NRC “Kurchatov institute”

FUTURE DEVELOPMENT OF NUCLEAR POWER AND ROLE OF FUSION NEUTRON SOURCE

Green Nuclear Power

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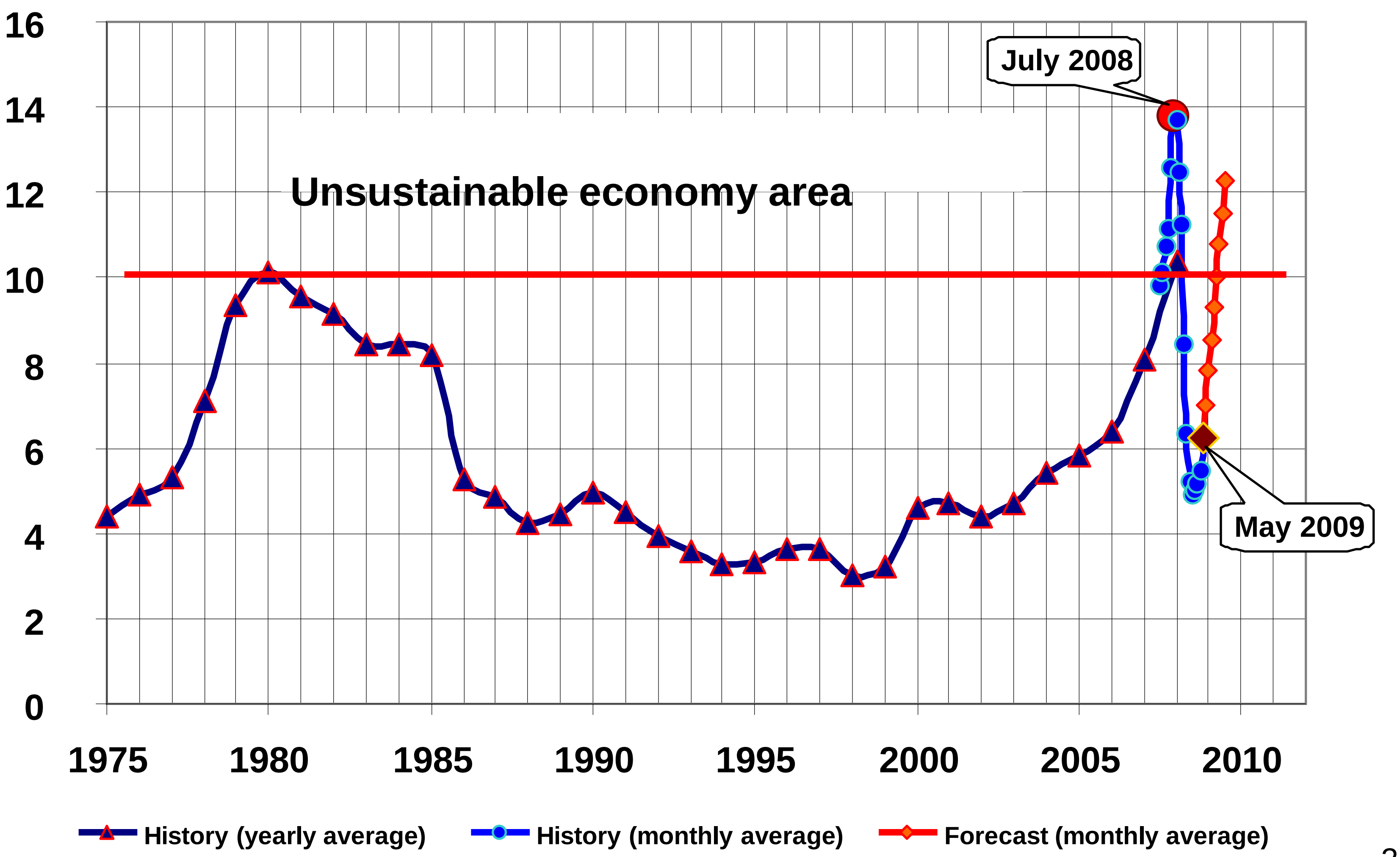
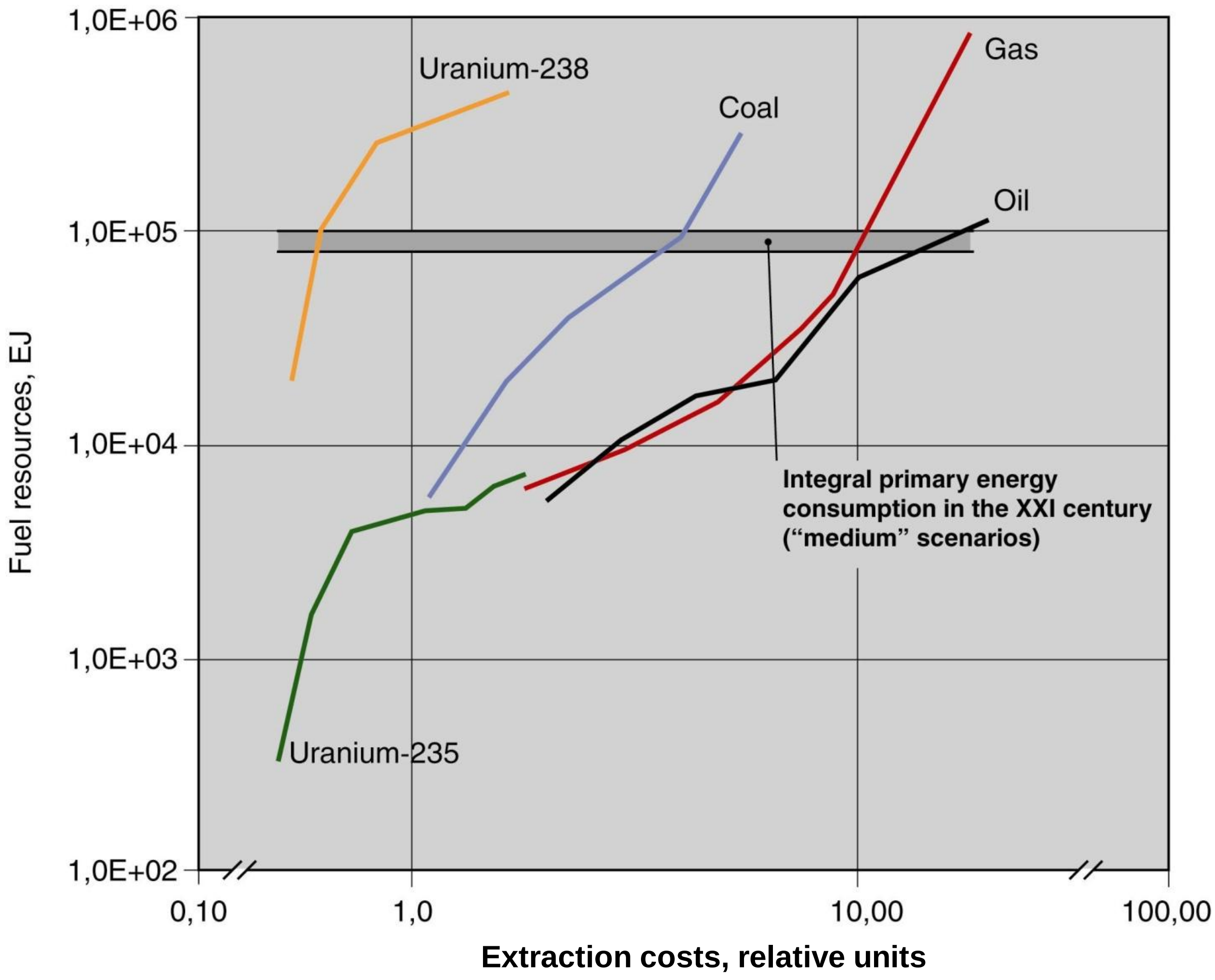
Primary energy share in the world GDP, %



