ASPO06 Conference
Cork, September 17-18, 2007

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The Nuclear Energy Option
facts and fantasies

- **What this talk will not contain (because of time constraints)**
- **Energy from nuclear fission**
  - **Conventional Reactors: Status and Perspectives**
  - **Fast Breeders and Generation IV power plants**
  - **Perspectives of uranium extraction**
- **Energy from nuclear fusion or**
  Why Deuterium Tritium fusion will not lead to commercial energy production!
- **Summary**

What this talk will not contain:

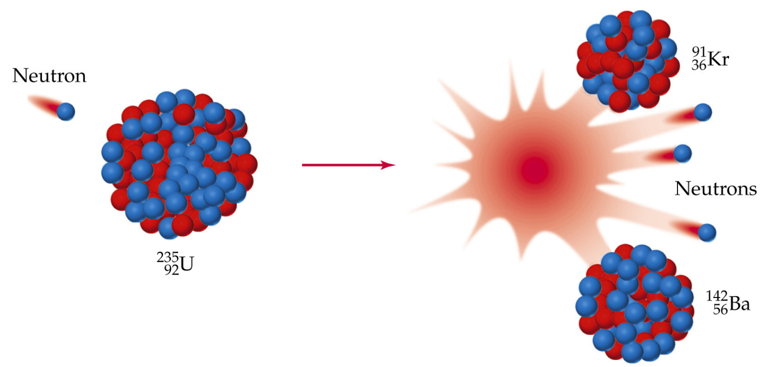
but what a more detailed nuclear energy debate should discuss!

- **The physics of nuclear fission and fusion energy.**
- **Nuclear fission energy and nuclear weapons.**
- **Real and imagined health effects from α, β, γ radiation.**
- **The problems of nuclear waste.**
- **How CO_2 free is nuclear fission energy.**
- **Why high energy physics is fascinating even though it is not energy related.**

Energy from nuclear fission

neutron (slow)+$U^{235} \to X + Y +$ 2.5 fast neutrons + 200 MeV energy

1 neutron needed for the chain reaction and $\approx$ 1.5 free for other reactions
A 1 GW(e) fission power plant needs $\approx 10^{20}$ fission processes/sec.



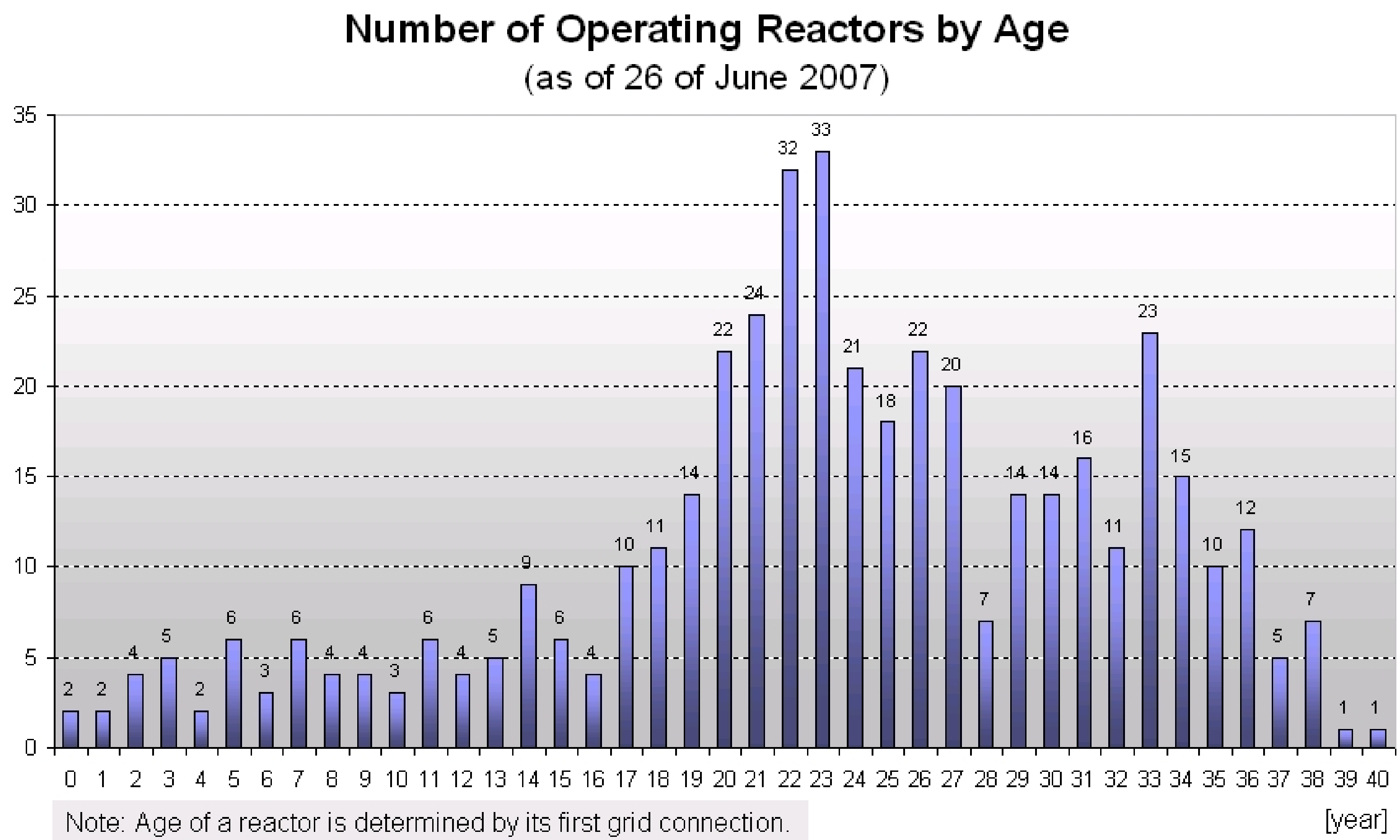
Energy from deuterium tritium fusion

$$H^2 + H^3 \to He^4 + n + 17.59 \text{ MeV energy}$$

A hypothetical 1 GW(e) fusion power plant needs $\approx 10^{21}$ fusion reactions/sec

The age structure of nuclear power plants

- Since 10 years about 3-4 reactors are completed per year
- From 1980-1985 about 20 to 30 reactors were completed per year
- about 100 reactors are between 30 and 40 years old.
  Expected to "retire" during the next 10-15 years!



