Nuclear power

in cauda venenum

Firenze, 30 May 2010

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Nuclear power in our society

- energy security
- industrial & financial interests
- political & economic interests
- military & geopolitical stability aspects
- public interests: health risks & sustainability

Nuclear power:
technically the most complex energy system ever

- opaque to decision makers
- culture of secrecy
- costs and safety practically uncontrollable
- politicians advised by interest groups, e.g.
  IAEA, NEA, WNA, NEI, Areva, EdF

This study

Life cycle assessment (LCA) + energy analysis
- physical
- global perspective
- long time horizon

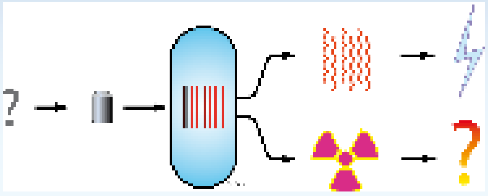
Objectives:
- transparency
- independent scientific arguments

Outline

- LCA + energy analysis
- nuclear CO_2 emissions
- uranium *E*-quality
  - energy cliff
  - coal equivalence
  - CO_2 trap
- tail of the chain
  - energy on credit
  - après nous le déluge
- conclusions

What lies behind and ahead of this glossy image?

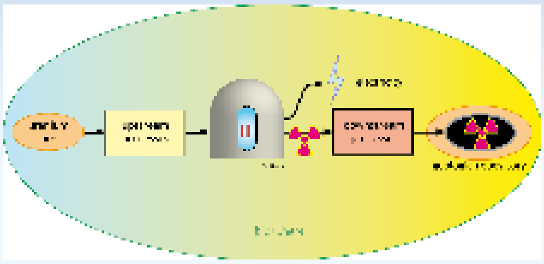
A nuclear reactor generates
heat and **radioactivity**
inextricable and irreversible



Where does the nuclear fuel come from?

What happens to the human-made radioactivity?

The nuclear chain:
nuclear power from cradle to grave



Life cycle assessment LCA-1

Upstream processes (head of the nuclear chain)

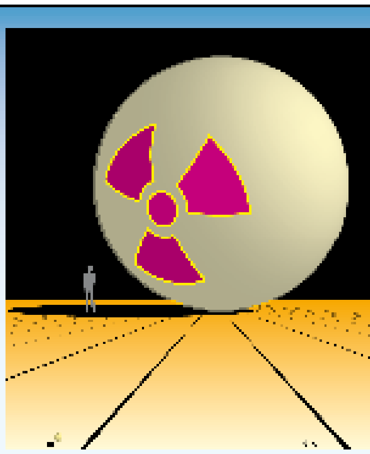
- uranium mining
- conversion
- enrichment
- fuel fabrication

+

- construction nuclear power plant
- operation + maintenance + refurbishments NPP

Human-made radioactivity by fission:

1 billion
x
natural



Life cycle assessment LCA-2

Downstream processes (tail of the chain)

- spent fuel interim storage
- spent fuel packaging
- other rad waste handling and packaging
- construction geologic repository
- definitive storage all rad wastes in geologic repository
- restoration uranium mine site to habitable condition

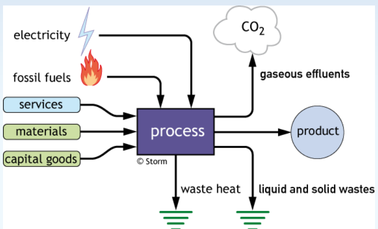
+

- cleanup + dismantling NPP
- definitive storage of dismantling debris in geologic repository

Energy analysis

Balance of all energy inputs and outputs

- direct E inputs (fossil fuels + electricity)
- indirect E inputs, embedded in materials, services, buildings, equipment



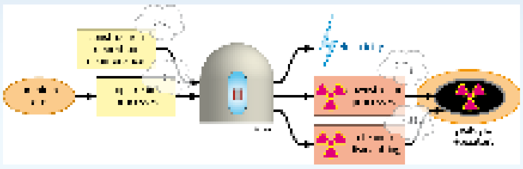
General outline industrial process

All processes of the nuclear chain, except the nuclear reactor itself, are conventional industrial processes, emitting CO_2.

Ergo: nuclear power produces CO_2.

The nuclear chain:
nuclear power from cradle to grave

- nuclear fuel chain: ore – fuel – fission – spent fuel
- reactor chain: contruction – operation – dismantling



cradle to grave

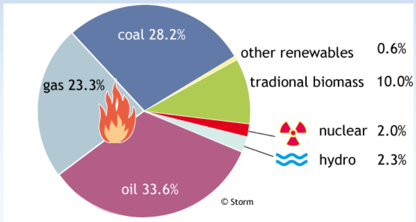
Nuclear power and greenhouse gases (GHGs)

- current lifetime emission 85-130 gCO_2/kWh
- increases over time
- emission other GHGs not known, but very likely
- ‘no data’ does not equal ‘no emission’

Enrichment in USA: ~5 gCO_2eq/kWh freon-114

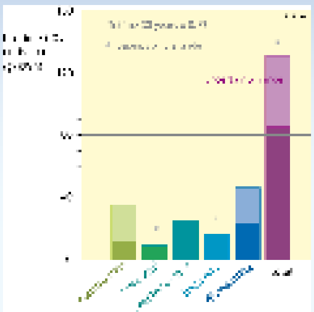
Note difference gCO_2/kWh and gCO_2eq/kWh !