Some remarks

- A large proportion of the costs of energy sources in GDP restrains economic development, leads to stagnation or decline of the economy. This means that scaling up energy in the future should take place only at the expense of such energy sources that are not very expensive and are able to cover the deficit and to ensure normal conditions for the functioning of the economy.
- Currently, the issue of nuclear energy development in different countries is seen as a long-term strategic direction of energy development.
- Relying only on the proven so far nuclear technology, which is based on pressurized water reactors and an open fuel cycle, there is little reason to regard it as an essential stabilizing factor.

Energy resources' availability depending on their extraction costs



Problems of modern NP

Modern NP cannot be considered as basis of sustainable development for the following reasons:

- Inefficient fuel utilization (the effective resource is less, than of oil and gas);
- Degradation of neutron potential (consumption of uranium - 235, absence of nuclear fuel breeding);
- Accumulation of waste products proportionally energy production (there comes that moment when the electricity tariff will not be sufficient for SNF and RW management);
- Limitation of scales and regions of use;
- Increase of threat of uncontrollable use of nuclear materials.

Open fuel cycle
2030 y. – 600 GWe   2050 y - 1500 GWe

Uranium demand and annual extraction potential .

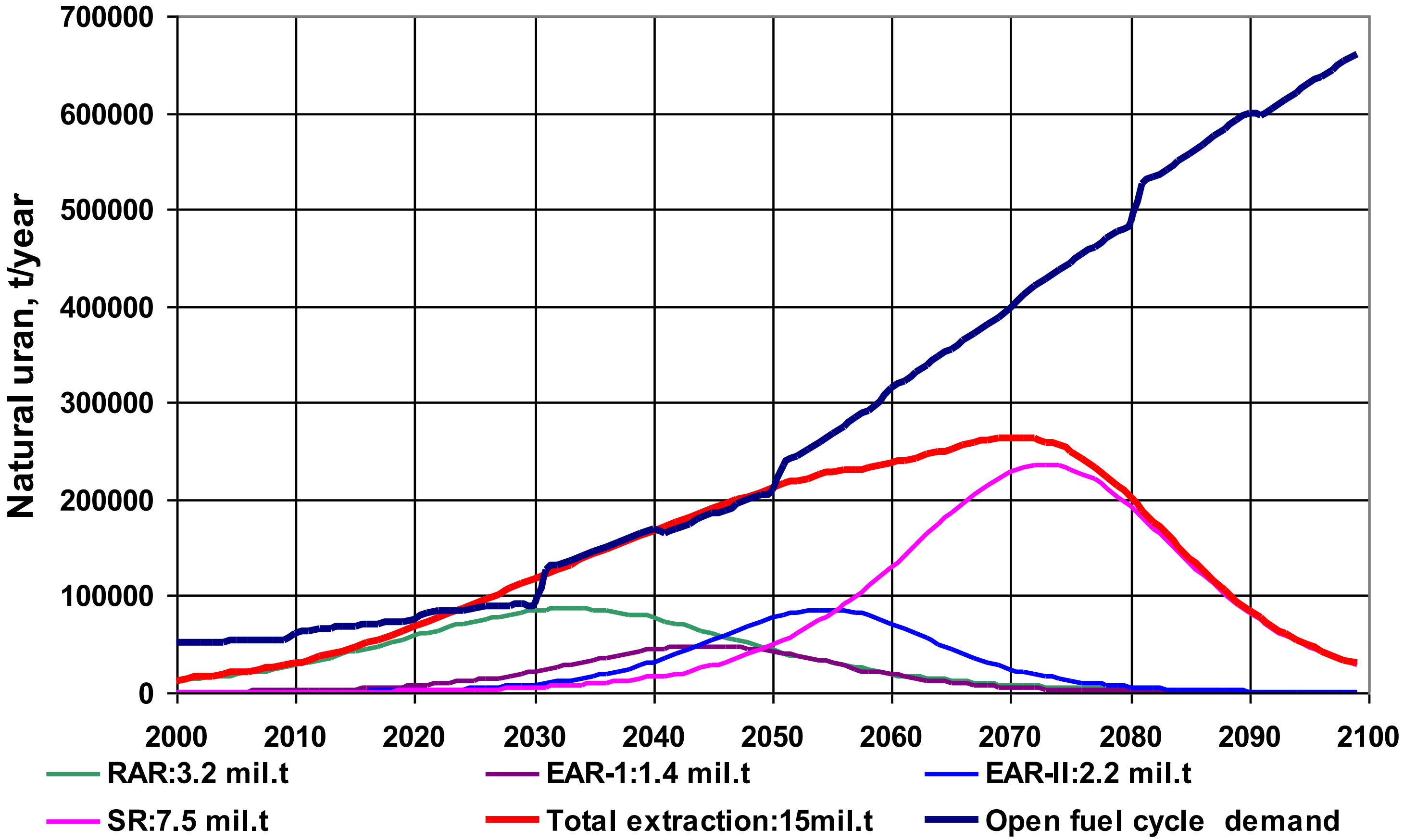
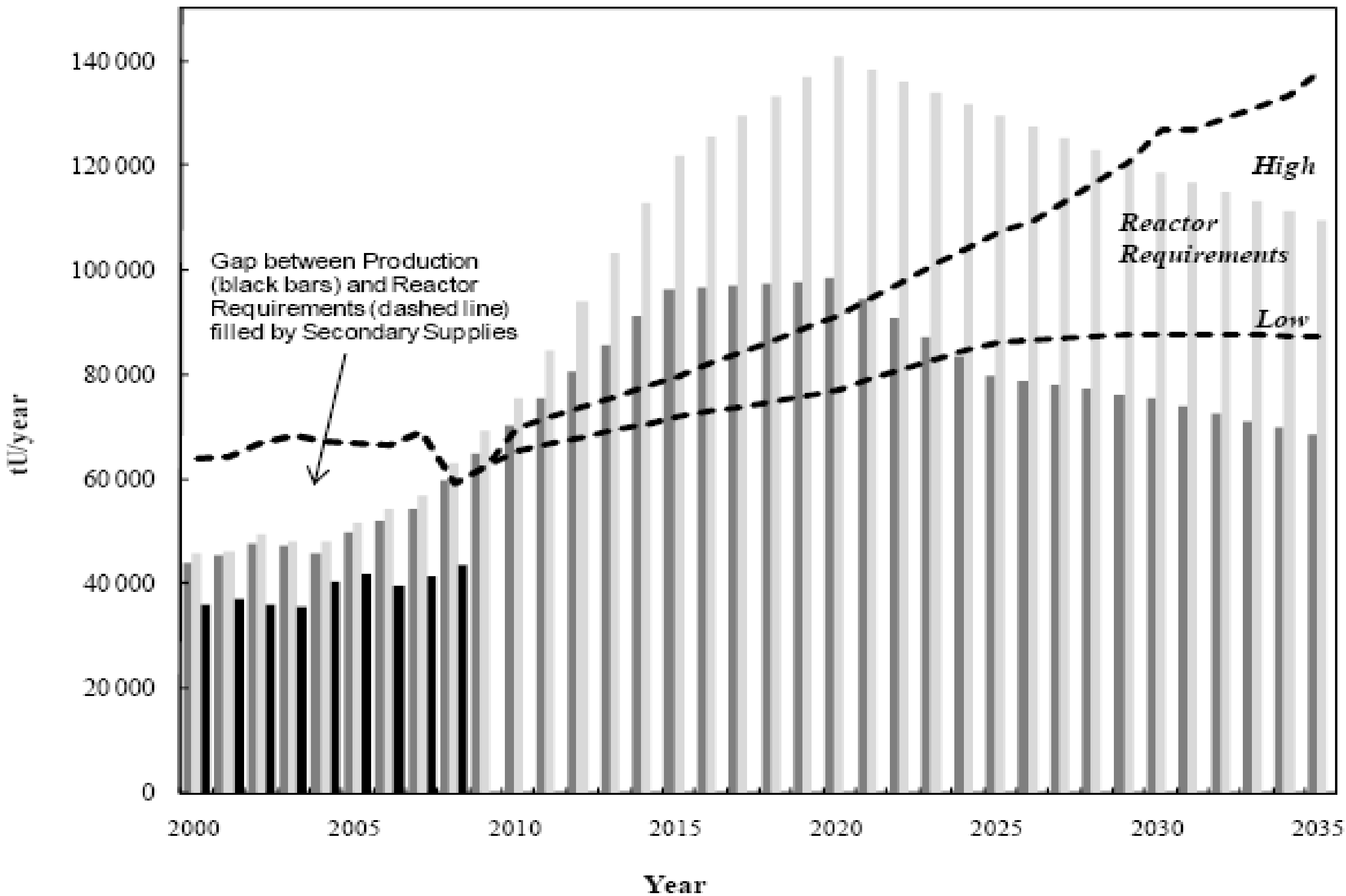