source www.iaea.org

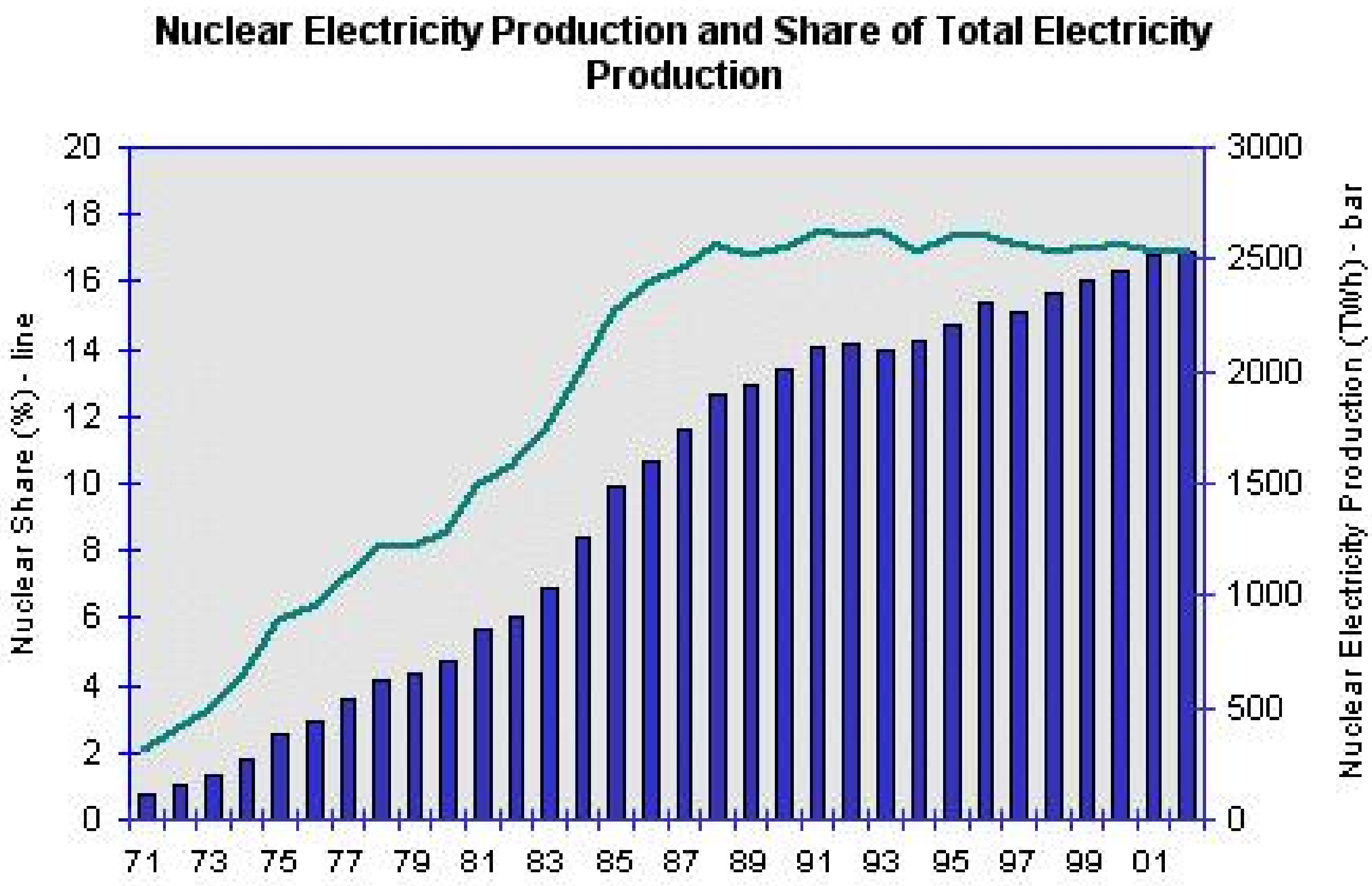
Nuclear Fission Energy today (I)

Some numbers from the International Atomic Energy Agency, IAEA (website: www.iaea.org):

- **439 nuclear power plants with 371 GW(e) in operation;**
- **World nuclear electric energy production (2005): 2768 TWh**
  Today nuclear power plants make 15.2% of the world's electric energy, maxium fraction so far was 18% in 1993.
- **30 reactors under construction (2007),**
  current planning indicates that 3-4 reactors with about 4 GW(e) will be completed per year during next 5-10 years.
  compared with expected yearly shutdown of about 3 GW(e)
  $\rightarrow$ limited "growth" rate of $\approx$ 0.3% per year.

Nuclear Fission Energy 1970-2002 (II)
Electricity from nuclear fission:

Electric energy makes 16.3% of todays world energy mix!
(→ only 2.5% of world's energy mix from nuclear fission!)



source www.iaea.org

Fast breeder reactors

A fast reactor operates with prompt fission neutrons ("fast")
needs higher enrichment of U235 or PU239 and sodium cooling

theoretical ideas/hopes/claims from 30-40 years ago:

optimal use of the "unused" 1.5 fission neutrons to
increase fissile resources by a factor of $\approx$ 60(!)
by "breeding" fissile material faster than fissioning it

U238 + neutron $\rightarrow$ Pu239 and Th233+ neutron $\rightarrow$ U233

30 years of fast reactors are not really a success story!

Few countries tried to construct (larger) expensive prototypes:
Only one operating 0.56 GW(e) reactor remains today in Russia

Other 12 larger fast reactors never functioned well, are now closed or not operating.

Little is known (openly?) about fast reactor running experience.

Fast breeder Reactors status and perspectives

2 prototype fast reactors are currently under construction:
India 470 MW(e) and Russia 750 MW(e),
expected start 2010 and 2012.

No commercially functioning fast breeder exists today!

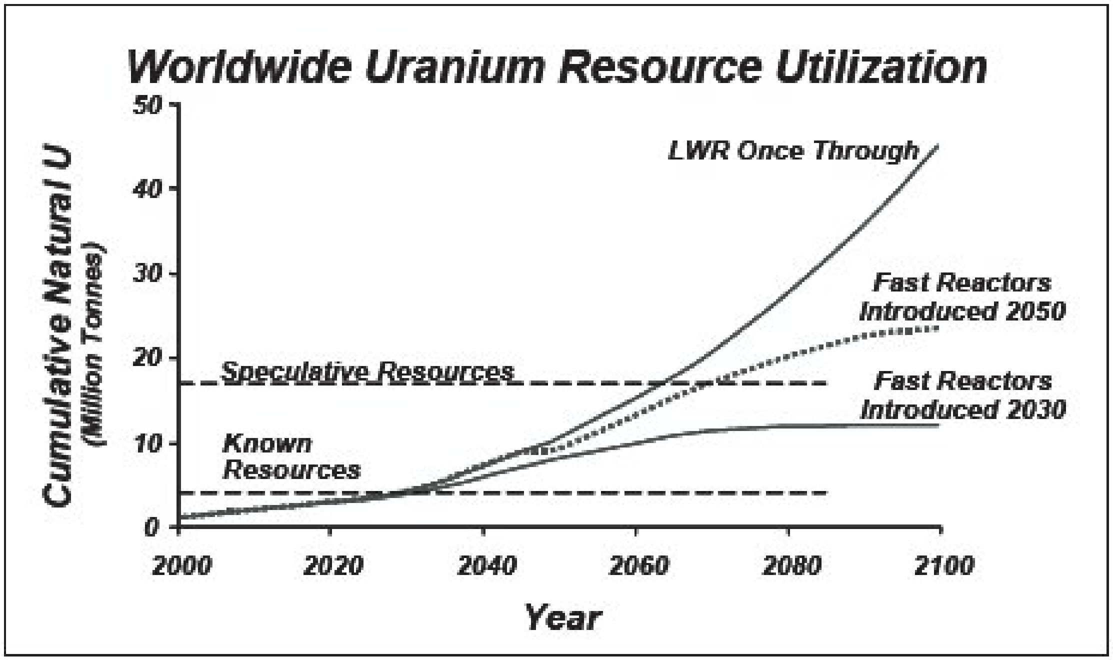
No public scientific document seems to exist which quantifies the achieved longer term useful Pu(239) breeding factor!

Were all fast reactors operated without achieving efficient breeding?

Generation IV (fast reactor) perspectives

around 2000, a world wide initiative for a nuclear revival started to develop new safe and very efficient reactors

Document claims that known uranium resources will be used up ≈ 2030-2040!



source: 2002 roadmap, http://gif.inel.gov/roadmap/

Generation IV reactor perspectives

goals and plans of the 2002 roadmap:

- Be ready for commercial construction around the year 2030.
- Develop high efficiency fast reactor with a closed fuel cycle using Pu239 and or U233 breeding/burning $\approx$ 1.
- Make detailed studies about "six" new reactor prototypes requested research budget (for next 10-15 years): $\approx$ 1 billion dollar for each reactor type!

The initiative five years later

It seems that not much funding has been found so far and no(?) experimental results published during the last 5 years!

Little or no funding will give little or no results
$\rightarrow$ it is impossible to have commercial "wonder" reactors within 20-30 years!

