WWS-304 November 25, 1996

RISK ASSESSMENT

Actuarial data for frequent events

Probabilistic risk assessments for new technologies

Cancer dose-risk assessment

Using Actuarial Data to Assess Risks from Frequent Events

(courtesy of *Statistical Abstracts of the United States, 1994*)

Probability of Death from Accidents or Violence[1]
(Percent assuming 75 years at U.S. 1991 rates)

Race:	White		Black		
Sex:	**Male**	**Female**	**Male**	**Female**	
--Accidents	3.6	1.7	4.5	1.7	
--Suicide	1.7	0.4	0.9	0.1	
--Homocide	**0.7**	0.2	5.4	1.0	
Total	*5.9*	*2.4*	*11.0*	*2.9*	**5.8 av.**

[1] *Statistical Abstracts of the United States, 1994*, Tables 133, 127.

Motor Vehicle Accidents[2]

(about half of total accidents, 1992)

39,000 total deaths (down from 55,000 in 1972)

31,000 vehicle occupants,
6,000 pedestrians,
2,000 motorcyclists, and
700 bicyclists

5.4 million injuries

0.012 deaths & 1.6 injuries projected per average 75-year person-lifetime

2.2 trillion vehicle miles in 1992

$1.8*10^{-8}$ deaths & $2.5*10^{-6}$ injuries per vehicle-mile

On what basis do you make your decision on whether or not to fasten your seatbelt?

Lifetime Occupational Death and Injury Rates

(assuming 50 years on the job, 1992 rates)[3]

Occupation	Deaths	
All	0.35 %	(about same as nonwork, considering work =15% of lifetime, 0.9 % in 1970)
Dominated by non-work hazards:		
--Transportation	40%	
--Homicides/suicides	20%	
--Equipment	16%	
--Falls	10%	
--Shocks, poisoning, suffocation, drowning	10%	
--Fires, explosions	3%	
--Other	1%	

[2] *Statistical Abstracts of the United States, 1994*, Tables 1014.
[3] *Statistical Abstracts of the United States, 1994*, Tables 690, 679.

Risk Assessment for Nuclear Power

Worst-case

1957: AEC: Wash-740 (160 MWe reactor, release of volatiles)[8]

--2-900 early deaths, 10-13,000 injuries

1965: AEC: Wash-740 suppressed update (1000 MWe, melt release, upwind of city, night-time)

--25,000 Early deaths

Probabilistic:

1975: AEC-NRC: Wash-1400 *Reactor Safety Study*[9]

Probability/year (given 100 reactors)	**Consequences**
1/1000	**no "early fatalities"** **1000 cancer deaths** 7500 thyroid cases 400 mi^2 contaminated
1/100,000	**100 "early fatalities"\ Chernobyl**[10] **12,000 cancer deaths /** 100,000 thyroid cases 3,000 mi^2 contaminated

[8] Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants: A Study of Possible Consequences if Certain Assumed Accidents, Theoretically Possible but Highly Improbable, Were to Occur in Large Nuclear Plants (U.S. Atomic Energy Commission, WASH-740, 1957). Probability estimates, based on the range of expert opinion, were also offered: 10^{-3} to 10^{-7} per 100 reactor-years.

[9] *Reactor Safety Study*, Executive Summary, p. 2.

[10] See Frank von Hippel and Thomas B. Cochran, "Estimating the Long-Term Health Effects," Bulletin of the Atomic Scientists, August/September 1986.

P.R.A. for Nuclear Accidents

(The calculation that destroyed the credibility of the *Reactor Safety Study*)

What is the probability of meltdown for a Boiling Water Reactor due to failure of automatic control-rod insertion?[11]

1000 unplanned shutdowns/yr for 100 reactors

x 0.1 chance that operator will fail to execute a manual shutdown

= 100 automatic shutdowns required per year

Shutdown system fails if any of 3,000 combinations of **three adjacent control rods fail to insert.**

Observed probability of one out of 185 rods failing to insert: 10^{-4} **per try**

Probability of three failing independently simultaneously is:

$10^{-4} \times 10^{-4} \times 10^{-4}$
x(3000 combinations of adjacent rods in a core)
x(100 shutdowns per year) = 0.3×10^{-6} **per year**

But a "common-mode failure" could cause three adjacent rods to fail to insert

Not observed: < 0.3 per year for 100 reactors

Calculated uncertainty range: 0.3×10^{-6} **to 0.3 per year**

Too great, so **reported as** 10^{-4} **to** 10^{-3} **per year!**

Conclusion: only charlatans can get politically useful answers.

[11] *Reactor Safety Study*, Appendix II: "Fault Trees," p. 362.

Actuarial Data on U.S. Catastrophes[4]

	Lives Lost
Earthquakes	
--1906, San Francisco	750
--1964, Anchorage	125
--1971, San Fernando, CA	58
Hurricanes	
--1900	6000
--1928	1800
--1938	600
--1957	390
--1972	122
Dam Failures	
--1889, Johnston, PA	2000
--1928, St. Francis Dam, CA	450
--1972, Buffalo Creek, W. Va	125

Worldwide Airline Death Rate per100 million passenger miles

--1970	0.29
--1980	0.14
--1993	0.05 (vs. about 1 for autos)

Chemical Plant Accidents (Bhopal) 2500?

Wars[5]	**U.S. (Total) Deaths**
Civil War (1861-65)	820,000
WW-I (1917-18)	126,000 (26 million total deaths)
WW-II (1941-45)	408,000 (52 million)
Korea (1950-54)	34,000 (3 million)
Vietnam (1961-73)	47,000 (2.5 million)
WW-III (??)	hundreds of millions?

[4] *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Main Report* (U.S. Nuclear Regulatory Commission: Wash-1400 [NUREG-75/014] 1975), Tables 6-8, 6-9, 6-12.

[5] *Statistical Abstracts of the United States, 1991*, Table 564; Ruth Legeer Sivard, *World Military and Social Expenditures, 1991* (World Priorities, Box 25140, Washington, D.C. 20007).

