Does Nuclear Energy have a future ?

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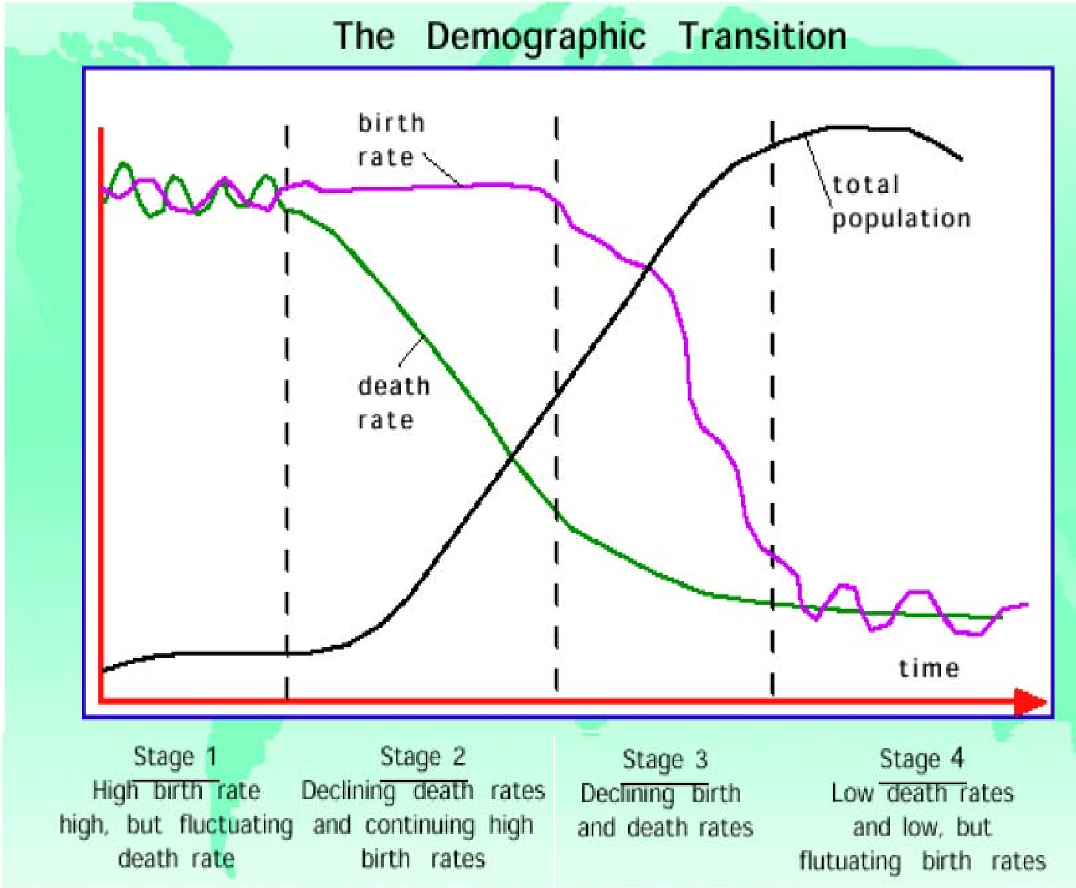
The population explosion



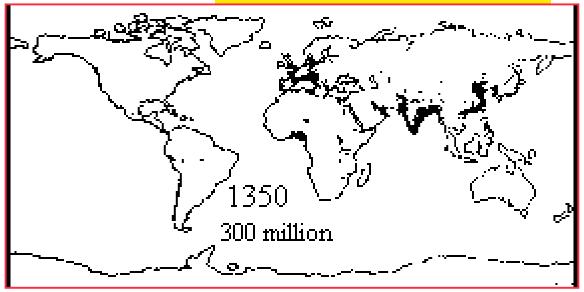
An "explosive" population growth: 90 M/year

Everybody will agree on the fact that future progress of mankind will be impossible without a very substantial amount of available energy, namely

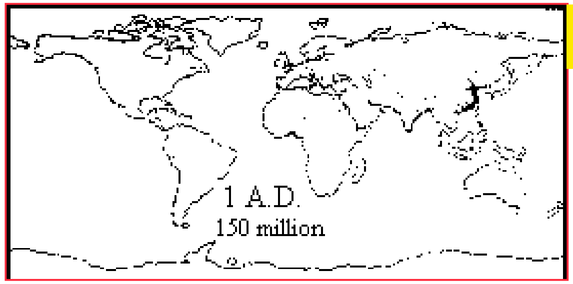
"Energy is necessary to preserve Mankind"

The population explosion

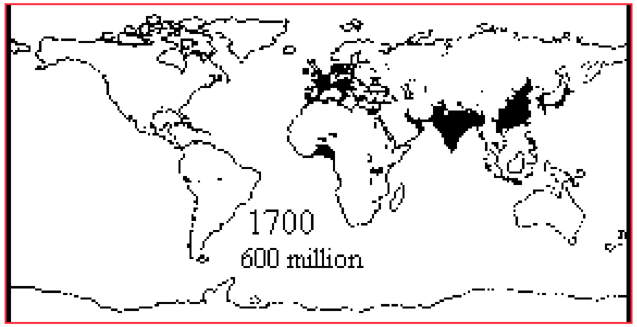
1350; 300 million



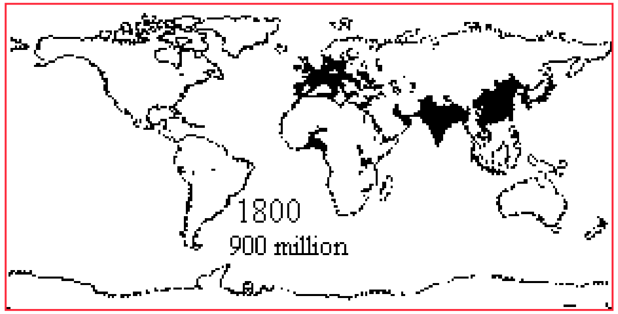
AD ; 150 million



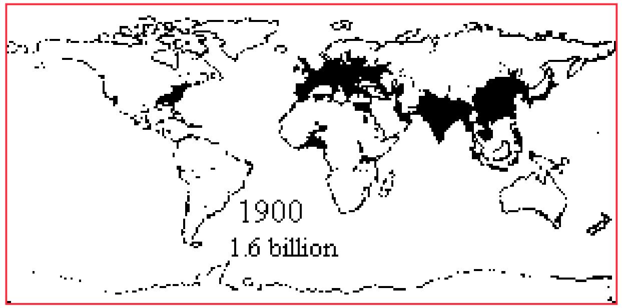
1700; 600 million



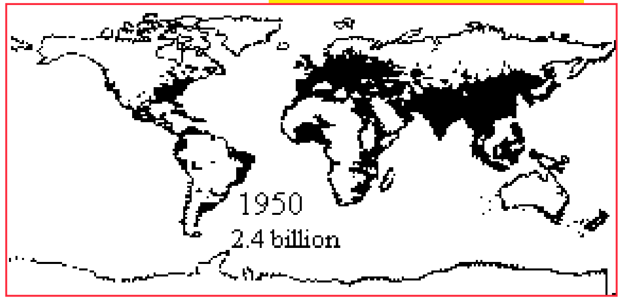
1800; 930 million



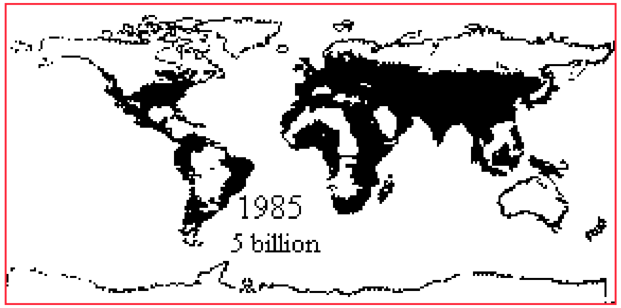
1900; 1.6 billion



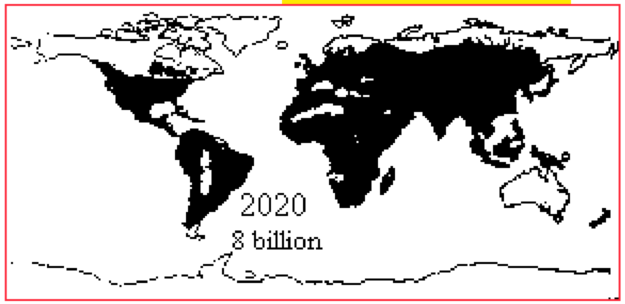
1950; 2.4 billion



1985; 5 billion



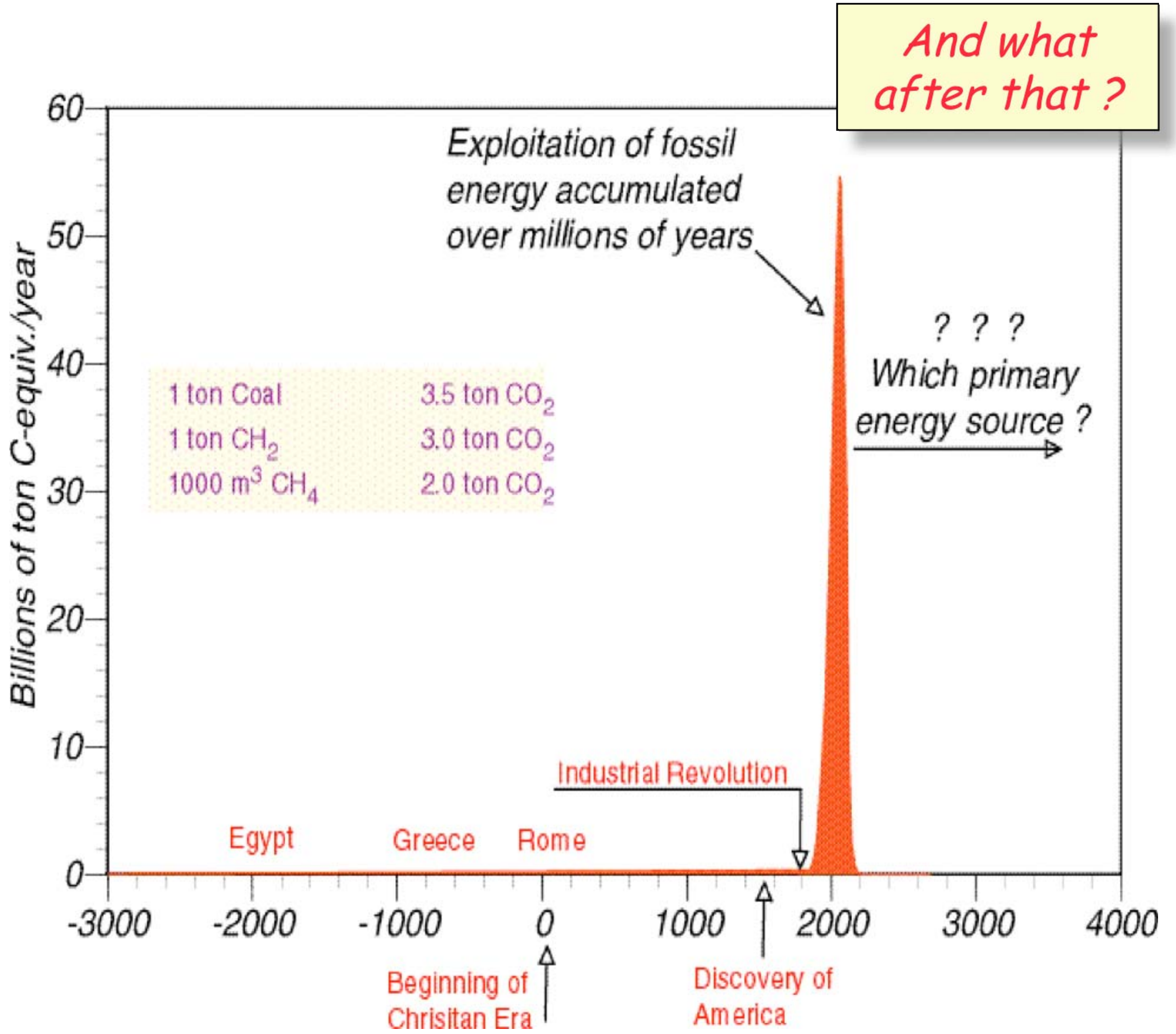
2020; 8 billion



Energy and human life

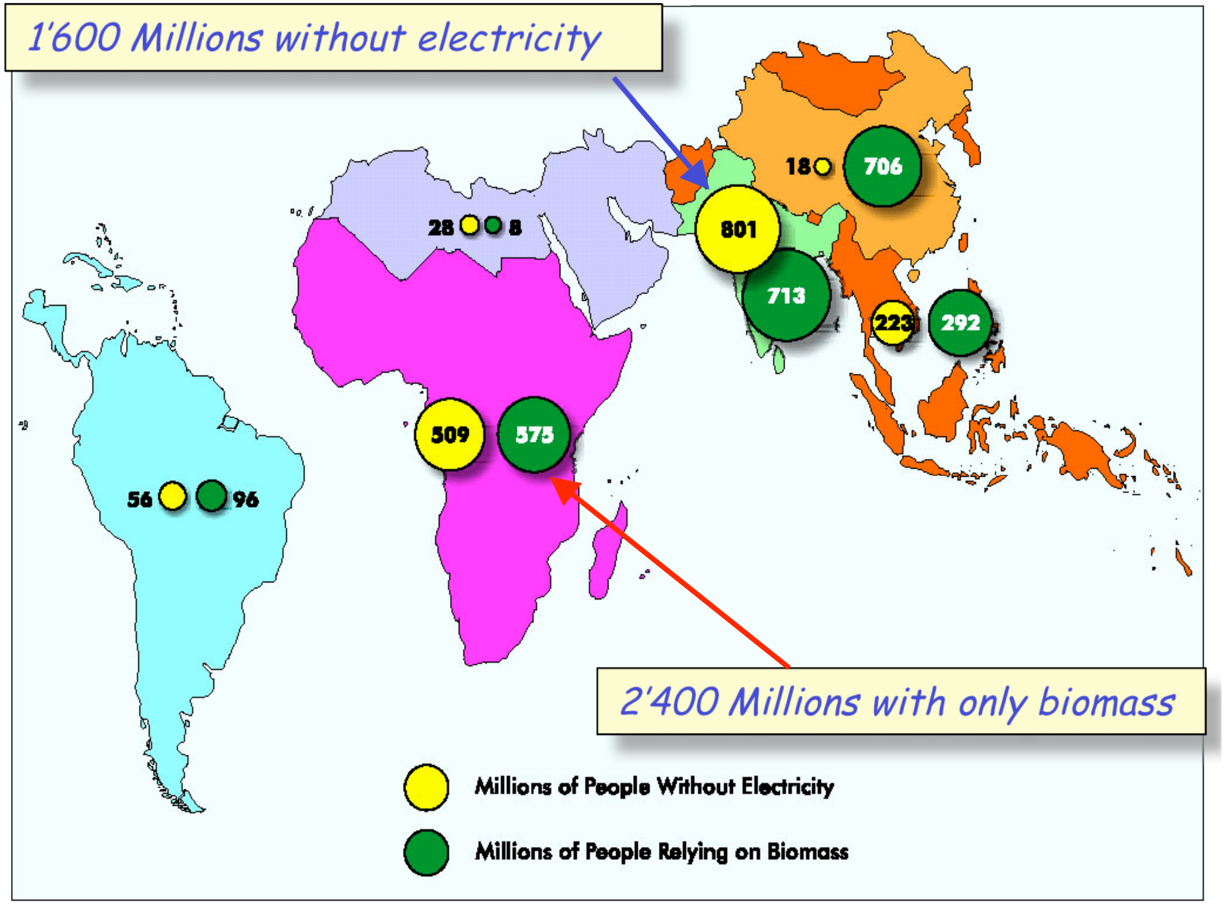
- The individual energy consumption of the *most advanced part of mankind* has grown about 100 fold from the beginning of history.
- The corresponding daily emission rate of CO_2 is about 100 kg/day

Energy consumption/person now increments by +2 %/y (fossil dominated)



Energy and poverty

- A huge correlation between energy and poverty
  - ⇨ Sweden: 15'000 kWh of electricity/ person/year
  - ⇨ Tanzania: 100 kWhe /p/y
- 1.6 billion people - a quarter of the current world's population - are without electricity,
- About 2.4 billion people rely almost exclusively on traditional biomass as their principal energy source.
- Of the 6 billion people, about one half live in poverty and at least one fifth are severely under nourished. The rest live in comparative comfort and health.



