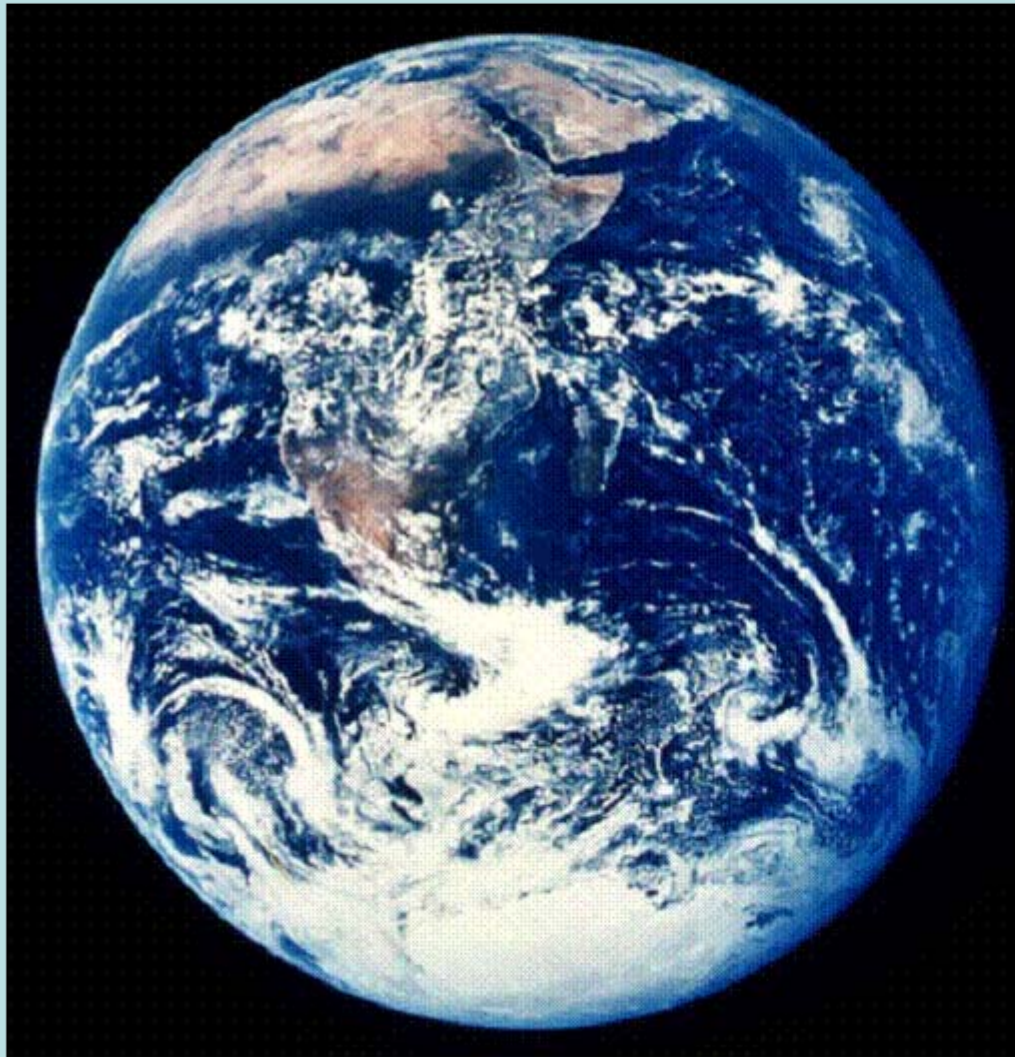
ng(o)<sub>3</sub>

**Such is the extent of nuclear anxiety that even scientists seem to forget our planet's radioactive history.**

**Life began nearly four billion years ago under conditions of radioactivity far more intense than those that trouble the minds of certain present-day environmentalists.**

James Lovelock, in Bruno Comby (2006), Environmentalists for Nuclear Energy  
([www.ecolo.org/aa\\_tiroir/Nuclear-en.doc](http://www.ecolo.org/aa_tiroir/Nuclear-en.doc))

