International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century

Sustainability of Water Cooled Reactors - energy balance for low grade uranium resources

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Nuclear power has many advantages- but will there be enough uranium?

Nuclear power provides energy security, because

(i) generates electric energy without air, water and soil pollution

(ii) increases diversity of energy sources,

(iii) reduces hazards of abrupt changes of electricity prices

Nuclear power is presently the least expensive source of electricity (opinions of Finland, France, Italy, UK, EC Parliament)

Nuclear power lets preserve precious organic resource (gas, coal) for future generations

Nuclear power provides the option of fuel recycling, thus gaining the key position in sustainable development of the world.

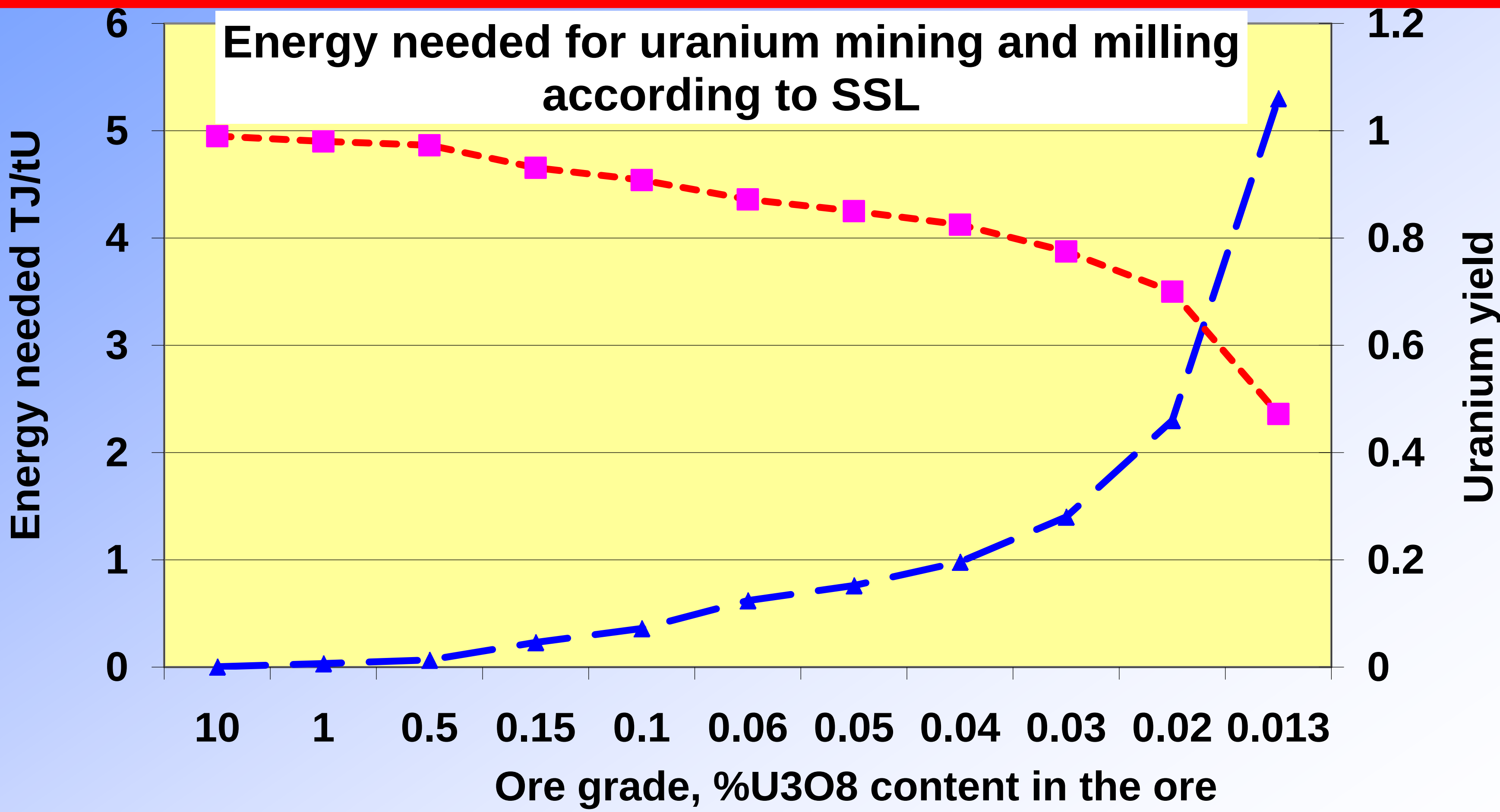
But nuclear power opponents claim, that the uranium resources will not last long...