Source: IEA analysis.

Technologically advanced countries have the responsibility of showing the way to the most needy ones !

New energies: how soon ?

- During this brief lecture of mine, 60 minutes, about 10'000 new people have entered the world, at the rate of 3/sec, most of them in the Developing Countries. They will need plenty of energy to survive decently.

- At the present consumption level, known reserves for coal, oil, gas and nuclear correspond to a duration of the order of 230, 45, 63 and 54 years.

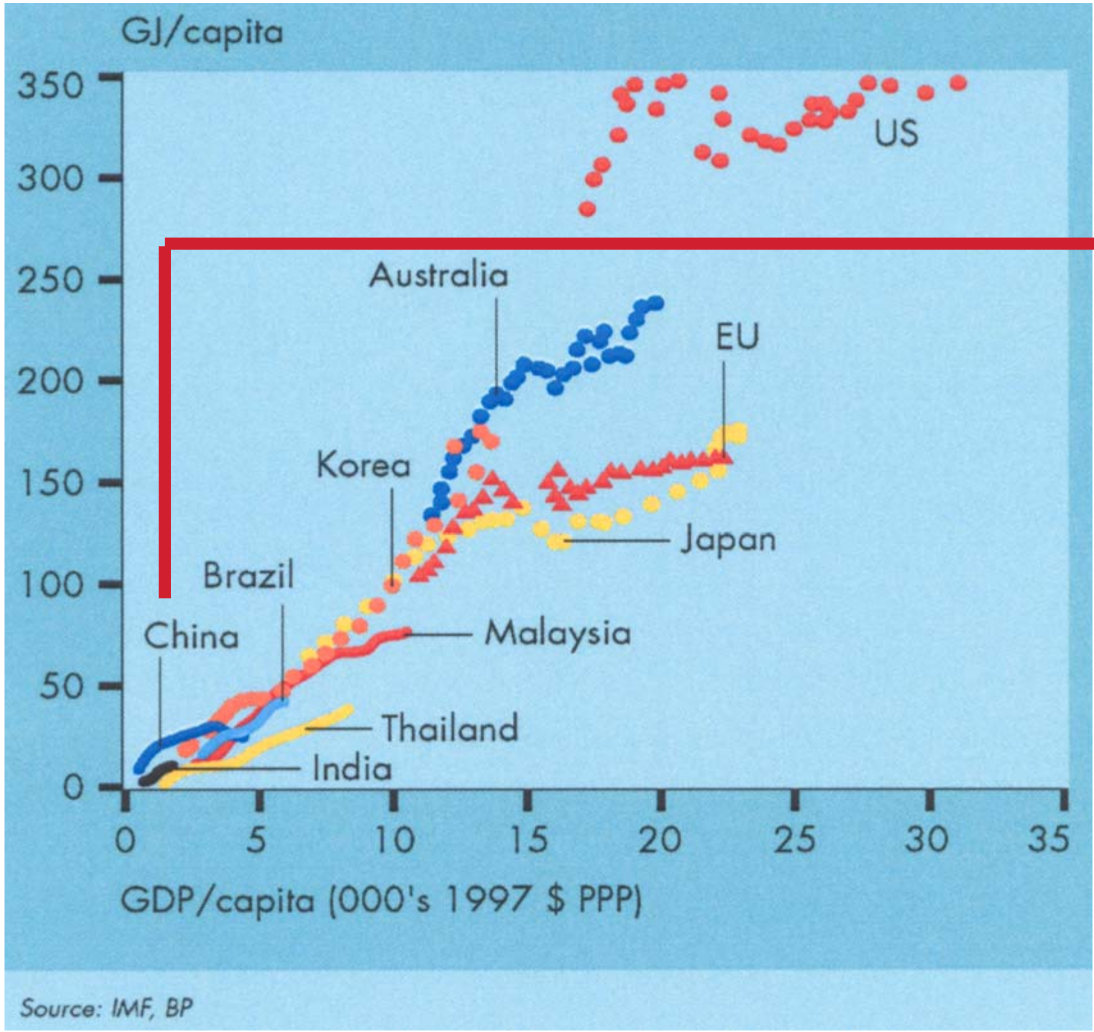
- The longevity of the survival of the necessarily limited fossil's era will be affected on the one hand by the discovery of new, exploitable resources, strongly dependent on the price and on the other by the inevitable growth of the world's population and their standard of living.

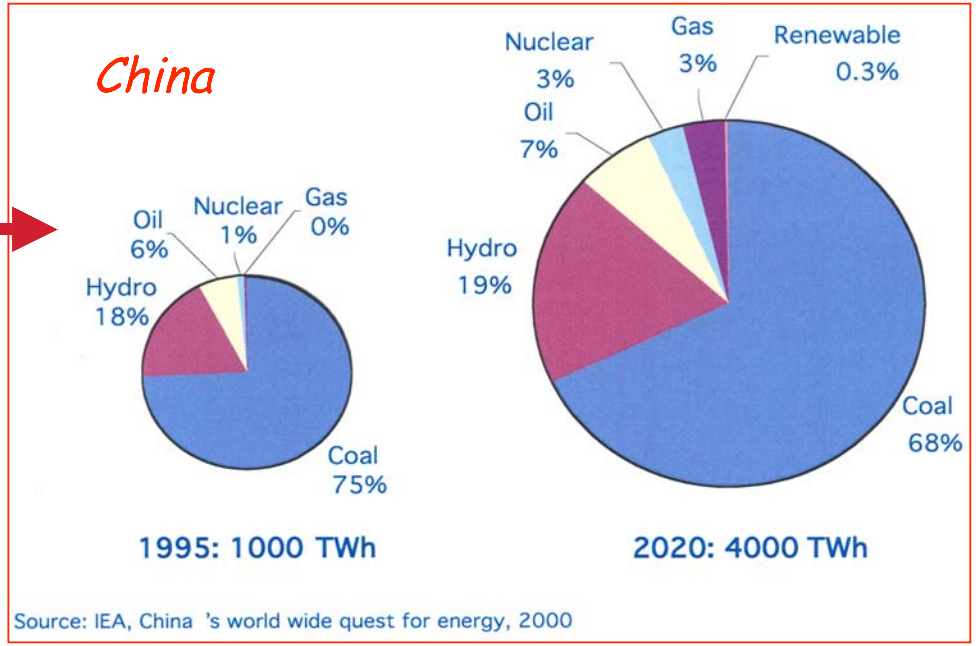
- Even if these factors are hard to assess, taking into account the long lead time for the massive development of some new energy sources, *the end of the cheap and abundant fossils may be at sight*.

Climatic changes ?

- The consumption of fossils may indeed be prematurely curbed by unacceptable greenhouse related environmental disruptions.
- The climatic effect of the combustion of a given amount of fossil fuel produces one hundred times greater energy capture due to the incremental trapped solar radiation (if we burn 1 with a fossil, the induced, integrated solar heat increment is >100 !).
- Doubling of pre-industrial concentration will occur after *roughly* the extraction of 1000 billion tonnes of fossil carbon. We are presently heading for a greenhouse dominated CO_2 doubling within *roughly* 50-75 years.
- It is generally believed (IPCC, Kyoto…) that a major technology change must occur before then and that *in order to modify drastically the present traditional energy pattern* a formidable new research and development would be necessary.
- New dominant sources are needed in order to reconcile the huge energy demand, growing rapidly especially in the Developing Countries, with an acceptable climatic impact due to the induced earth's warming up.

Correlation Energy/GDP





There is a clear correlation between energy consumption and national wealth.
This will lead to an explosion in demand in developing economies - a phenomenon that is already being seen in China and India.

New energies: which ones ?

- Only two natural resources have the capability of a long term energetic survival of mankind:

  1. **Solar energy**. The world's primary energetic consumption is only 1/10000 of the one available on the surface of Earth in sunny countries. Solar energy may be either used directly as heat or PV or indirectly through hydro, wind, bio-mass and so on. *If adequately exploited, solar energy may provide enough energy for future mankind.*
  2. **A new nuclear energy.** Energy is generally produced whenever a light nucleus is undergoing fusion or whenever a heavy nucleus is undergoing fission. Practical examples are *natural Uranium (U-238) or Thorium (fission) and Lithium (fusion) both adequate for many thousand of years at several times the present energy consumption*.

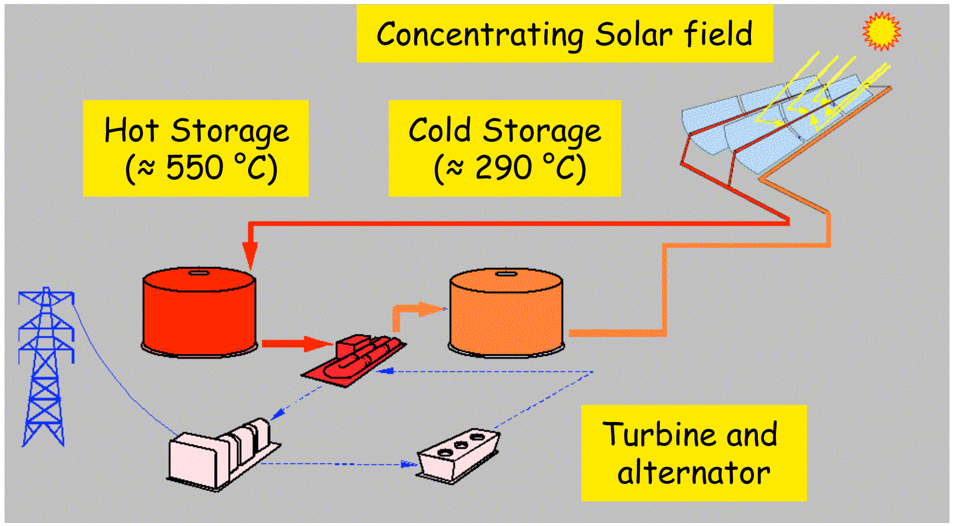
- It is unlikely that any stable, long term development of mankind will be possible without both of them.

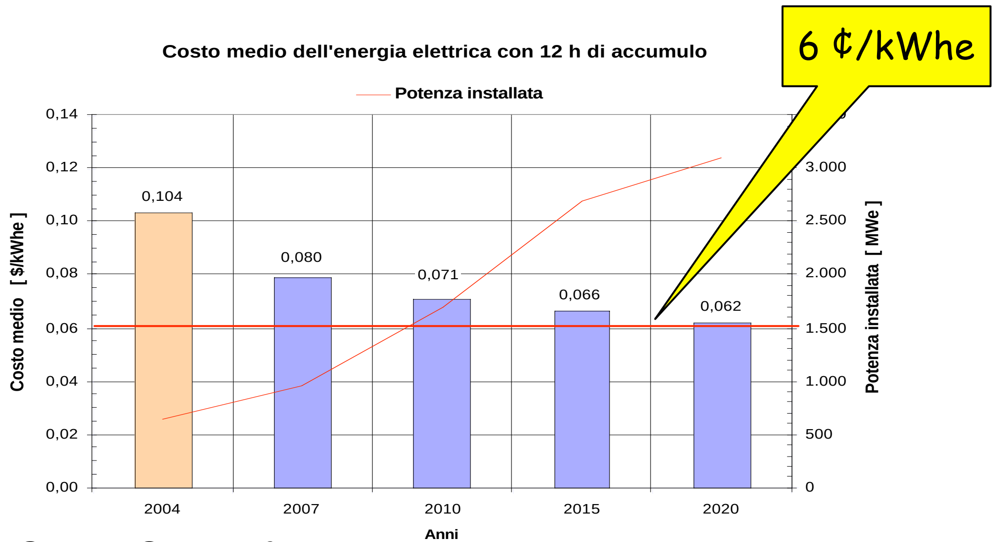
But this nuclear energy is not today's Nuclear and this solar energy is not today's Solar.
Completely new technologies must be developed.

Novel forms Of Solar Energy (very brief)

New solar energies

- *On 1 m² in a good location (sun belt), it '"rains" yearly the equivalent of ≈ 25 cm of oil.*
- Produced energy can either be directly collected, eventually with concentrating mirrors or alternatively converted, although with a lower efficiency, into wind, bio-mass,hydro or photovoltaic.
- With the exception of hydro and of biomass, today's renewable wind and photovoltaic have so far reached a modest penetration and this for two main reasons:
  1. The cost of the produced energy is generally higher than the one from fossils.
  2. The energy is produced only when the source is available and not whenever needed.
- In order to overcome these limitations, new technological developments are vigorously pursued in several countries in order to (1) reduce the cost to an acceptable level and (2) to introduce a thermal storage between the solar source and the application.

