NUCLEAR ISSUES

CURRENT NUCLEAR STATUS

Hiatus in development in U.S. and W. Europe

Opportunity for review of past and future

BASES FOR OBJECTIONS TO NUCLEAR POWER

- Concerns about radiation exposures.
  reactor accidents, nuclear wastes
- Dislike of institutions, including their military links.
  perhaps of fading importance now

FRAMING THE EVALUATION BY LEVEL OF RISK

- Issues range in importance from minor to momentous.
- It is timely to identify and focus on the major issues.

CLASSIFICATION OF ISSUES BY DEGREE OF RISK

- Confined risks: can be analyzed; limited in scope
  nuclear reactor safety
  nuclear waste disposal
- Open-ended risks: cannot be well analyzed; global in scope
  nuclear weapons proliferation
  climate change
  energy scarcity in a world of growing population

LANDMARKS IN NUCLEAR ENERGY

1896 DISCOVERY OF RADIOACTIVITY

Recognition of "enormous stores of energy" in atoms

1932 DISCOVERY OF THE NEUTRON

Chain reaction soon suggested (Szilard) [based on Be !!]

"Power production . ..on such a large scale and probably with so little cost that a sort of industrial revolution could be expected; it appears doubtful, for instance, whether coal mining or oil production could survive after a couple of years." *(Ward,* 1934)

1938 FISSION DISCOVERED

1942 CHAIN REACTION ACHIEVED (CHICAGO): 200 W

1944 FIRST LARGE REACTOR (HANFORD): 250 MWt

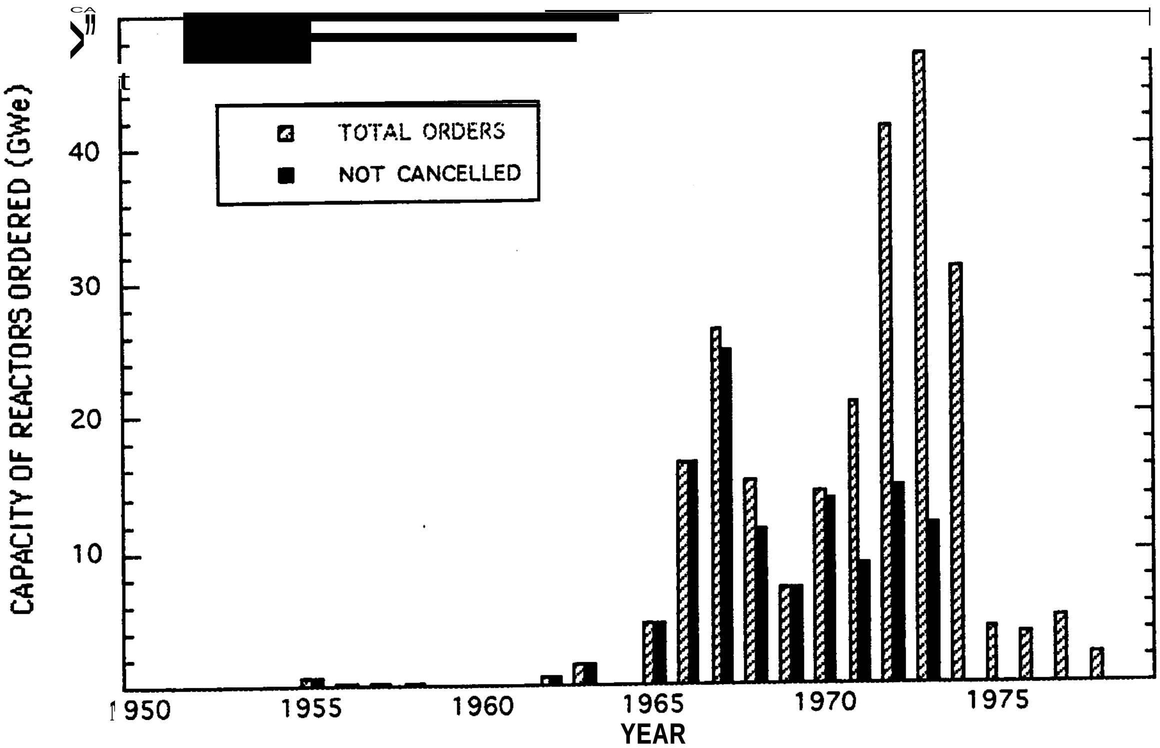
1957 FIRST U.S. COMMERCIAL REACTOR:
Shippingport (65 MWe) [AEC auspices]