A closer look at uranium requirements

- A 1 GW(e) reactor needs ≈ 180 tons of natural uranium per year. First reactor load requires about a factor of three more!
- Todays 371 GW(e) with 439 reactors need ≈ 67000 tons/year!
- Uranium requirements in 2030 (breeder reactors not ready!)? How much nuclear energy does the "world" want/need in 2030?
- Nuclear Energy Association (OECD) estimated (2006):
  "Uranium resources, plenty to sustain growth of nuclear power" (assuming a small growth between 1-2% per year for the next 20 years)
- World Nuclear Association (2007 Market report) 6 Sep. 2007 assumes:
  reference growth scenario (installed power by 2030):529 GW(e)
  WNA high and low growth scenarios: 720 GW(e) and 282 GW(e)

  yearly requirement (2030): between 51000 to 130000 tons uranium

"Known" uranium in the ground?

OECD NEA(Nuclear Energy Agency) and IAEA report:
Uranium 2005 (red book):

- "Known" recoverable uranium resources ($<$ 130 dollar/kg): 3.296689 million tons (or 49 years with todays use).
- Inferred (expected to exist and extractable with known technology) uranium resources: 1.446164 million tons.
- Undiscovered or speculative resources (prognosticated and speculative): 7.5359 million tons.
- the unconventional resources ((large sale) extraction technology does not exist today): phosphates = 22 million tons, seawater = 4000 million tons.

Fantasies about uranium from sea water (concentration 3 mg/m^3):
often claimed extraction cost: 200 dollar/kg (at most 1000 dollar/kg??)

Fact is: A single huge multi million(?) dollar experiment running over many months claims to have extracted about 1 kg of uranium from sea water. No follow up or control experiment has been performed so far!

1 GW(e) conventional reactor "burns" about 6 grams of uranium/sec
$\rightarrow$ "extract" uranium from about 10000 m^3/sec (20% efficiency)!
Rhine river discharges on average about 2000 m^3 per second!
$\rightarrow$ Good luck!

Some contradictions with “known” uranium resources

- Why did uranium mining stop in many mines and countries if energy independence is a goal?

- Like with oil reserves ... country numbers “never” seem to decrease!

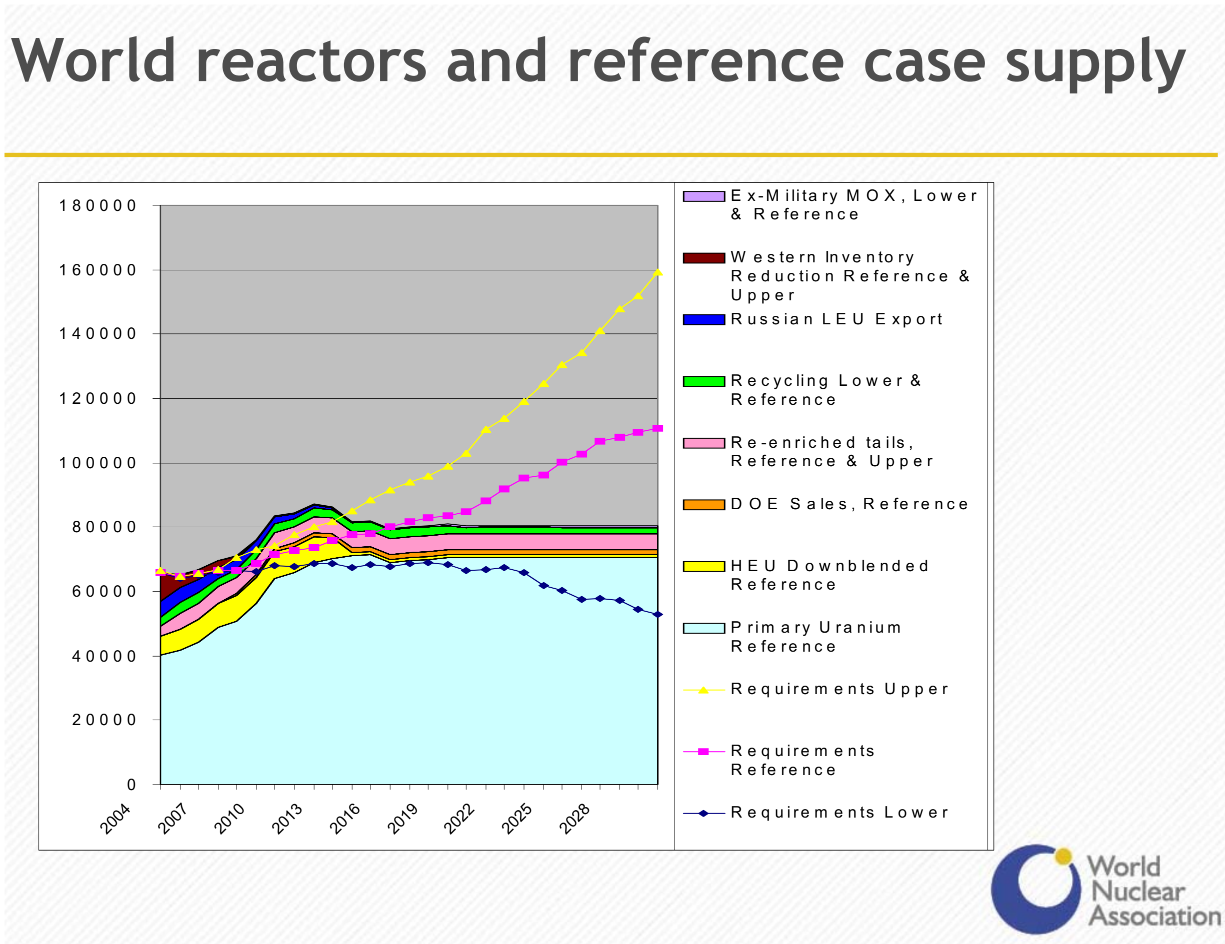
- How are costs of uranium resources/ mining defined? Shouldn’t the uranium resource/dollar numbers change because of inflation and higher oil price?

Real question for commercial nuclear energy production is:

“Do we know how to extract uranium fast enough?”

Do we know how to extract uranium fast enough?

World wide mining extracts about 40000 tons (blue area) of uranium per year (only two thirds of the required 67000 tons!).
How to satisfy even a 1.5% growth after 2015?



source: S. Kidd, the global uranium market 4th Uranium Newsletter 17-19 Jan. 2007

2006, a black year for uranium extraction and nuclear energy?

Hopes of additional uranium (about 7000 tons/year) from the Cigar Lake mine (Canada) ended with flooding in fall 2006! 2007 startup is now delayed to at least to 2011!

Incident looks like the nuclear equivalent of
"loosing the oil from Saudi Arabia" for a few years!

In addition uranium extraction/mining not really going up, despite the high uranium price:

2006 world uranium production result: 39429 tons
(2005 result was 41702 tons)