Nuclear experts:
the energy balance is positive.
Opponents: the balance does not include full energy costs of the nuclear fuel cycle,

- the ***energy incorporated in materials and product***s bought from other industries is left aside
- the ***energy needed for plant dismantling***, mine area reclamation and waste management is neglected.

Result: ***Claimed loss of sustainability of nuclear power, negative energy balance within the next 40-60 years***.

The main source for opponents statements – the work of Smith and Storm van Leeuven



LCA study of the Institute of Atomic Energy (IAE) in Poland

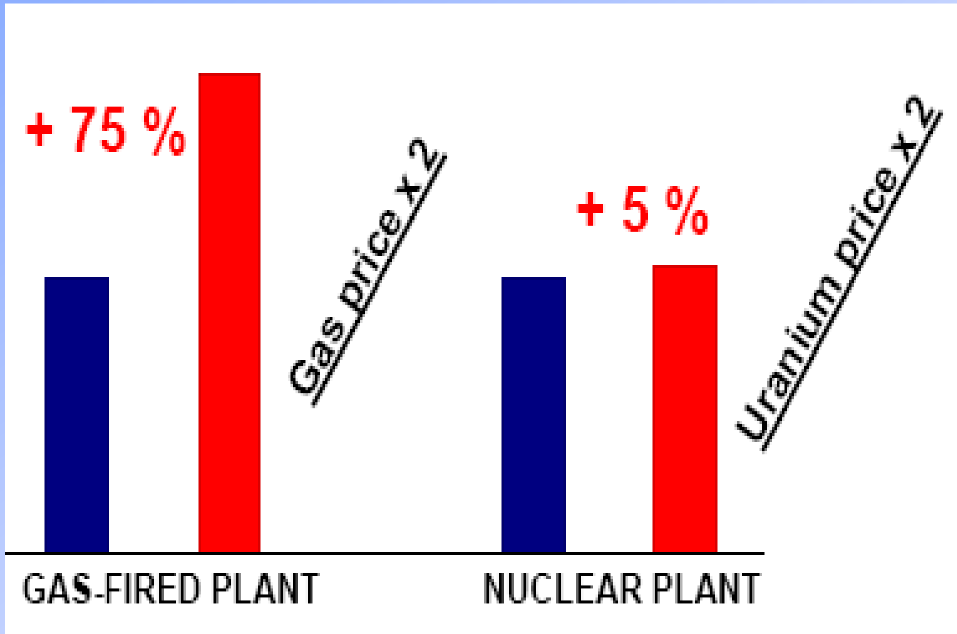
IAE in Poland has performed a LCA study of the energy needed for the whole nuclearf fuel cycle with special attention to uranium mining and back-end energy needs.

Total energy needs for uranium mining were considered, including:

- electricity needed for mining and milling,
- for water treatment and delivery to the mine and to the neighboring settlements,
- fuel for transportation and ore crushing,
- explosives for rock blasting,
- chemicals for uranium leaching
- energy needed for mine reclamation after completed ore exploitation.