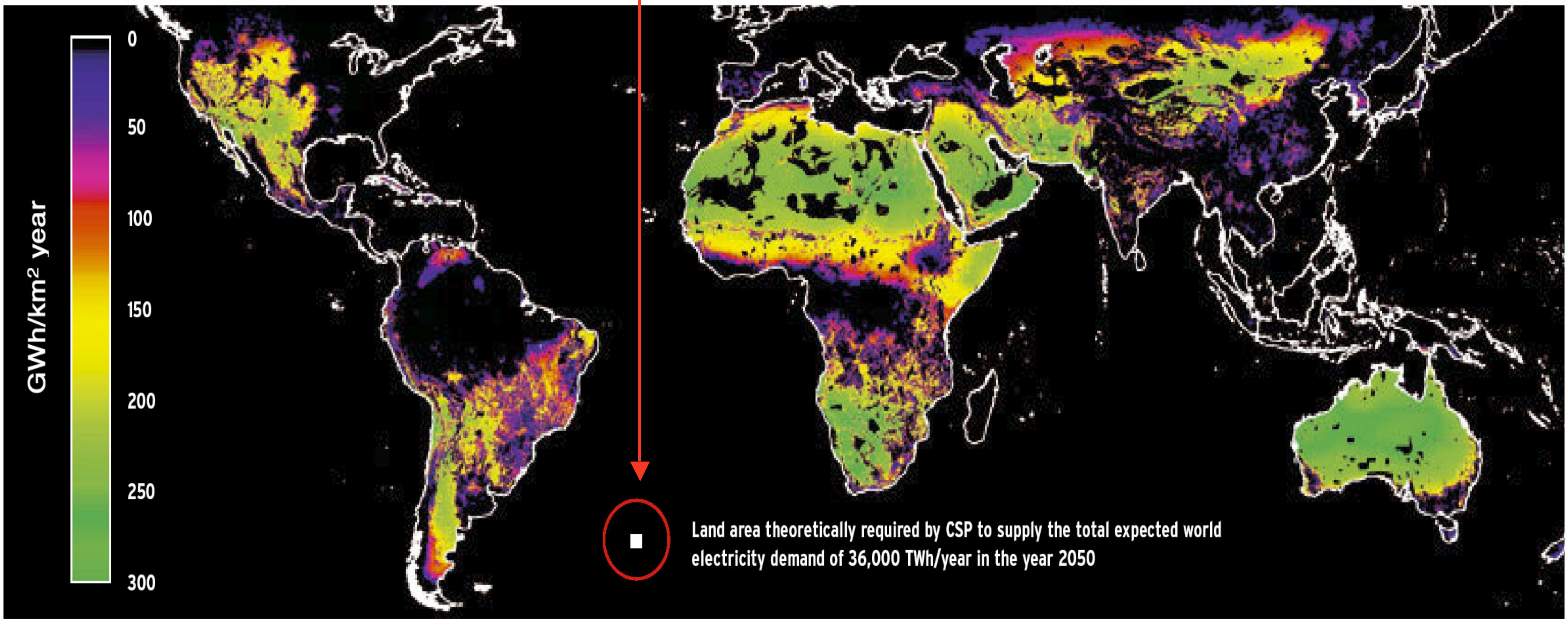




Source: Sargent & Lundy,

Concentrating solar power (CSP)

Land area theoretically required by CSP to supply the total expected world's electricity demand of 35'000 TWh/year in2050



World wide potential of solar electricity generation by CSP in GWh/km² year (based on radiation data from G. Czisch, ISET).

Novel forms of nuclear energies

They are environmentally friendly - no greenhouse gases

They must be non proliferating

No long-lived radioactive by-products

No chance of runaway reactions

A very small fuel inventory

Is there a room for nuclear energy ?

- Einstein had vividly underlined the relationship of nuclear energy with the nuclear bomb.
- In the sixties,"atoms for peace" promised a cheap, abundant and universally available nuclear power, where the few "nuclear" countries would ensure the necessary know-how to the many others which have renounced to nuclear weaponry.
- *Today, the situation is far from being acceptable*: due to technological developments, the link between peaceful and military applications has been shortened :
  - ⇨ *Uranium enrichment* may be easily extended to a level sufficient to produce a "bomb grade" U-235 (f.i. see the case of Iran);
  - ⇨natural Uranium reactors (CANDU) *generate a considerable amount of Pu*, such as produce easily Pu-239 "bomb grade" (f.i. the case of India).
- A free nuclear penetration in all countries may become acceptable *only once the umbilical chord between energy and weapons production is severed.*
- ***Some totally different but adequate nuclear technology must be developed***.

Nuclear energy without U-235

- Today's nuclear energy is based on U-335, 0.71 % of the natural Uranium, fissionable both with thermal and fast neutrons. A massive increase of this technology (5 ÷ 10 fold), such as to counterbalance effectively global warming is facing serious problems of accumulated waste and of scarcity of Uranium ores.

- But, new, more powerful nuclear reactions are possible. Particularly interesting are fission reactions on U-238 or Th-232 in which
  - ⇨ the natural element is progressively converted into a readily fissionable energy generating daughter element
  - ⇨ the totality of the initial fuel is eventually burnt
  - ⇨ the released energy for a given quantity of natural element *is more than one hundred times greater than the one in the case of the classical, U-235 driven nuclear energy*.

- Natural reserves U-238 or Th-232 can become adequate for many tens of centuries at a level several times higher than today's primary fossil production.

Choosing a nuclear energy without proliferation

- Energy is produced whenever a light nucleus is undergoing fusion or whenever a heavy nucleus is undergoing fission. Particularly interesting are fission reactions in which a natural element is bred into a readily fissionable energy generating process.

$$^{232}Th + n \rightarrow ^{233}U; \quad ^{233}U + n \rightarrow fission + 2.3n \quad (Th \ \ cycle)$$

Non Proliferating

$$^{238}U + n \rightarrow ^{239}Pu; \quad ^{239}Pu + n \rightarrow fission + 2.5n \quad (^{238}U \ \ cycle)$$

Proliferating

- The energies naturally available as ores by [1] and [2] are comparable to the one for the D-T fusion reaction:

$$Li + n \rightarrow T; \quad T + D \rightarrow He + n \quad (Fusion)$$

Non Proliferating

- While reaction from U-238 is again strongly proliferating, reactions on Th-232 and on Lithium may be safely exploited in all countries.

Closing the nuclear cycle with Th-232 and U-238

- Two neutrons are required within the basic cycle, one for the breeding and the other for the fission, in contrast with the ordinary U-235 process, in which only one neutron is necessary.
- After a time the process has to be recycled since:
  - ⇨ The fraction of the produced fission fragments has affected the operation of the system
  - ⇨ Radiation damage of the fuel elements requires reconstruction of the materials.
- In practical conditions this corresponds to the burning of about 10 ÷ 15 % of the metal mass of the natural element (Th-232 or U-238) and to a specific energy generation of 100 ÷ 150 GWatt x day/ ton.
- For practical conditions, this may correspond to some 5 ÷ 10 years of uninterrupted operation.
- *The cycle is "closed" since the only material inflow is the natural element and the only "outflow" are fission fragments.*

Why Thorium is not proliferating

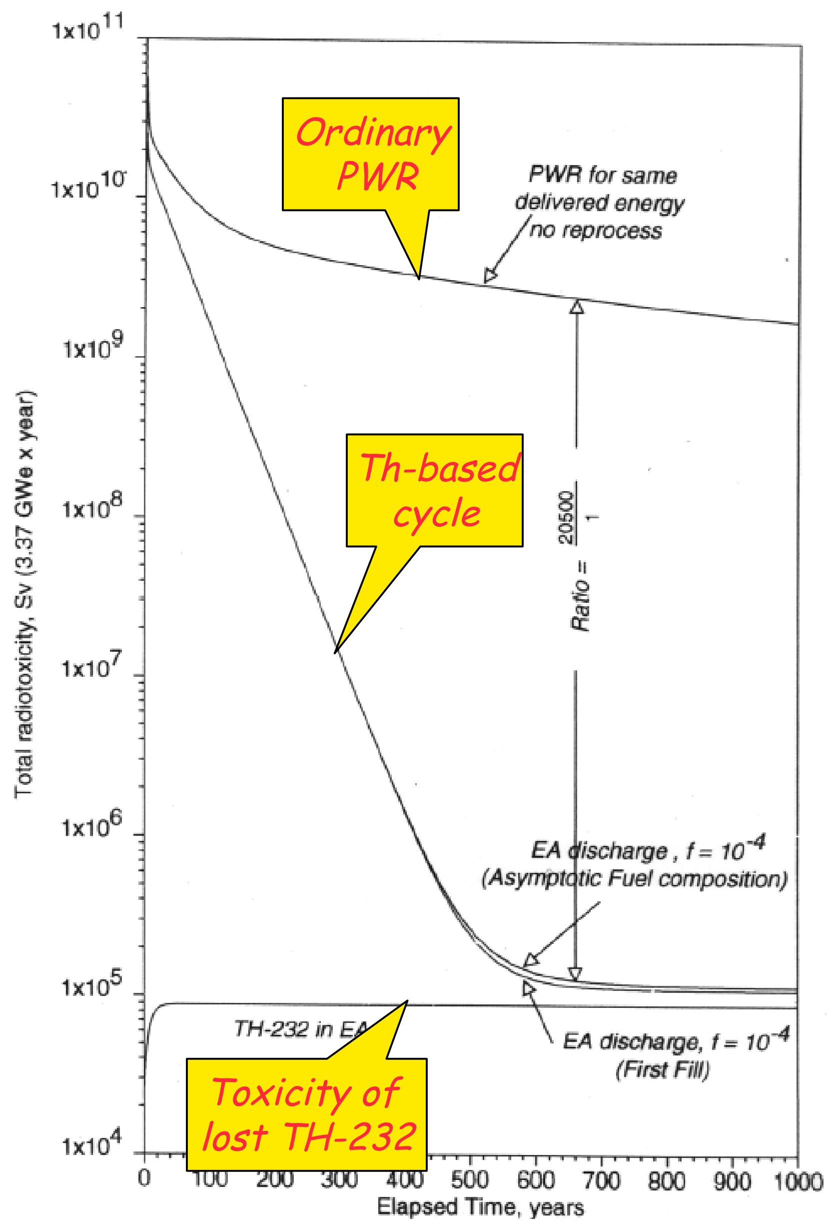
- The U-238/Pu-239 breeding reaction is unfortunately strongly proliferating.
- This is not so for the Thorium cycle, since the three main elements of the discharge, if chemically separated, namely Uranium, Neptunium and Plutonium (Pu-238) limit the feasibility of an actual explosive device which has critical mass of about 30 kg:
  - Decay heat of the α-decays is much larger than the 8 W emitted from the approximately 3 kg of weapon grade Pu-239, with conflicts with the low temperature required by the explosive around the core (190 °C for 100 W)
  - Gamma activity of the decay products make the handling and transport virtually impossible. The contamination of ^{232}U (2×10^3 ppm) due to Tl-208 (2.6 MeV) is asymptotic after 10^3 days and is about 72 Sv/h (50% lethal dose after 5 minutes).
  - Spontaneous fissions strongly reduce its potential yield because of pre-initiation of the chain reaction. Easier to build Gun-type implosion systems are already excluded for Pu-239 with 66 n g^{-1} s^{-1}. Our fuels lead to a too small "fizzle yield".

Element	Bomb grade Pu-239	Uranium (U-232)	Neptunium [3] (Np-237)	Plutonium [3] (Pu-238)
Critical mass (CM), kg	3	28.0	56.5	10.4
Decay heat[1] for CM, Watt	8	**380**	1.13	**4400**
Gamma Activity, Ci/CM	negligible	**1300**	small	small
Neutron Yield[2], n g^{-1} s^{-1}	66	**3000**	**$2.1\ 10^5$**	**2600**

(1) Equilibrium temperature ≈ 190 °C for 100 W, due to presence of HP explosive shield
(2) Neutron yield must be ≤ 1000 n g^{-1} s^{-1}
(3) Very small amounts produced at discharge

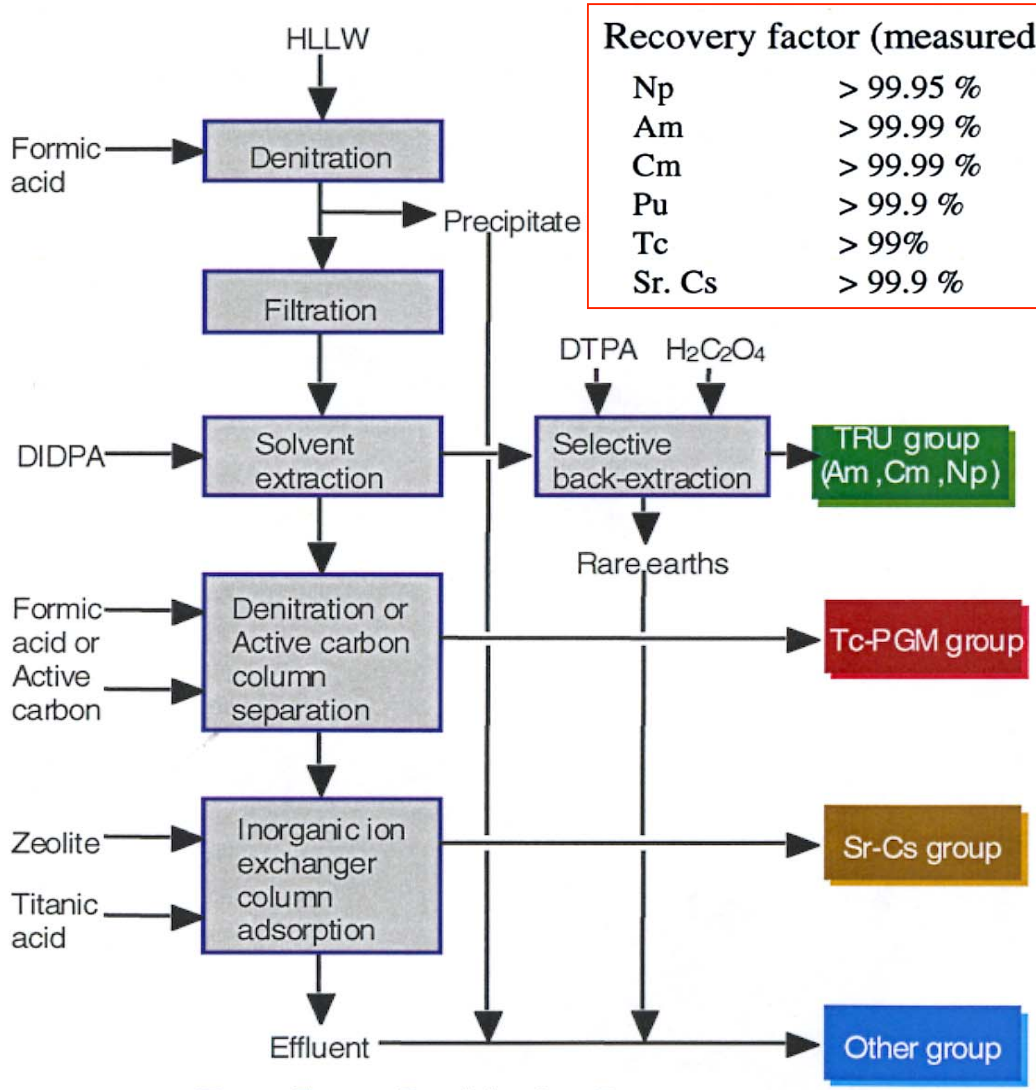
Fuel reprocessing

- At this moment the fuel is reprocessed and
  - ⇨the only waste are Fission fragments Their radio-activity of the material is intense, but limited to some hundreds of years.
  - ⇨Actinides are recovered without separation and are the "seeds" of the next load, after being topped with about 10 ÷ 15 % of fresh breeding element (Th or U-238) in order to compensate for the losses of element.
  - ⇨A small fraction of Actinides is not recovered and ends with the "waste"
- *The cycle is "closed" in the sense that the only material inflow is the natural element and the only "outflow" are fission fragments.*