"The (Zero)x(Infinity) Problem"

Probabilistic Risk Assessment for Potent New Technologies

But probabilistic risk estimates are very uncertain and subjective

Shuttle[6]

-- Engineers 1/200 per flight
-- Management 1/100,000

Optimism in the Estimate of probability of a large spill of LNG in New York or Providence Harbor[7]

(125 arrivals per year) x (8/10,000) historical accidents per large ship transit

Actuarial = 0.1 accident/year

"Corrections"

x (1/5) for special precautions

x (1/100) observed probability of a massive spill given a tanker accident

x (1/7.5) for better design of LNG tanker

=> P.R.A. estimate = 1/40,000 per year

But what was left out? (Fairley's Questions)
(1/100 year could overwhelm the estimate)

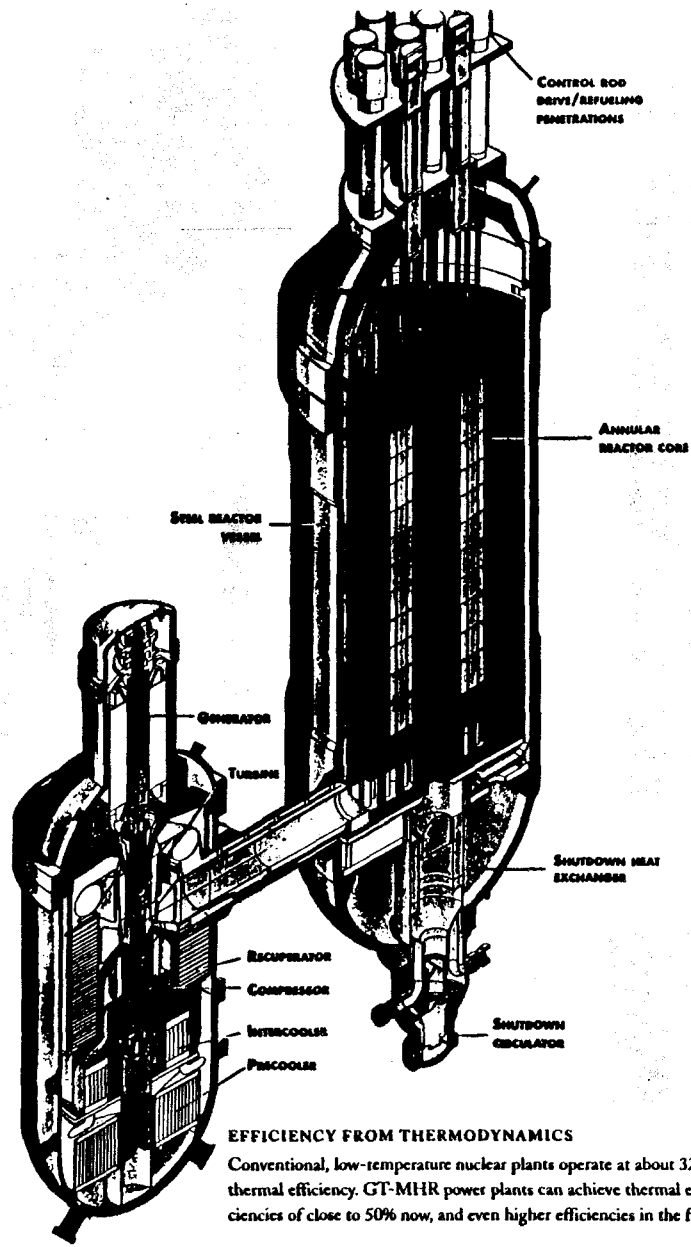
-- sabotage?

--crew panic?

[6] Richard P. Feynmann, "An Outsider's Inside View of the Challenger Inquiry," Physics Today, February 1988, p. 26.

[7] William B. Fairley, "Evaluating the 'Small' Probability of a Catastrophic Accident from the Marine Transportation of Liquified Natural Gas" in Statistics and Public Policy, William B. Fairley and Frederick Mosteller eds. (Addison-Wesley, 1977), p. 331.

The GT-MHR combines a meltdown-proof reactor and advanced gas turbine technology in a power plant with a quantum improvement in thermal efficiency. . . approaching 50%. This efficiency makes possible much lower power costs, without the environmental degradation and resource depletion of burning fossil fuels.



EFFICIENCY FROM THERMODYNAMICS

Conventional, low-temperature nuclear plants operate at about 32% thermal efficiency. GT-MHR power plants can achieve thermal efficiencies of close to 50% now, and even higher efficiencies in the future.

- 50% more electrical power from the same number of fissions.
- Dramatically lower high-level radioactive waste per unit of energy – today's reactors produce 50% more high-level waste than will the GT-MHR.
- Much less thermal discharge to the environment. Plants can use air cooling.

C FUEL RETAINS ITS INTEGRITY EVEN UNDER THE MOST NDITIONS AND SIMPLIFIES THE SAFETY EQUATION

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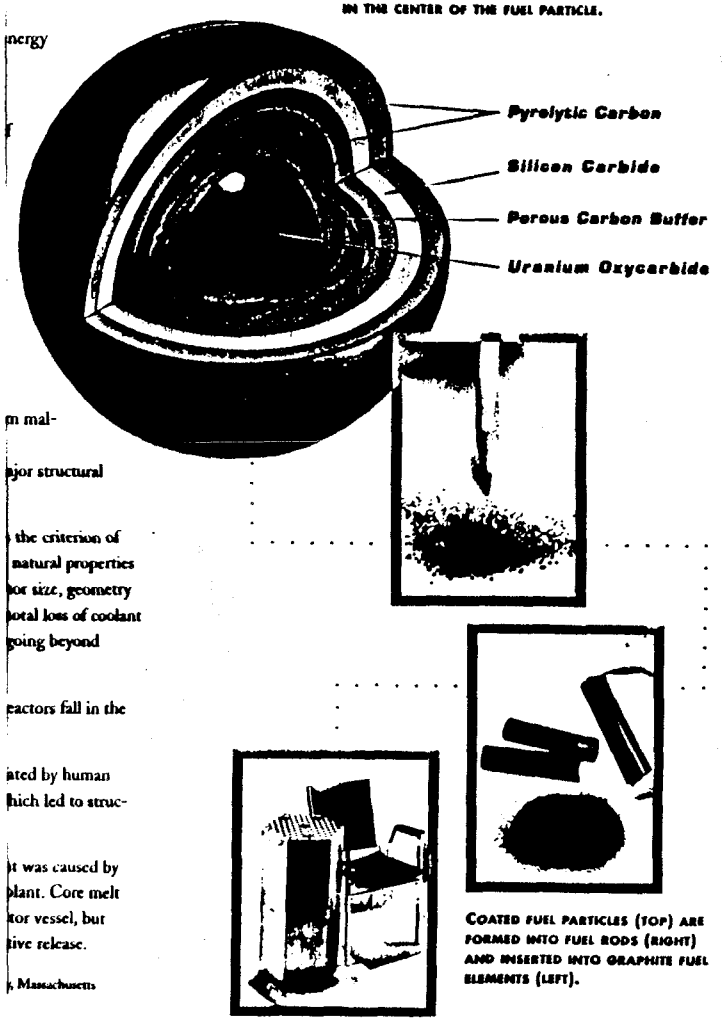
, Massachusetts