Nuclear fuel – small quantity and low price

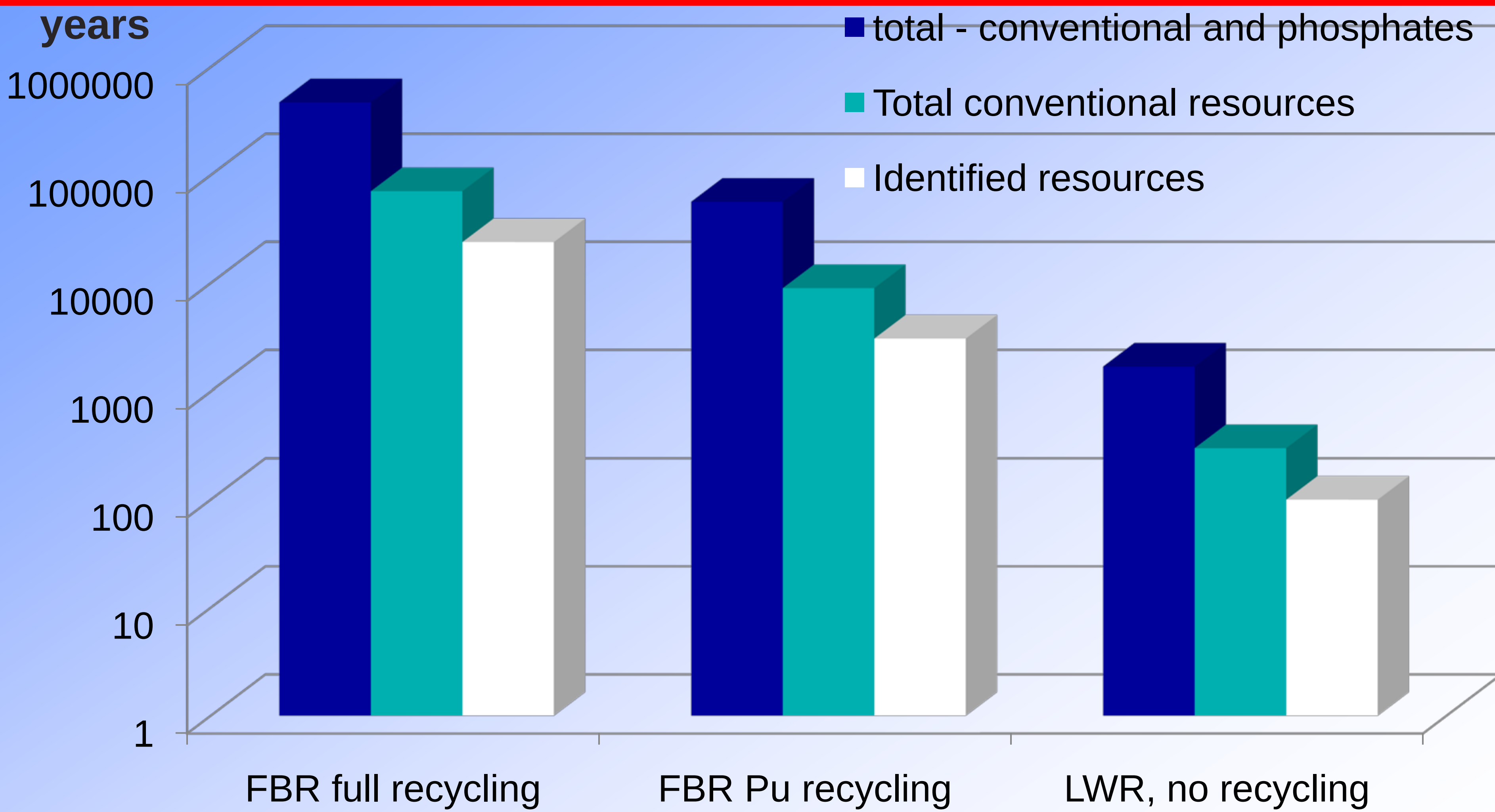
The quantity of fuel for a NPP is small
For 1000 MWe opver 1 year some 20 tons of fuel - or 1 truck per year.
For a coal fired plant – 3 million tons!