# 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

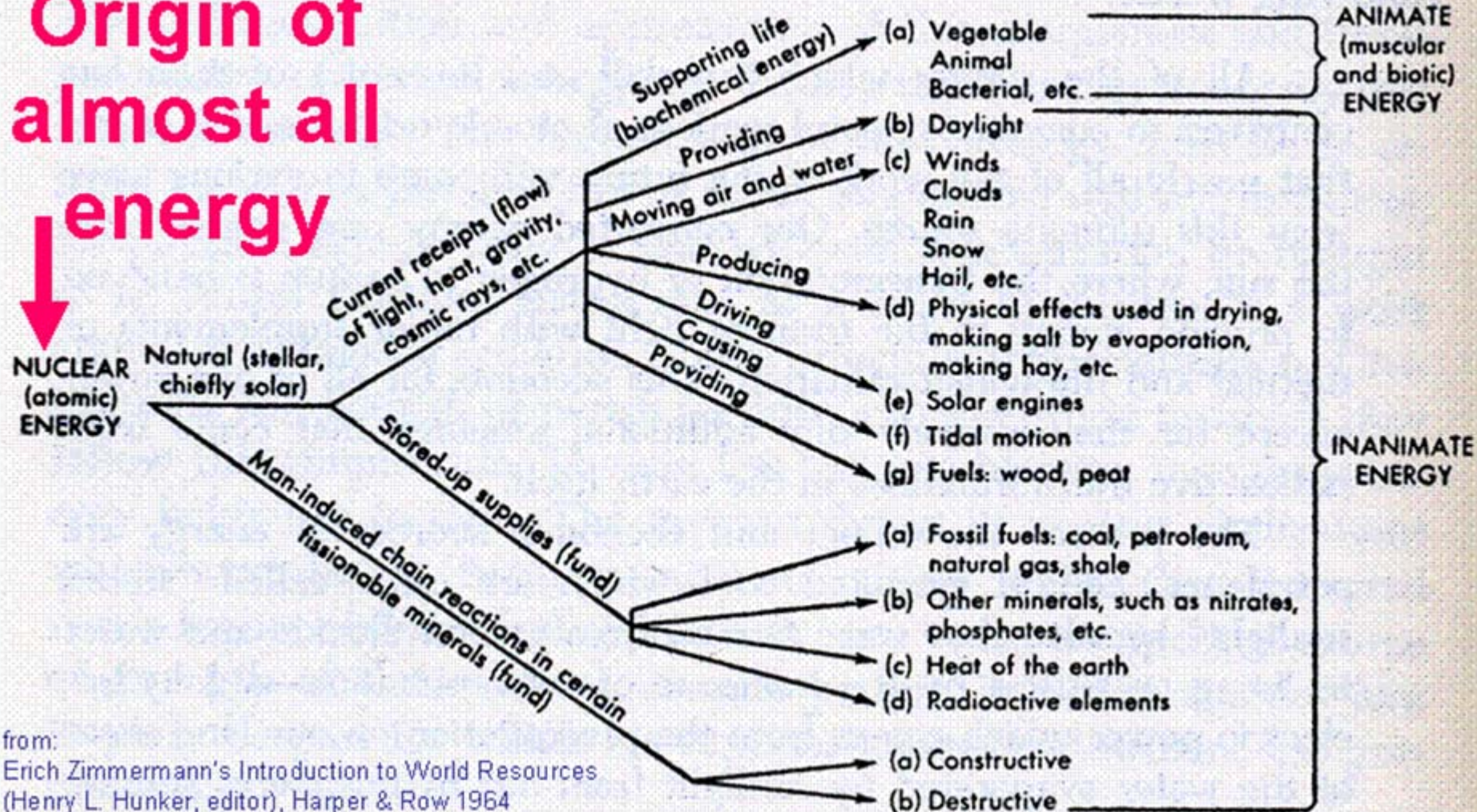
<http://www.lbl.gov/abc/Basic.html>

...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

**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)



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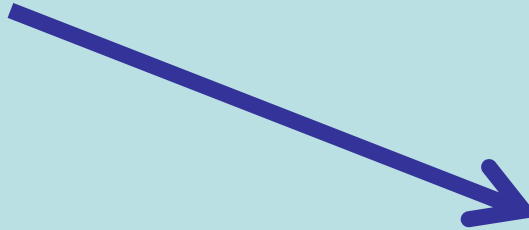


**The strength of the Oklo  
analogue lies in the fact  
that it represents more  
extreme conditions than  
those likely to be met in a  
deep geologic repository**

(D.J. Mossman et al., 2008)

# Scientific American

November 2005



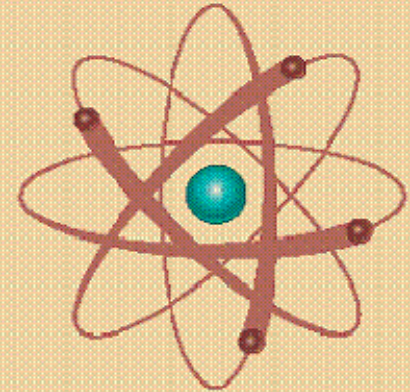
## Oklo Nuclear Geysers (16 individual reactors)

- 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.

**We also know that nuclear fusion  
(sun and other stars) is natural**

## 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

uranium mine



pre-Fermi (*natural*) reactors



Oklo  
Gabon

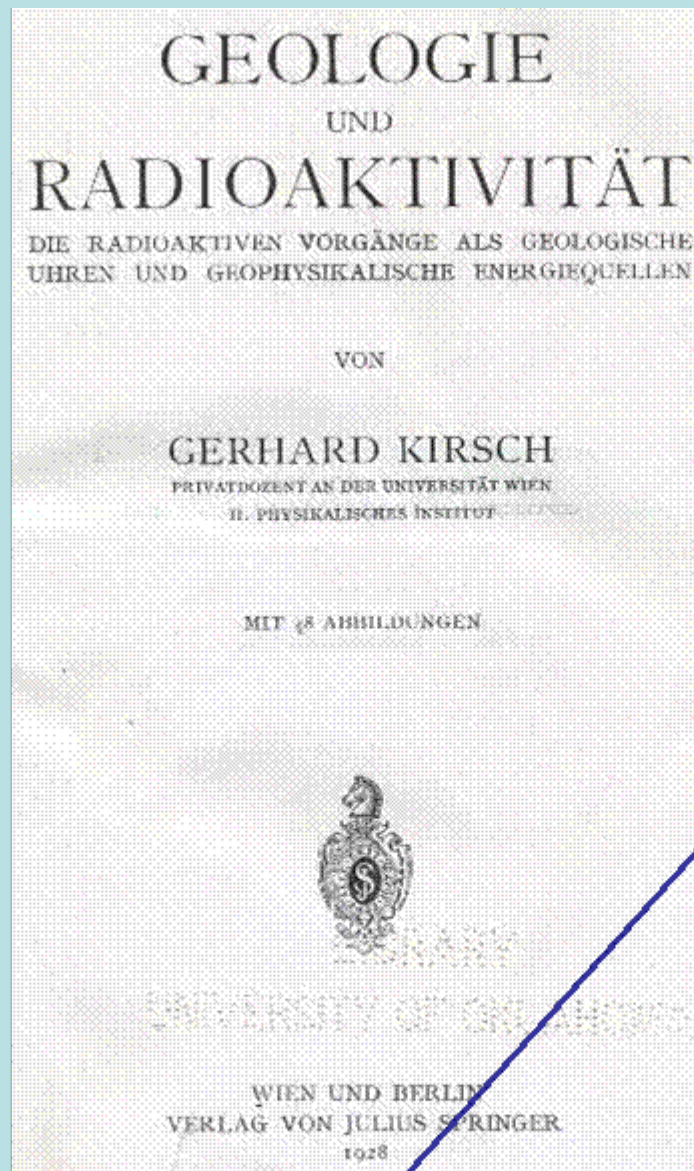




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1928



“... theories - (that are) the youngest children of the marriage between geology and radioactivity ...”

from the foreword:

... für die im zweiten Abschnitt dargestellten Theorien ermöglicht werde. Diese letzteren als die jüngsten Kinder aus der Ehe zwischen Geologie und Radioaktivität weisen naturgemäß mehr Hypothetisches auf als die radioaktiven Altersbestimmungsmethoden. Wir haben daher den

## Natural Radioactivity by the Square Mile, 1 Foot Deep

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 <sup>3</sup> ) soil	11 µg	0.2 curies (7.4 GBq)
Total:			>17 curies (>653 GBq)

# Decrease in the activity of the earth's crust due to 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

**Not everybody realizes  
that geothermal energy  
is just another name  
to describe  
the radioactivity of our planet**

(Bertrand Barré, 2005)





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# “Microbes from Hell’s Zip Code”