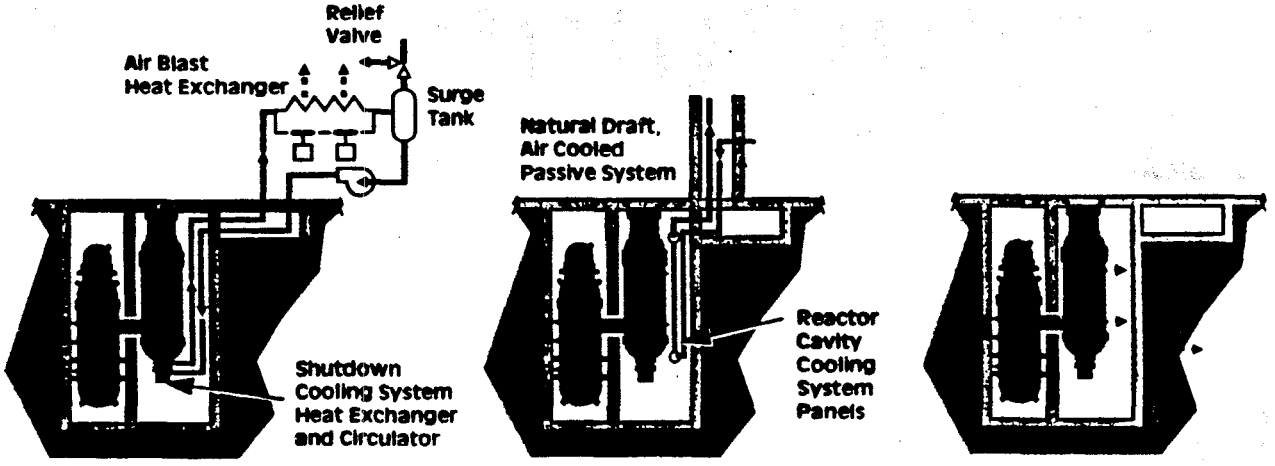
MULTIPLE LAYERS OF TOUGH, HIGH TEMPERATURE TOLERANT PYROLYTIC CARBON AND SILICON CARBIDE CONFINE THE RADIOACTIVE FISSION PRODUCTS AT THEIR SOURCE, IN THE CENTER OF THE FUEL PARTICLE.



COATED FUEL PARTICLES (TOP) ARE FORMED INTO FUEL RODS (RIGHT) AND INSERTED INTO GRAPHITE FUEL ELEMENTS (LEFT).

The MHR is the on

POSSIBLE DECAY HEAT REMOVAL PATHS WHEN NORMAL POWER CONVERSION SYSTEM IS UNAVAILABLE



A) Active Shutdown Cooling System

B) Passive Reactor Cavity Cooling System

C) Passive Radiation and Conduction of Afterheat to Silo Containment (Beyond Design Basis Event)

. . . DEFENSE-IN-DEPTH BUTTRESSED BY INHERENT CHARACTERISTICS

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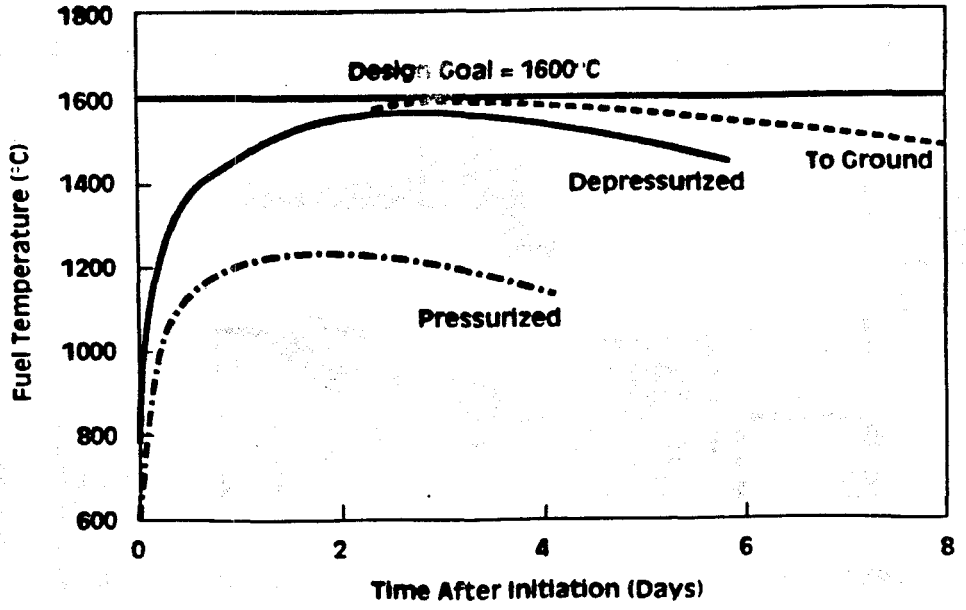
GENERAL ATOMICS

GT-MHR FUEL TEMPERATURES REMAIN BELOW DESIGN LIMITS DURING CONDUCTION COOLDOWN EVENTS



. . . passive design features ensure fuel remains below 1600°C

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GENERAL ATOMICS

Cancer Risk[15]

U.S. population = 266 million in 1996

2.2 million people die in the U.S. each year

-- 41% of heart, cerebro-vascular diseases and atherosclerosis
-- **24 % of cancer**
-- 12% of other chronic diseases (pulmonary, diabetes, liver and cirrosis
-- 4% of pneumonia and flu

What is Cancer? Uncontrolled growth of cells

If localized can be removed surgically or destroyed by ionizing radiation

If has spread throughout body (metastasized) can be attacked by chemicals which preferentially destroy rapidly-dividing cells or targeted techniques sensitive to the different biochemistry of the tumors.

[15] *Statistical Abstracts of the United States, 1994*, Table2 126, 97

At the Molecular Level[16]

Proteins produced by **suppressor genes** prevent uncontrolled division. Damage to both copies of the gene releases cancer.[17]

P53 gene produces a protein that is a supressor-gene activator. Damage to the gene results in non-activation of supressor gene.

Proteins produced by **proto-oncogenes** (e.g. ras) may stimulate cell division when signaled by other proteins. Damage to part of the gene that codes for the signal receptor may leave it turned on as an **oncogene**.

Repair genes produce proteins that can repair damaged DNA. Damage to repair genes makes it more probable that cells will accumulate multiple genetic defects.

Damage to many genes may be required to produce a cancer (multiple hit model).[18]

Carcinogens can **mutate** genes, or **promote** the multiplication of mutant cells.

Familial histories of cancer indicate that some people may be born with some cancer "switches" already thrown in their genetic material.

[16] See e.g. "The Genetic Basis of Cancer," by Webster Cavanee and Raymond White, *Scientific American*, March 1995, pp. 72-79.
[17] Robert A. Weinberg, "Finding the Anti-Oncogene," *Scientific American*, September 1988, p. 44.
[18] Jean Marx, "Many Gene Changes Found in Cancer," *Science*, 15 December 1989, p. 1386.