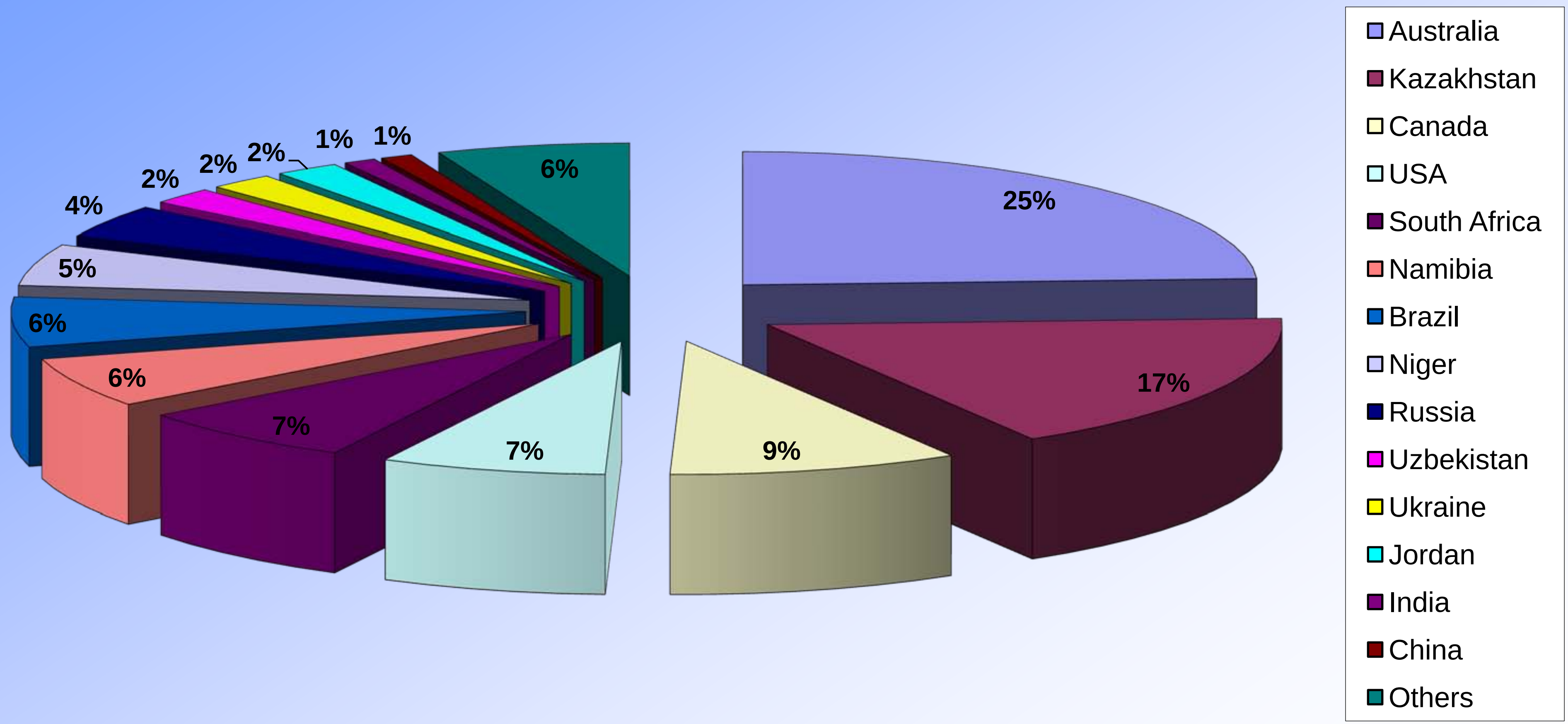
Nuclear power provides electric energy at fixed price, practically independent from variations of fuel price in the world market.

This supports stability of world economy and thus supports sustainable development.