S. African gold mine & Nevada Test Site

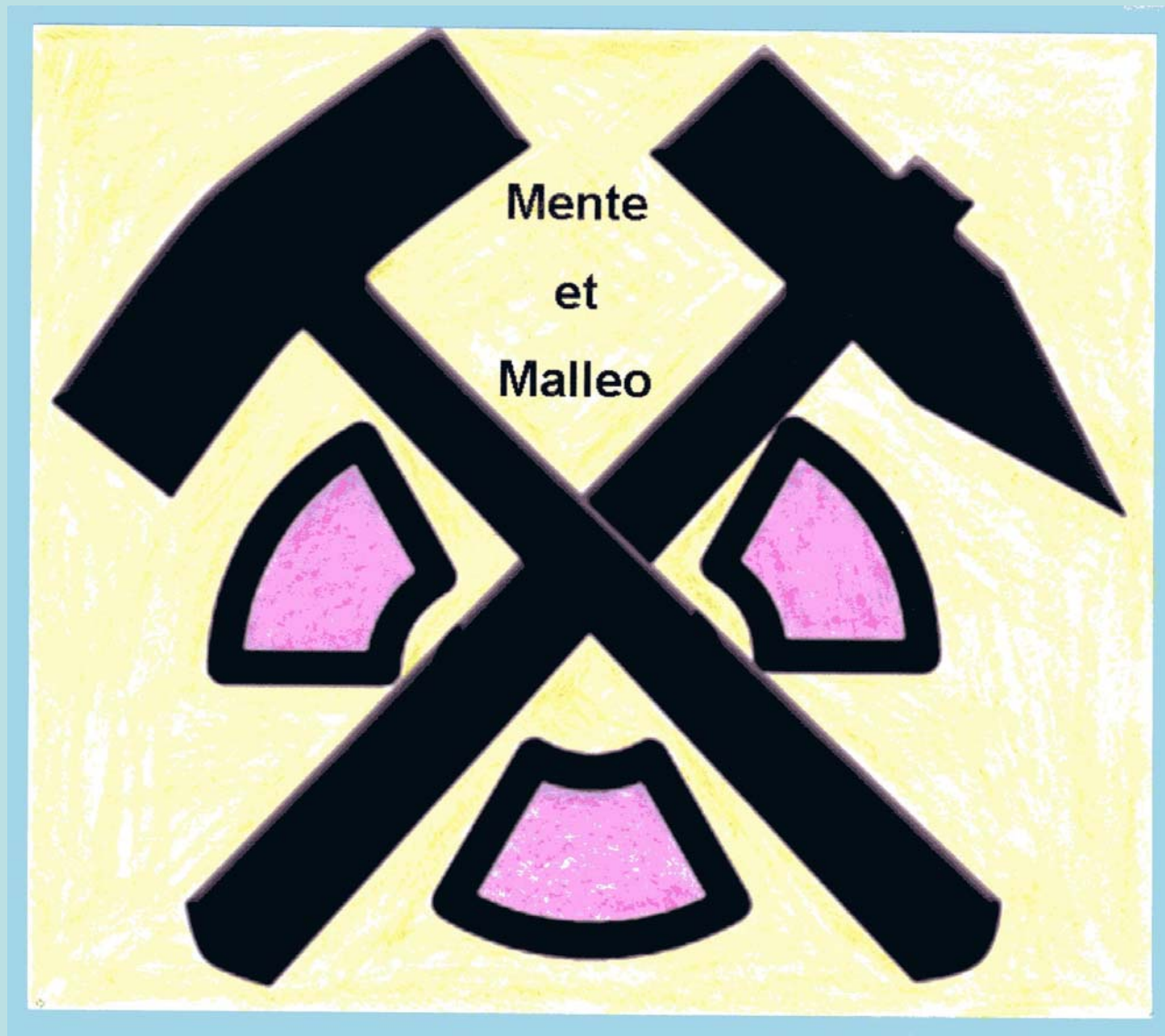
Water plus  
rock plus  
radiation can  
sustain life for  
millennia

Radiation may  
keep life going,  
thriving, and  
evolving

Tullis Onstott, Princeton

(Hometown: Carlsbad, NM)





**An anti-nuclear geologist is an oxymoron**

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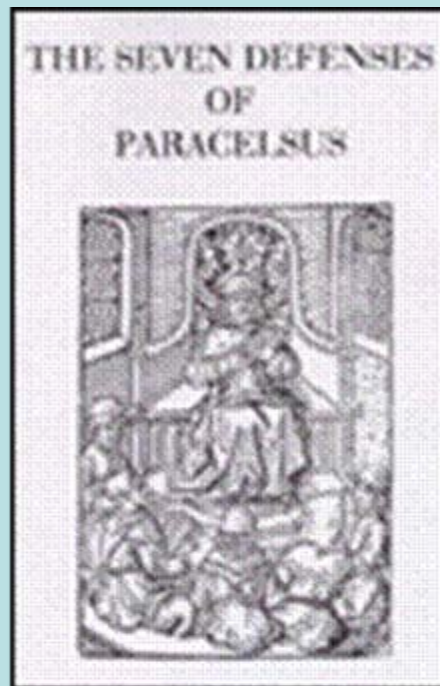


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Paracelsus (1493 - 1541)