1965 START OF LARGE-SCALE ORDERS IN U.S.

1973 PEAK YEAR FOR U.S. ORDERS
Also the <u>last</u> year for orders that resulted in <u>completed</u> reactors; ***period of active orders less than ten years!***

1996 LAST U.S. REACTOR COMPLETED
Watts Bar I, Tennessee (1177 MWe)

REACTOR ORDERS IN U.S., 1953 - 1978



YEAR FOR MOST ORDERS: 1973

YEAR FOR MOST COMPLETED ORDERS: 1967

YEAR FOR LAST COMPLETED ORDER: 1973

WHAT WENT WRONG FOR NUCLEAR POWER?

DROP IN DEMAND FOR ELECTRICITY

- Electricity sales growth, 1963-73: averaged 7.5% per yr
- Electricity sales growth, 1973-93: averaged 2.6% per yr

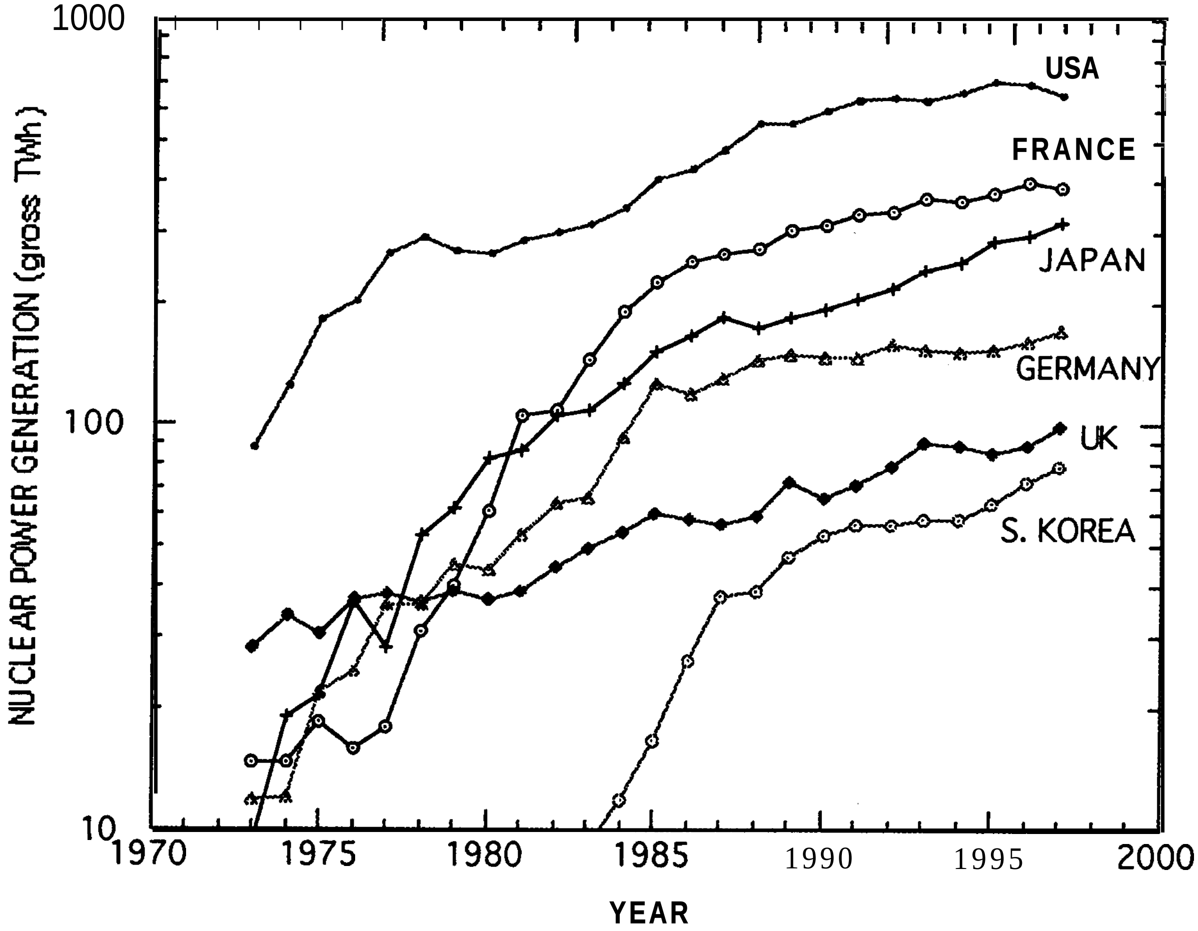
NUCLEAR ELECTRICITY BECAME TOO EXPENSIVE