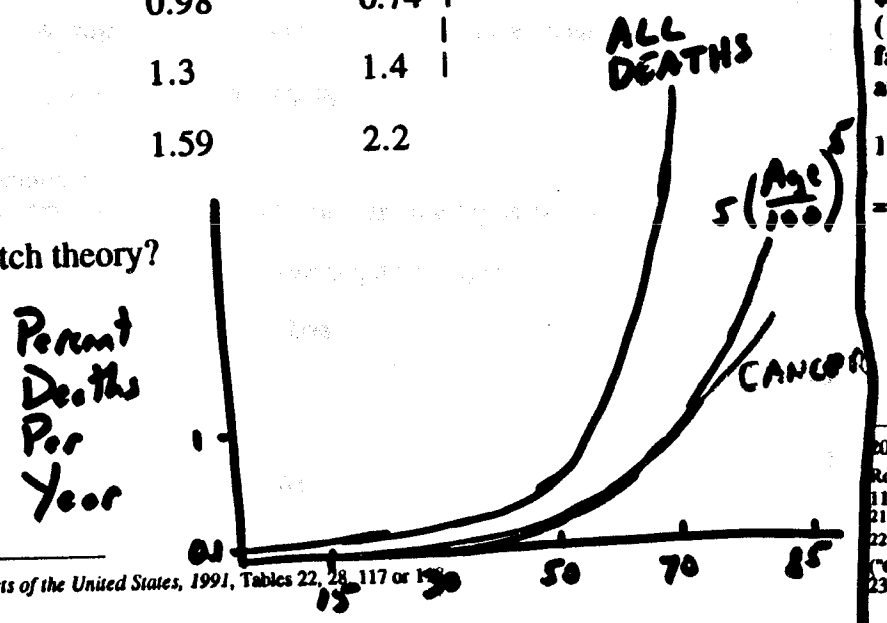
Probability of Cancer Death Increases as High Power of Age[19]

Age	Deaths/Year (percent) All causes	Cancer	$5(Age/100)^5$
>15	0.10	0.0032	0.00004
15-24	0.10	0.0051	0.0015
25-34	0.14	0.012	0.011
35-44	0.22	0.044	0.045
45-54	0.49	0.16	0.14
55-64	1.23	0.45	0.34
65-74	2.73	0.98	0.74
75-84	6.17	1.3	1.4
85-	15.1	1.59	2.2

Cancer not signif. cause of death among young

Cancer significant

Multiple-switch theory?



[19] *Statistical Abstracts of the United States, 1991*, Tables 22, 28, 117 or 118

Smoking[20]

~ 500,000 total deaths (~ 25 percent of all U.S. deaths, ~one half of all regular smokers plus 100,000 from passive smoking)

160,000 from cancer[21]
(~30 % of all U.S. cancer deaths)

180,000 cardiovascular disease

84,000 pulmonary disease
(pneumonia, emphysema, bronchitis, influensa)

53,000 from passive smoking

15 years of life loss on average[22]

The U.S. Tobacco Industry[23]

$32 billion value of shipments, $25.5 billion value added in manufacturing (1991, 2.4% of national total value added in manufacturing); **$3 billion to farms** (2% of total farm income, 1992, p. 672). $3,750/acre (vs. $280 for average crop, pp. 680-681).

13% of world production (p. 677)

=> tobacco industry earns $60,000 ($6,000 for farmers) per death it causes (perhaps one death per job created per year)

[20] "The Global Tobacco Epidemic," *Scientific American*, May 1995, pp. 44-51. Brian E. Henderson, Ronald K. Ross and Malcolm C. Pike, "Toward the Primary Prevention of Cancer, *Science 254* (22 November 1991), pp. 1131-1138.

[21] *Cancer Statistics Review, 1973-1989* (Washington, D.C., National Institutes of Health, 1992)

[22] Based on 5.5 minutes per cigarette, 2850 cigarettes/capita, 250 million population, and 500,000 deaths/yr ("Global Tobacco Epidemic").

[23] *Statistical Abstracts of the United States, 1994*, p. 423.

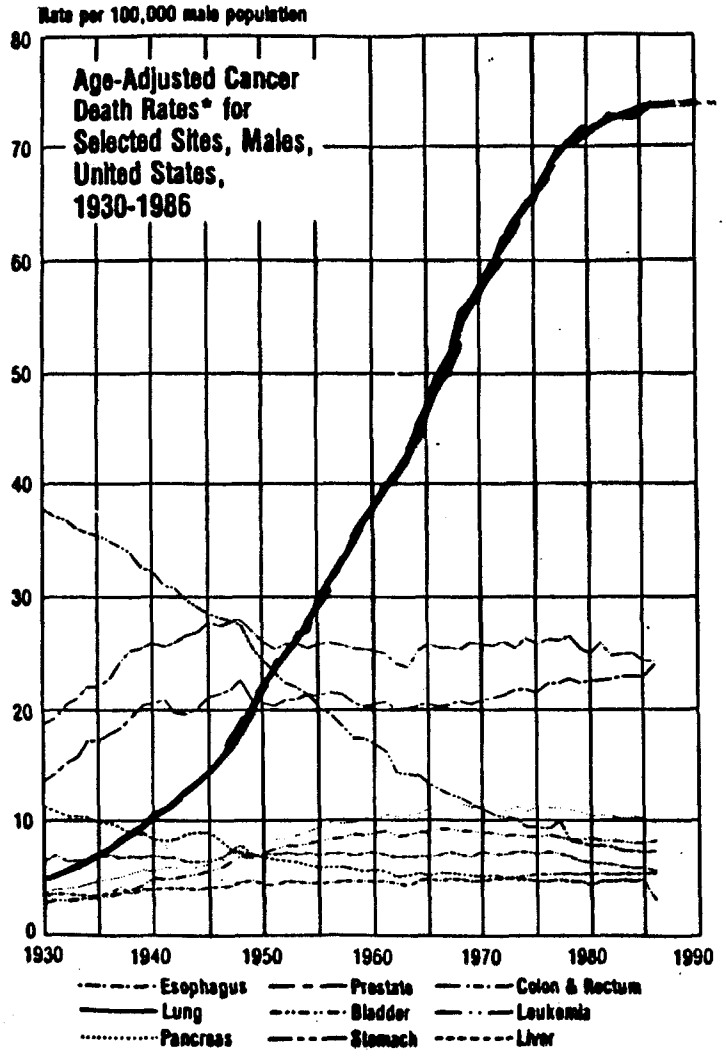


Figure 4-1. Age-adjusted cancer death rates* for selected sites, males, United States, 1930-1986.

*Adjusted to the age distribution of the 1970 U.S. census population.

Source: U.S. DHHS, 1989.