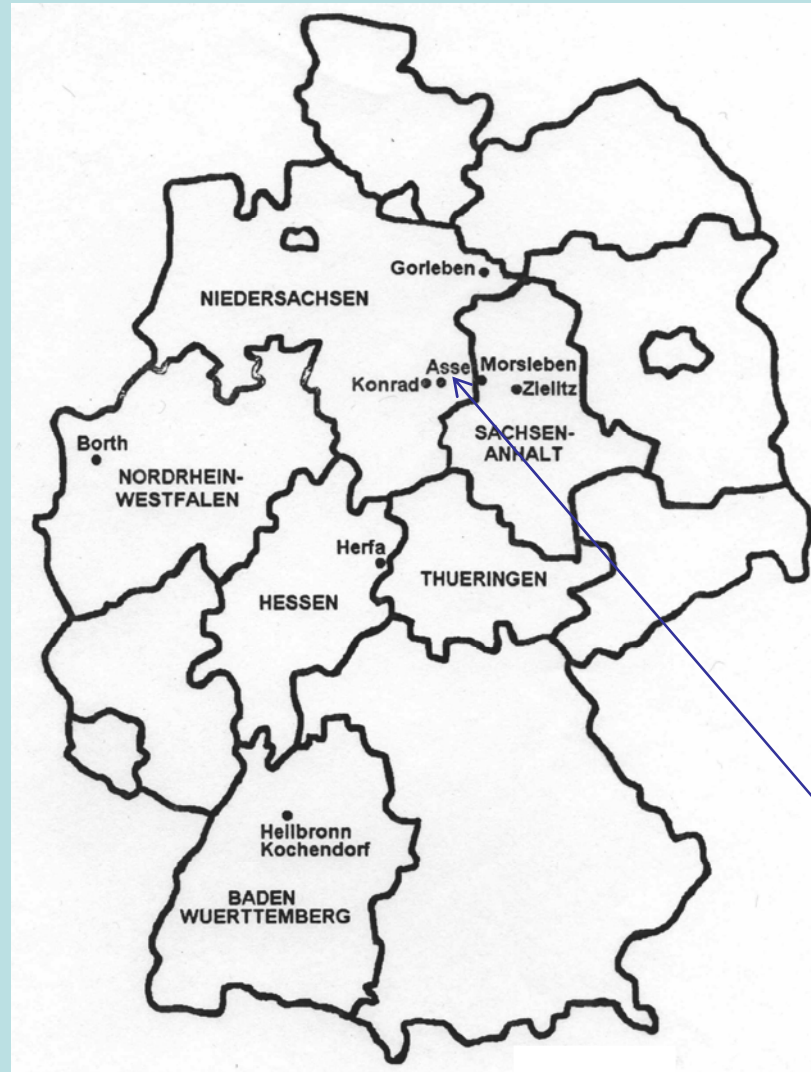
If you wish justly to explain poison, what is there that is not poison?

All things are poison, and nothing is without poison: the dose alone makes a thing not poison.

For example, every food and every drink, if taken beyond its dose, is poison: the result proves it.

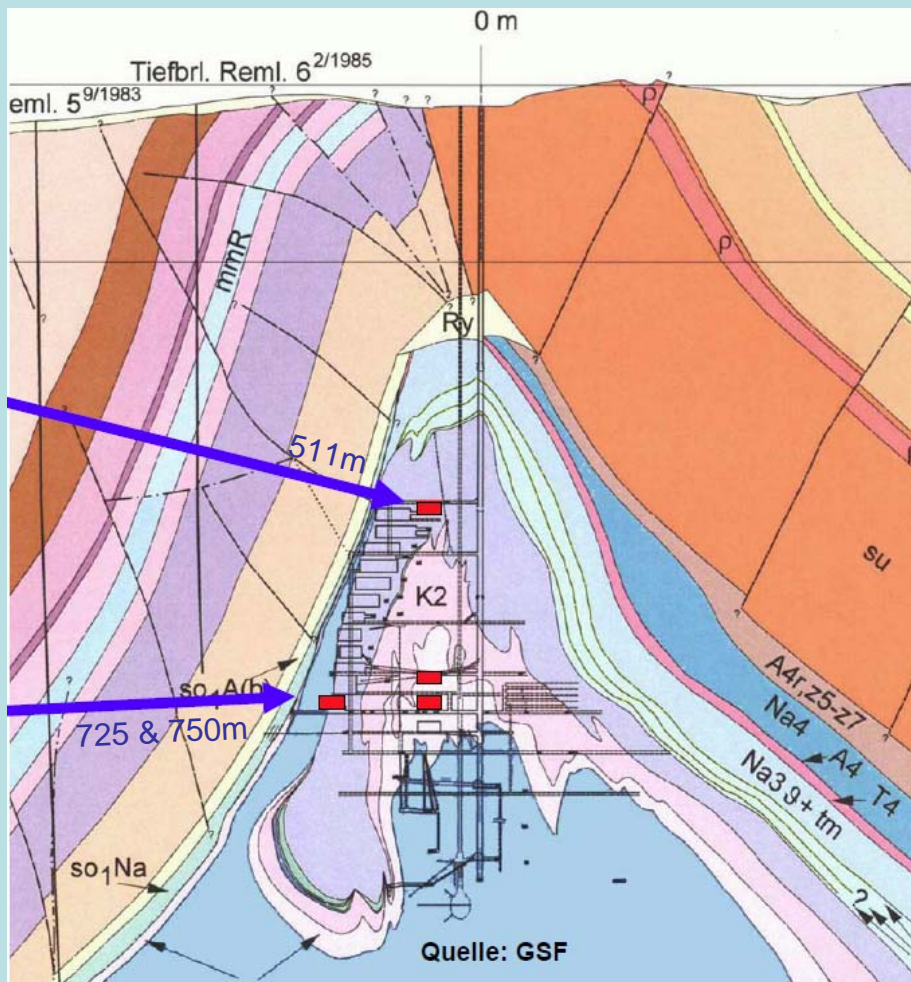
Written 1538, published 1564, in the third of his seven "Defensiones"