- Nuclear costs rose sharply until 1990
  - delayed construction and new requirements
  - low efficiency of operation [now much better]
- Coal costs stopped rising after 1982

EFFECTIVE OPPOSITION TO NUCLEAR POWER

- Fear of reactor accidents: increased by TMI (1979)
- Concern over nuclear waste disposal
- Dislike of connections with nuclear weapons
- Effective means to slow nuclear construction
  - complex regulatory system: NRC and state bodies
  - availability of court challenges

GROWTH OF NUCLEAR GENERATION IN SELECTEDCOUNTRIES:1973-1997



REACTORS NOW OPERATING IN 32 COUNTRIES

NUCLEAR SHARE OF GENERATION, 1997 (BY UTILITIES)

France:	78%	Japan:	35%	U. Kingdom:	27%
Korea:	34%	Germany:	32%	USA:	20%

WORLD: 17%

REACTORS UNDER CONSTRUCTION(3/98--IAEA): 36

FSU & East Eur: 15 Asia: 18 France: 1 S. Amer: 2

U.S. ELECTRICITY GENERATION

GENERAL

Growth in electricity sales, 1977-97: ≈ 2.4% per year

Total generation (1997): 403 gigawatt-years

Share from non-utility generators has risen to 12%

SOURCES OF ELECTRICITY GENERATION (%) [1997]

Fossil fuels	69	(mostly coal)
Nuclear	18	(20% of generation by utilities)
Hydroelectric	10	
Other renewable	2	

RENEWABLE SOURCES (OTHER THAN HYDRO) (%)

Wood and waste	1.7	(mostly forest product industry)
Geothermal	0.5	
Wind	0.10	
Direct solar	0.03	(photovoltaic and thermal)

PROSPECTS FOR RENEWABLES

- Controversial
- Possibility of large (absolute) expansion correlates *inversely* with magnitude of present use
- Little experience with large-scale use of wind and '--direct solar (large available resource; intermittent)

Would reliance on renewable energy as <u>the</u> replacement ***for fossil*** *fuels be a prudent policy or too* ***large a*** *gamble?*

REACTOR SAFETY

GOOD PAST SAFETY RECORD OUTSIDE THE FSU

- > 8000 reactor-years of operation as of end 1998
- One accident with core damage (Three Mile Island)
  No accidents with large external radionuclide release

CHERNOBYL ACCIDENT (Ukraine, 1986)

- Large radionuclide release and many casualties
- Precipitated by poorly executed experiment
- Design defects
  - Positive void coefficient
  - Positive feedback at start of control rod insertion (!)
  - No containment
- Main lesson: confirms need for care in design and operation

IMPROVEMENTS IN U.S. REACTORS SINCE TMI

- Probabilistic safety analysis: shows that precursors of potential core damage events have been greatly reduced.
- 1997: no precursor event with as much as 10-4 chance of core damage (for ≈ 100 reactors)

FUTURE REACTORS ARE EXPECTED TO BE SAFER

- Benefit of past experience (evolutionary reactors)
- Greater reliance on passive features (advanced reactors)

U.S. PROGRAM FOR HANDLING NUCLEAR WASTES

PRESENT STORAGE OF SPENT FUEL

- most at reactors in water-filled cooling ponds
- some in dry storage in air-cooled protective casks at site

PLANS FOR EVENTUAL STORAGE

- wastes are to be placed in deep geological site
- only site under investigation: Yucca Mountain (Nevada)
- viability assessment (1998): "remains a promising site"
- schedule: if site is found suitable, to open in 2010 (??)

BASIC PROTECTION STRATEGY: DEFENSE-IN-DEPTH

- engineered barriers
  - multi-wall waste package to protect spent fuel
  - impediments to water reaching waste package
- natural barriers
  - little water flow into repository site
  - slow motion of water and escaping nuclides from site

EXPECTED PERFORMANCE

- Studied with Total System Performance Assessments
- Negligible releases for 10,000+ years
- Maximum releases after 100,000 years (most has decayed)

PROPOSED STANDARDS FOR YUCCA MOUNTAIN

PREVIOUS EPA PROPOSAL

- time horizon: 10,000 years
- radioactivity releases: < 1000 deaths in 10,000 years limits:
- possible show-stopper: 0.1% increase in atmospheric ^{14}C due to escape of carbon dioxide (gas).