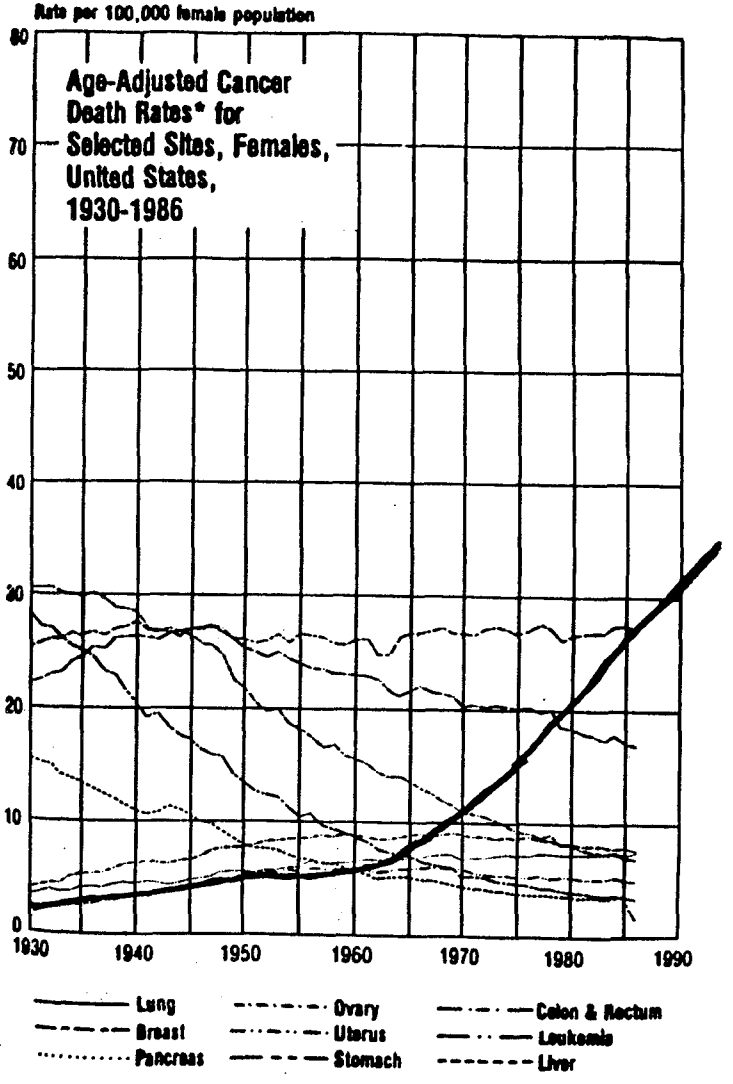


Figure 4-2. Age-adjusted cancer death rates* for selected sites, females, United States, 1930-1986.

*Adjusted to the age distribution of the 1970 U.S. census population.

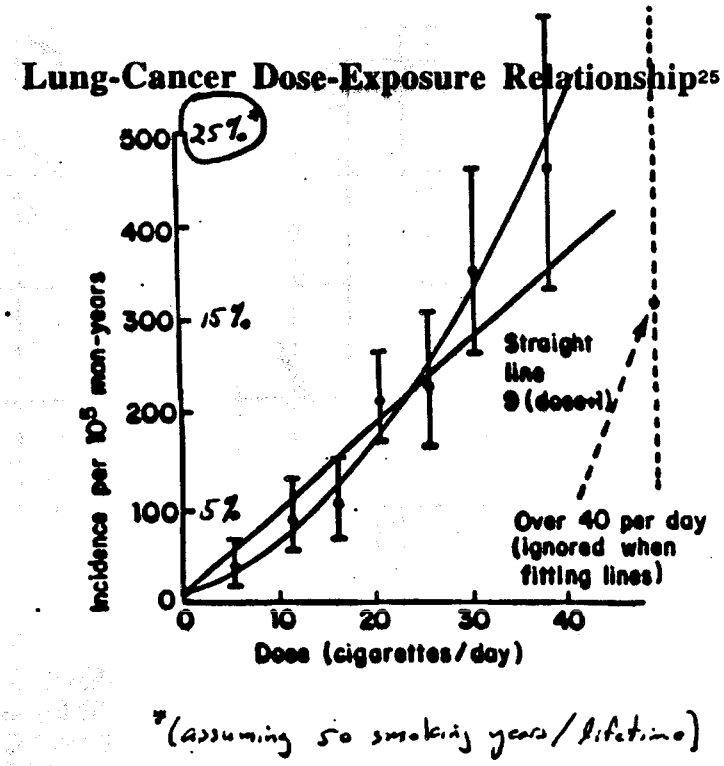
Source: U.S. DHHS, 1989.

Why a War on Cancer but No War on Smoking?

Twice average U.S. % profit on sales (5.1 percent, p. 559)

$3.2 billion in advertising, 1988
(68% on promotions, 3% of national total, p. 580)

$2 million in contributions to political parties and many high-level volunteers in 1992[24]