# Geologic Repositories in Germany

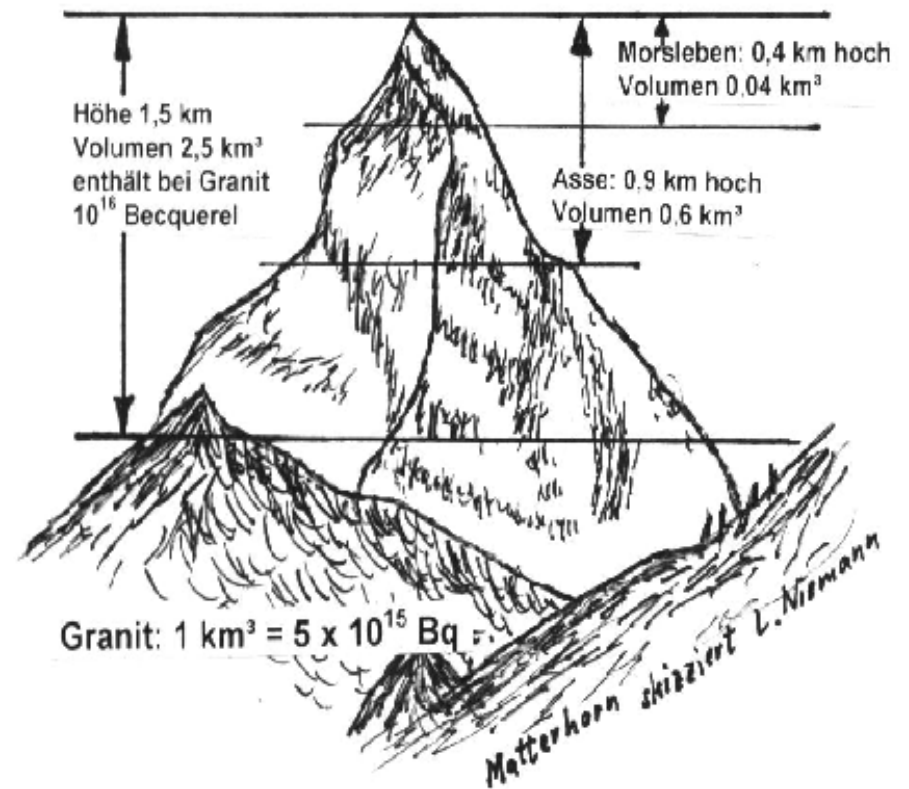


Asse

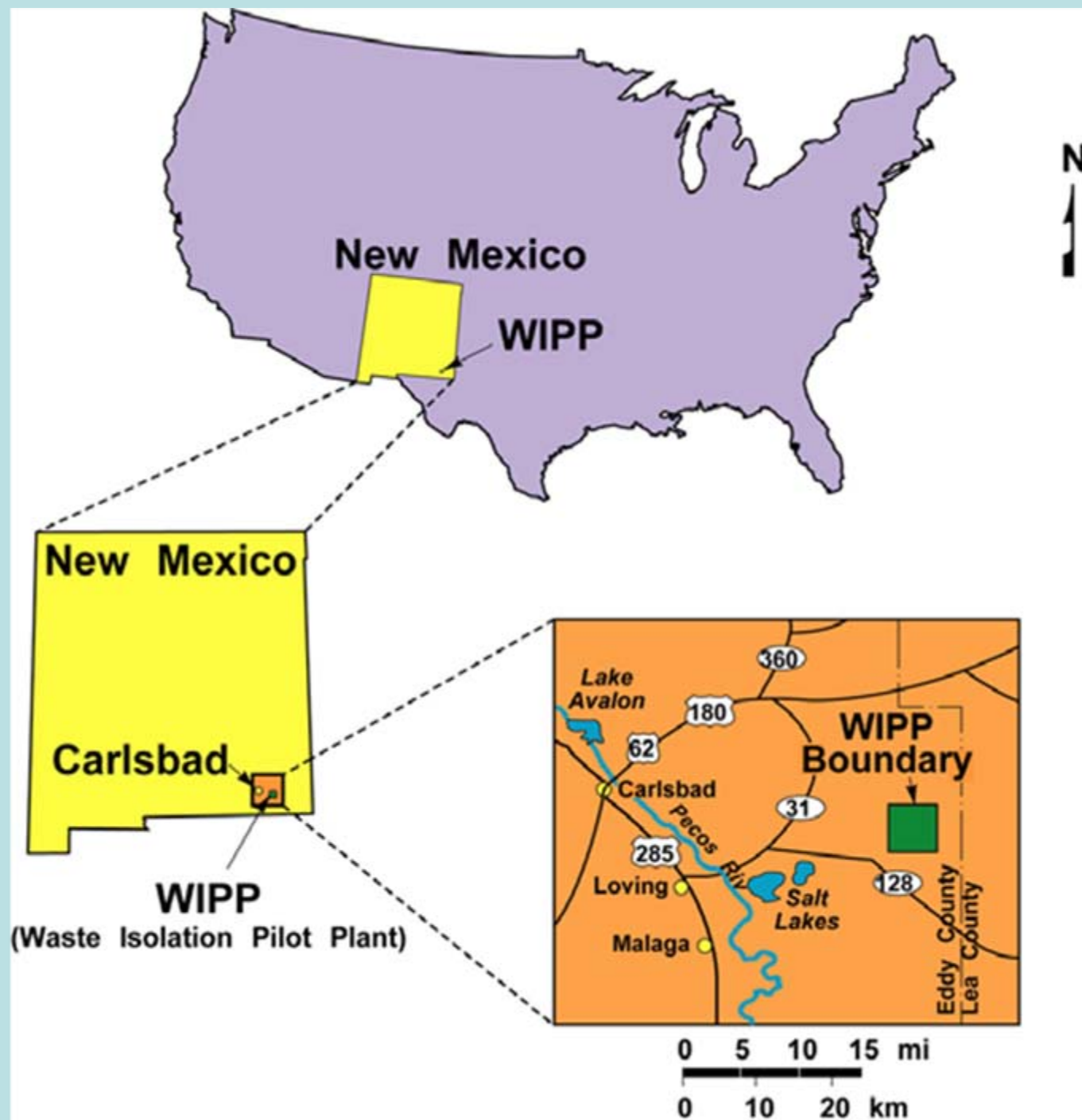
# Matterhorn



## Asse










WIPP radiation levels average       $3.1 \mu\text{R/hr}$  at the surface,  
    $0.6 \mu\text{R/hr}$  655m underground  
WIPP underground is a **radiation-deprived** environment






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# ON BULLSHIT



Harry G. Frankfurt

PRINCETON UNIVERSITY PRESS

PRINCETON AND OXFORD

## Tri-Valley CAREs

Communities Against a Radioactive Environment

2582 Old First Street, Livermore, CA 94550 • (925) 443-7148 • [www.trivalleycares.org](http://www.trivalleycares.org)



Peace Justice Environment  
since 1983

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...**



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**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”



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**



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

“no consistent detrimental effect has been detected so far”

[http://www.ecolo.org/documents/documents\\_in\\_english/RamsarHLNRPaper.doc](http://www.ecolo.org/documents/documents_in_english/RamsarHLNRPaper.doc)

“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



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

# Ionizing Radiation Dose Ranges (Sievert)



Whole body, acute: G-I destruction;  
lung damage; cognitive dysfunction  
(death certain in 5 to 12 days)\*

**Cancer Radiotherapy**  
total dose to tumor

acute exposure = all at once;  
chronic = hours, days, years

Whole body, acute:  
cerebral/vascular  
breakdown  
(death in 0-5 days)\*

Life Span Study  
(A-bomb survivor  
epidemiology)

**Total Body  
Irradiation  
(TBI) Therapy**

Whole body, acute: circulating blood  
cell death; moderate G-I damage  
(death probable 2-3 wks)\*

**Acute Radiation  
Syndromes**

Whole body, acute: marked G-I  
and bone marrow damage  
(death probable in 1-2 wks)\*

\*Note: Whole body  
acute prognoses assume  
no medical intervention.