Aqueous method (Japan)

Recovery factor (measured)	
Np	> 99.95 %
Am	> 99.99 %
Cm	> 99.99 %
Pu	> 99.9 %
Tc	> 99%
Sr. Cs	> 99.9 %



Four-Group Partitioning Process

Test Facility at NUCEF

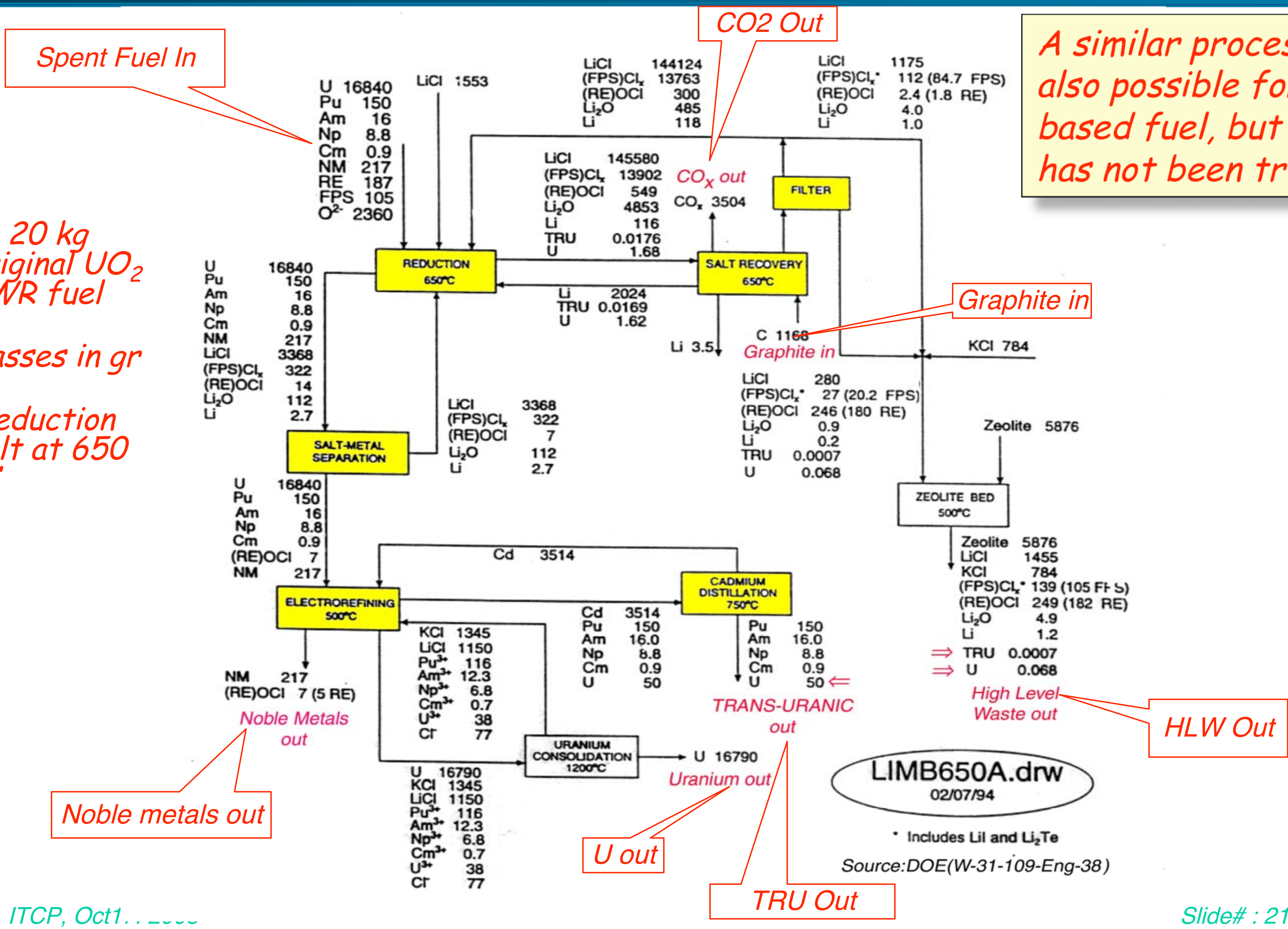
Lithium Pyro-process: material balance flow-sheet

A similar process is also possible for Th based fuel, but it has not been tried

Basis: 20 kg original UO_2 LWR fuel

All masses in gr

LiCl reduction salt at 650 °C



"Breeding" equilibrium

- The process is periodically restarted as an indefinite chain of cycles. The fuel composition progressively tends to a "secular" equilibrium between the many actinides composing the fuel, with rapidly decreasing amounts as a function of the rising of the atomic number.

- In the case of Th-232, the secular mixture is dominated by the various U isotopes with a fast decreasing function of the atomic number.
- Np and Pu (mostly the Pu-238) are at the level of grams/ton !
- Proto-actinium (Pa-233) is the short lived precursory element to U-233 formation.

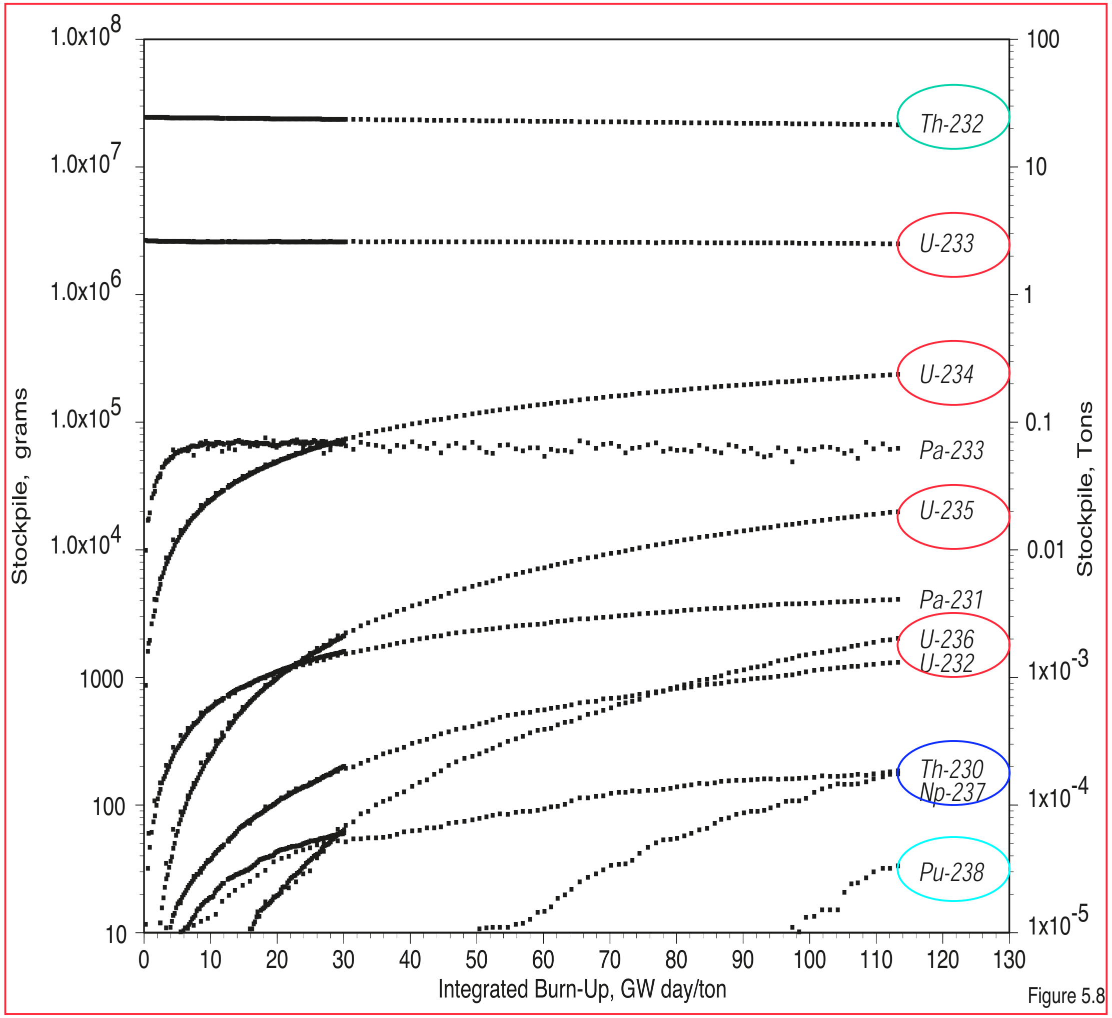
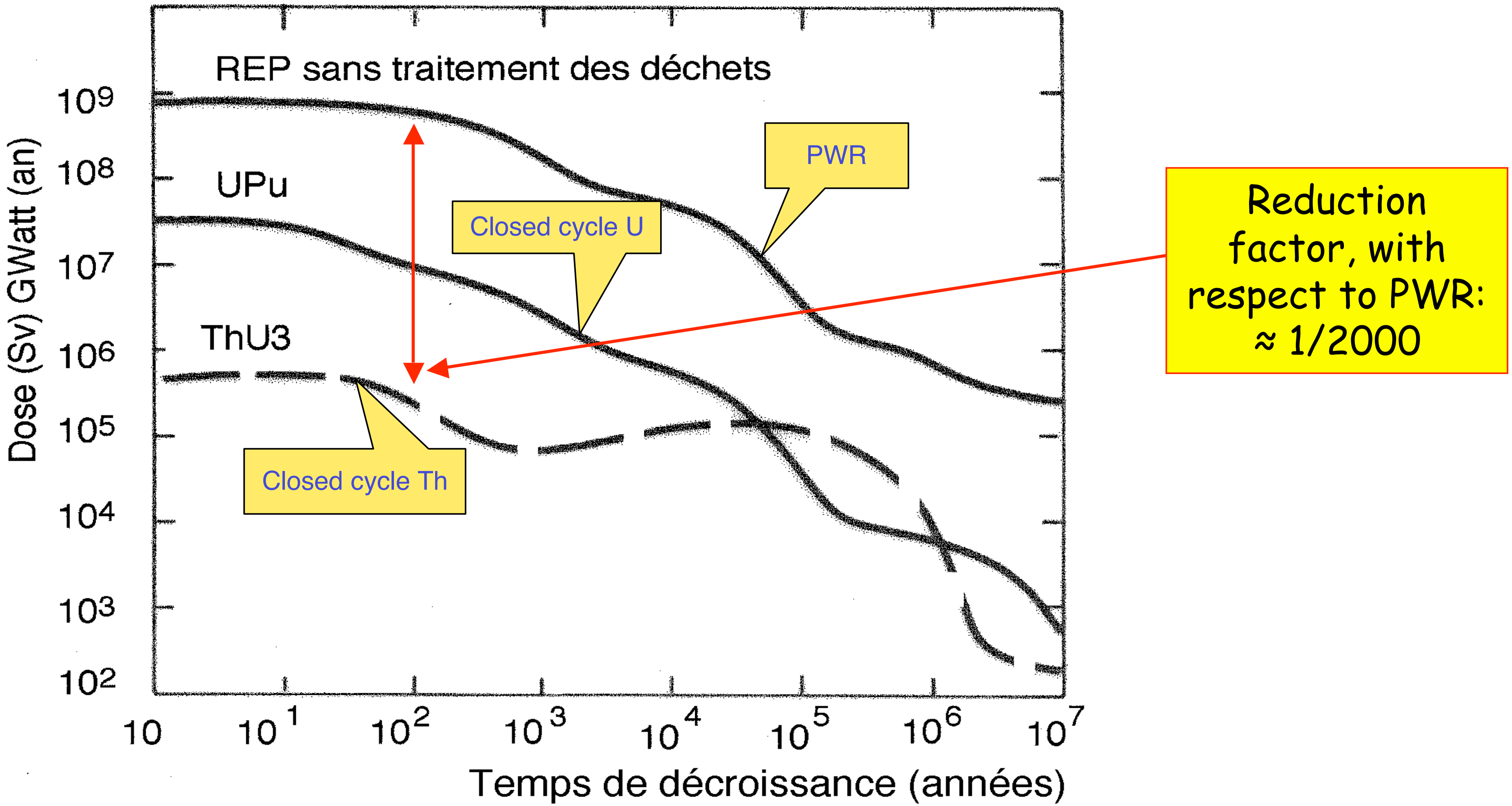


Figure 5.8

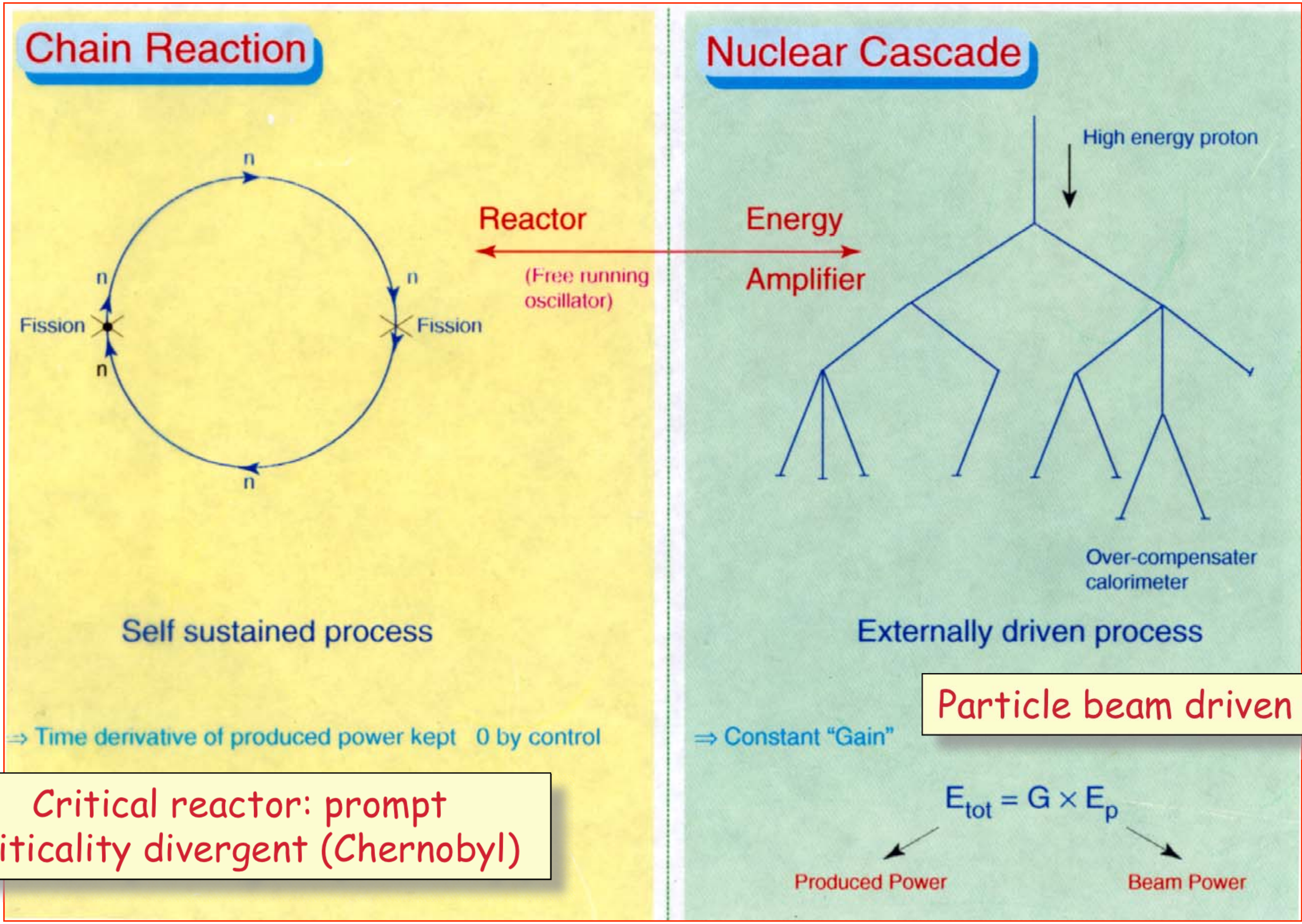
Residual radio-toxicities of waste as function of time