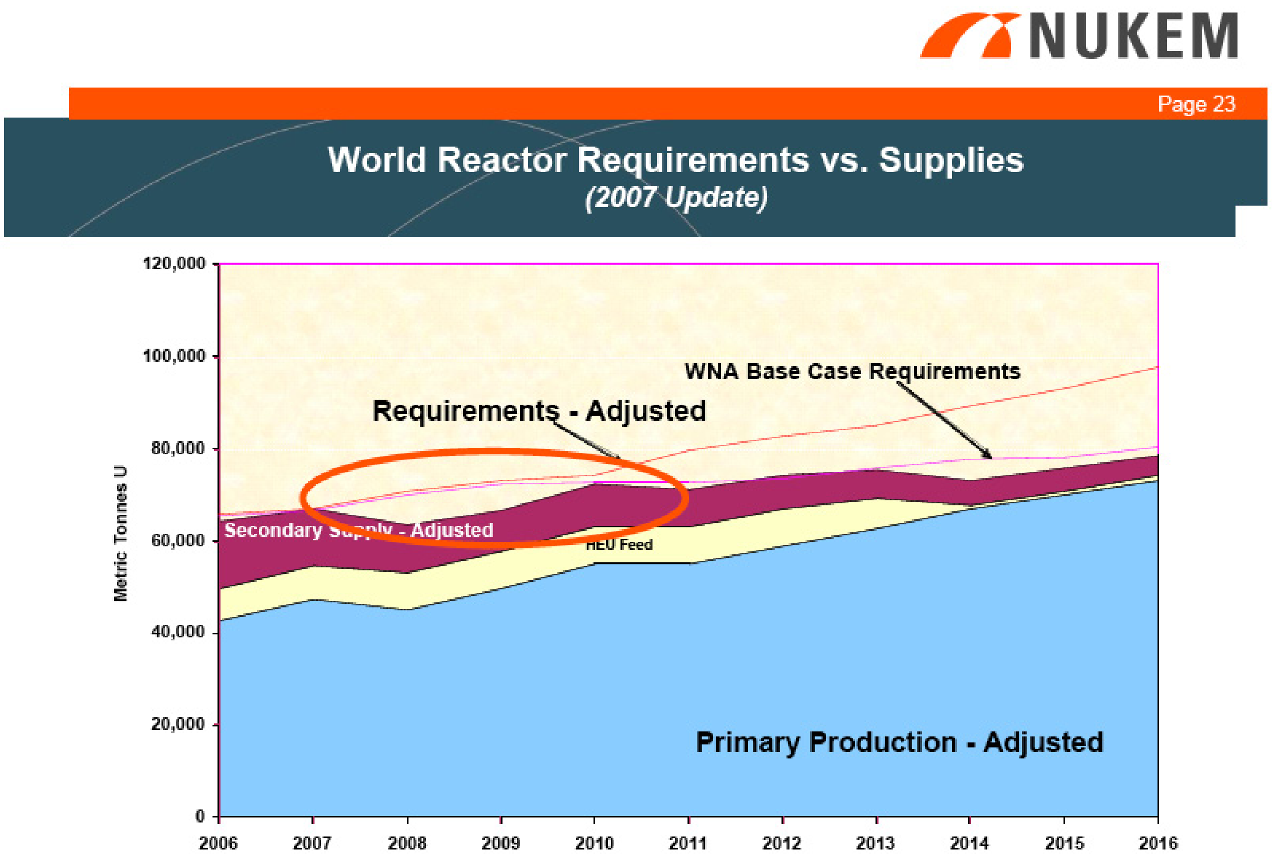
First 2007 results from Canada (25% of world production):
uranium extraction $\approx$ 10% lower than first half of 2006!

Will the "nuclear renaissance" be ended by missing uranium supply?

Where to find the missing ≈ 5000 tons uranium/year for the next few years?

→ either 5-10% of world reactors (20-40 GW(e)) will be without uranium!
or a "divine intervention" (like converting all nuclear weapons!) is needed!

Will nuclear fission power ever recover from this uranium shortage?



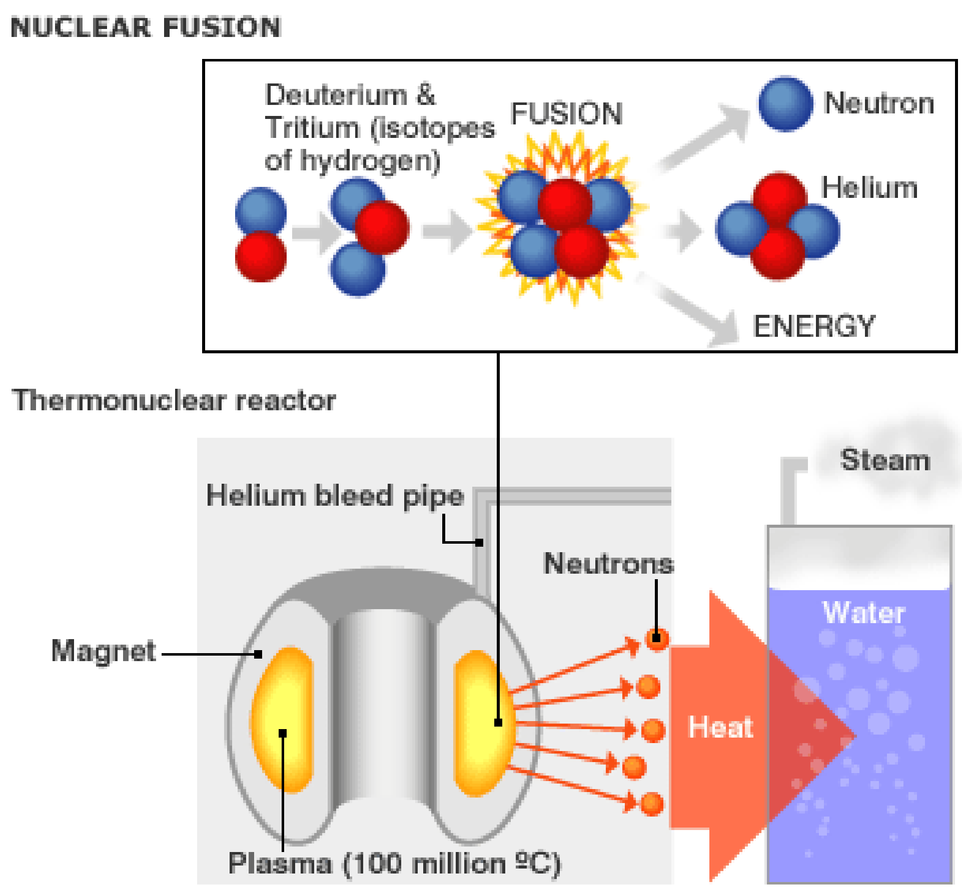
Source: J. Cornell (Nukem CEO Feb. 2007) www.nukeminc.com/pdfs/Sprott_NY_022007.pdf

Nuclear Fusion Illusions (I)

"A fusion time line, a 50 year planning?"

European Strategy Group, June 2000 (http://www.efda.org/):
ITER- the (10 billion Euro) "Next Step" 2007–2030 followed by DEMO- (the demonstration Step) 2020?–2040? and PROTO- (the prototype power station) 2040?–2060?

Fusion explained(?) from BBC science news 21. Nov. 2006



Nuclear Fusion Illusions (II)

Some media headlines about ITER without complains from the fusion community!

- “If succesful, ITER would provide mankind with an unlimited source of energy” (Novosti, 15. Nov. 2005)

- “Officials project that 10% to 20% of the worlds energy could come from fusion by the end of the century” (BBC news 24 May 2006)
  (todays 370 GW(e) nuclear power make only 2.5% of the energy mix!)

- ITER says within 30 years, the electricity could be available on the grid!” (BBC news 21. Nov. 2006)

Nuclear Fusion Illusions (III)

the only potentially possible fusion reaction on earth!

deuterium + tritium → helium (3.5 MeV) + neutron (14.1 MeV)

tritium does not exist naturally and must be made somehow!

1000 MW(therm) reactor (continuous running) “burns”:

≈ 56 Kg tritium per year!

But only few kg per year can be supplied from fission reactors!

→ real fusion reactor must achieve tritium self sufficiency!

More tritium must be made and extracted than burned!

Proposed tritium breeding reaction (every neutron must be used!):

n + lithium → helium + tritium + 4.8 MeV

Nuclear Fusion Illusions (IV)

Four major barriers to fusion energy on our earth

- Commercial energy production requires a "steady state" 1 GW(e) power plant operation, running for years not for minutes!
  The ITER timeline: a 0.5 GW(thermal) 400 second pulse in 2022!

- High temperature and high neutron flux resistant material unknown!
  Such neutron resistant material can not be developed/tested with ITER!

- Tritium handling: Running a hypothetical 1 GW(e) reactor "burns" about 200 Kg of tritium/year. (ITER experiments require a few Kg)
  External tritium sources can provide only a few kg per year, world tritium inventory by 2027 at best 30 kg!