Solar flare dose on  
moon, no shielding

Estimated dose for  
3-yr Mars mission  
(current shielding)

Human LD<sub>50</sub> range, acute exposure  
with no medical intervention  
(50% death in 3-6 weeks)\*

Human LD<sub>50</sub> range, acute exposure  
with medical intervention

**Cancer Epidemiology**

Evidence for small increases in human  
cancer above 0.1 Sv acute exposure,  
0.2 Sv chronic exposure

Typical mission doses on  
Int'l. Space Station (ISS)

Natural bkg /yr  
Ramsar, Iran

EPA guideline for  
lifesaving: 0.25 Sv

EPA radiological emergency  
guideline for public relocation

**DOE Low Dose Program**

"Storefront" full-body  
CT screening (one scan)

Natural bkg /yr  
Kerala coast, India

DOE administrative control:  
20 mSv/yr = 2 rem/yr

DOE, NRC Dose Limit for Workers:  
50 mSv/yr = 5 rem/yr

Typical annual doses for  
commercial airline flight crews

**Medical Diagnostics (A-J)**

NRC cleanup criteria for  
site decommissioning/  
unrestricted use: 0.25 mSv/yr

Natural background,  
U.S. average = 3 mSv/yr  
(includes radon)

Natural bkg /yr  
Yangjiang, China

**Regulations & Guidelines**

Max releases  
DOE facilities

Round-trip  
NY to London

EPA dose limit applicable  
to public drinking water  
systems: 0.04 mSv/yr

EPA dose limit  
from releases in air:  
0.10 mSv/yr

ANSI Standard N43.17 Limit  
Security Personnel Scanners  
0.25 mSv/yr/person  
(0.1-10 µSv/scan)

DOE, NRC Dose Limit for Public:  
1 mSv/yr = 100 mrem/yr  
(ICRP, NCRP)

**Medical Diagnostics, mSv**

A- Chest x-ray (1 film)	0.1
B- Dental oral exam	1.6
C- Mammogram	2.5
D- Lumbosacral spine	3.2
E- PET	3.7
F- Bone (Tc-99m)	4.4
G- Cardiac (Tc-99m)	10
H- Cranial CT (MSAD) (multiple scan average dose)	50
I- Barium contrast G-I fluoroscopy (2 min scan)	85
J- Spiral CT- full body	30-100

LD<sub>50</sub> = Lethal Dose to 50%  
(the acute whole body dose that results in  
lethality to 50% of the exposed individuals)

Absorbed dose: 1 Gray = 100 rad  
Dose equivalent: 1 Sievert = 100 rem  
1 mSv = 100 mrem  
(1 Sv = 1 Gy for x- and gamma-rays)

Note: This chart was constructed with the intention of providing a simple, non-technical, "order-of-magnitude" reference for relative quantities of ionizing radiation. It is not intended to be used for regulatory purposes. In this chart, most quantities were expressed in the units commonly used in radiation protection (i.e., the sievert for human exposure, and the rad for material damage). It is acknowledged that the decision to use one unit or another may be arbitrary, and that the use of different units may lead to confusion. The chart is intended to provide a general overview of the relative magnitudes of different radiation doses, and is not intended to be used for regulatory purposes. The chart is intended to provide a general overview of the relative magnitudes of different radiation doses, and is not intended to be used for regulatory purposes.

Chart compiled by NF Metting, Office of Science, DOE/BER  
"Orders of Magnitude" revised March 2006

Source: Office of Biological and Environmental Research (BER), Office of Science, U.S. Department of Energy  
<http://www.science.doe.gov/ober/>



# Background Radiation and EPA and NRC Regulations

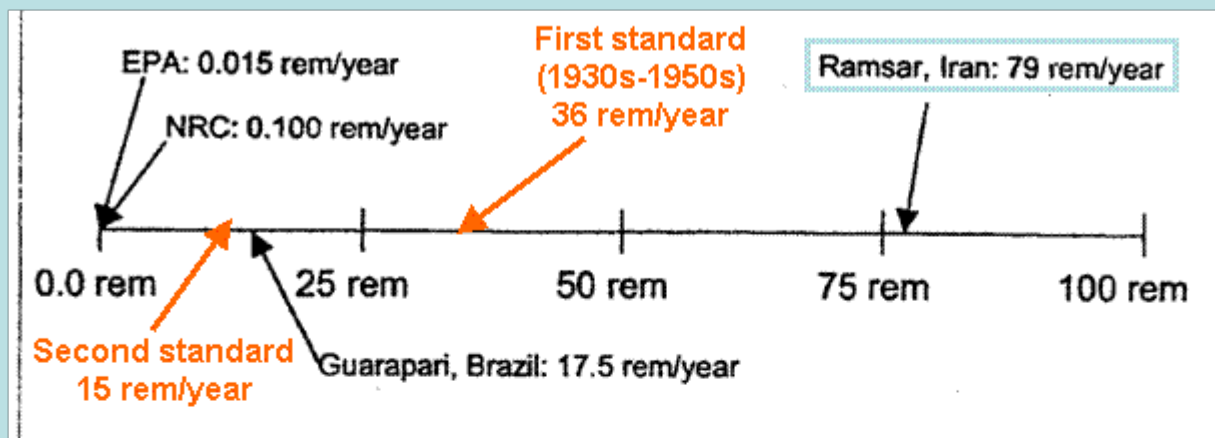


Fig. 2. Scale comparing EPA and NRC regulatory limits to natural background radiation environments (100 rem = 1 sievert; 100 rad = 1 gray)