  [natural ^{14}C: 1 mrem/yr, 10^{10} people ---> 10^{5} person-Sv/yr implies 5000 deaths/yr if regulatory guidelines are correct]
- Congress mandated NAS study and recommendations

NAS RECOMMENDATIONS (1995)

- peak risks likely to occur after 10,000 years
- time horizon should extend to 1 million years
- risk should be calculated for members of "critical group"
  this is the most exposed group; probably < 100
- cancer risk limit for these individuals: 10^{-5} to 10^{-6} per year

PERSPECTIVE ON RECOMMENDATIONS

- corresponding dose limits (present regulatory calculations):
  20 mrem/yr to 2 mrem/yr
- technological improvements not considered (cancer cure ?)
- new EPA standards not yet established

NUCLEAR POWER AND NUCLEAR WEAPONS

POSSIBLE POSITIVE LINKAGES

- Existence of nuclear power infrastructure provides personnel and equipment which could ease path to nuclear weapons.
- Plutonium might be diverted from power reactors for weapons.
- With breeder reactor program, plutonium might be widely available.

POSSIBLE NEGATIVE LINKAGES

- Energy shortages, in particular oil shortages, may produce conflict leading to war, including nuclear war.
  Examples: Japan, 1941; mid-east in future??
- Strong civilian program may increase US influence on reactor design and operation, as in efforts with North Korea.

NO CLEAR LINKAGE TO DATE

- Major nuclear weapon states developed weapons first, then obtained civilian nuclear power: US, ***USSR, UK, France, China***
- Other countries
  India and Pakistan: bomb program started separately
  Iraq, Israel, North Korea: have no civilian nuclear power
  Iran: beginning civilian programs; weapons goal suspected
- Ending nuclear power in US unlikely to have much impact
  Other countries will continue its use: ***France, Japan, S. Korea*** . . . . .
  U.S. and other countries will retain nuclear weapons
- Net sign of linkage in doubt.

GLOBAL CLIMATE CHANGE

CARBON DIOXIDE CONCENTRATIONS

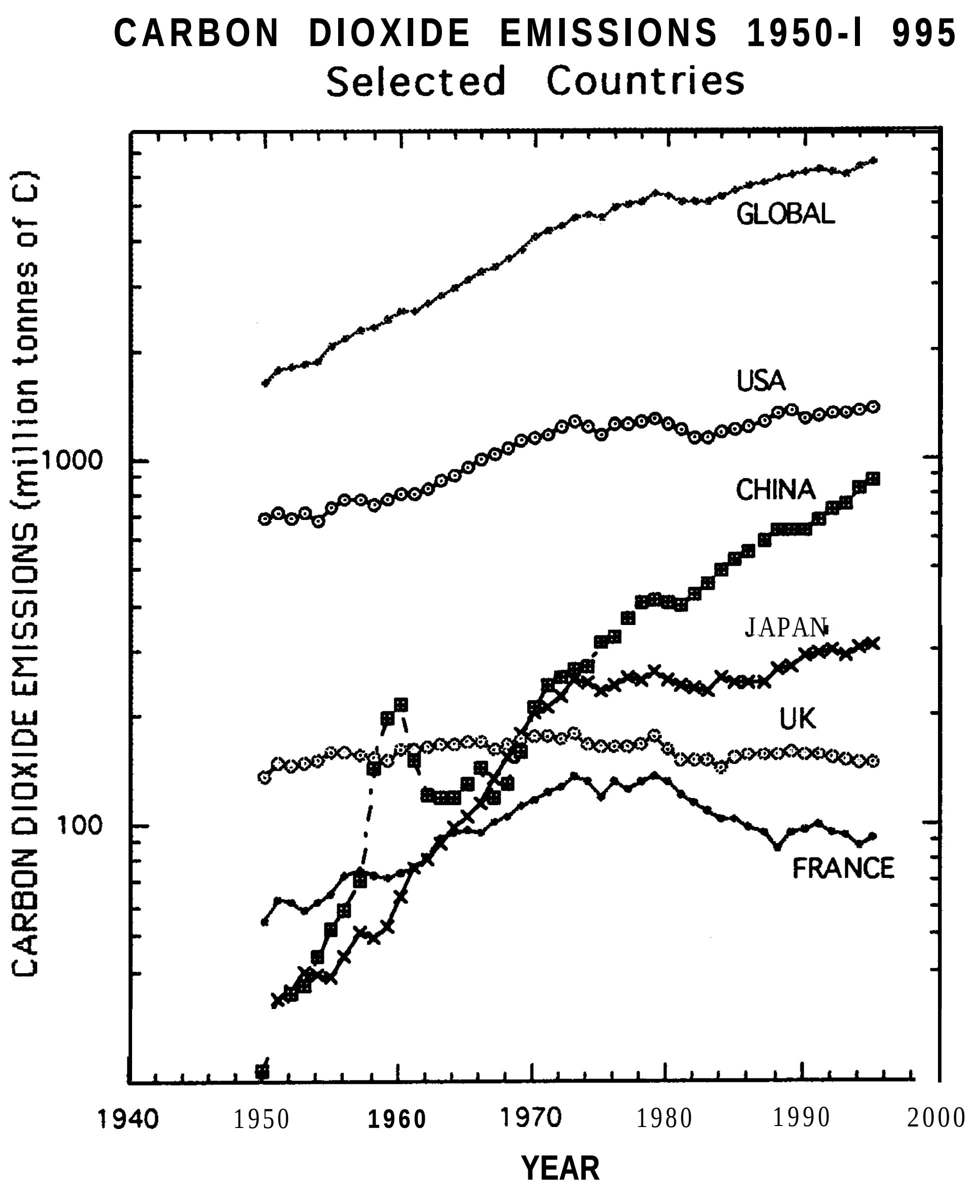
- CO_2 is dominant anthropogenic greenhouse gas; accounts for 85% of global warming potential for U.S. emissions
- Produced by fossil fuel combustion.