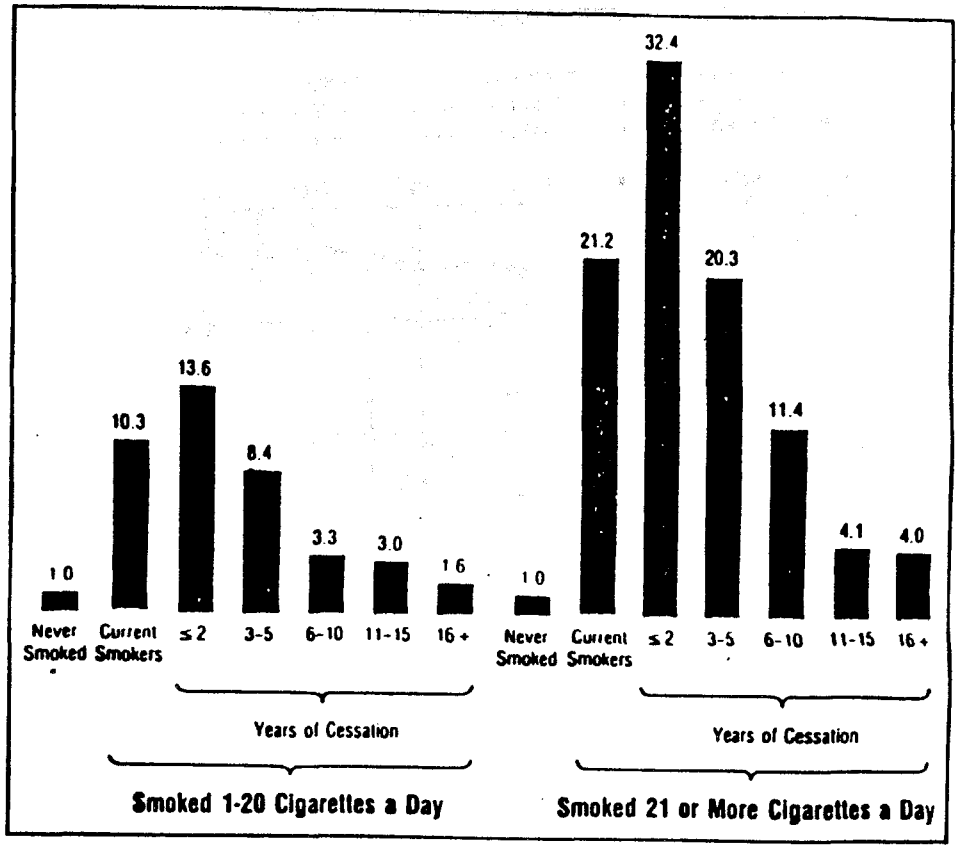


Fig. 8. Age standardized tumor incidence associated with smoking habits of British physicians. Plotted error bars represent 90% confidence limits. Plot redrawn from Doll and Peto (1978).

Figure 4-3. Relative risk of lung cancer in ex-smokers, by number of years quit, women, Cancer Prevention Study II.

Source: Garfinkel and Silverberg, 1991.

[24] *Tobacco Money, Tobacco People, Tobacco Policies* (Public Citizen Health Research Group and Advocacy Institute, August 1992).

[25] *Respiratory Health Effects of Passive Smoking: Lung Cancer and Other Disorders* (Washington, D.C., EPA/600/6-90/006F, 1992), p. 4-9.

Cancer Risk from Chemicals and Radiation

Occupational rates of cancer can be very high[26]

Chemicals:

Excess lung-cancer incidence increased from 0.6 to 6 percent as a function of exposure of coke-oven workers

Incidence of bladder cancer 100 percent among distillers of b-napthylamine and benzidene after 5 years.

Radionuclides:

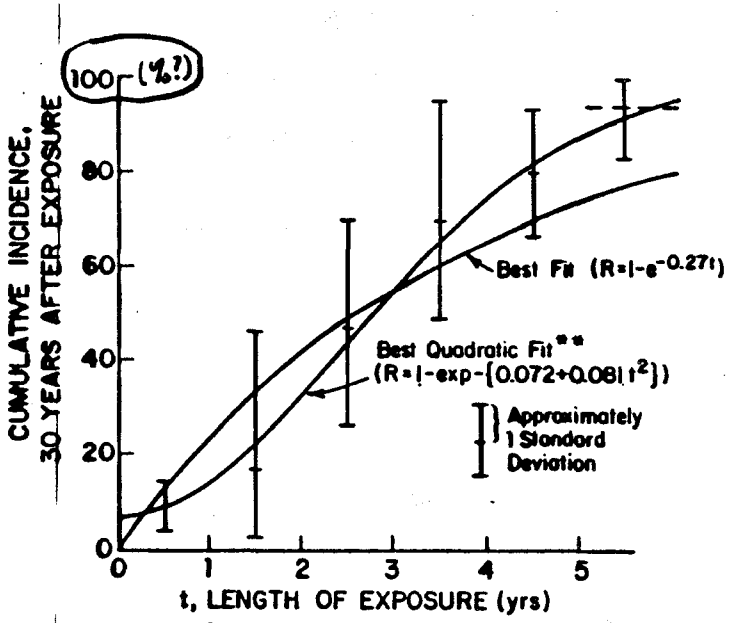
Incidence of radon-induced lung cancers in uranium miners up to 100 percent at highest exposure levels

Incidence of bone cancer in radium-dial painters tens of percents.

Non-occupational exposures much lower but exposed populations much larger

[26] See e.g. Zeise, Wilson and Crouch, *The Dose Response Relationships of Carcinogens: A Review* (Harvard University, John F. Kennedy School of Government, Energy and Environmental Policy Center, Report E-86-07, 1986).

Chemicals Can Hurt You



* Data given in Table 7

** Nonlinearity not statistically significant (p = 0.36)

Fig. 21. Urinary bladder cancers in 78 distillers of β-napthylamine and benzidene. Data from Williams (1958).

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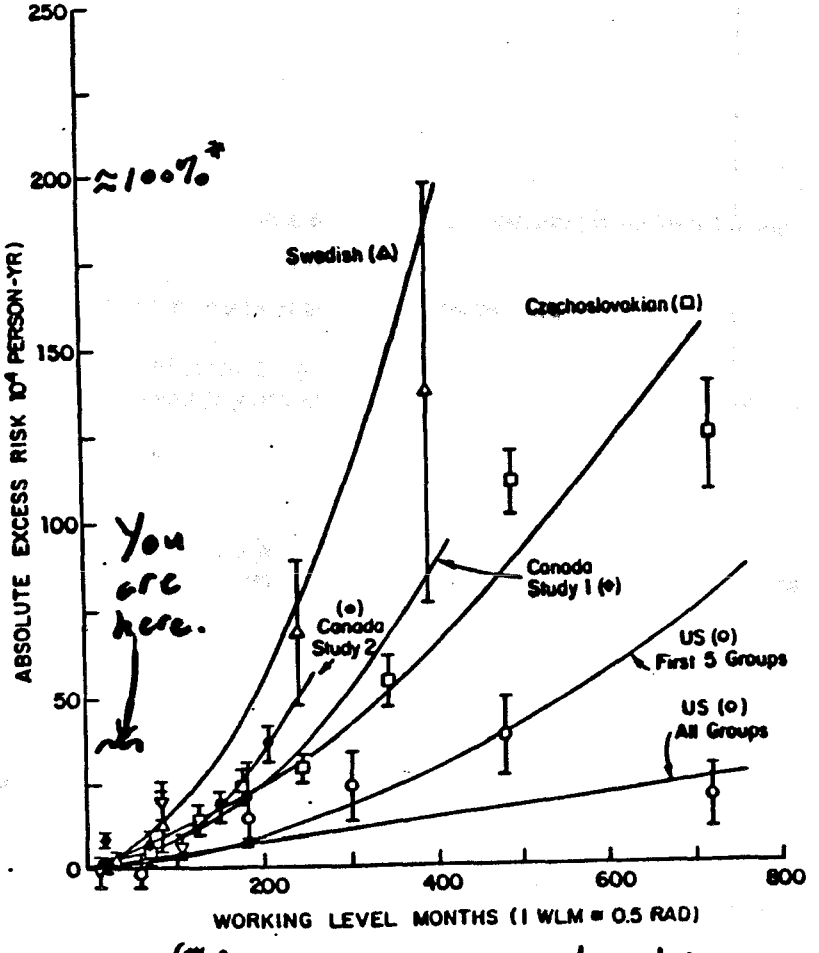

Fig. 13. Lung cancer in men occupationally exposed to radon gas in underground mines. Absolute excess risk (per 10^4 person-years) *versus* exposure in

Low-dose Cancer-risk Assessment[27]

"Torture it Enough and [like a captured spy] it will tell you anything."
-- William Ruckeshaus, former EPA Administrator

Hazard Identification

Epidemiological data:
(from occupational exposure, medical treatment, Hiroshima, etc.)