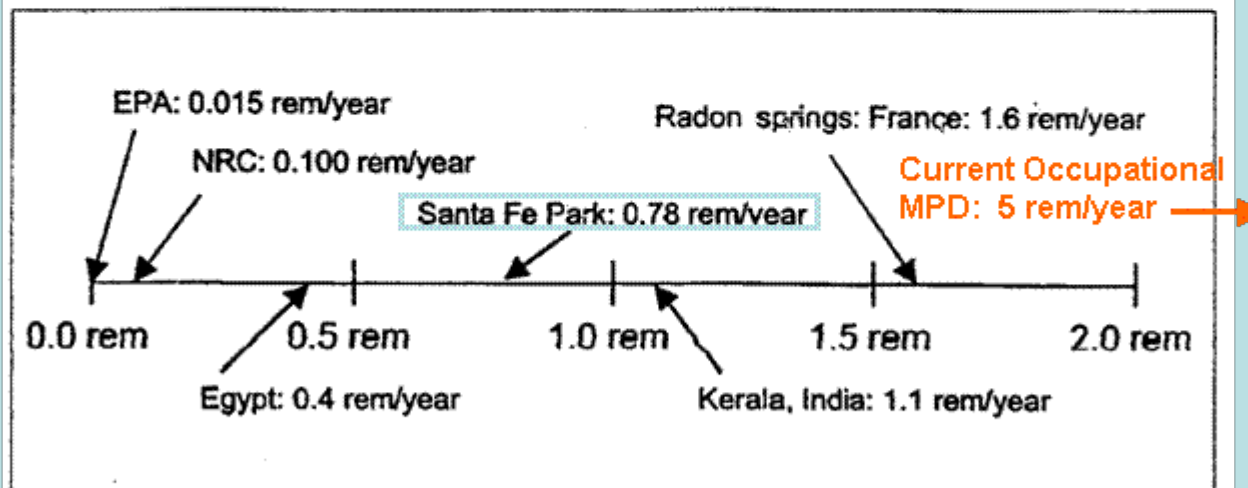


Fig. 3. Expanded scale comparing EPA and NRC regulatory limits to natural background radiation environments (100 rem = 1 sievert; 100 rad = 1 gray)







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# UNDER- EXPOSED

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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

2005  
ISBN 0-930073-35-5

1995  
ISBN 0-944838-96-0

# Has radiation protection become a Health Hazard

Gunnar Walinder

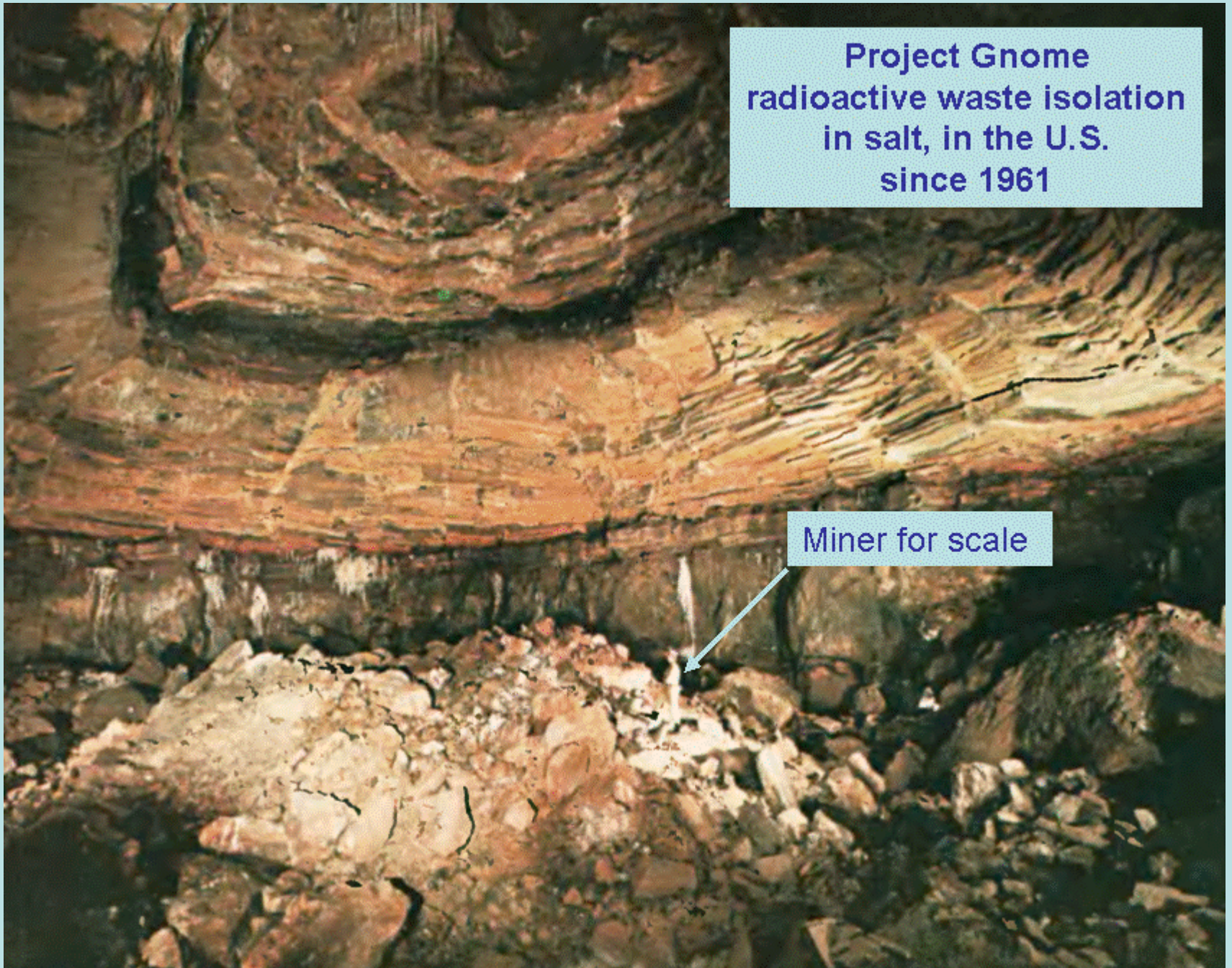
Nuclear Training & Safety Center, Nyköping, Sweden  
Medical Physics Publishing, Madison WI , USA