PREDICTIONS FOR YEAR 2100 (*IPCC* 1995):

- increase in temperature: $\approx 2°C$ [range: 1°C to 3.5°C]
- higher sea level: $\approx$ 50 cm [range: 15 cm to 95 cm]
- changes in rainfall patterns, possibly in storm patterns

ENERGY POLICIES AND PROJECTIONS

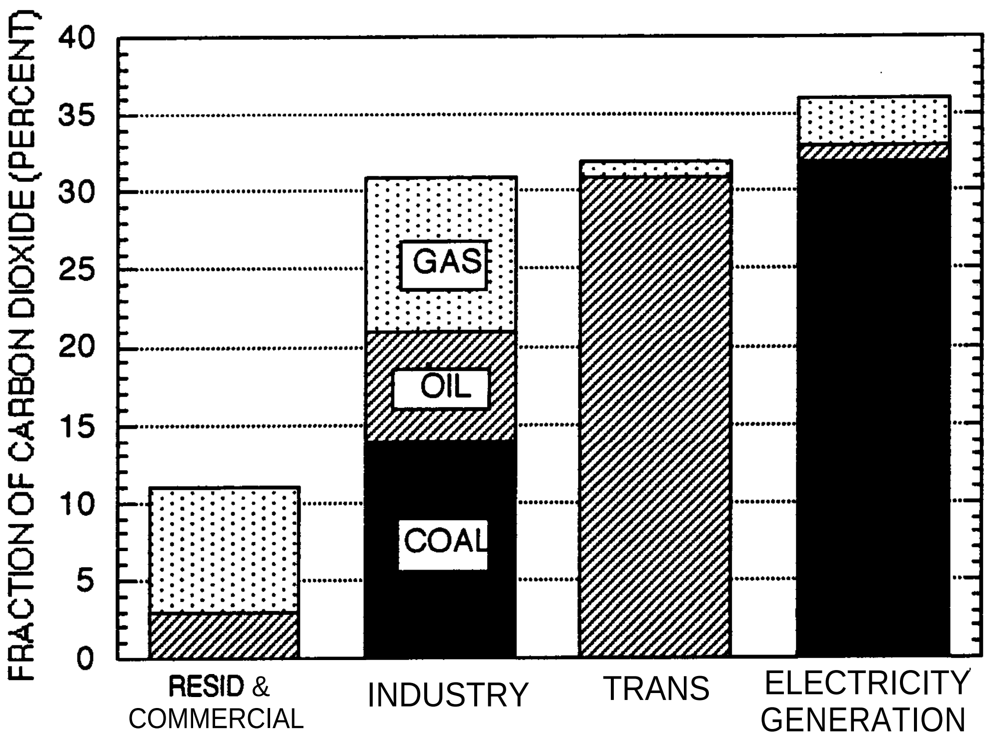
- mitigation options
  conservation [desirable in any case]
  switch from coal to natural gas [half-measure]
  sequestration of carbon dioxide [practical ??]
  renewable energy [how expandable?]
  nuclear energy
- U. S commitment at Kyoto (1997):
  emissions in 2010 are to be 7% <u>below</u> 1990 levels
  corresponds to 15% below 1997 levels
- Unlikely that Kyoto target will be met.