Animal bioassays: Feed `em all they can stand[28]

Bacterial mutagenicity: Ames test, etc.

Molecular structure: Similar to known carcinogens?

Dose-Response Assessment

Low-dose extrapolation:

Threshold? Linear? Multi-switch (quadratic, etc.)?

Animal-to-human extrapolation:

Effect of different lifetimes? (ordinarily ignored)

Effect of different body weights
(doses ordinarily scaled mg/kg-day)

Exposure Assessment

(ppm in air) · [20 kg (~20 m^3)] air/day = 20 mg/day

(ppm in water) · (2 liters water/day) = 2 mg/day

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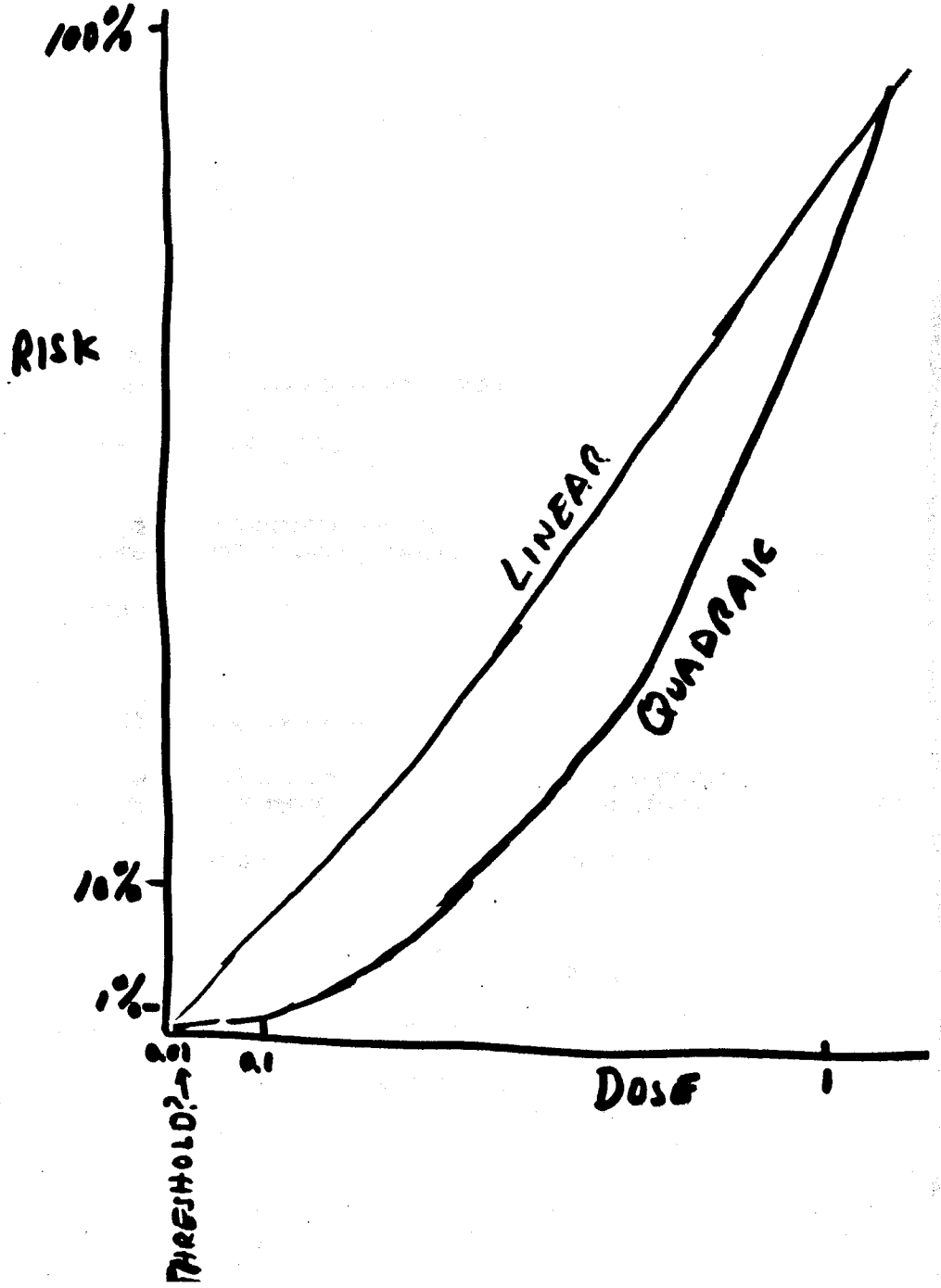
27 See e.g. *Risk Assessment in the Federal Government: Managing the Process* (National Academy Press, 19