Nuclear contribution to the world energy in 2008



world energy consumption in 2008: ~491 EJ
traded energy: 439 EJ

CO_2 emission of the nuclear chain
(conditions 2010)



Energy quality of uranium resources:
the ignored factor

E quality =
E output 1 kg U in reactor
minus
E input chain + extraction 1 kg U from ore

The larger a uranium resource,
the lower its E quality

(A common geologic feature)

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The *average E quality* of world uranium resources goes down over time

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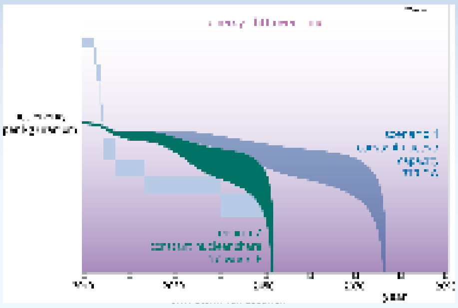
Energy cliff over time



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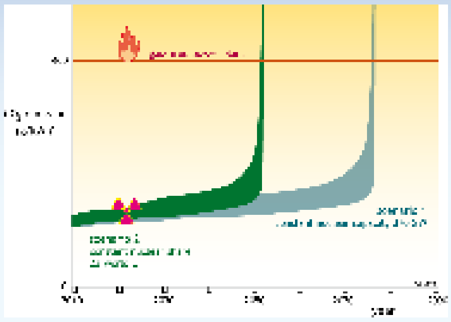
The CO_2 trap:
nuclear CO_2 emission over time



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Uranium resources: **economic** view

- criterion: price of U
- higher U price >
  more exploration >
  more discoveries >
  larger U resources
- ergo: U resources practically inexhaustible

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Uranium resources: **energy** view

- criterion: net energy
- not U price, but E quality decisive
- beyond energy cliff:
  nuclear power = energy sink
- ergo:
  net energy content world U resources limited

Coal equivalence

E content uranium ore = E content coal

At ore grade G = 0.1-0.2 kg U/tonne ore

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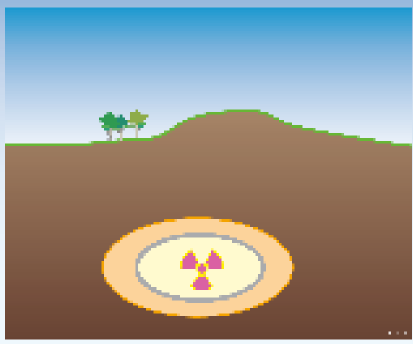
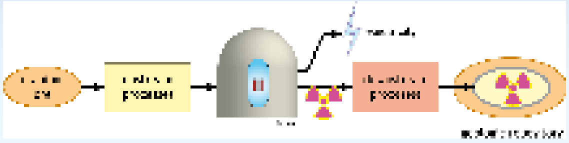
One reactor (1GWe) generates each year
1000 nuclear fission bomb equivalents (15 kt)
of radioactivity

Each year 370000 Hiroshima bomb equivalents
added to world radioactive inventory



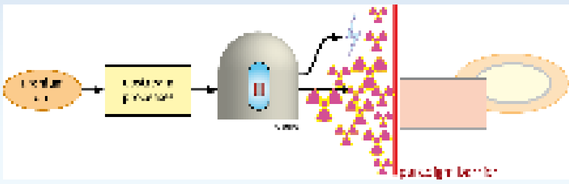
The least dangerous option: all human-made
radioactivity in a geologically stable repository

The nuclear chain as it ought to be



cooking the meal consuming the meal washing the dishes

The nuclear chain as it happens to be



the dishes are piling up

Paradigm barrier

- short-term profit seeking
- habit of living on credit
- *après nous le déluge* attitude
- belief in unproved technical concepts

Increasing nuclear health risks

- growing chances of spread of radioactivity
  - increasing amount bomb-equivalents
  - deteriorating materials & facilities
- Chernobyl-like disasters with spent fuel

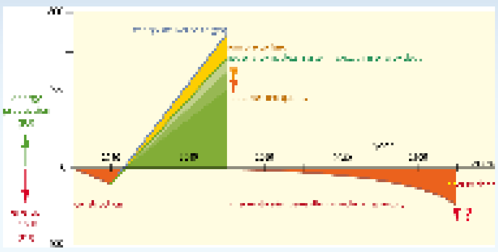
No priority in the nuclear industry:
après nous le déluge

Après nous le déluge

Nuclear power = energy on credit (1)

- energy debt
- CO_2 debt
- material debt

Energy debt



Energy payback time

	years	depends on
• nuclear	10 - 27	ore grade
• wind	< 0.5	
• photovoltaics	1-3	location

nuclear power = energy on credit (2)

Economic concepts invalid

- energy = conserved quantity
- size unprecedented
- timescale (>100 years) unprecedented
- investments pure losses
- debt grows over time

Monetary debt, NDA first cost estimates:

- cleanup and decommissioning
  - Sellafield reprocessing plant €**60-120bn**
  - 1 nuclear power station €**5-10bn**/GWe
- geologic repository €**xbn**

Man on the moon (Apollo project)
final cost (€2008) < €100bn

Conclusion 1

Nuclear power does not comply with any sustainability criterion

- energy cliff
- CO_2 trap
- energy debt
- high & rising consumption of scarce materials (non-recyclable)

Conclusion 2

Nuclear power seriously delays transition to sustainable energy supply

- monetary black hole
- ties down future economic means
- diverts societal commitment

Conclusion 3

We do not need nuclear power:
there are by far better solutions

- cheaper
- faster
- safer
- constant flow (inexhaustible)
- constant quality
- capacity meets world demand
- without further deterioration of the biosphere
- geopolitical stability

Conclusion 4

We don't need new technology
We just need a new paradigm