SOME KEY FEATURES:

- Most countries show steady rise.
- China has low per capita rate, but very high growth rate.
- Drop for France 1979- 1988 due to switch to nuclear power.

SOURCES OF CARBON DIOXIDE EMISSIONS
UNITED STATES, 1997



TOTAL U.S. ANNUAL EMISSIONS (fossil fuels)

Total = 1.48 billion tonnes (≈ 23% of world total)

Kyoto goal (2010): 7% below 1990 level (15% below 1997)

MAJOR SOURCES, 1997

Coal for elect generation: 32% (straightforward to replace)

Oil for transportation: 3 1% (more difficult to replace)

CARRYING CAPACITY OF THE EARTH

WORLD POPULATION

- Has risen from 2.5 billion in 1950 to 6 billion in 1999
- Heading to 10 billion (and beyond ?) in next century.
- Conflict coming between rising population and decreasing fossil fuel supplies.

CARRYING CAPACITY OF THE EARTH

Comprehensive treatment:

How Many People Can the Earth Support? by Joel Cohen

"If an absolute numerical upper limit to human members of the Earth exists, it lies beyond the bounds that humans would willingly tolerate." --- Joel Cohen

" What one really wants to know is this: after we define the minimally rich sort of life we human beings would consent to live, what is the maximum number of people possible."- --Garrett Hardin

ESTIMATES OF CARRYING CAPACITY

Van Leeuwenhoeck (1679): 12 billion

Recent estimates (as summarized by Cohen)
Range: < 2 billion to >> 20 billion
Central: in neighborhood of 10 billion

Extrapolation from national densities:
United Kingdom ---> 31 billion; U.S. ---> 3.6 billion

CONSTRAINTS ON WORLD CARRYING CAPACITY

TYPES OF CONSTRAINT

- *Material*: availability of necessities and desired material ameni ties.
- Ecological: impact on environment, including destruction of wilderness and species extinction.
- *Aesthetic or philosophical:* The attractiveness, or value, of open spaces; the distastefulness of crowding.

Material constraints are the easiest to quantify, although ecological or aesthetic constraints may be more compelling.

CONSTRAINTS BASED ON FOOD SUPPLY

- These are the most frequently cited.
- Related to availability of arable land, water, and energy.
- Energy is used for irrigation, fertilizer production, farm machinery, transportation of crops.
- Carrying capacity depends on assumed diet
  meat calories $\approx$ 10 times more expensive in grain than direct carbohydrate calories
  (20% from meat means 2.8 times as much grain)

ENERGY LIMITS AND POPULATION LIMITS

EXAMPLE: ESTIMATES OF DAVID PIMENTEL et al (1994)

- Target for per capita energy use: 1/2 present U.S rate
  implies 175 MBTU/yr = 5.9 kW (primary)
- Assumes that solar energy is sole fossil fuel replacement
- Assumes limit on solar energy in US: 35 quads/yr
  [based on estimates of land area, too conservative ??]
- Acceptable U.S. population: 200 million
- World: 200 quad/yr ---> 1.1 billion (if 175 MBTU/yr)

"Does human society want IO to I.5 billion humans living in poverty and malnourishment or I to 2 billion living with abundant resources and a quality environment? "

EXAMPLE: ESTIMATES OF EHRLICH ***et al*** (1994)

- Takes energy use as measure of human impact on Earth
- Deduces optimal population of about 2 billion.

CAVEAT: In each case numbers are arbitary, questionable

BUT ESSENTIAL POINT REMAINS:

Will (or should) energy supply set limits on population?