# Augmentation slides



**Project Gnome  
radioactive waste isolation  
in salt, in the U.S.  
since 1961**

**Miner for scale**



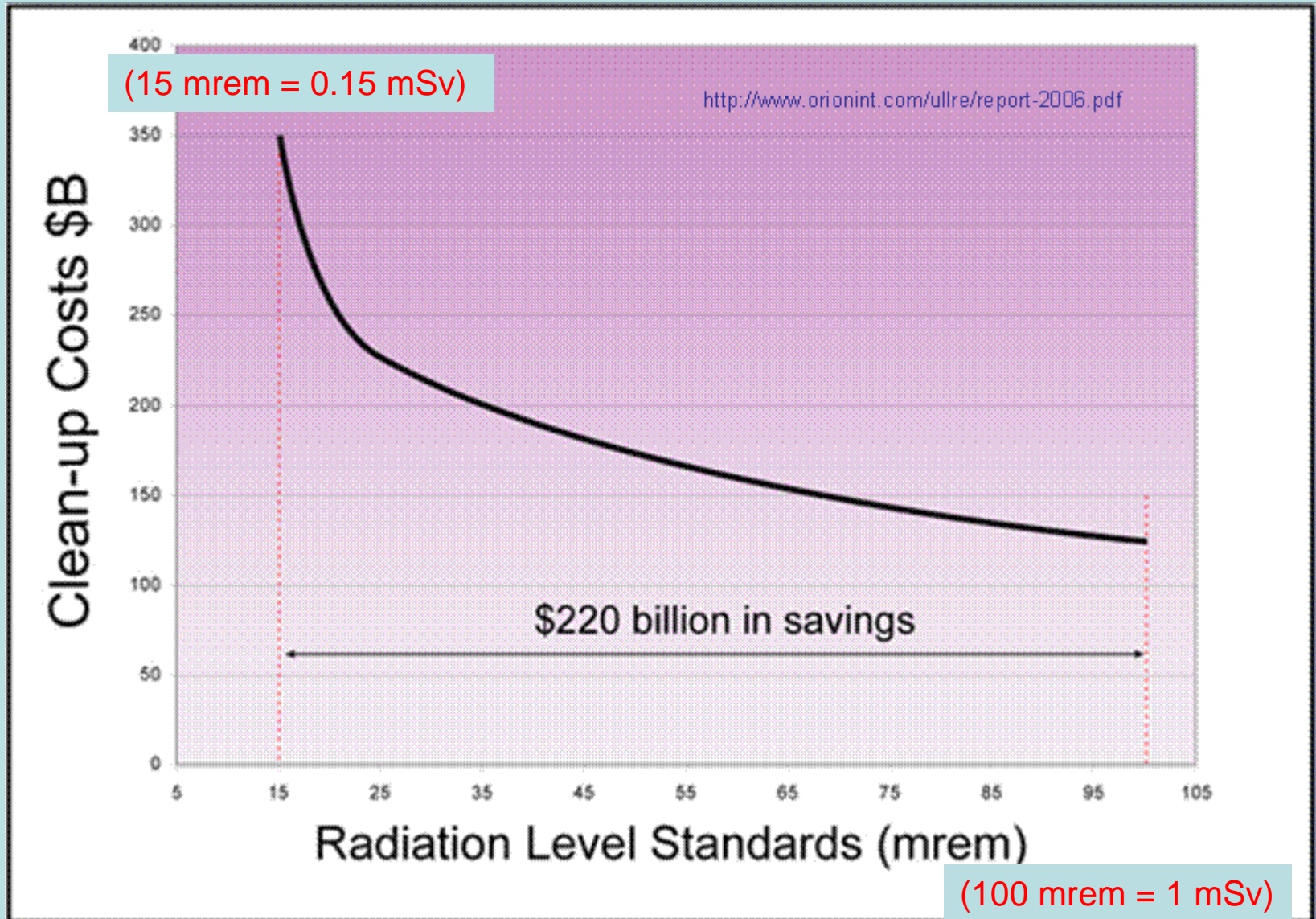
# Annual terrestrial radiation doses in the world



Area	mean (mGy/year)	maximum (mGy/year)
<b>Ramsar, Iran</b>	<b>10.2</b>	<b>(260)</b>
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)



**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)



**Excerpts from William C. Clark, Witches, Floods, and Wonder Drugs: Historical Perspectives on Risk Management. (International Institute for Applied Systems Analysis, Laxenburg, Austria, 1980)**

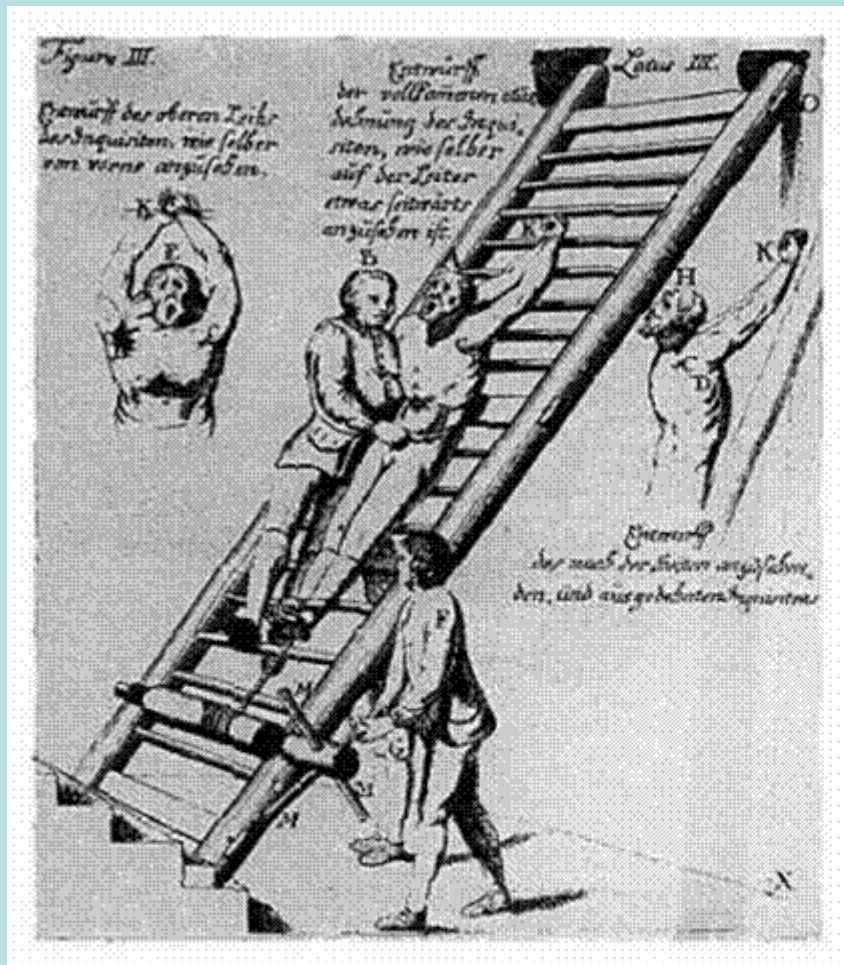
**From the Renaissance through the Reformation, risk assessment was used to justify witch hunting.**

**Then, as now, experts were called upon to provide explanations of the unknown. Rather than acknowledge their own limitations and ignorance, they assigned the generic name “witchcraft” to the phenomenology of the unknown. They founded a new professional interest dedicated to the investigation and control of “witchcraft”.**

**Witch hunting became the growth industry of the day, offering exciting work, rapid advancement, and wide recognition to its professional and technical workers.**

**Creative and energetic efforts to create a “witch-free” world unearthed risks in the most unlikely places.**

**(People are deluded in groups and come to their senses as individuals)**



# Precautionary Principle

In Action



Anneken Hendriks, Amsterdam, executed 1571