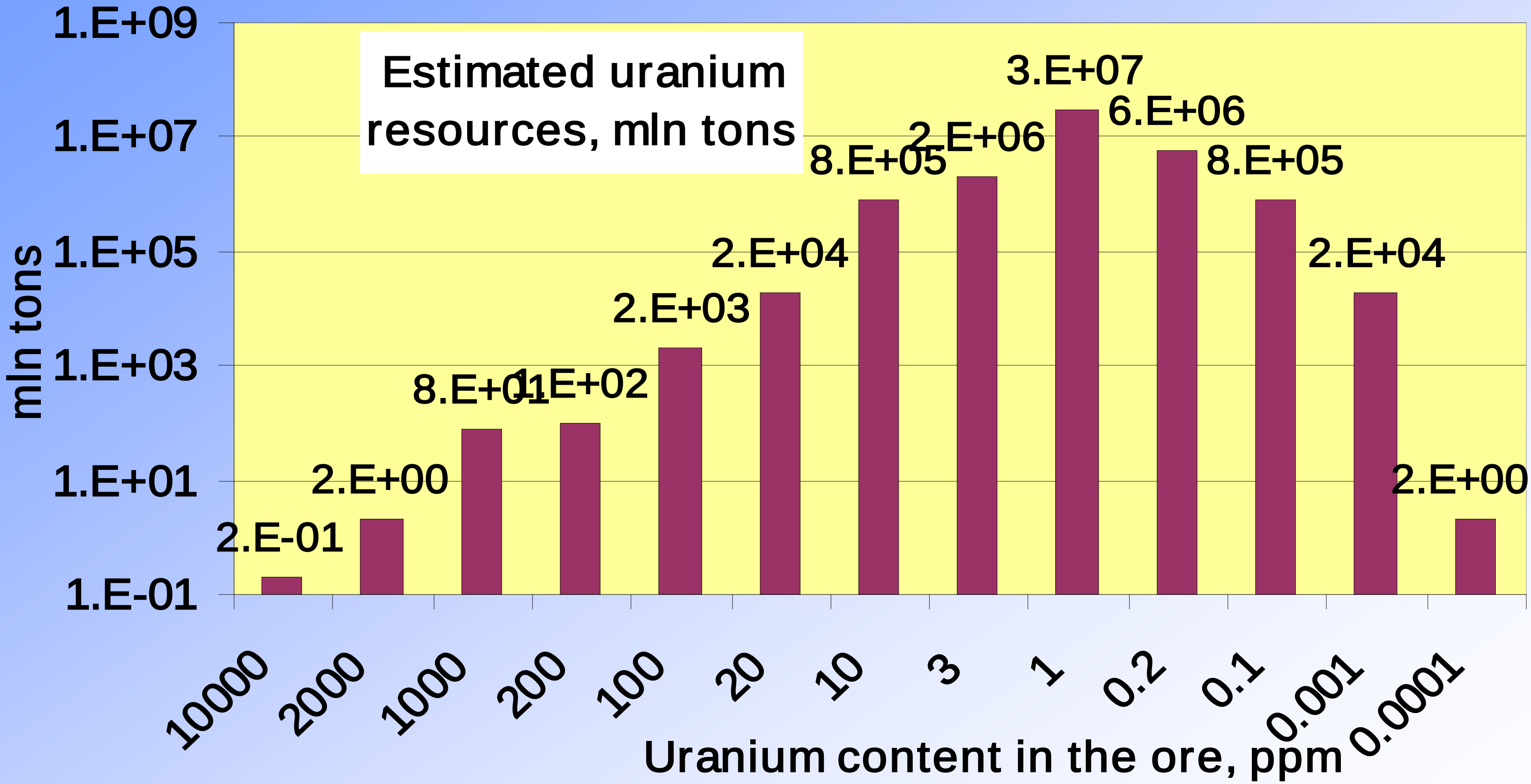
How long will last the uranium resources available for mining at less than 130 USD/kg(U)?



Distribution of uranium ore in the world – no worry of monopoly



Uranium resources at various uranium ore grades



The drawing shows the lower limit of each range, i.e. for the range 100-200 the number 100 is shown. Data from Deffeye&MacGregor

No problem of absolute shortage of U3O8 but of energy gain at low ore grade

- Further exploration and higher prices will result in increases of known uranium resources.
- As the ore grade falls down, the overall amount of uranium in the ore of that grade increases.
- Within the range of 0,1% down to 0,0001% of U3O8 the decrease of ore grade 10 times results in uranium amount increase 50 to 100 times.
- So there is enough uranium. The key question is – at what grade can we gain net positive energy output from the nuclear cycle as the ore grade is decreased
- Energy balance is more important than financial balance- but we shall check both.