ENERGY ABUNDANCE: OPTIONS CREATED
WATER DESALINATION

OVERALL CONTEXT

- Water supplies may become major population constraint.
- Shortages exist now in some parts of world, even U.S., and increasing shortages are anticipated.
- Water conservation and transfer often the best solution.
- Fallback Itemative: desalination of sea water

PRACTICALITY OF DESALINATION

- Energy required (reverse osmosis): ≈ 6 kWh per m^3
- Total cost ≈ \$1 per m^3
- Per capita water withdrawal rates (approx in 1980s)

U.S.	2200	m^3/yr
Europe (big variations)	730	
World	660	
Possible U.S. target	1000	m^3/yr (6000 kWh/yr)

- Per capita cost: \$1000/yr (mostly indirect, e.g. food)
- National elec demand: 1600 TWh/yr = 180 GWe (av)
- Would be "affordable" if essential
  represents 45% increase over present electricity use

ENERGY ABUNDANCE CAUTIONS

CONCERN:

Unlimited energy supplies may foster excessive growth.

"If an abundant source of low-cost energy could be found it may be the worst thing that has every happened to the human race"

Albert Bartlett (1989), in re cold fusion "discovery"

" A population may be too crowded, though all be amply supplied with food and raiment. It is not good for man to be kept perforce in the presence of his species...Solitude, in the sense of being often alone, is essential to any depth of meditation or of character; and solitude in the presence of natural beauty and grandeur is the cradle of thought and aspirations....

John Stuart Mill (1848), as cited by Joel Cohen
[world population was then about one billion]

Other concerns: land degradation, species extinction. . . .

POPULATION QUESTIONS

- What is an desirable, sustainable world population?
- "' Can it be reached peaceably?
- Would ample energy supplies smooth the transition or encourage excess?

ENERGY ABUNDANCE: OPTIONS CREATED
WATER DESALINATION

OVERALL CONTEXT

- Water supplies may become major population constraint.
- Shortages exist now in some parts of world, even U.S., and increasing shortages are anticipated.
- Water conservation and transfer often the best solution.
- Fallback ltemative: desalination of sea water

PRACTICALITY OF DESALINATION

- Energy required (reverse osmosis): ≈ 6 kWh per m^3
- Total cost ≈ \$1 per m^3
- Per capita water withdrawal rates (approx in 1980s)

U.S.	2200	m^3/yr
Europe (big variations)	730	
World	660	
Possible U.S. target	1000	m^3/yr (6000 kWh/yr)

- Per capita cost: \$1000/yr (mostly indirect, e.g. food)
- National elec demand: 1600 TWh/yr = 180 GWe (av)
- Would be "affordable" <u>if</u> essential
  represents 45% increase over present electricity use

ENERGY ABUNDANCE CAUTIONS

CONCERN:

Unlimited energy supplies may foster excessive growth.

"If an abundant source of low-cost energy could be found it may be the worst thing that has every happened to the human race"

Albert Bartlett (1989), in re cold fusion "discovery"

"A population may be too crowded, though all be amply supplied with food and raiment. It is not good for man to be kept perforce in the presence of his species...Solitude, in the sense of being often alone, is essential to any depth of meditation or of character; and solitude in the presence of natural beauty and grandeur is the cradle of thought and aspirations....

John Stuart Mill (1848), as cited by Joel Cohen
[world population was then about one billion]

Other concerns: land degradation, species extinction....

POPULATION QUESTIONS

- What is an desirable, sustainable world population?
- Can it be reached peaceably?
- Would ample energy supplies smooth the transition or encourage excess?

CONCLUDING POINTS

CRUCIAL ISSUES IN CONSIDERING NUCLEAR POWER

- The most feared dangers, of reactor accidents and nuclear waste disposal, involve risks of limited scope.
- Much greater risks are involved in nuclear weapons, global warming, and energy scarcity.
- The implications of weapons issues for nuclear power are ambiguous.
- Nuclear power can clearly help restrain CO_2 emissions.
- Nuclear power can clearly mitigate energy scarcity.
- It is an imprudent gamble to count on renewable energy as the sole replacement for fossil fuels.

STEPS TOWARD REVITALIZING U.S. NUCLEAR POWER

- University educational and research programs (given a a credible belief in a nuclear future).
- Progress at Yucca Mountain, within a framework of reasonable waste disposal standards.
- Federal encouragement of prototype next-generation reactors.
- A reappraisal of the environmental risks of using nuclear power vs. those of trying to do without it.