Relative amounts of leaked Actinide waste, excluding fission Fragments. In the case of a closed cycle the rejected fraction is x = 0.1% for U and Pu and of x = 1% for the other actinides

[J.L. Bobin, H. Nifenecker, C. Stéphan : L'énergie dans le monde : bilan et perspectives]

Critical(reactor) and sub-critical (energy amplifier) operation

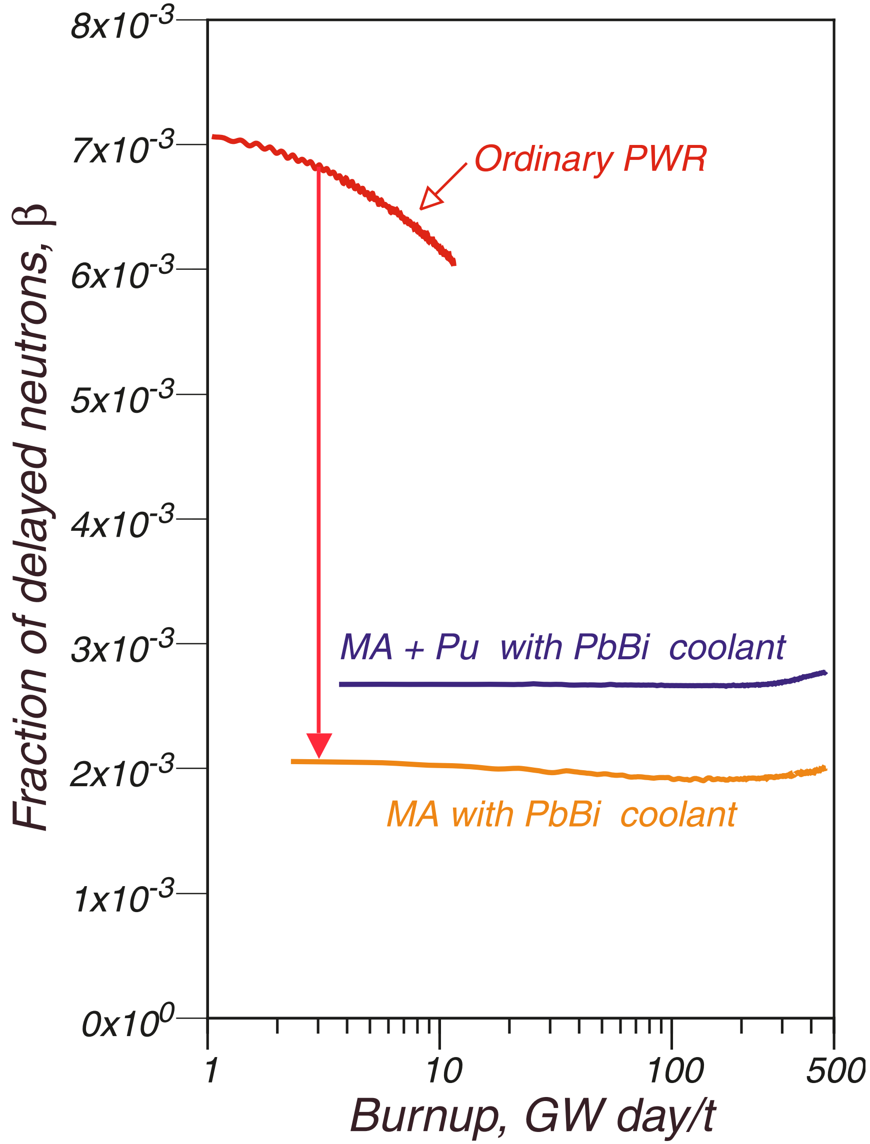


Particle beam driven EA

Critical reactor: prompt criticality divergent (Chernobyl)

Prompt and delayed neutrons in a reactor

- As well known, the operation of a critical reactor is possible only because of the presence of delayed neutrons, which provide enough time to exercise the multiplication coefficient.
- The amount of delayed neutrons, a fraction β of all neutrons is:
  1. For a standard PWR, β Å 0.0070
  2. For MA, β ≤ 0.0020
- The reduction of β represents a fundamental problem for incineration with critical reactors and it favors the choice of sub-critical systems.
  - ⇨ For instance an uncontrolled sudden reactivity change Δβ ≈ 0.0036 implies a hundred fold power increase in 140 μs.
  - ⇨ In the case of a sub-critical system with k = 0.99, the corresponding power increase will be a mere +50%.



Benefits of the sub-critical operation

- A critical reactor operation with U-233 is far more delicate than an ordinary PWR.
- These problems are best solved with the help of an external contribution of neutrons produced with a high energy proton beam hitting a spallation target.
- In absence of the proton beam the assembly is sub-critical with an appropriate criticality parameter $k_{eff} < 1$ and no fission power is produced.
- With the beam on,the nuclear power is directly proportional to the beam power, namely the power gain *G* = [Fission thermal power]/[beam power] is related to the value of the multiplication coefficient k_{eff} by a simple expression:

$$G = \frac{\eta}{1 - k_{eff}} \quad ;\eta \approx 2.1 \div 2.4 \;\; for \;\; Pb - p \; coll. \; > 0.5 \;\; GeV$$

- For instance, in order to correct for the reduction in β Å 0.007- 0.002= 0.005 of the delayed neutrons, such as to operate with U-233 in the same delayed neutron conditions of ordinary U-235, $k_{eff} \approx 0.995$ and $G \approx 480$, namely the controlling beam power is 2.1 MWatt for each GWatt of thermal power. For $k_{eff} \approx 0.99$, $G \approx 240$.

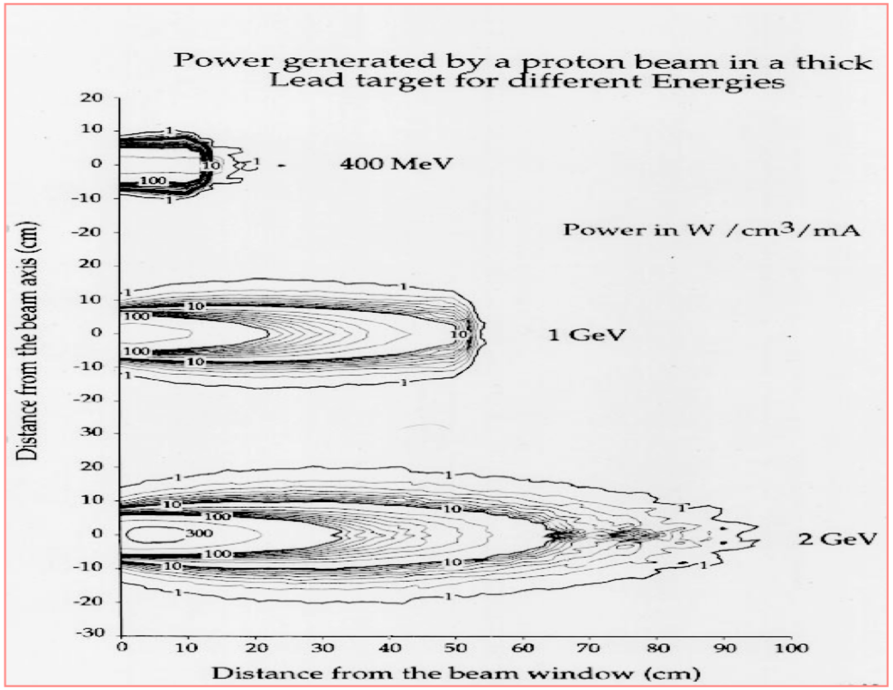
Principle of operation of the Energy Amplifier

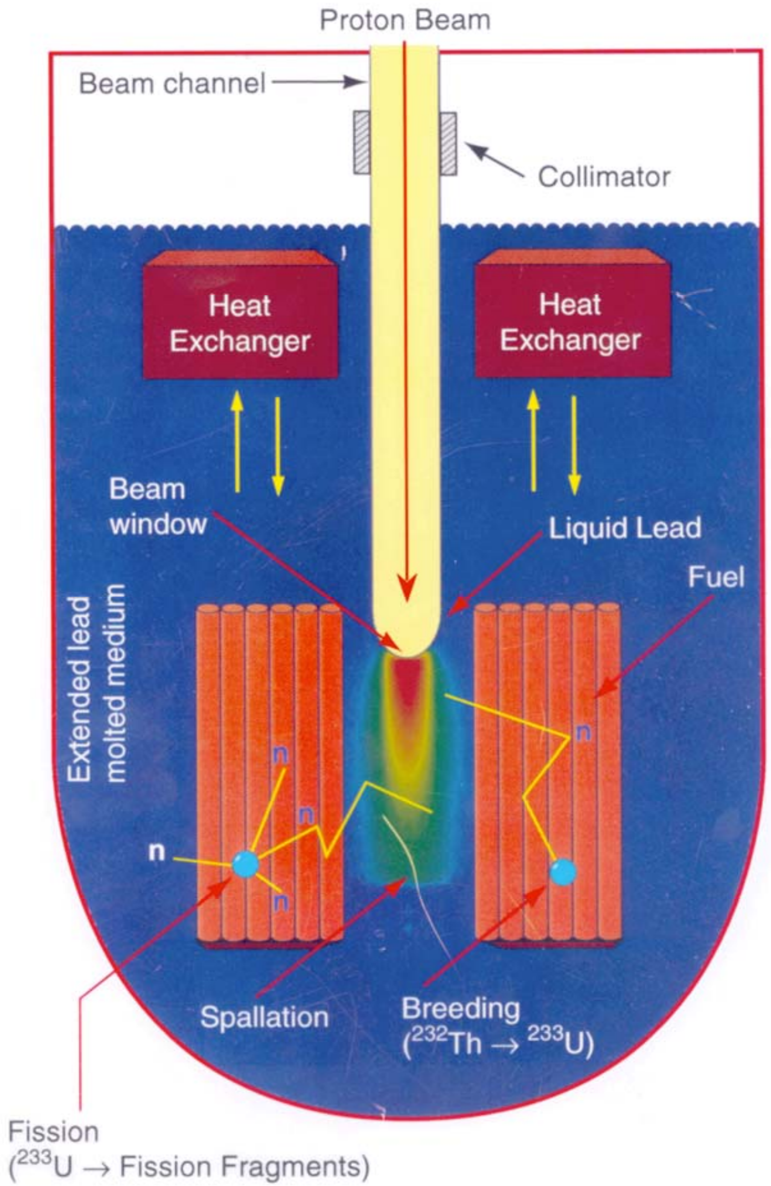
Thorium related Fission

$$^{233}_{92}U + ^{1}_{o}n \rightarrow 2.53[^{1}_{o}n] + 2FF + 200\ MeV$$

$$^{232}_{90}Th + ^{1}_{o}n \rightarrow ^{233}_{91}Pa + \gamma \xrightarrow[(27\ days)]{\beta-decay} ^{233}_{92}U + ^{o}_{-1}e$$

$$^{233}_{92}U + ^{1}_{o}n \rightarrow ^{234}_{92}U + \gamma$$





Basic choices

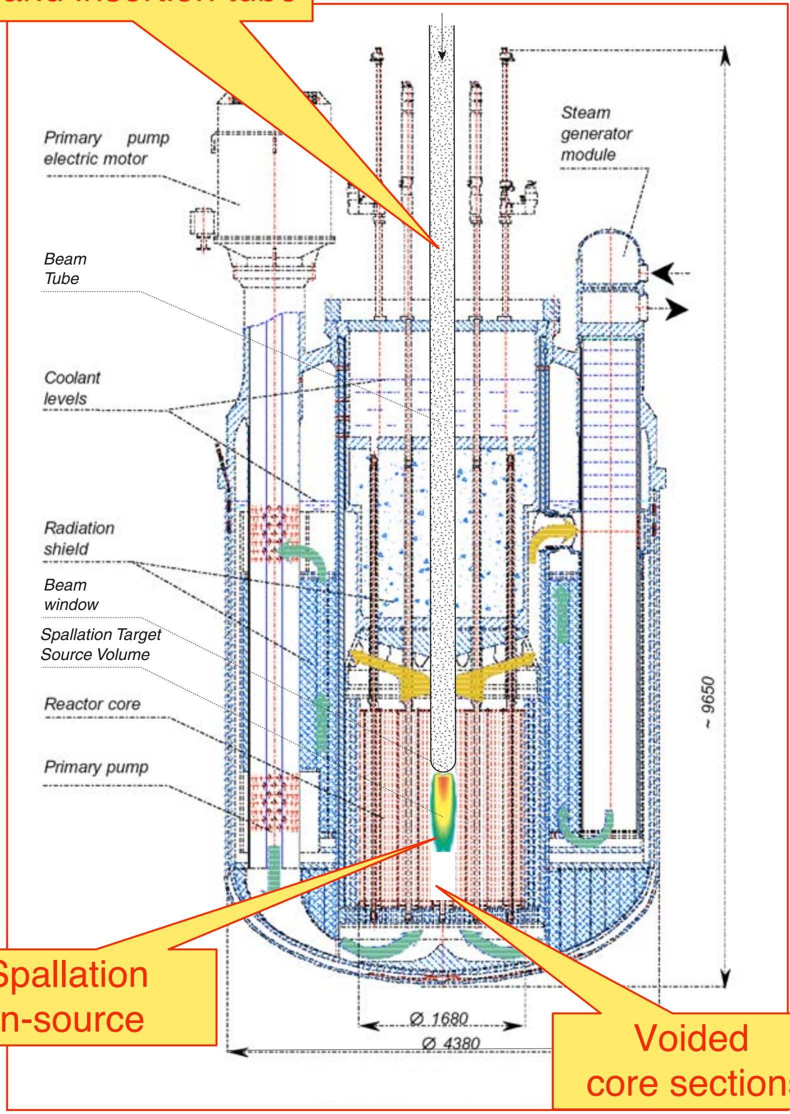
FUEL	Depleted Uranium (U-238)	Natural Thorium (Th-232)
Fast Neutrons (metal coolant)	Same as Super-Phenix. Pu/U @ equilibrium ≈ 20 % It produces both Plutonium and minor Actinides (Cm, Am, etc). Positive void coeff. Both a critical reactor and sub-critical system (external neutron supply) are possible For critical reactor, very small fraction of delayed neutrons (<0.2 %)-hard to control	Up to 15% mass burn-up but small multiplication coefficient, though very stable (k_o=1.20) U/Th @ equilibrium: ≈10 % Hard to maintain criticality over long burn-up. Not a good reactor. Needs an external neutron supply High power density(≤200MW/m^3) No Plutonium, neg. void coeff. No proliferation (denaturation)
Thermal Neutrons	It does not have an acceptable multiplication coefficient (k_o ≈ 0.7). Not practical	Up to 4% mass burn-up, but small multiplication coefficient, though stable (k_o =1.12) U/Th @ equilibrium: ≈ 1.3 % Hard to maintain criticality Needs an external neutron supply No Plutonium, no Proliferation Low power density (≤ 10 MW/m^3)
	Proliferation risks	**No ploriferation risk**