According to SLS no energy net gain is possible using low grade ore

As we use lower grade uranium ore the costs of mining and milling will increase. But what is the final balance?

Storm van Leeuwen claims *„The existence of the energy cliff implies that no net energy from uranium is possible below an ore grade of about 0.02-0.01% U^3O^8. This limit hardly depends on the state of technology nor on the assumptions on which the energy analysis of this study is based"* (Energy from Uranium, Oxford Research Group, July 2006, p. 21″)

This claim is repeated in other analyses of SLS. It is based on extrapolation of old data (1976) obtained in the US for uranium ore of high grade, with a large ratio of waste rock to ore.

SLS do not consider progress which has occurred over the lat 30 years in uranium mining technoloogy, nor the fact, that with low uranium grade the ratio of barren rock to ore volume is dramatically reduced.

The energy produced in an NPP

NPP 1000 MWe, load factor 82%, lifetime 40 y. – assumptions of SLS .

These are parameters of generation II reactors with burnup of 30 000 MWd/t(U). Presently the burnup is 60 000 MWd/t(U). (average 50 000 MWd/tU, load factor 90%, lifetime 60 years.

The values used by SDLS are very pessimistic.

According to SLS, such a reactor will burn 162.35 t of natural uranium per year and produce electric energy

***E*gross = 25 860 TJ(el)/y = 7.183•TWh/y**

or in thermal units, TJ(t)

The energy produced in an NPP per ton of uranium is 478 TJ(t)/t (Unat).

Energy balance for nuclear fuel cycle - the energy for mining and milling is a small part of the energy produced

Minijg and milling - 230 t/yr U3O8 in Ranger	1.56 PJ (th)
Conversion (data of ConverDyn of 2000 r)	9.24 PJ (th)
Enrichment, centrifuge @ 63 kWh/SWU	3.26 PJ (th)
Fuel production (ERDA 76/1)	5.76 PJ (th)
NPP construction and operation (ERDA 76/1)	4.69 PJ (th)
Fuel storage, radwaste storage and transport (Sweden 2002)	1.5 PJ (th)
NPP dismantling (Ontario data)	6.0 PJ (th)
Total (with centrifuge enrichment)	**52 PJ (th)**
Production of electricity: 7 TWh/y	**3020 PJ (th)**
Total: ratio of energy needed to energy obtained)	**1.7%**

Energy balance for Ranger, ore grade 0.234% U in the ore

Yearly production of U_3O_8 in Ranger mine is 5910 ton.

Acc. to WNA, the energy locally needed (in the mine and around the mine, including production of sulphuric acid, but without energy in purchased materials) was 0,165 TJ(t)/t U_3O_8, i.e. 0,195 TJ(t)/tU.

The energy in chemicals such as explosives, sulphur, natrium, limestone oxide, chloride, ammonia, and others was 2000 TJ/y (calculated assuming that electical energy is equivalent to 3 times larger thermal energy),

The energy needed locally and purchased was **0,5 TJ(th)/t(U_3O_8)**, **or 0,59 TJ(t)/t(U)**

But since we consider LCA, we must add the energy for mine reclamation

What is required for mine reclamation?

Open cast mines require reclamation because millions tons of rock are excavated there , but the radioactivity of the rock after uranium leaching is lower than before it was mined..