Figure 17. Projected annual world uranium production capability to 2035 compared with projected world reactor requirements*



Uranium 2009: Resources, Production and Demand, OECD 2010, NEA No 6891

Comparison of oil and open nuclear fuel cycle NP energy production potentials

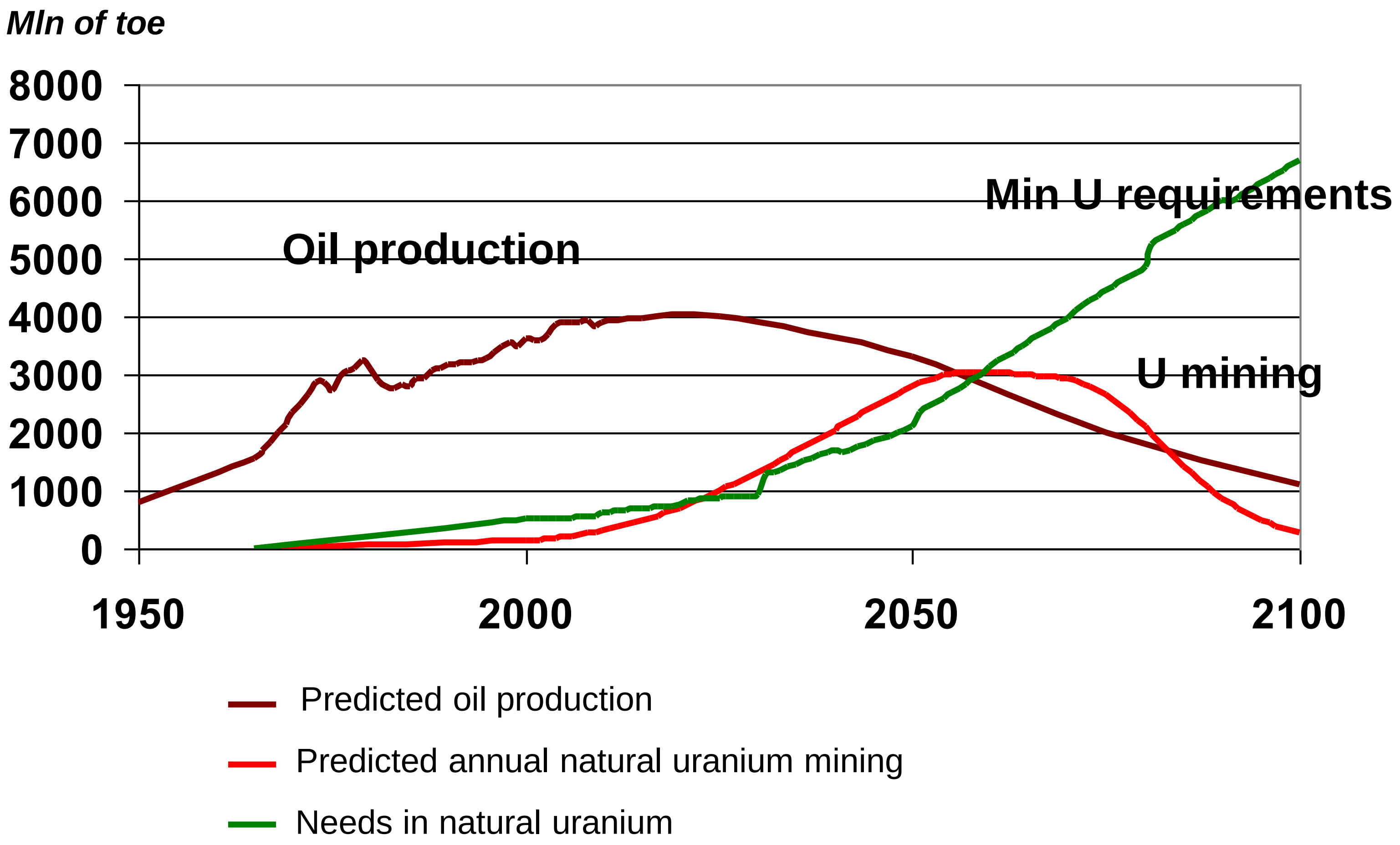
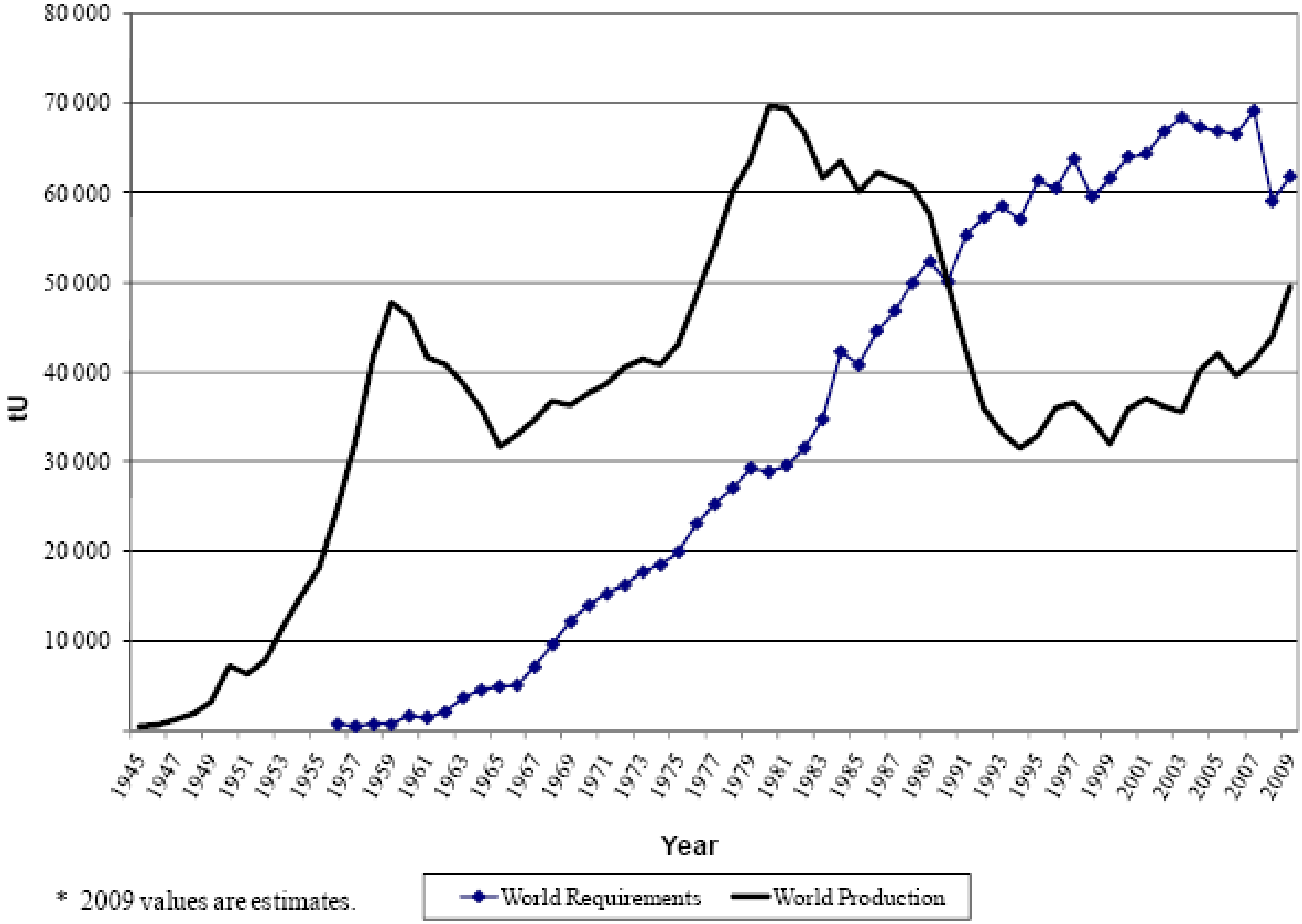