- **The impossible self-sustained tritium breeding chain.**

Nuclear Fusion Illusions (V)
the tritium breeding problem

- Known fractional tritium burn up in JET (and ITER) about 1 in a million! A factor of at least 10000 is missing for a real fusion reactor!
- Computer simulations indicate that the potential tritium breeding is too low even without simulating the “heat transfer mechanism” and material aging!
- Tritium extraction and transfer efficiency have not been studied.
- Simplified neutron+ lithium breeding experiments demonstrate that computer simulations are systematically far too optimistic and thus wrong!
- Real tritium breeding experiments can not be done with realistic high neutron flux! (neither with ITER nor anywhere else!)

for details see: M. E. Sawan, M. A. Abdou, Fusion Engineering and Design 81 (2006) 1131-1144 and www.fusion.ucla.edu/abdou)

Nuclear Fusion Illusions (V)
the tritium breeding problem

M. A. Abdou, Director of Fusion Science and Technology Center at UCLA in his own words:

Quote I:

"There is NOT a single experiment yet in the fusion environment to show that the DT fusion fuel cycle is viable."

Quote II:

"Tritium supply and self-sufficiency are "Go-No Go" issues for fusion energy, as critical NOW as demonstrating a burning plasma"

Quote III:

"What should we do to communicate this message to those who influence fusion policy outside DOE?"

(Briefing to DOE Office of Science on Fusion Chamber Technology on behalf of the US Fusion chamber community June 3, 2003)

Summary: The nuclear option

- The fraction of the worlds electricity coming from nuclear fission is going down, maximum was 18% (1993) to now 15.2% (2005).
- Uranium might be plenty in the earth, but known extraction technologies are not fast enough to allow for an even modest increase in nuclear power.
- Only a "divine intervention" can prevent the uranium shortage during the next few years! 5-10% of the reactors will be out of uranium by 2009/2010!
- Commercial fast breeder and fast reactors (Generation IV) do not exist right now! No proof exists that "Generation IV reactors" might work!
  But for sure, without a large amount of research money these new reactors will not be ready in 2030!
- A self sustained deuterium-tritium fusion chain is impossible to achieve under large scale fusion conditions!
  Commercial nuclear fusion energy will always be 50 years away!

Energy shortages from oil/gas depletion can not be compensated with nuclear energy!

Some references /internet documents about uranium and all that:

- IAEA and PRIS database: http://www.iaea.org/ and http://www.iaea.org/programmes/a2/
  The Red book IAEA and OECD (Uranium 2005 Resources, Production and Demand)
  http://www.oecdbookshop.org/oecd/display.asp?sf1=identifiers&st1=662006031P1
  and much more at http://www-pub.iaea.org/mtcd/publications/publications.asp
  like: Energy, Electricity and Nuclear Power Estimates for the Period up to 2030
  http://www-pub.iaea.org/MTCD/publications/PDF/RDS1-26_web.pdf
  See also: World Nuclear Association (http://www.world-nuclear.org/) and
  Uranium Information Centre http://www.uic.com.au/

- Critical review of uranium resources and production capability to 2020 (1998 report)
  IAEA-TECDOC-1033: http://www-pub.iaea.org/MTCD/publications/PDF/te_1033_prn.pdf
  and Analysis of Uranium Supply to 2050 (2001 report)
  http://www-pub.iaea.org/MTCD/publications/PDF/Pub1104_scr.pdf

- A conference on "Operational and Decommissioning Experience with Fast reactors
  Cadarache, France, 11-15 March 2002
  http://www.iaea.org/inisnkm/nkm/aws/fnss/fulltext/twgfr109.pdf

- Generation IV (fast reactor 2002 roadmap): http://www.gen-4.org/PDFs/GenIVRoadmap.pdf
  and Advanced Fuel Cycle Initiative: Objectives, Approach, and Technology Summary
  http://www.gnep.energy.gov/pdfs/afciCongressionalReportMay2005.pdf

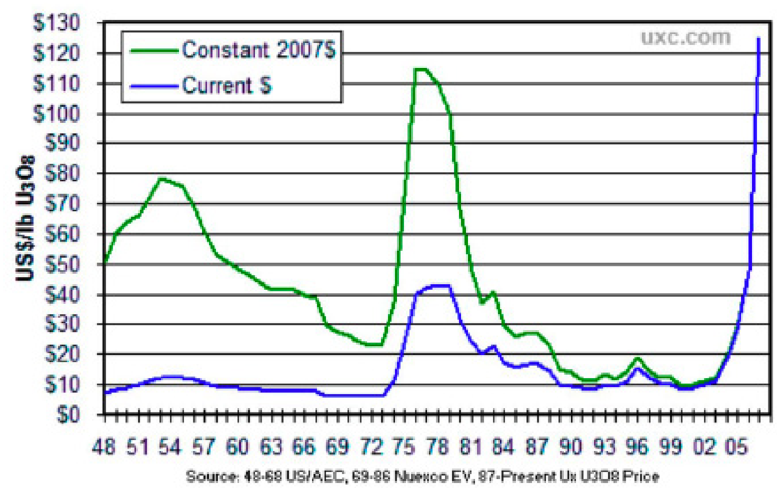
- Uranium Resources and Nuclear Energy (Energy Watch Group Dec. 2006)
  http://www.energiekrise.de/uran/docs2006/REO-Uranium_5-12-2006.pdf and
  a talk Uranium supply and demand http://www.wise-uranium.org/stk.html?src=stkd03e

Some reserve slides

Uranium extraction history and price

Warnings from IAEA and uranium miners at least since about 1998!
(e.g. http://www-pub.iaea.org/MTCD/publications/PDF/te_1033_prn.pdf)
Critical review of uranium resources and production capability to 2020

Ux Consulting Company (UxC) writes (2005) (www.uxc.com/):
"Long-term indicators are pointing toward a demand curve that will exceed supply within the next several years and ultimately lead to higher prices."



sources: IAEA Redbook 2005 and UXC http://www.uxc.com/

Enough uranium to run conventional fission reactors?

Where are the "known" uranium reserves (tons) (price $<$ 130 $ /kg)

Uranium Information Centre Australien (UIC) 2005 and 2006/7 versions
source www.uic.com.au/nip75.htm and nip41

country	reserves [tons] (UIC Sep. 2006)	reserves [tons] (UIC June 2005)	production [tons U] 2006
Australia	1.143 000	1.074 000	7593
Kazakhstan	816 000	622 000	5279
Canada	444 000	439 000	9862
South Africa	341 000	298 000	534
USA	342 000	102 000	1672
Brazil	279 000	143 000	190
Namibia	282 000	213 000	3067
Russia	172 000	158 000	3262
Usbekistan	116 000	93 000	2260
world	4.743 000	3.537 000	39429
world (thorium)*	4.500 000	—	—

* myth about thorium? The UIC report 75 (2006 and 2005) says: "In the earth crust, thorium is three times as abundant as uranium")

Predictions ($\approx$ 1975) about (nuclear) energy

Energy type	Predictions for the year 2000 [Quad]			Reality
	Model 1	Model 2	Model 3	2001 [Quad]
Total	609	528	540	403
nuclear energy	86	80	108	26.5
coal	143	125	116	95.9
oil	225	185	184	156
gas	96	87	83	93
renewable	60	51	50	32