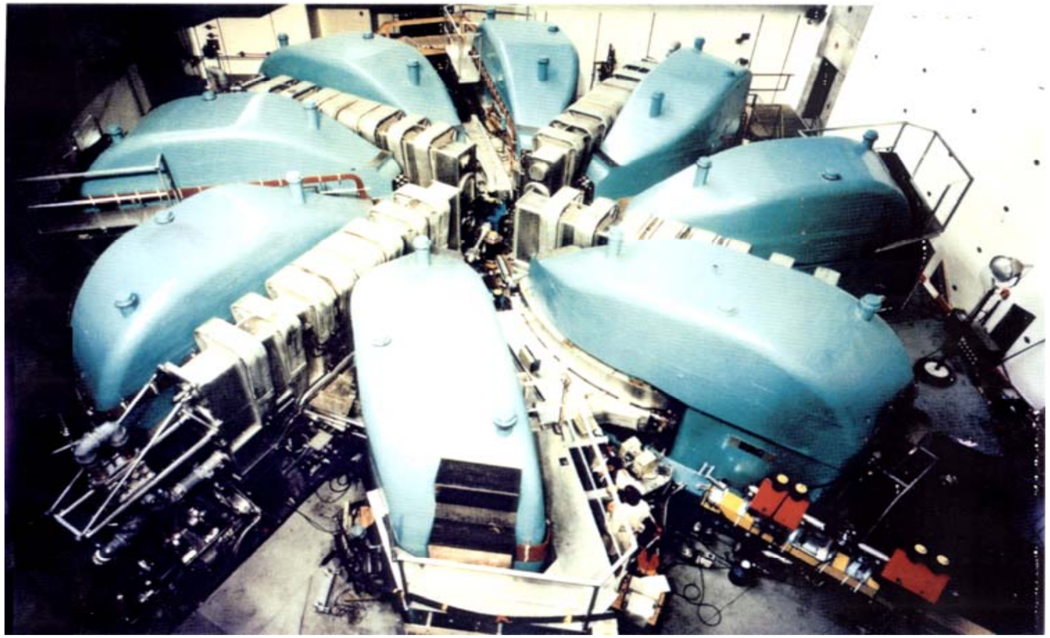
Operation	Thorium (^{232}Th) cycle	Uranium (^{238}U)cycle
Thermal neutrons	Sub-critical	Not possible
Fast neutrons	Sub-critical	Sub-critical and Critical

Fast Energy Amplifier

$$^{232}Th + n \rightarrow ^{233}U; \quad ^{233}U + n \rightarrow fission + 2.3n \quad (Th \ \ cycle)$$

Submarine derived russian design, BMV75





600 MeV cyclotron at PSI

·Present beam power ≈ 1 MWatt

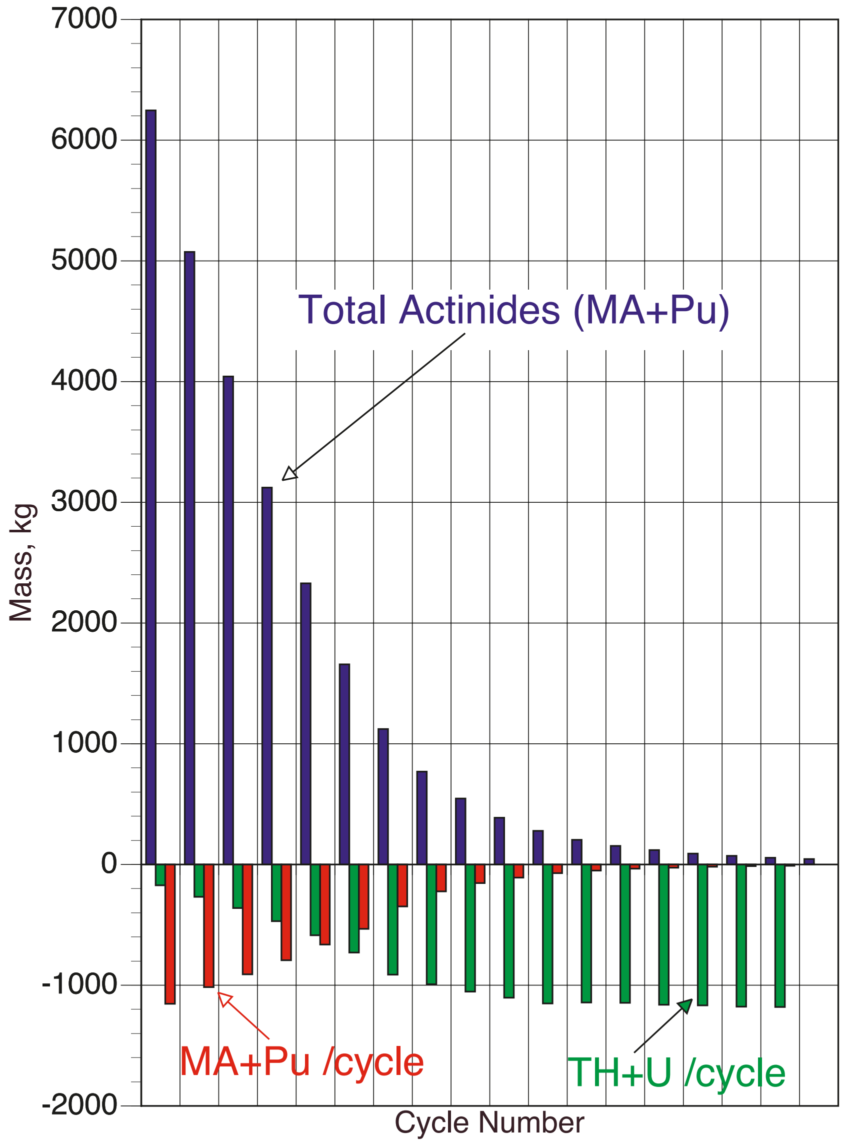
Upgrade to about 3 x foreseen

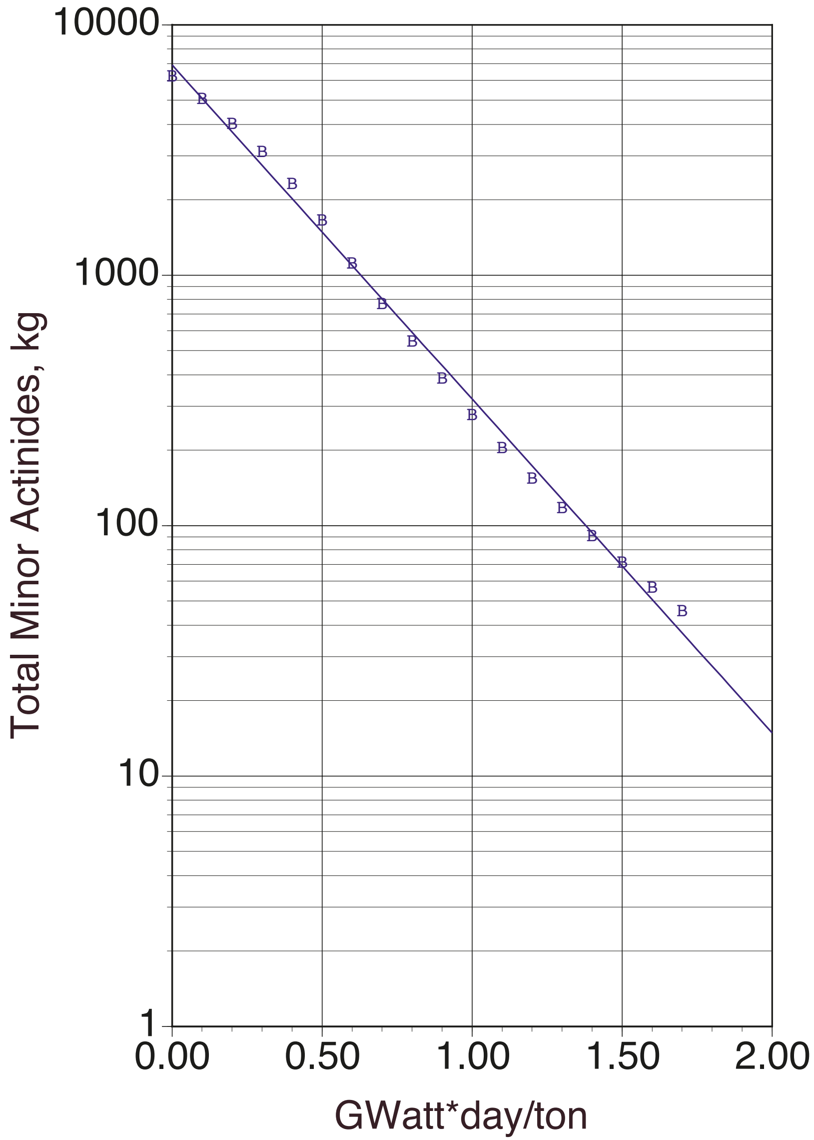
For $k_{eff} \approx 0.99$, $G \approx 240$ the controlling beam is 2.1 MWatt for each GWatt of thermal power

The initiation of the breeding process.

- The Th fuel is not directly fissile: an adequate amount of U-233 must be in equilibrium with Th in order to produce fissions and energy.
- Several methods are considered in order to start-up the breeding process with the addition to Thorium of a provisional fissile element recovered from an ordinary reactor which has no appreciable proliferating risks.:
  - An adequate mixture of Plutonium, with an advanced isotopic composition. (fast and/or thermal)
  - An adequate mixture of Minor Actinides (Am,Cm,Np...), only with fast breeders.
- Another more advanced method is the so-called electro-production, in which a Th target is directly bread into U-233 by a high energy proton beam and a very strong current. As an example, a powerful accelerator with 2 GeV and 150 mA (300 MWatt) can bread and extract about 1-1.5 ton of U-235 every year.
- Once the initial U-233 has been produced, the breeding process will continue indefinitely in an equilibrium condition between production and fission, slowly tending to the asymptotic mixture and with a remarkably constant multiplication value k.

Transition from initial MA to Th-U

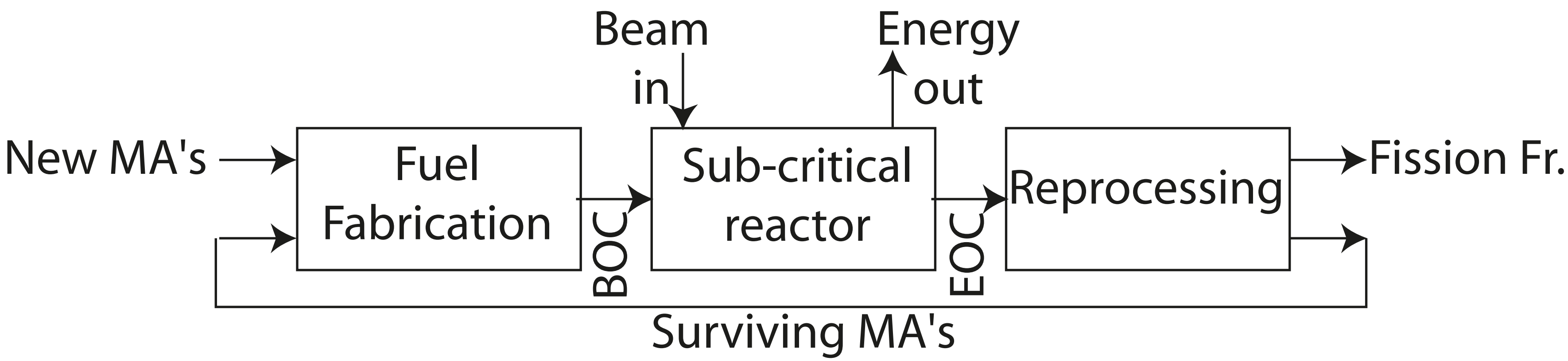




In short:

Item	Energy Amplifier
Safety	Not critical, no meltdown
Credibility	Proven at zero power
Fuel	Natural Thorium
Fuel Availability	Practically unlimited
Chemistry of Fuel	Regenerated every 5 years
Waste Disposal	Coal like ashes after 600 y
Operation	Extrapolated from reactors
Technology	No major barrier
Proliferating resistance	Excellent, Sealed fuel tank
Cost of Energy	Competitive with fossils