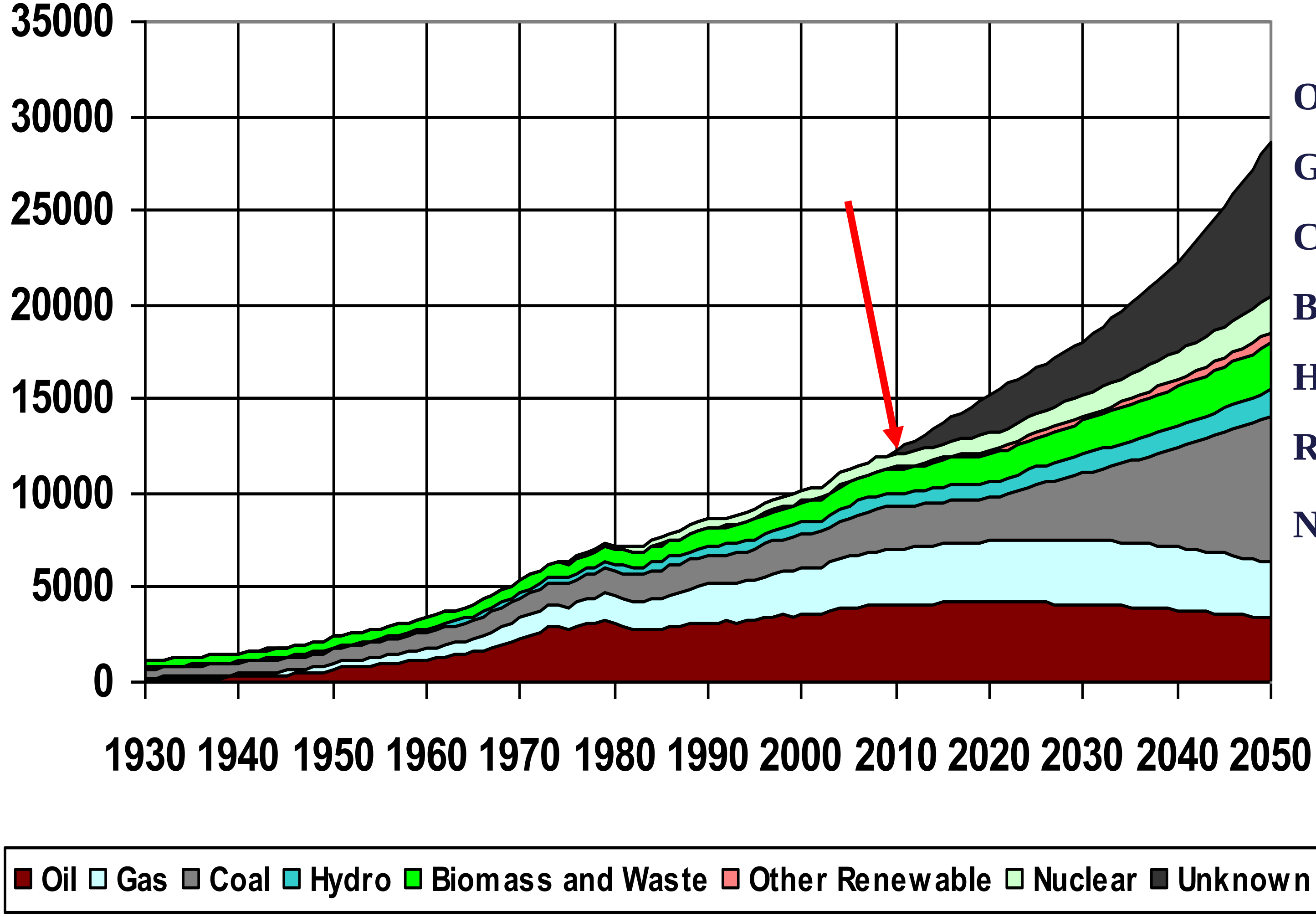
Figure 13. Annual uranium production and requirements*
(1945-2009)



* 2009 values are estimates.