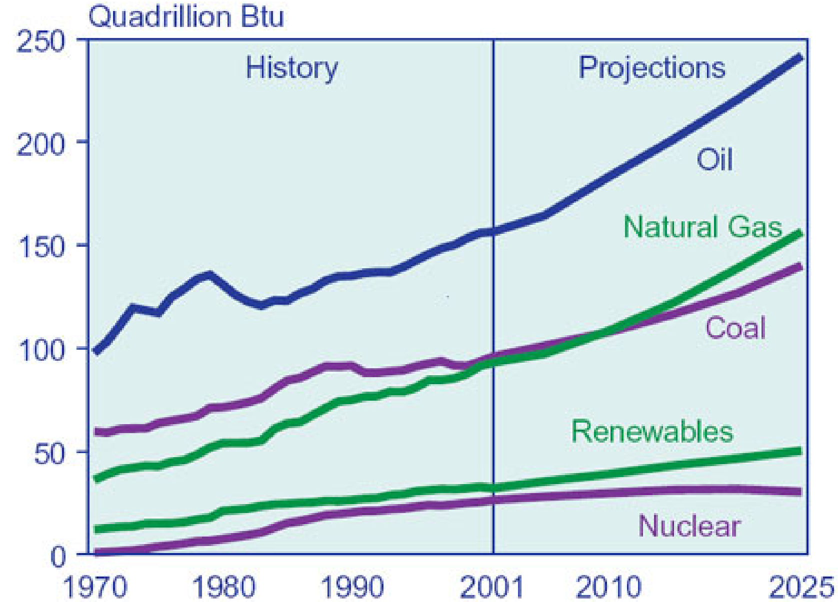
Predictions: Workshop on alternative Energy Strategies for the year 2000, MIT Press 1977 (Global 2000 Report) and EIA Report (2004).
(1 Quad = 10^{15} Btu = 1.055 $\times 10^{18}$ Joule = 2.93 $\times 10^{11}$KWh)

Demand based predictions for the energy use in the year 2000 were completely wrong!

What does this tell us about todays demand predictions?

Today's (demand based) "energy" predictions.

Figure 14. World Primary Energy Consumption by Energy Source, 1970-2025



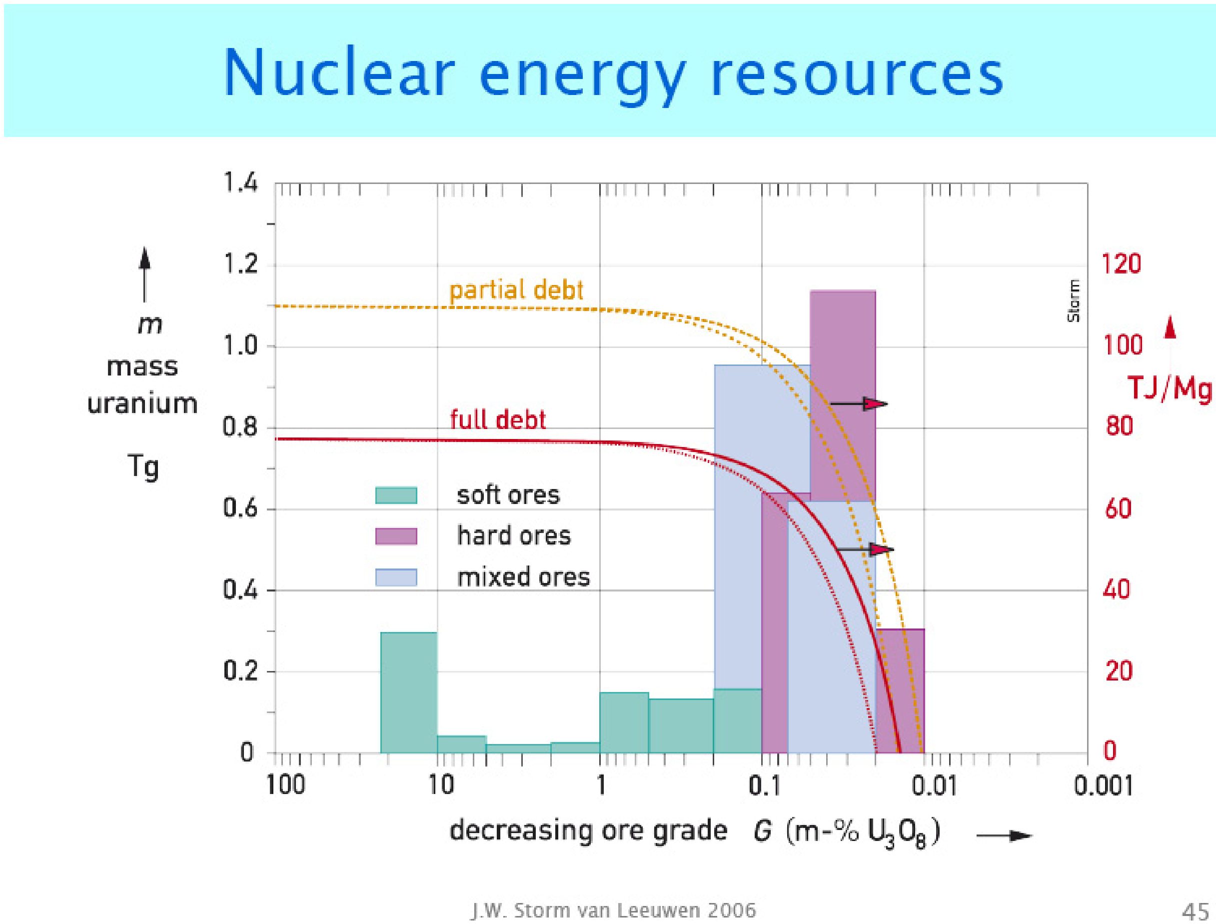
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2001*, DOE/EIA-0219(2001) (Washington, DC, February 2003), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2004).

uranium in the earth crust:

http://www.uic.com.au/nip75.htm (2006 version)

uranium content of:	concentration [ppm U]	kg/ ton
High-grade-or 2% U	20 000 ppm U	20 kg/ton
Low -grade-or 0.1% U	1 000 ppm U	1 kg/ton
Granite	4 ppm U	0.004 kg/ton
Sedimentary Rock	2 ppm U	0.002 kg/ton
Earth continental crust (average)	2.8 ppm U	0.003 kg/ton
Sea water	0.003 ppm U	3 mgramm/ton

NER (Netto Energy Return) and uranium mining

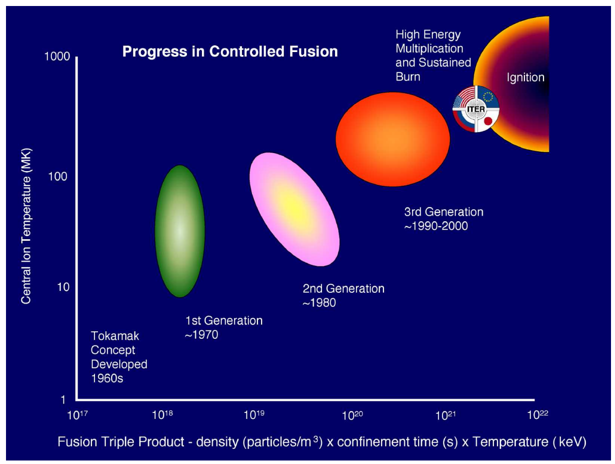


from J. W. Storm (CERN 3.4.06)
(http://ihp-lx2.ethz.ch/energy21/CERN-3Apr06.ppt)

The wish of plasma physicists:
a big (world) tokamak

	ITER	original ITER
cost (2000 Dollar?)	4.3	7.8
Q ("steady state")	5	10-15
Tokamak major radius	6.2 m	8.1 m
Tokamak minor radius	2.0 m	2.8 m
Burn time (steady state)	2000 s	10,000 s
Power output	400 MW	1500 MW
Plasma volume	840 m3	2000 m^3
Average neutron wall load	0.6 MW/m^2	1 MW/m^2
Integrated neutron wall load	0.3 MW-year/m^2	1-3 MW-year/m^2