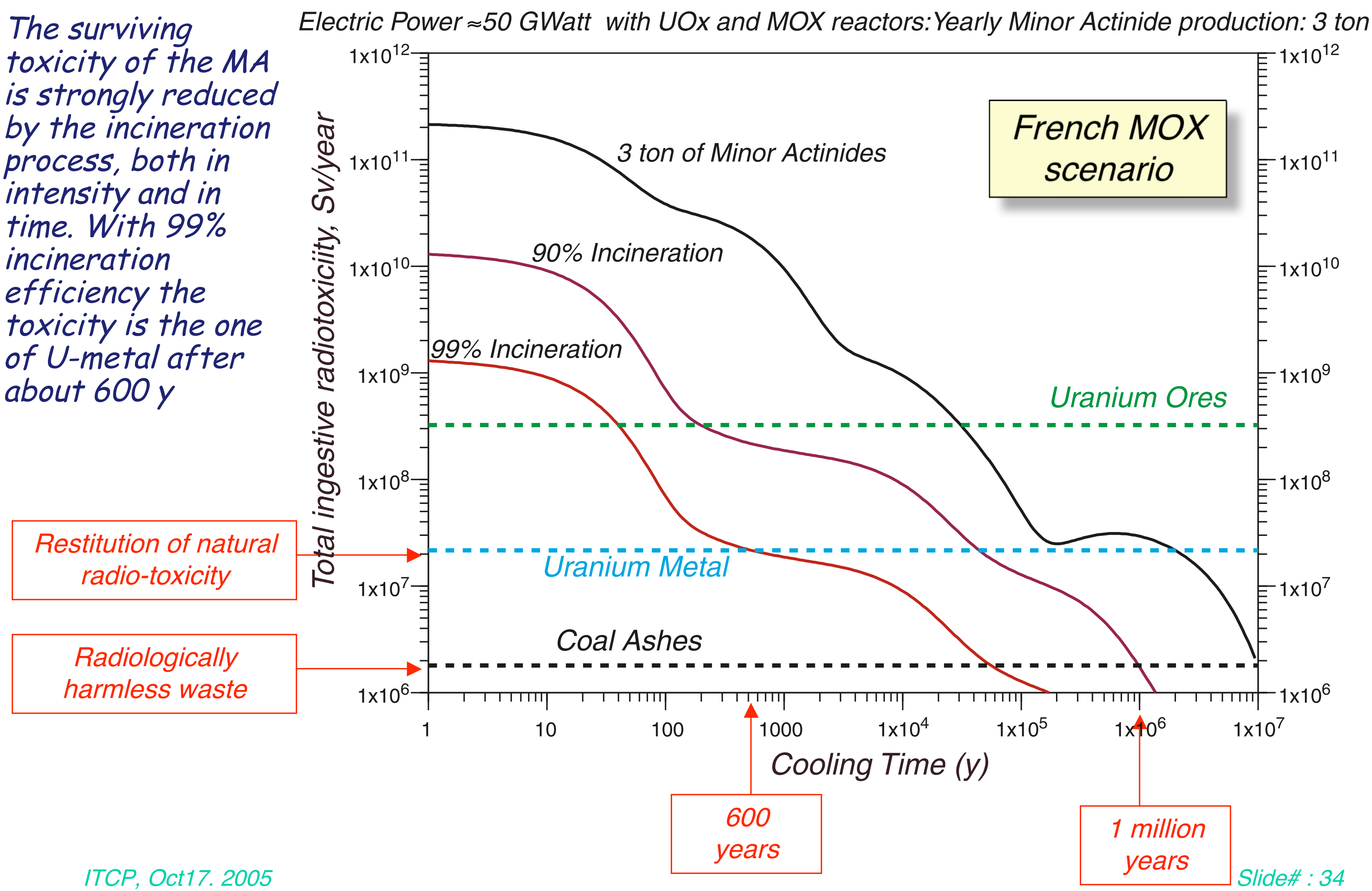
Burning the Minor Actinide waste



- The elimination of MA is occurring in a closed cycle, in which MA's are used to fabricate the fuel, which is inserted in the sub-critical reactor at the beginning of the cycle (BOC).
- The sub-critical reactor operation is extended for a given period of time, with a proton beam controlling both the energy production and the fuel transmutation.
- At the end of the cycle (EOC) the fuel is extracted and re-processed, separating the FF ashes which are sent to the repository and the Actinides, which are used to re-fabricate the fuel, topped with some new MA's.
- The whole cycle is indefinitely repeated, with the net transmutation of MA's into FF's which are later to be stored for a few hundred of years in a repository.

Expected reductions in radio-toxicity

The surviving toxicity of the MA is strongly reduced by the incineration process, both in intensity and in time. With 99% incineration efficiency the toxicity is the one of U-metal after about 600 y

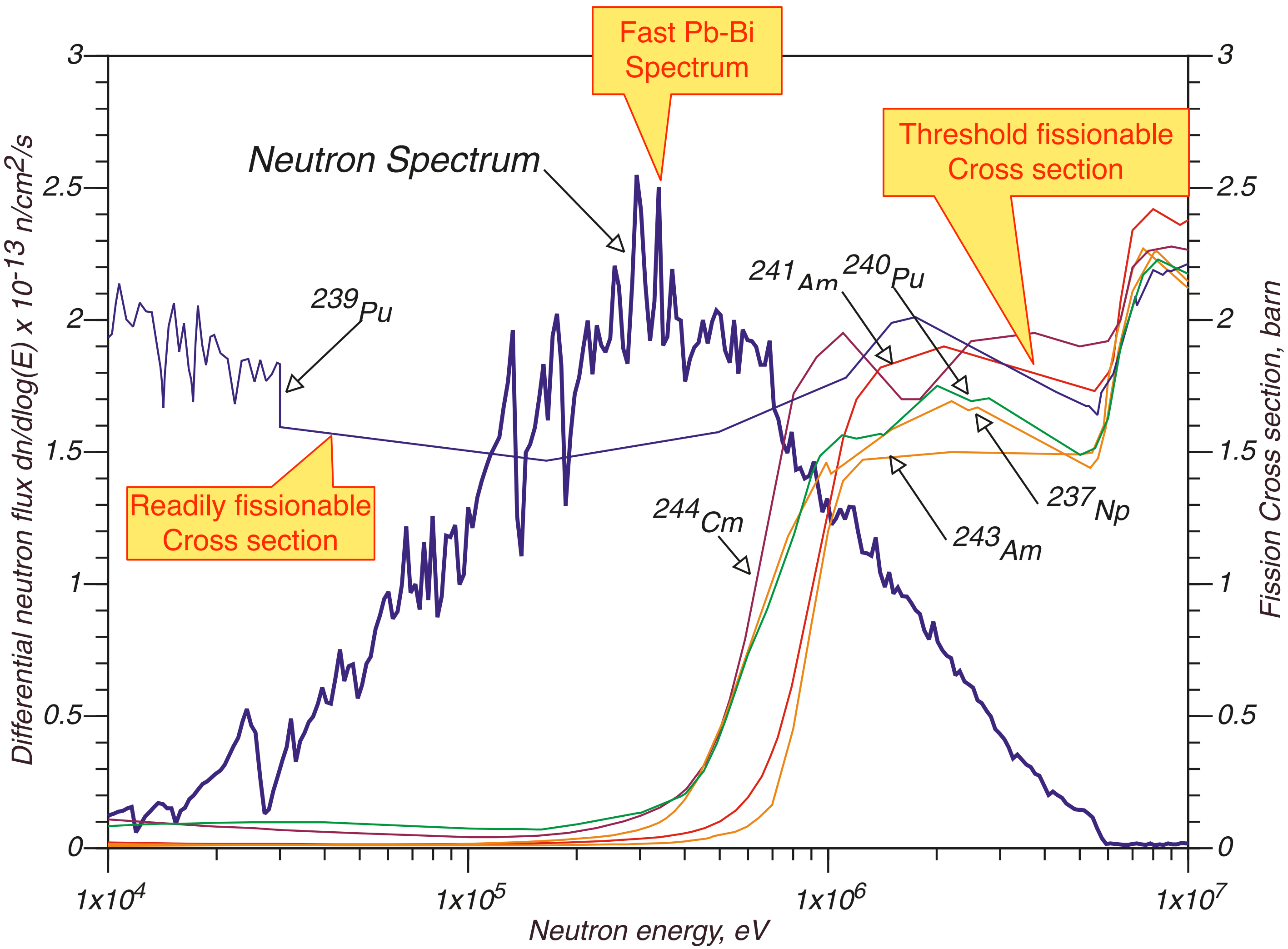


Features of incineration

- An incinerator, in contrast with an ordinary PRW's, has unique requirements which imply a different mode of operation:
- The incineration process is a closed reaction chain based on fission: but in order to be complete, an equilibrium chain involving several cascading elements has to take place, in which only a fraction of the elements is fissioned at each step, the rest being transmuted by neutron capture to subsequent isotopes with a sufficiently long decay time, in order to be subsequently either transmuted again or undergoing fission.
- To this effect, the number of fission neutrons must be at all times sufficiently large throughout the process in order to supply also for the neutrons which are producing conversion to captures in the less readily fissionable elements.
- A thermal neutron environment is not capable of sustaining incineration, because of the excessive number of elements which are dominated by capture rather than fission. But with the help (very) fast neutrons, an efficient incineration process can be readily sustained.
- Neglecting the small energy produced in the captures of intermediate isotopes, the amount of energy produced in the incineration is determined by fissions at about 930 GWatt/ton of incinerated material,irrespectively of the details of the chain.

Cross section dependence of fission for MA Mixture

As a difference for instance of ^{239}Pu, most of the leading MA isotopes are readily fissionable only with very energetic neutrons, like the ones produced in a (very) fast reactor.

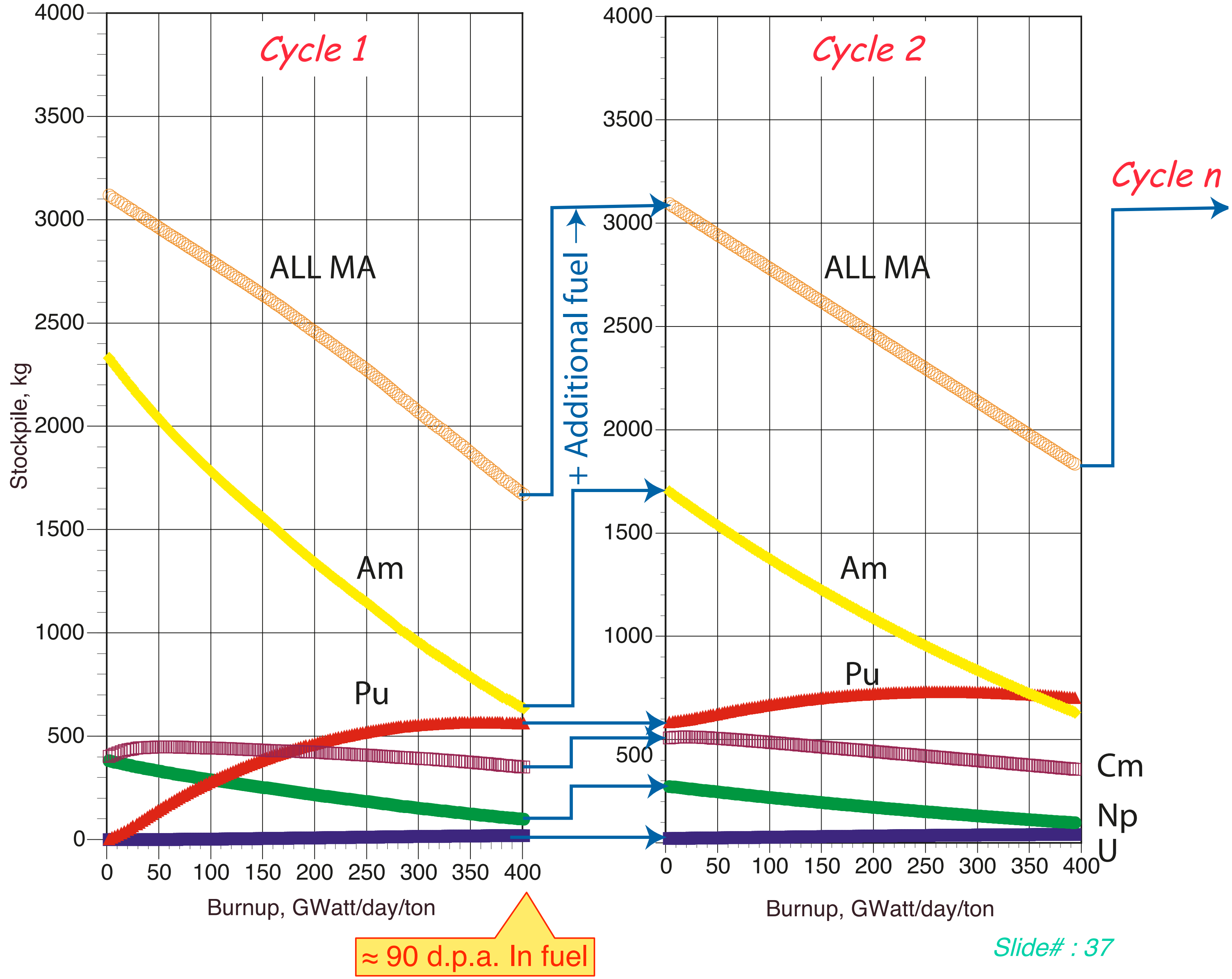


Cyclic time evolution of the MA's stockpile

*About 3.1 ton of h.m. MA's are burnt for about 400 GW*d/t, in a sub-critical fast reactor (Pb-Bi), at which the final MA h.m. mass is 1.7 ton. At each subsequent cycle additional fuel is added to the surviving MA's, topping each cycle to the 3.1 ton of h.m.*

The cycle is indefinitely repeated.

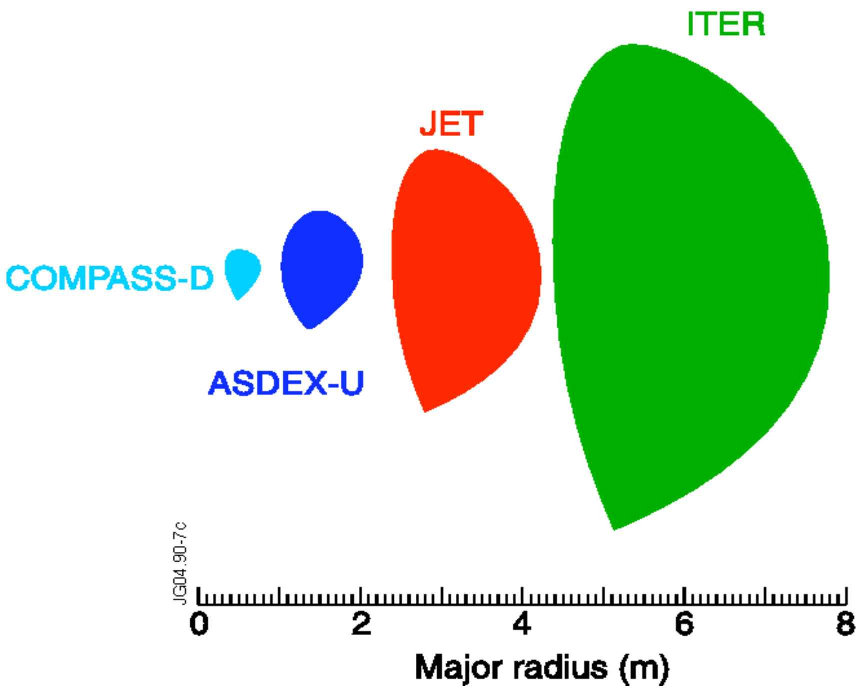
Secondary Pu and U are generated and incinerated during the cycles. No appreciable Bk, Cf, Es etc. are produced.