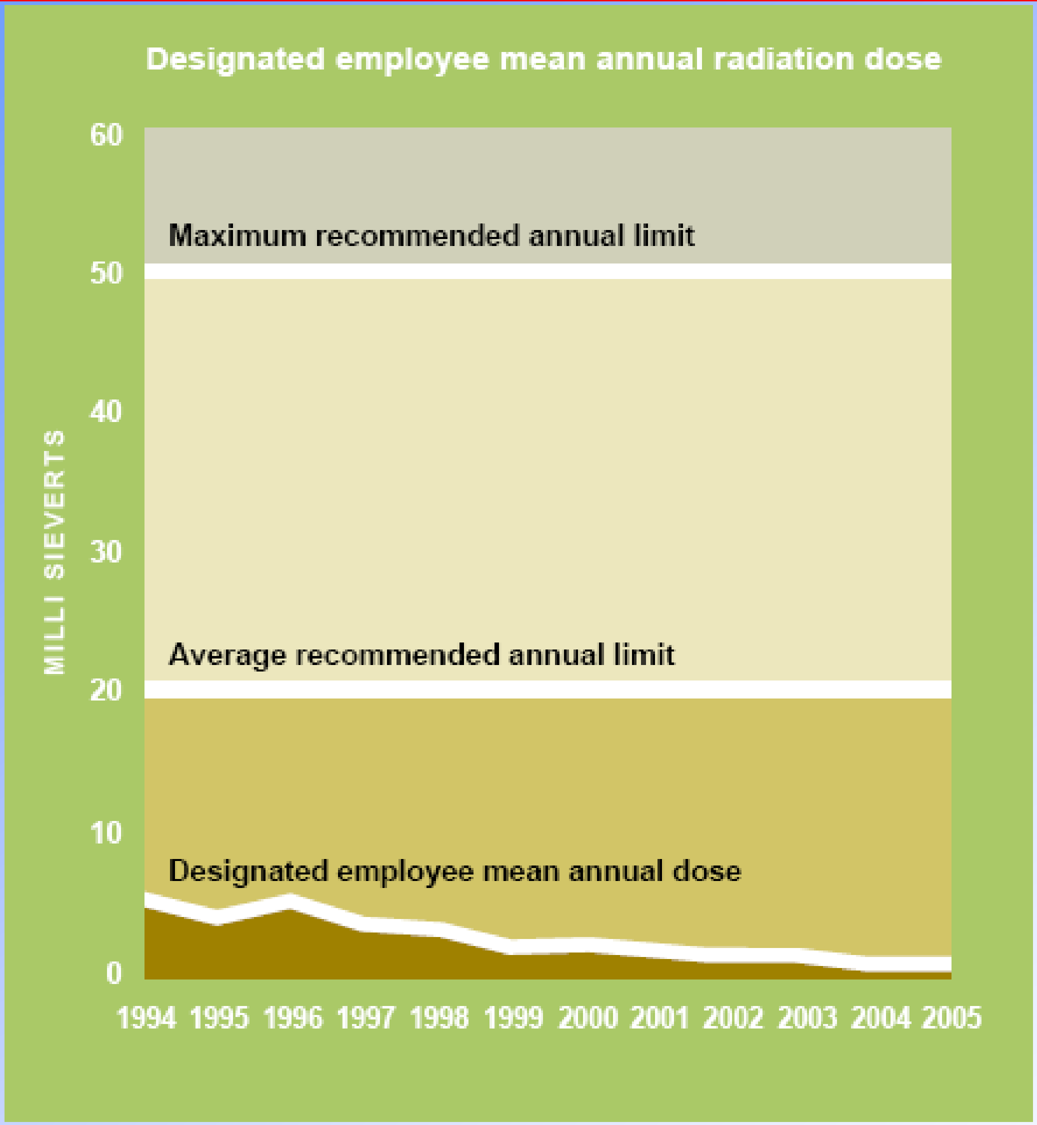
It would be enough to place the waste rock back in the excavation to return to the original conditions.

However, in view of the presence of heavy metals in the rock, and also of chamicals used for uranium leaching, the extent of work is larger.

Uranium mining is allowed only when very strict regulations on environment protection are observed. In Australa there is a set of 53 regulations which determine these requirements.

Mine reclamation .involves drainage, covering the terrain with soil, planting grass, shrubs and trees. The radiation level is lower than before mining.