Uranium 2009: Resources, Production and Demand, OECD 2010, NEA No 6891

Total primary energy supply, mil toe



Oil	0.9 times
Gas	1.1 times
Coal	4 times
Biomass	3 times
Hydro	2 times
Renewable	9 times
NE	3 times

WAYS
to THE NUCLEAR POWER RENAISSANCE and VITAL RISK FREE REACTORS

Hybrid

(Thermonuclear reactor with molten salt fission-fertile blankets) - MSHT

The reasons of the current NP stagnation are determined by the existence of **substantial threats and risks** – i.e. factors capable of either making the considered technology unacceptable, or/and significantly limit its applicability scope.

Now there are no objective reasons for NP renaissance,
since the basic factors responsible for cautious attitude to nuclear energy are still present, despite all "innovative designs" proposed in the international framework of GEN-IV and INPRO.
Criteria for selecting the direction of long-term development, as well as the principles for choosing the technological solutions for the future, are still vague.

Several general issues ("painful points") seem to cause the most significant doubts in the society impeding the nuclear energy renaissance:

1. non-eliminated threat of disastrous accidents (with high and hazardous for the society uncertainties of their probabilities);
2. weapons-grade material proliferation risks;

3. indefinite risks related to long-term long-lived toxic waste storage;
4. threats of major investment loss in conditions of limited capitals, economic crises and deep inflation processes;

5. "progressive deadlock" effect in NP development scenario caused by the looming nuclear fuel resource constraints.

COMMENTS

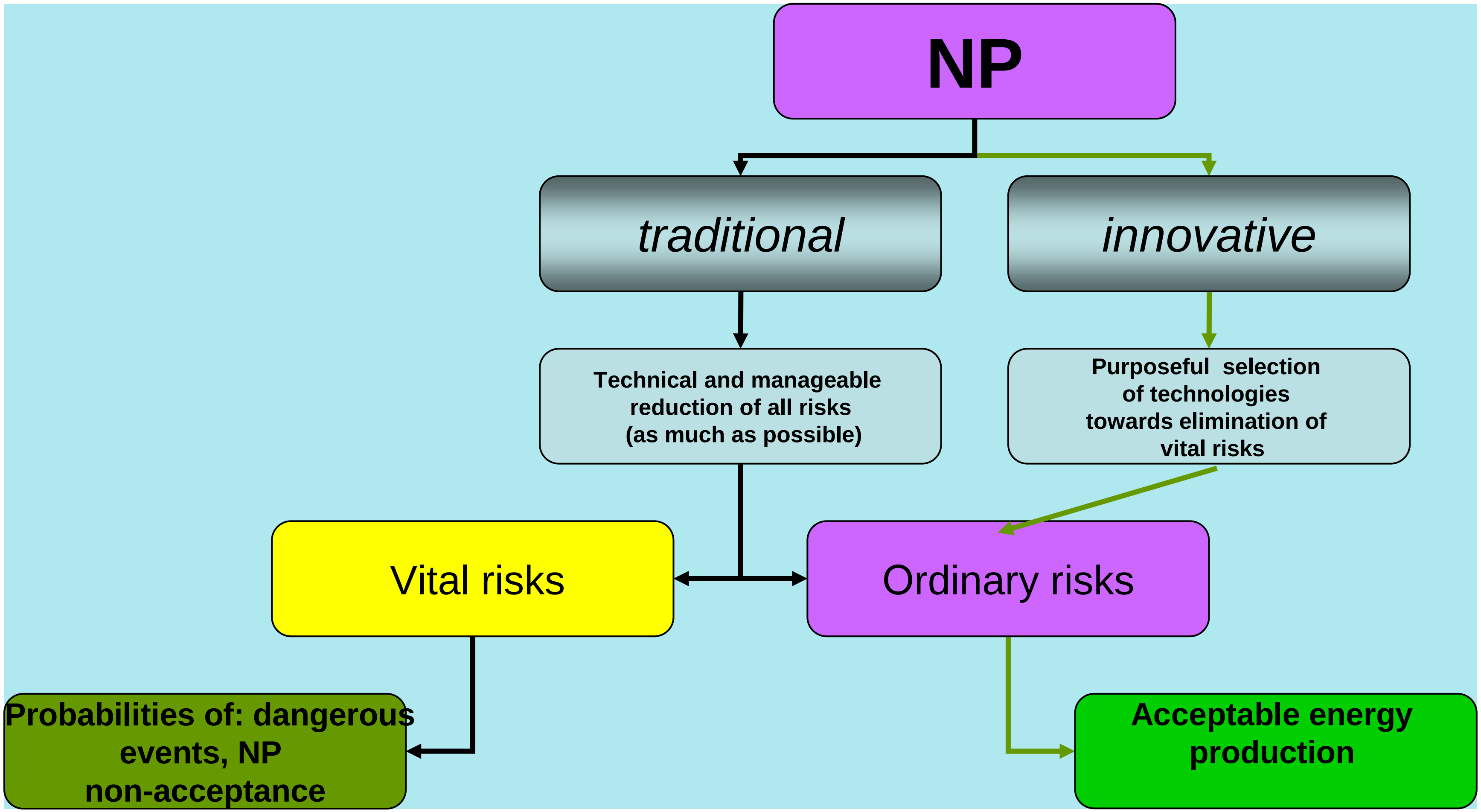
- All these issues, along with the respective risks/threats they involve, are substantial according to the definition explained above and they are decisive **(“vital”)** ones respecting the fate of this technology.
- Development of an innovative nuclear technology capable of evoking the true nuclear energy production renaissance would necessarily require nuclear reactors and fuel cycles deliberately provided with counter-risk qualities (with known ways of implementation) relative to all vital risks. The available thermal nuclear reactors, as well as ordinary fast sodium-cooled reactors using oxide fuel (such as BN and SuperPhenix), do not definitely possess these qualities.

On new-quality Nuclear Power

The new Green Nuclear Power quality concept leading to its accelerated revival should consist of exclusion of substantial threats and guaranteed elimination of vital risks attributable to the contemporary NP at once.

It doesn’t mean that there are no more problems in the nuclear technology, however these problems could be reduced to the category of “ordinary” issues imposing no principal constraints on the sustainable and long-term application of NP in the future.