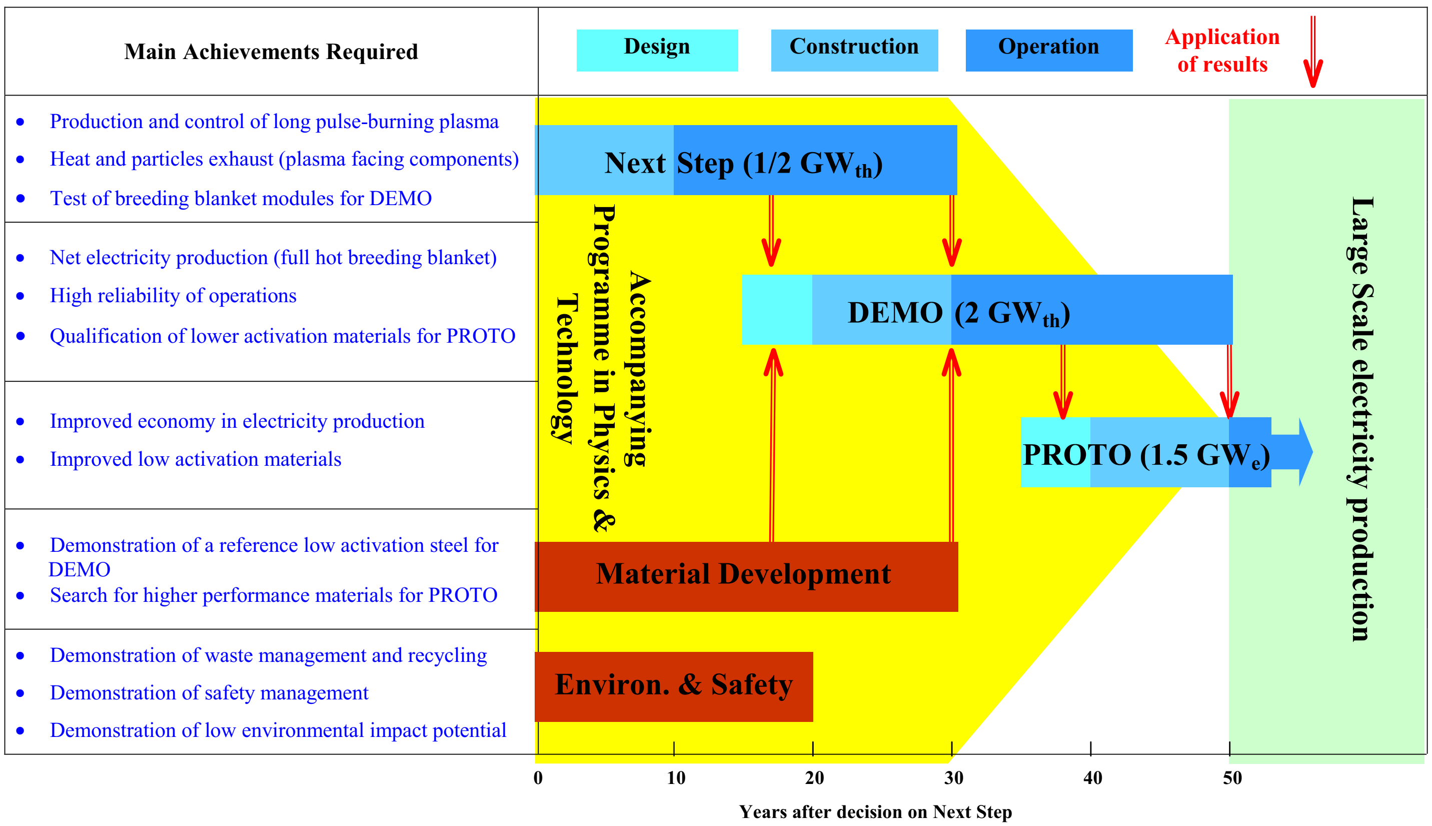
(numbers from Physics Today March 2000)



Fusion energy at the end of the 21st century?

from the European Strategy Group (June 2000): (http://www.efda.org/)

Tentative Roadmap of Achievements starting from the decision to construct the Next Step



Extracted from:
“Five Year Assessment Report related to the specific programme:
Nuclear energy covering the period 1995-1999” June 2000

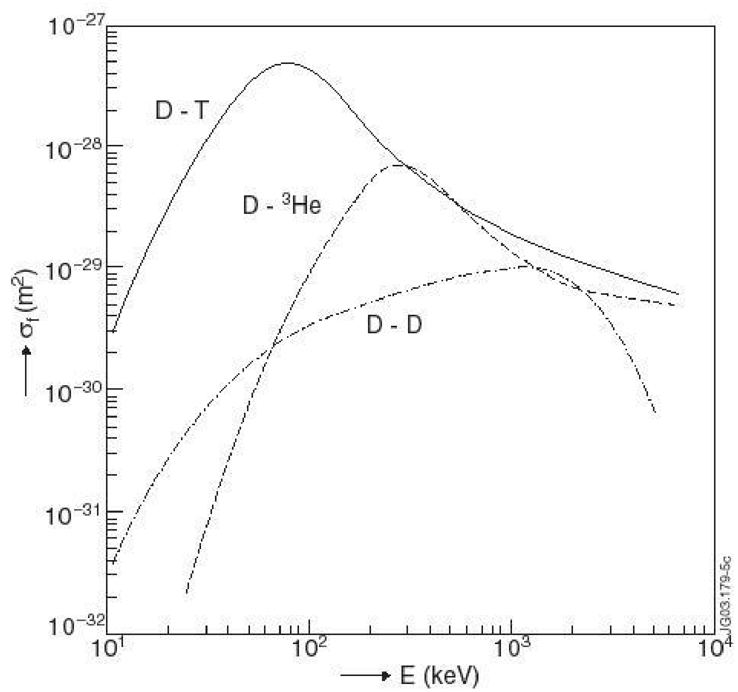
Nuclear Fusion Illusions
planning for the next 50 years

European Strategy Group (June 2000): (http://www.efda.org/)

- ITER- the (10 billion Euro) "Next Step" (200x–2030)
  - Fusion power: 500 MW_{therm}
  - Long-Duration burning plasma
  - Test tritium breeding blankets concept
- DEMO- the demonstration Step (2020?–2040?)
  - Fusion Power: 2000 MW_{therm}
  - Net electricity production
  - Tritium self sufficiency
  - High reliability of operation
- PROTO- the prototype power station (2040?–2060?)
  - Electric Power: 1500 MW_{el}
  - Improved commercial electricity production

Why hopes are high for the deuterium-tritium fusion chain?

Lowest "temperature" combined with highest fusion cross section!



Nuclear Fusion Illusions

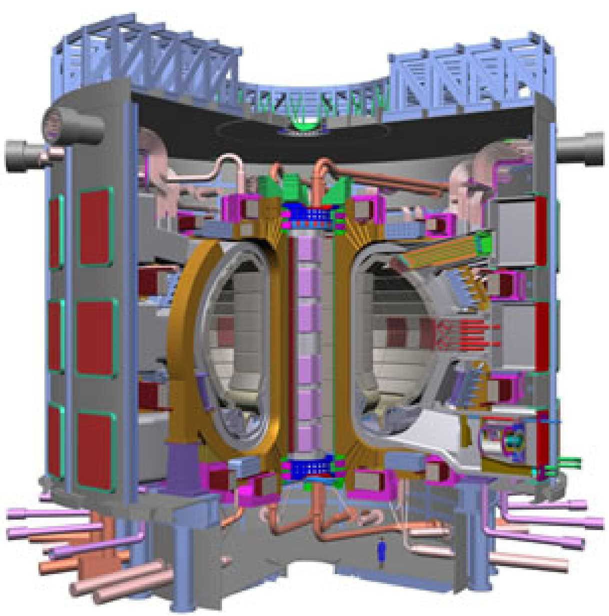
after 50 years of fusion energy research and development:
what has been achieved with JET (is expected for ITER) and what is known about the requirements for a commercial project:

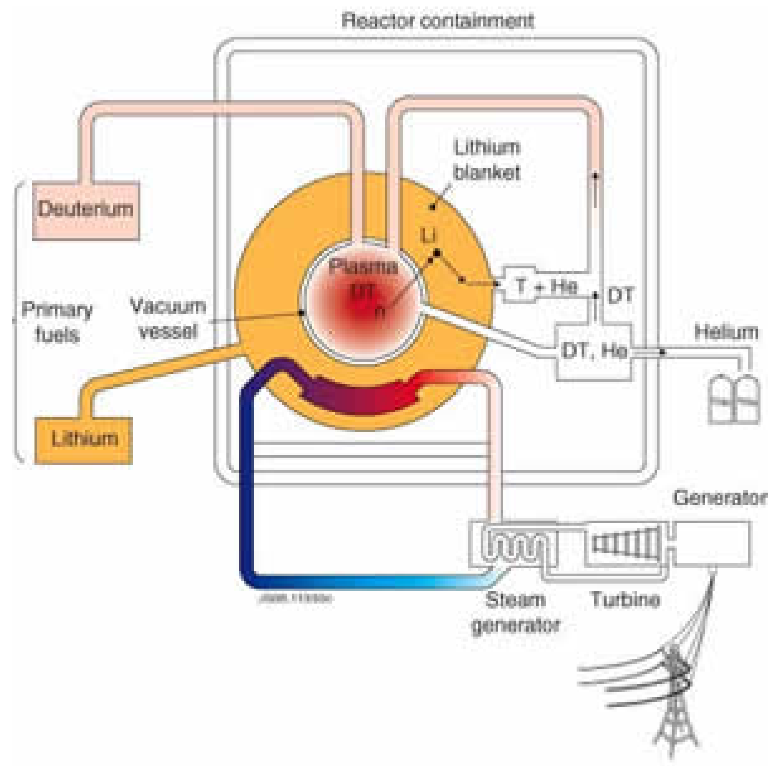
- Plasma volume = 90 m^3 (ITER 840 m^3) need at least 2000 m^3 for a 1.5 GW_{therm}
- Q-value (Power out/ Power in) = 0.6, (5-10 for ITER?) required Q at least 30!
- Peak Power = 4 MW Power for 4 seconds (ITER goal 500 MW for 2000 sec) need continuous 3000 MW
- Tritium handling = 20 gr (ITER a few kg?) need at least 56 Kg per year and 1 GW $_{therm}$.
- Efficiency of tritium burning in the plasma: JET/ITER about 1/million! Few % is assumed for tritium breeding simulations
- Today: No material and structure is known which can
  (1) stand the high neutron flux under realistic DT fusion conditions,
  (2) allows efficient tritium breeding and extraction,
  (3) transfers the produced heat away from the blanket to a "generator",
  (4) reduces unavoidable tritium losses to the environment.

ITER (DEMO) and the tritium breeding blanket

Status for the ITER project: small test program "to be defined"
But, for the DEMO prototype(?): must achieve tritium self sufficiency!

The hypothetical DEMO design:
large "lithium blanket" (required thickness 2 m?)
but what happened with the DEMO magnet?

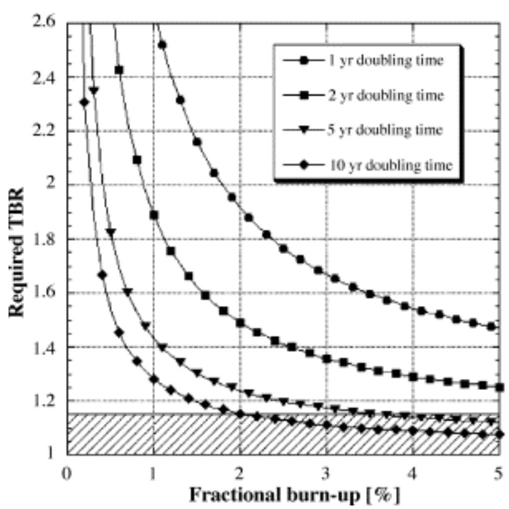


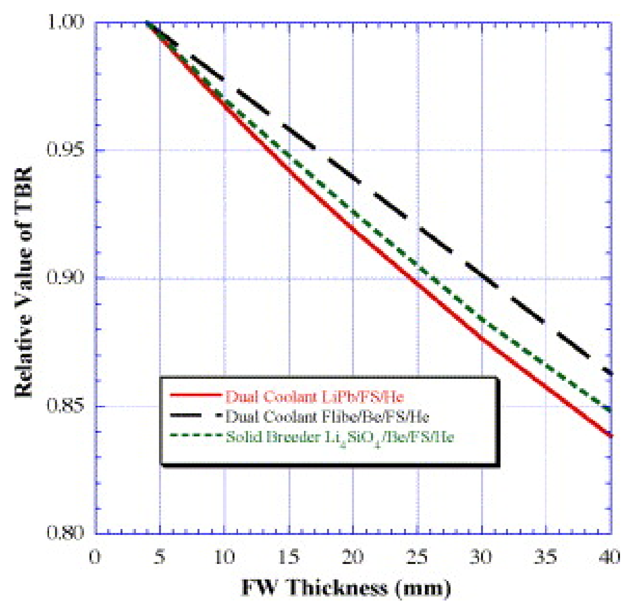


the DEMO design diagram from http://ec.europa.eu/research/energy/

From the computer imagination to reality? Well known and well hidden tritium problems I

- ITER Tritium supply mainly from CANDU heavy water reactors (shutdown ≈ 2020-2025?)
  Accumulated Tritium about 20 Kg (after 30 years), current price 30 Million dollar/Kg
  "Normal" fission reactors make Tritium 2-3 Kg/year, projected cost 200 Million dollar/Kg
- Optimistically guessed required tritium breeding ratio TBR = 1.15
  (for a 5-10 year doubling time), and $\geq$ 1.3 for a one year doubling time!
  (Sawan and Abdou assume an uncertainty for this number of 30%!)
- 3-D computer simulations of hypothetical FW (first wall) and breeding blankets
  (various versions of Li plus Be or Pb neutron multipliers)
  indicate an achievable (TBR) of ≈ 1.15 (*"uncertainty could be in the 1-3% range"*)





for details see: M. E. Sawan, M. A. Abdou, Fusion Engineering and Design 81 (2006) 1131-1144 and www.fusion.ucla.edu/abdou)

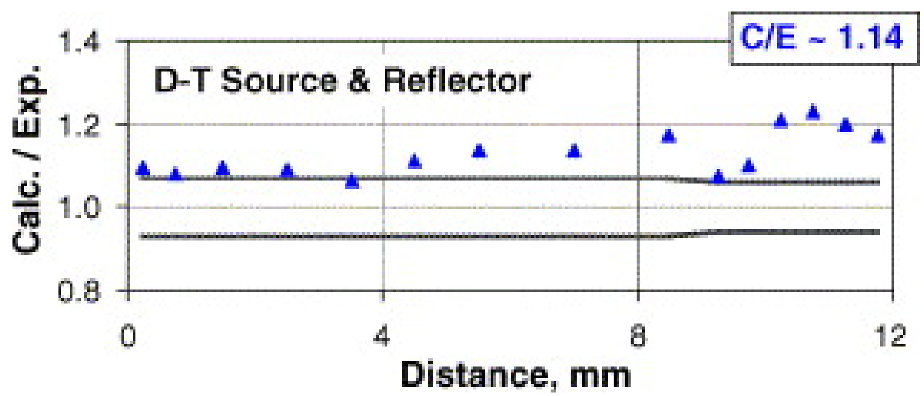
From the computer imagination to reality? Well known and well hidden tritium problems II

- Simplified neutron lithium experiments show that "computer simulations systematically overestimate experiments by a factor of $\approx$ 1.14" (or more?)
  (Quote from the publication: *"the large overestimate is alarming"*)

- *Computers do not know about "tritium extraction and transfer efficiency" and radioactivity protection.*

- *Computers do not know about "needed heat transfer mechanism" and material aging!*
  (They even assume impossible "First Wall thickness" for ITER)

- *TBR experiments can not study high neutron flux!*
  (neither with ITER nor anywhere else!)



for details see: M. E. Sawan, M. A. Abdou, Fusion Engineering and Design 81 (2006) 1131-1144 and www.fusion.ucla.edu/abdou)