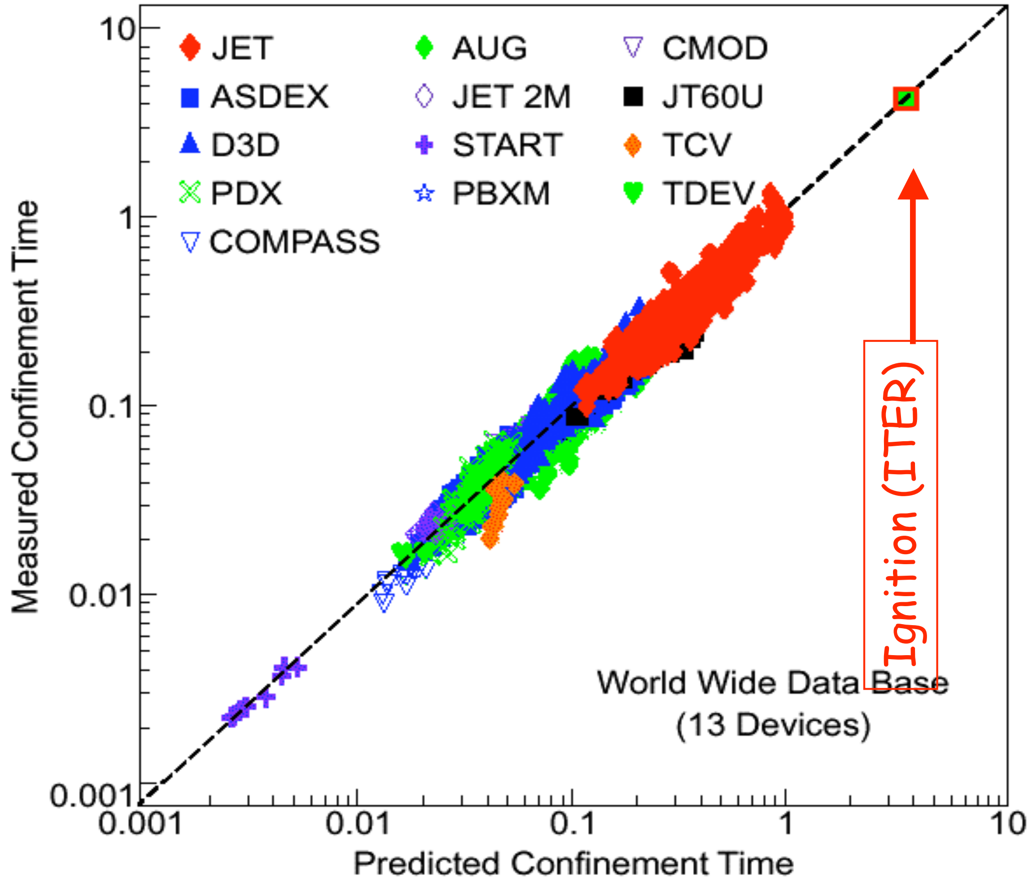


ITER has been approved !

Experimental results

- The results from all experiments running at present show the global value of t_E, across more than two orders of magnitude, as function of physical parameters linked by an experimental "scaling law".
- The next unknown is "ignition" in which energy is mainly produced by the plasma rather than by external sources





Why ITER? Why now?

From Physics Studies to a Power Reactor

Commercial Power Reactor

Power Reactor

Demonstration Reactor

DEMO

Optimisation of Tokamak Reactor Design
Availability of Electrical Power
Evaluation of Economics

Experimental Reactor

ITER

Demonstration of Technologies essential for a power reactor
- Superconducting coils
- Plasma power and particle exhaust component
- Remote maintenance
- Reactor-relevant tritium-breeding blankets

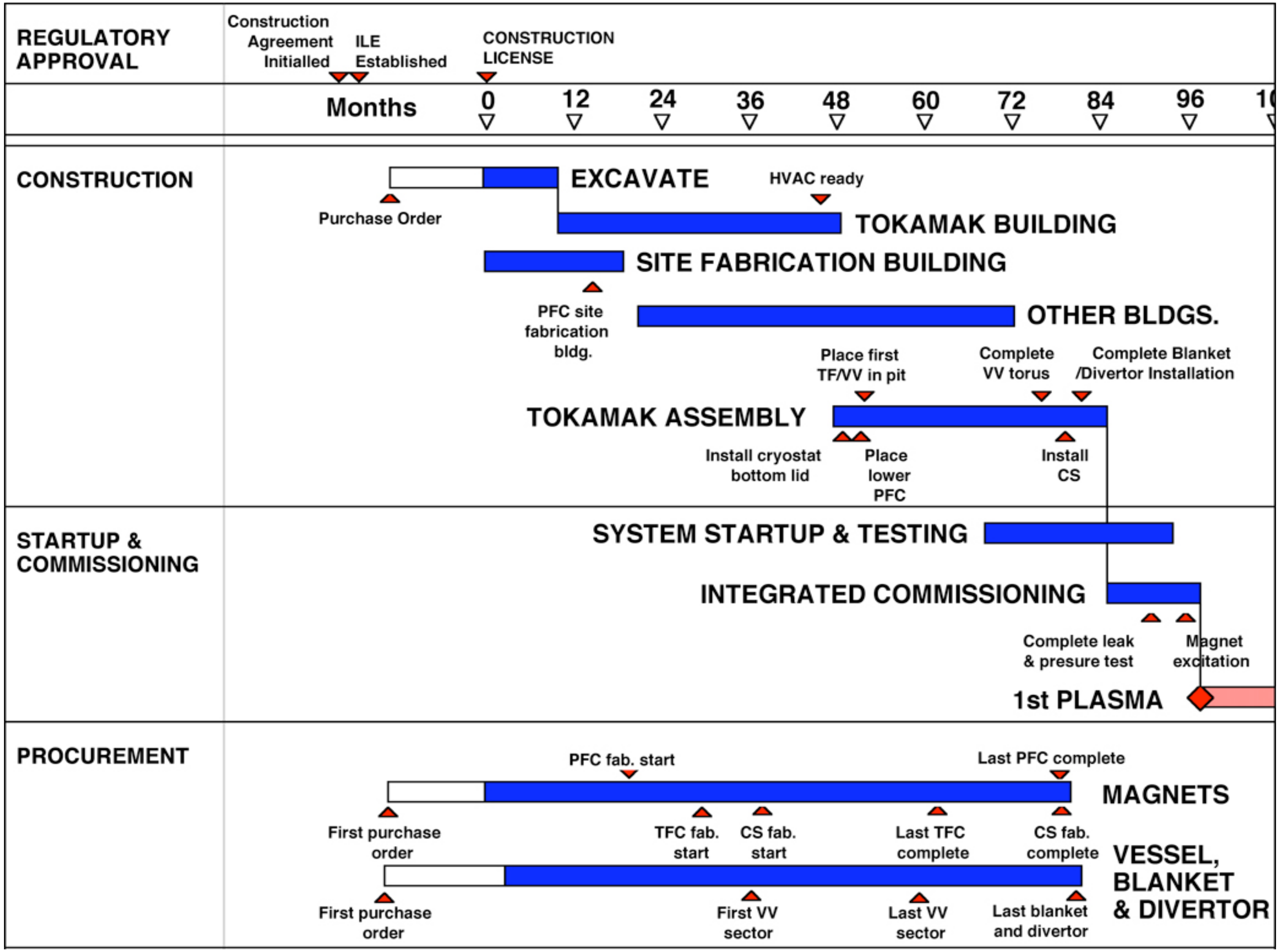
Confirmation of physics basis
- confinement
- alpha particle physics
- steady state operation

Present Generation of Large Tokamaks

JT-60
JET
TFTR

Physics basis for extrapolations and predictions of performances of next step machines

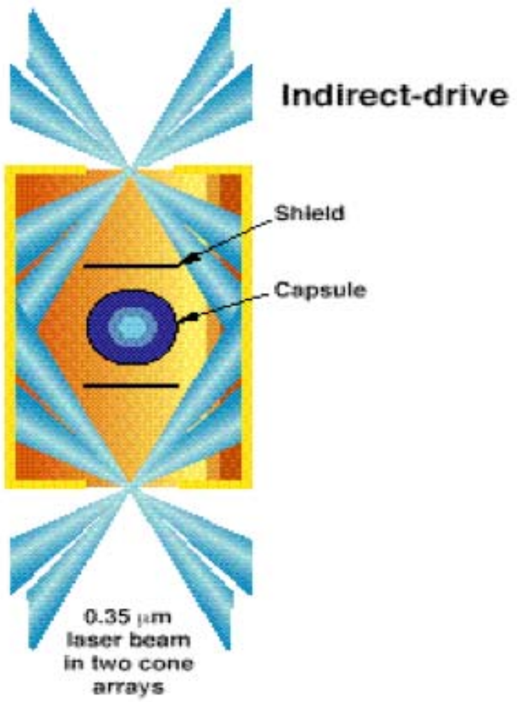
ITER construction schedule

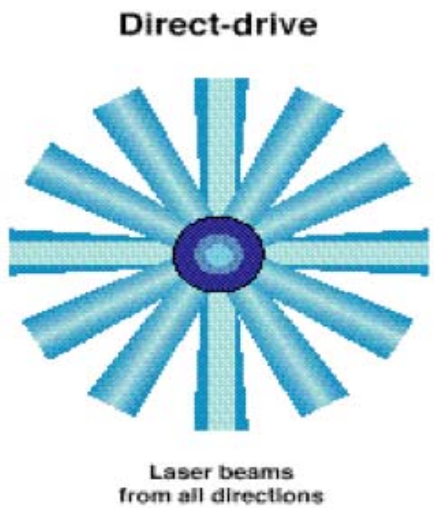


- 7 year construction
- 1 year integrated commissioning
- ILE (ITER Legal Entity) established about 2 years before award of construction license
- Long lead item calls for tender sent out and procurement started before license awarded
- Success-oriented schedule

Other concepts for Nuclear Fusion

- Magnetic fusion of other fuels: D-He3 fuel (≈ 50 times reduction in neutron yield but where to find the He3 ? P-B11, clean, but how to do it ?
- Inertial confinement during very short pulses:
  - a small pellet of fuel (D+T) is compressed and heated by intense laser or ion beams (direct or indirect drive)
  - the density is very high (~ 1000 n_{ice}) and the pressure (~M bars)
  - from the hot pellet centre, a burning wave propagates radially (spark ignition)

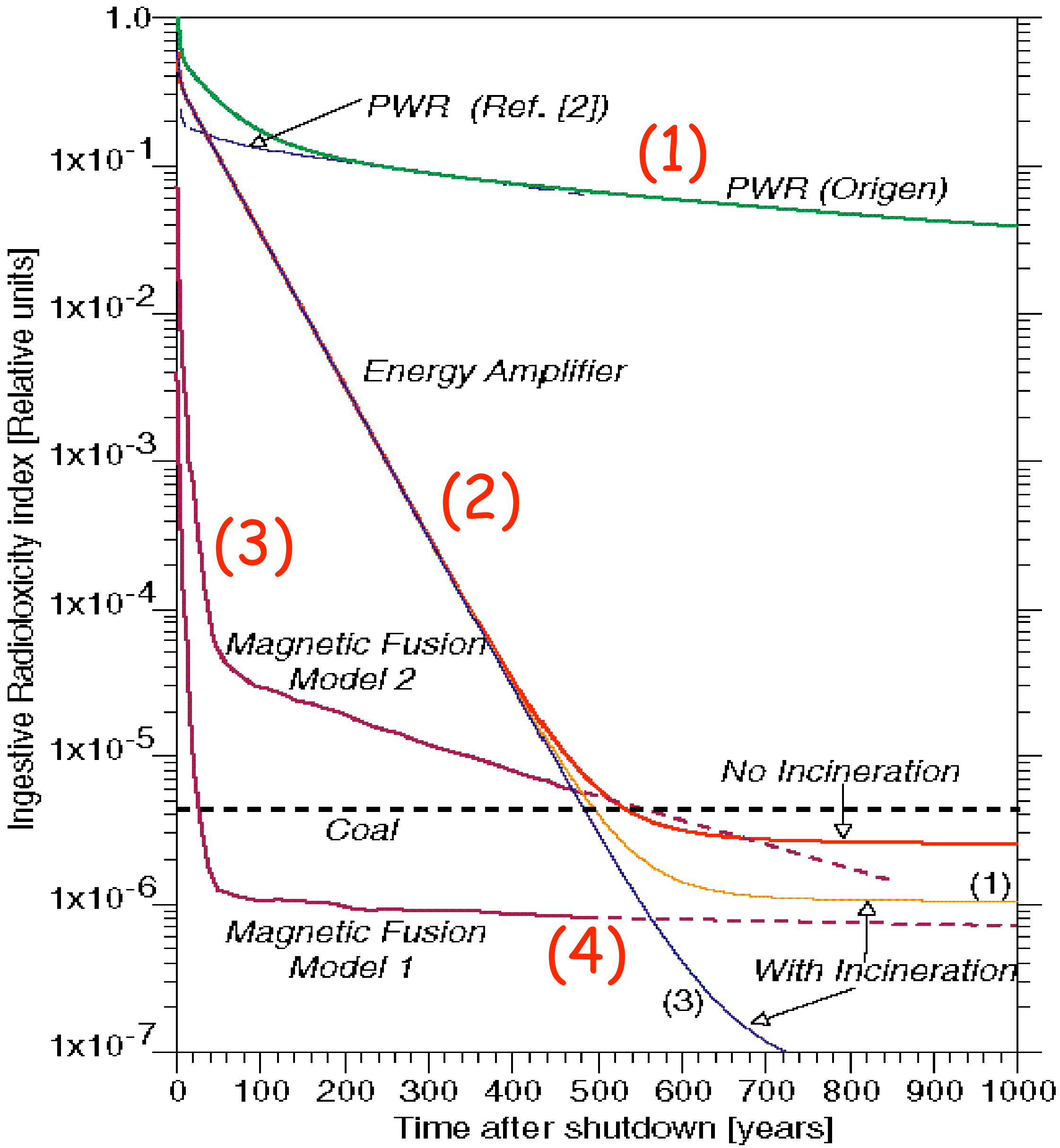




$$G = \frac{E_{Fusion}}{E_{input}}$$ large enough ≥ 50 - 100

$$n\tau_E T \geq \frac{T}{R(T)}$$ **the minimum is obtained for $T \simeq 3 \times 10^8$ K**

Radioactive decays for the various options



- *Relative ingestive radio-toxicity index* as a function of time in years for:
  1. Ordinary PWR
  2. Th-232 Energy Amplifier
  3. Magnetic fusion II
  4. Advanced Magnetic fusion I
- *Realistic availability of supplies*:
  1. Ordinary PWR: ≈ 50y at present consumption level
  2. Th-232 Energy Amplifier: about 20'000 years at 3 x present global consumption
  3. Magnetic fusion: Li has energetic yield comparable to Th-232 (U238)

Conclusions

- The future of mankind is crucially dependent on continued availability of cheap and abundant energy. *Should energy supply breakdown, mankind may suffer enormous consequences. .*
- Energy from fossils is not forever: furthermore it is likely to be prematurely curbed by *the emergence of serious and uncontrollable climatic changes*.
- Time has come to seriously consider other sources of energy, without which mankind may be heading for a disaster. *Nuclear and solar are the only candidates*. *But solar energy is not today's solar energy and nuclear energy is not today's nuclear energy*
- A serious alternative is a new nuclear energy without U-235 and without proliferation : Thorium fission and D-T fusion are likely candidates, capable of supplying energy for millennia to come— the difference between renewable and non renewable becoming academic.
- Depleted Uranium is also possible, but not for everybody, since it has strong links to military deviations.
- The other alternative is solar energy: particularly promising is the direct use of concentrated solar radiation in the wide regions of the "sun belt".
- It is unlikely that any stable, long term development of mankind will be possible without both of them.These two new methods are likely to be successful in the long run: however *a vast, urgent and innovative R&D is necessary.*
- Although innovative energies may eventually be more essential to developing countries, *our technically developed society can realistically foster such a change.*

Thank you !