Traditional and innovative strategies and consequences of their applications



NP renaissance is realistic
if
all painful points
would be eliminated

Ways of guaranteed elimination of the vital risks

1. It would be possible to assure guaranteed elimination of severe accident threats by providing the reactor with the quality of “self-protection” against destruction (particularly of the core) which is based upon, for instance:
   - *To exclude accidents with uncontrollable dispersal of reactor Transient Overpower (Reactivity Initiated Accidents) - it is possible at the expense of the organisation of its work in subcritical mode with an external source fusion neutrons*
   - *The problem shutdown decay heat removal from reactor can be solved at continuous clearing circulating molten salt fuel from fission products*
   - *limitation of the accumulated non-nuclear energy by the level unable to cause core disintegration in case an accident-initiating event occurs- In system there should not be reserved mechanical (pressure) and chemical (zirconium, sodium) energy*

2. Preventing the threat of weapons-grade materials' theft (just that very case can be considered as an important one), would be achievable when using only the reactors and fuel cycle technologies self-protected against any unauthorized removal of nuclear fuel,

e.g., by means of:
total abandonment of feed enrichment, as well of the enrichment technology in nuclear industry as a whole;

abandonment of re-enrichment (during spent fuel reprocessing) with fissile isotopes.

3. Vital risks of Transuranium wastes + Long Lived Fission Products storage

The task of preserving the radioactive balance at nuclear power development seems to be solvable by using the vital risk free fuel cycle, which should include:

- *reactors fed with non-enriched uranium;*
- *spent fuel separation from Short Lived (SLFP) and Long Lived (LLFP) fission products;*
- *abandonment of residual actinides' separation from lanthanides and creation the special "workspace" in reactors arranged for burning them (assuming a slow "exponentially type" growth of the reactor park);*
- *partial transmutation of highly toxic long-lived fission products in MSHT.*

4. Vital risks of investment loss are important

- **Recently they have considerably increased and still continue growing – mainly because of safety enhancement measures. Crediting conditions also became considerably worse, especially in view of long NPP construction time for nuclear industry.**
- **All these factors aggravate the economics and discourage investments even at the level of governmental orders.**

The importance of investment risks would level down in case of their essential reduction (twice or more). And this drastic reduction of investment risks coupled with considerable economy improvement would be possible through a significant reduction of NPP construction periods by using factory-made precision autonomous modules, simpler reactor safety means, and cheaper fuel inventories.

5. Vital risk of rapid exhaustion of fuel resources

It would be eliminated by addressing to **molten salt hybrid tokamak**, that is becoming the dominant idea of nuclear power in the nearest future.

Fuel self-supply and the growth of NPP park would be possible only in case of positive breeding gain.

Theoretically, such a nuclear power could start almost “from zero level” when first initial inventory of a Vital Risk Free Reactor would be available.

On vital risk free subcritical nuclear reactor and fuel cycle concepts

Elimination all the vital risks is complicated task and considered to be realistic not for all the reactor types known. Analyses show that MSHT are the best suited for this purpose, and this task would be solvable even in the currently available technology framework, on the basis of the novel ideas of MSHT accenting on:

- ***radical improvement of the neutron balance;***
- ***use of modular blanket configurations;***
- ***elongation of the fuel residence time respecting the equilibrium mode;***
- ***fuel cycle proper rearrangement.***

Marketing FEATURES

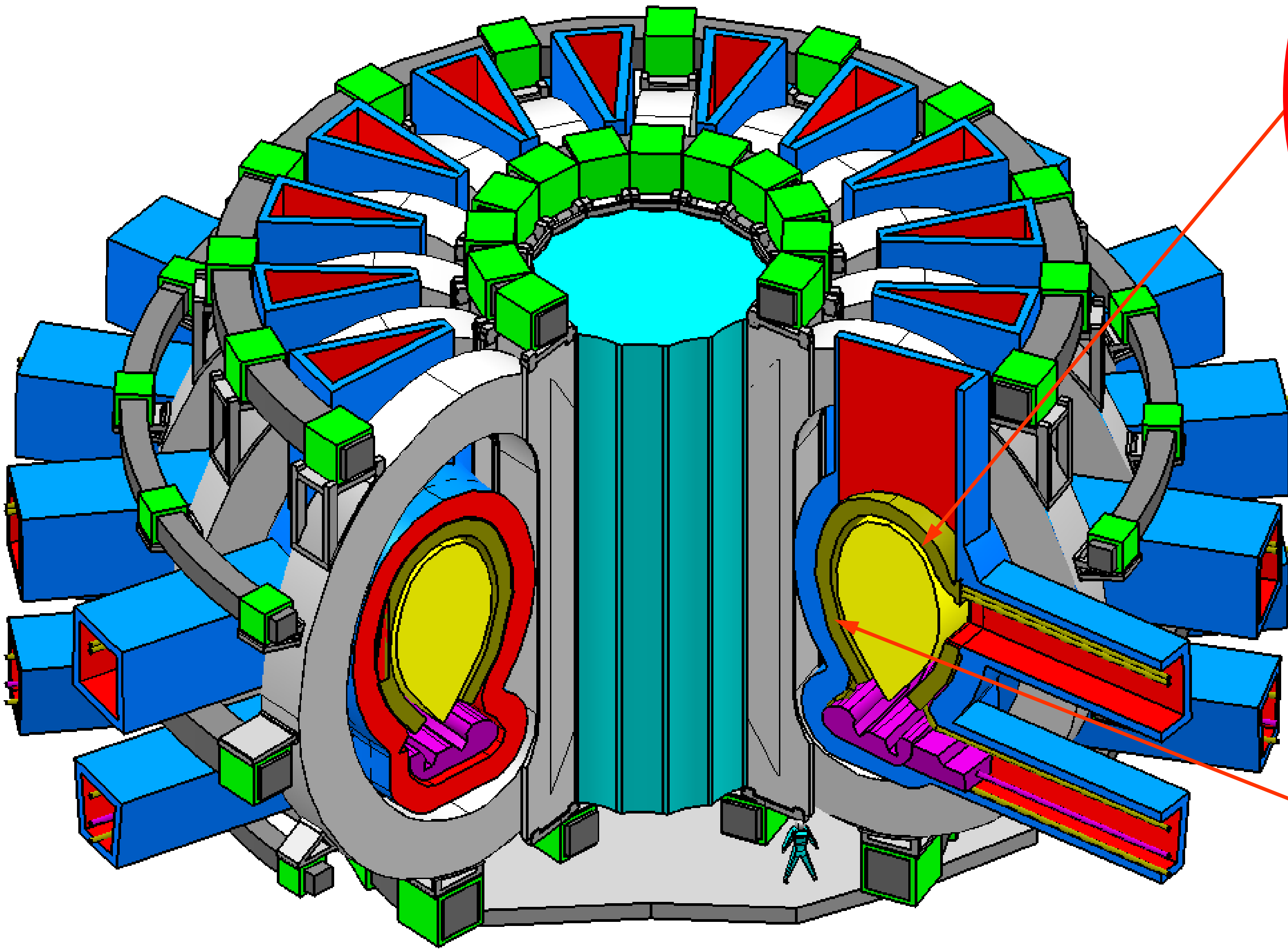
Nuclear power based on MSHT, would allow possessing possibilities both reactor inventory generation (including fuel reprocessing) and “simple” power generation (without fuel reprocessing) to be divided between different groups of countries, that would provide nuclear power with complementary security features relative to weapons-grade material proliferation, and contribute to its international marketing flexibility