28 For a good overview of the recent debate over the use of the "feed 'em all them can stand" approach, see Jea Marx, "Animal Carcinogen Testing Challenged," *Science*, 9 November 1990, p. 743.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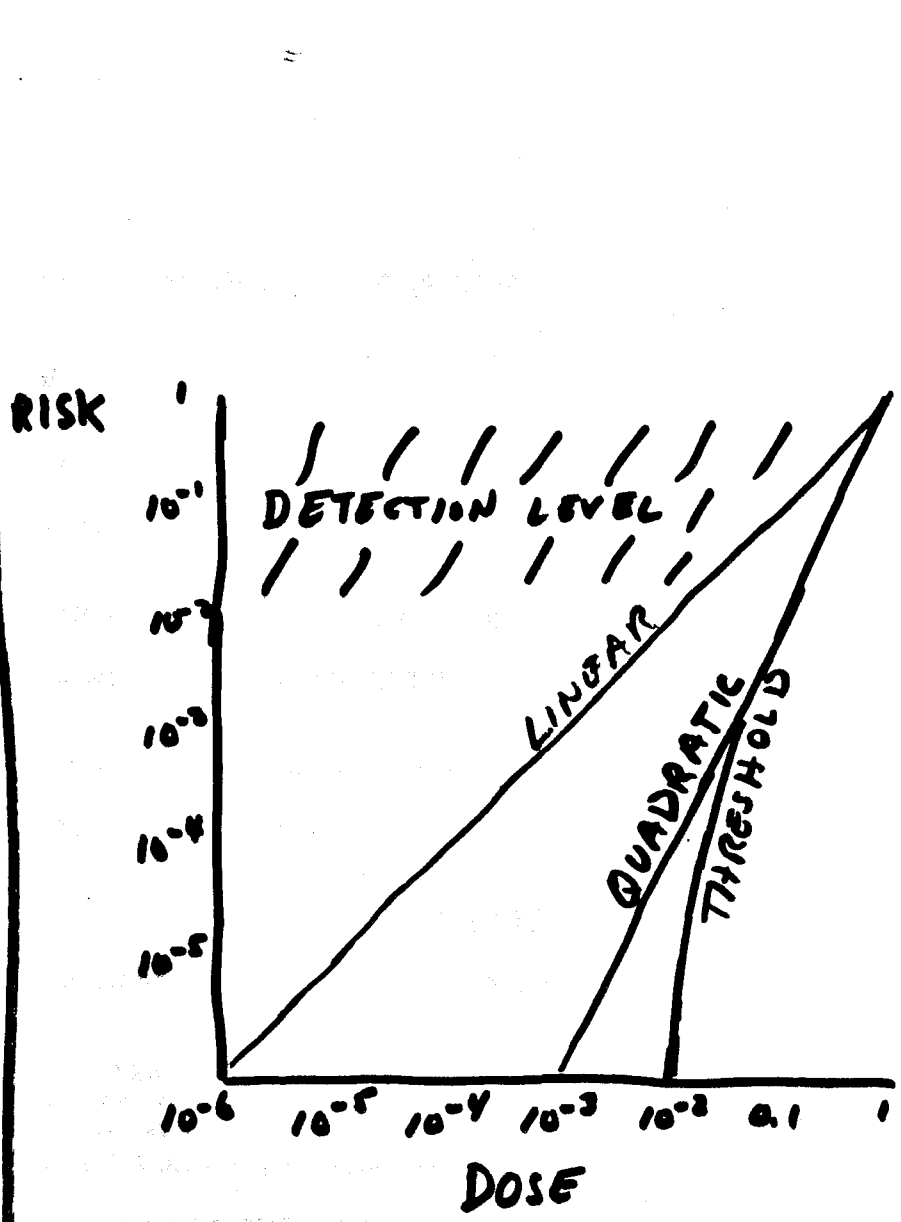
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What is an "Unreasonable Risk"?[29]

Occupational Safety and Health Act (OSHA)

To the "extent feasible," no employee will be injured
(20 substances regulated in 1985)

Food, Drug and Cosmetic Act (FDA, as amended in 1996)

"a reasonable certainty that no harm will result from aggregate exposure" to food contaminants and additives (saccarin exempted by Congress)

Balance risk of drugs with benefit

Clean Air Act (EPA)

"An ample margin of safety" (auto exhaust, asbestos, beryllium, mercury, vinyl chloride, benzene, arsenic, and radionuclides)

Clean Water Act (EPA)

Effluent should be cleaned with the "best available technology economically achievable"

[29] See e.g. *Risk Assessment in the Federal Government: Managing the Process* (National Academy Press, 1983)

Insecticide, Fungicide and Rodenticide Act and the Environmental Pesticide Control Act (EPA)

No "unreasonable adverse effects"

"Federal agencies do not tend to regulate risks of $1*10^{-5}$ or lower and tend to be ambivalent about risks between $1*10^{-4}$ and $1*10^{-5}$. Certainly (as absolute risks) these risks could never be detected in any normal way."
-- John Todhunter, Assistant EPA Administrator for Pesticides (1982)

Resource Conservation and Recovery Act (EPA)

Toxic wastes should constitute no "significant" hazard

Toxic Substances Control Act (EPA)

Toxic-waste dumps should not constitute an "unreasonable risk"

Hazardous Substances Act (CPSC)

"Highly toxic" substances should be banned

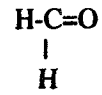
Consumer Product Safety Act (CPSC)

Products should not create an "unreasonable risk of injury"

Safe Drinking Water Act (EPA)

"to the extent feasible (taking costs into account)"

The Debate over Carcinogen Regulation: The Case of Formaldehyde[30]



6 billion pounds produced in U.S. in 1981 for use in plywood, particle board, paper & textile treatment, chemical intermediate,...

Animal Experiments:

Exposure (ppm)	Incidence of Nasal Carcinomas (cancer cases/animals)
14.3	103/232. (rats)
14.3	2/225. (mice) big species difference
5.6	2/235. (rats) threshold effect?
2.	0/236. (rats)

Exposures in U.S. Air:

3 ppm (8-hour average) limit in workplace (1.4 million workers [half in garment industry])

0.02-4.2 ppm in mobile homes & houses insulated with urea foam (11 million people)

0.1 ppm 24-hour average "frequently" in urban air

[30] F. Perera and C. Petito, "Formaldehyde: A Question of Cancer Policy? *Science 216* (1982), p. 1285.

Formaldehyde: The Regulatory Response

Results reported by Chemical Ind. Inst. of Toxicology (late 1980)

National Toxicology Program review group, National Institute for Occupational Safety and Health, academic experts and American Cancer Society all recommend treating formaldehyde as a potential occupational carcinogen

Consumer Product Safety Commission (CPSC) votes (Feb, 1982) to ban urea-formaldehyde foam insulation

but Formaldehyde Institute argues that "to regard formaldehyde as a likely carcinogen in man is not supportable" (argues also for threshold dose-effect curve)

EPA (after private meetings with Formaldehyde Inst.) concludes (Feb, 1982) that "rats seem to be particularly sensitive to formaldehyde...Long human experience does not seem to indicate any pressing concerns..."

and, in case brought by the Formaldehyde Institute, the Fifth Circuit Court overturns CPSC ban on urea-formaldehyde foam because of uncertainties in exposure and risk estimates (Reagan Administration barred appeal).

OSHA decided in 1982 not to issue an Emergency Temporary Standard because an estimated 4 formaldehyde-related cancer deaths per 1000 exposed workers at the then current standard would only double the average occupational mortality rate for manufacturing workers.[31] Standard lowered from 3 to 1 ppm in 1987.[32]

[31] N.A. Ashford, C.W. Ryan and C.C. Caldart, "Law and Science Policy in Federal Regulation of Formaldehyde" Science 222 (1983), p. 894.

[32] "U.S. Stiffens Rule on Formaldehyde Exposure" (*New York Times*, 22 November 1987, p. 45).

And What About Cost-Risk Assessment?

EPA staff advocated in 1985 that asbestos be removed from schools if cost is less than

$1,000,000 per life saved

Office of Management and Budget chief of regulatory policy, Douglas Ginsberg, **ruled** that, since the cancer deaths would be delayed by 40 years the **future benefit should be discount using the standard discount rate for federal projects of 10 percent.**

$1,000,000 = $22,000 today to save a life in 40 years
$[(1.10)^{40}]$

This story came out after President Reagan nominated Ginsberg to the Supreme Court.[33]

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33 New York Times, 1 November 1987, p. 1.