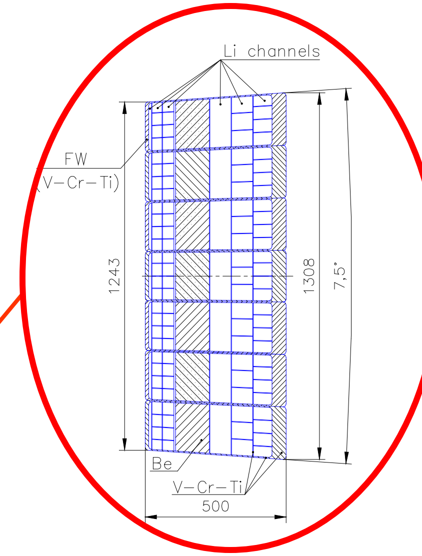
Recommended MSHT configurations

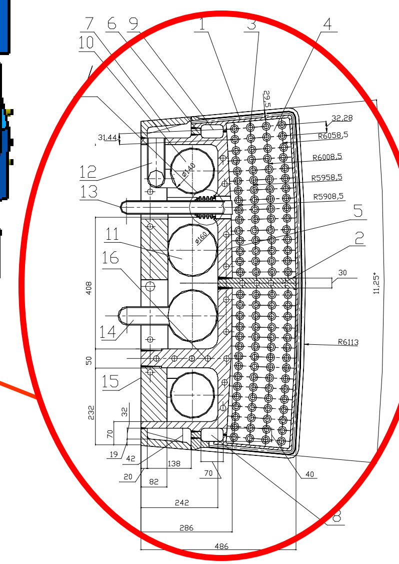
The following possible NPPs can be proposed:

- NPPs consisting of MSHTs with small modular molten salt blankets with hard neutron spectrum, all self-protected against severe accidents;
- combined with the vital risk free fuel cycle and burning of the residual transuraniums/the most toxic long-lived fission products in reactor blankets,
- NPPs with molten salt fast spectrum.

Reactor DEMO-S







Neutron and energy balance

Per 1 neutron 14 mev.

U-238		Th-232	
Capture	Fission	Capture	Fission
3.35	0.6467	1.73	0.14
Energy per 1 n (14 mev.)		Energy per 1 n (14 mev.)	
143 mev.		42 mev.	

Energy for one nuclei of fissile isotope production

U-238	Th-232
43 mev	**25 mev**

Energy for additional nuclei production in fast reactor is more than 500 mev

Nuclear fuel production potential

In condition of equal capacity 1GWe

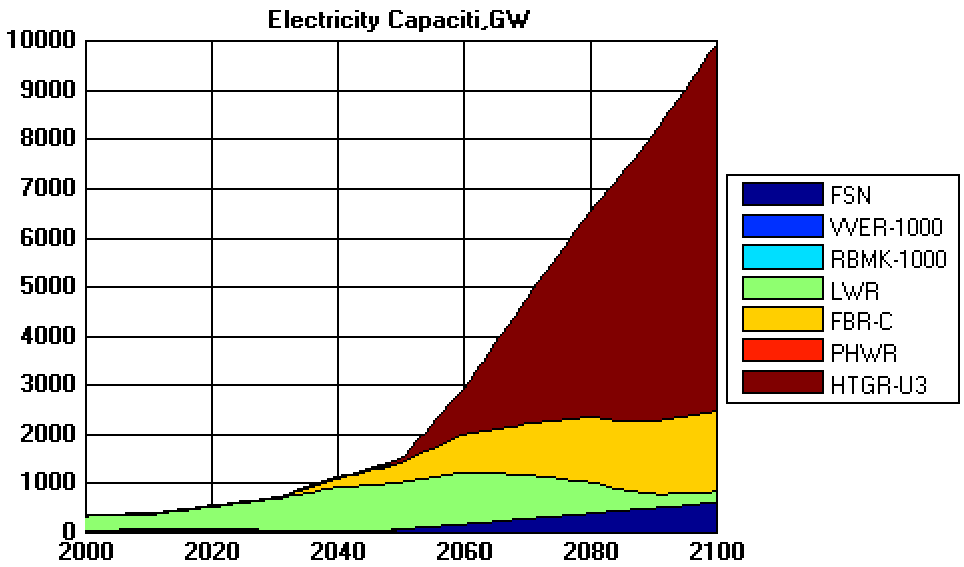
Production in fast reactor

(BR=1.6) **280 kg/GWe year**

FNS **2900 kg/GWe year**

Share of FNS in NE structure should be small.

Nuclear energy with thermonuclear neutrons



FNS beginning with 2050

Share of FNS in system by 2100 < 7 %

Since 2050 HTGR in thorium cycle

Since 2030 FBR-C with КВ=1 – plutonium utilization

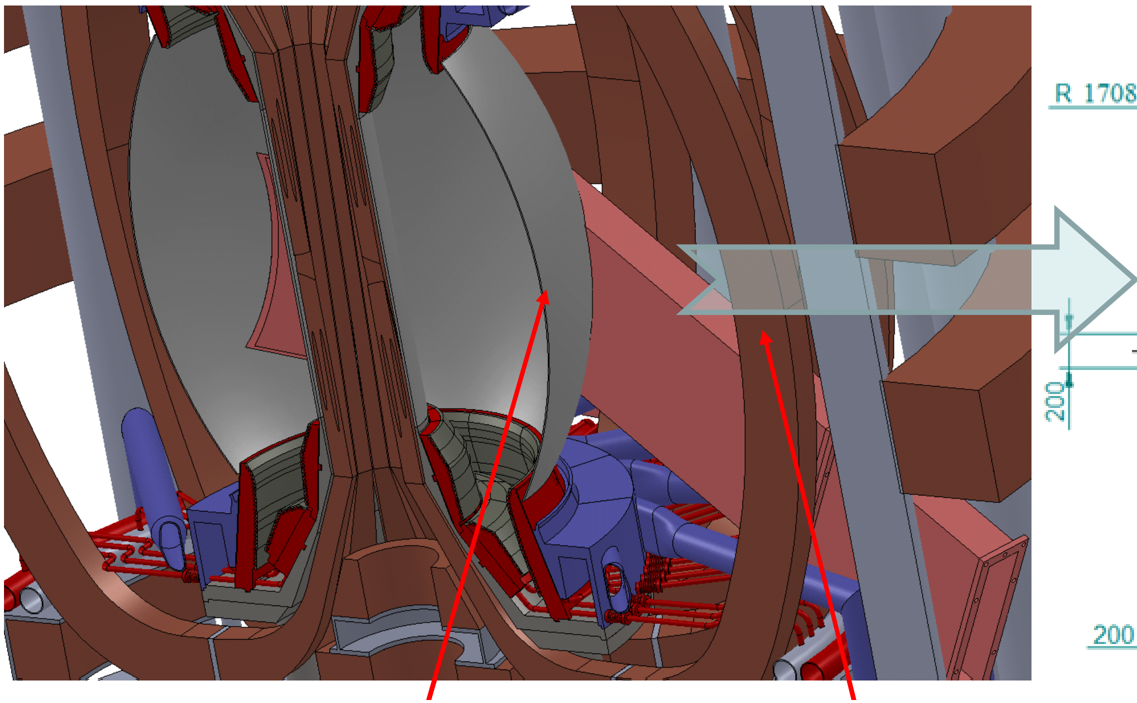
Natural uranium consumption till 2100 **10 mln. t**

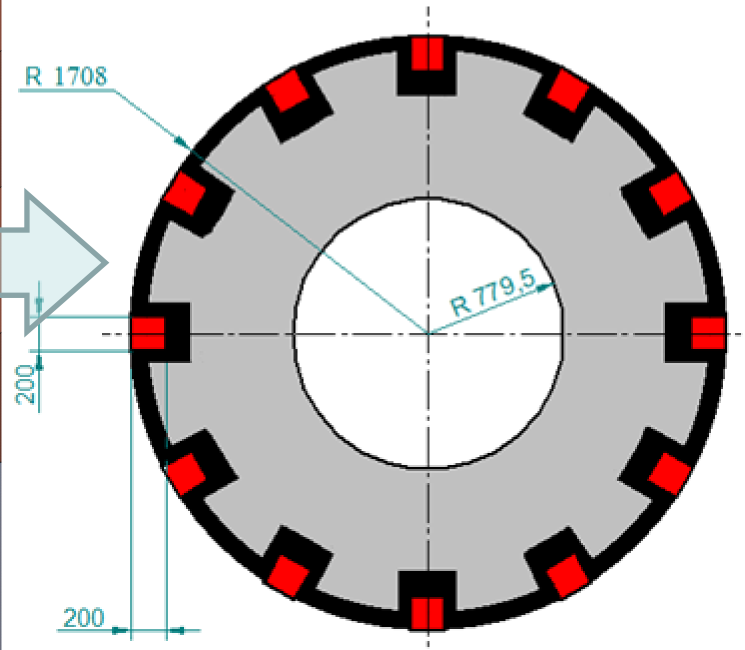
Annual consumption of natural uranium in 2100 - **30 000 t/year**

Conditions for placing LSB of TNS

TNS design

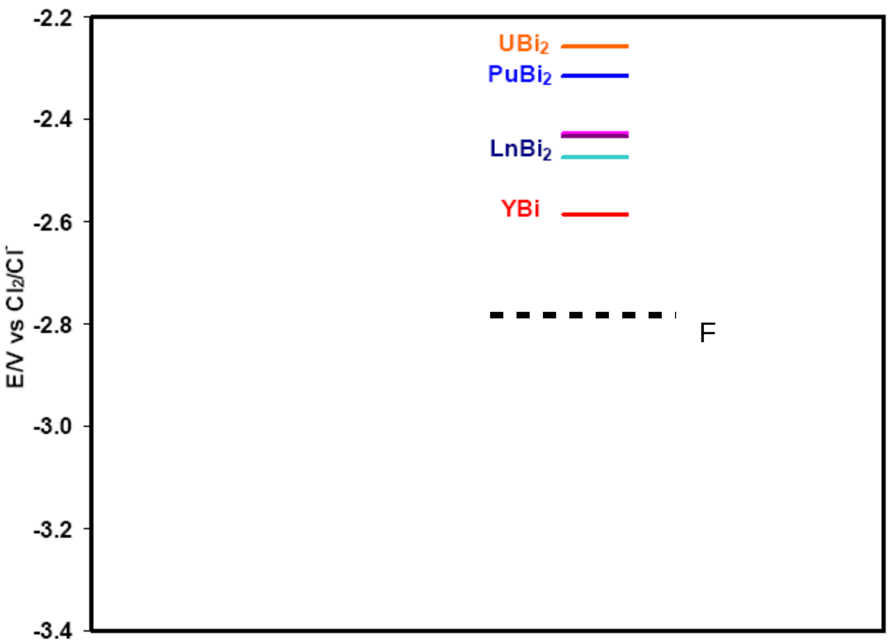
TNS model
(equatorial section)



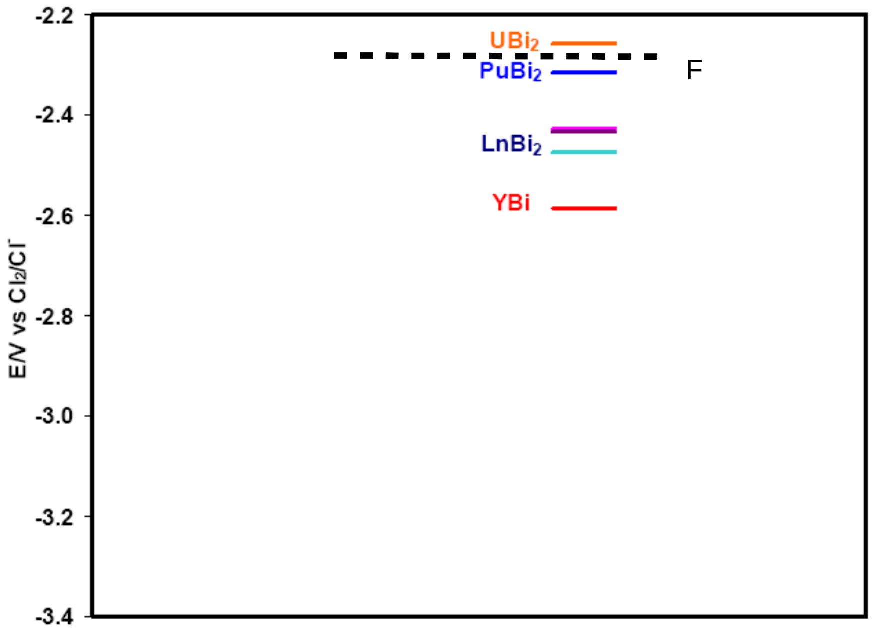


LST Composition Technology

PROBLEM: electron levels of impurity components are within the prohibited zone of the salt electrolyte. Therefore fine adjustment of the Fermi level and LST composition is required for managing of the extraction and solution of impurities.



A) – impurities are not extracted at all



B) – level of the salt redox-potential, when all metallic impurities (except for uranium) are extracted

EXAMPLE: Reduction potentials of An(III)/An(0) and Ln(III)/Ln(0) in LiCl–KCl eutectic with liquid bismuth at 723 K under the conditions: x_M(salt) = x_M(Cd) = x_M(Bi) = 0.001; dotted line indicates Fermi levels $_F$ (corresponding to the salt redox-potential)

CONCLUSION

- **FP Renaissance becames realisic if all (FIVE) vital risks would be eliminated**
- **Such elimination is possible on the base of MSHT –molten salt (MS) hybrid (H) tokamak (T) and fuel cycle of innovative design/strucure – modular, self-withstanding against unprotected dangerous events, fed by Th/natural U, dense subcritical blanket with essentially enhanced neutron balance and capability incinerating residual actinides and LLFP**

Vital Risk Free MSHT designs could be realized rapidly and mostly by application of already known technologic decisions like it was in the non-traditional projects ITER and MSR (MSBR).

Technological platform for such hybrid reactor can become ITER, and for it the current scientific and technological level is sufficient.

Thanks for attention!