Low radiation hazards for mine workers



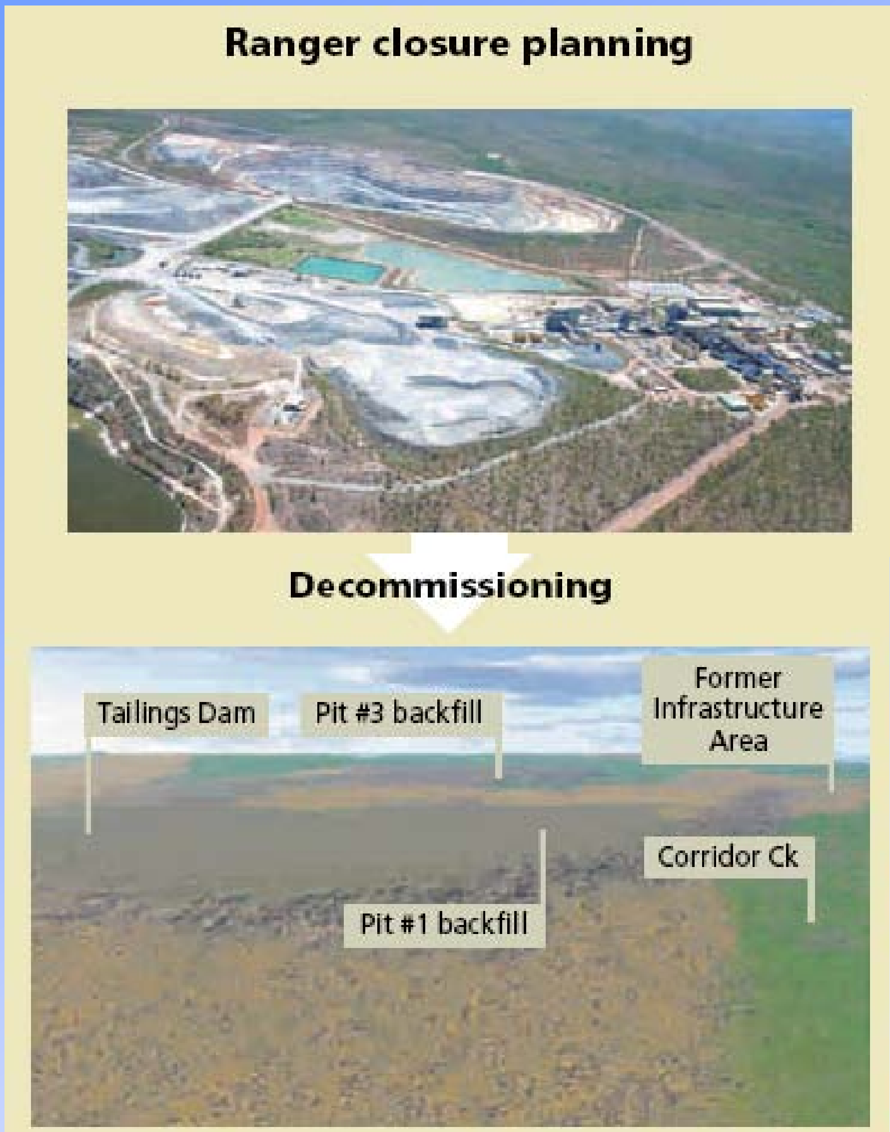
Radiation doses for Ranger mine workers are much lower than the limits and going down.

„Designated workers" are those who can potentially receive annual doses above 5 mSv.

Their mean annual doises are below 5 mSv is in recent zears going down to below 2 mSv.

For other workers the maximum dose in 2005 was 0.9 mSv.
Radiation background at the mine is 2-3 mSv/a.

Radiation hazards during normal operation and mine reclamation are small.



Around 95% of ore radioactivity is due to the decay chain of U-238. After removing U-238. two short lived radioisotopes Th-234 and Pa-234 disappear, so that after a few months ore radioactivity falls down to 70%.

During normal operation the material in the mine is covered with water layer to reduce surface radioactivity and radon releases.

After mine exploitation is over, the excavation is backfilled with rock, then covered with 2 m of clay and soil .

Radioactivity in the vicinity is lower than before ore mining.

The energy needed for Ranger mine operation and reclamation

In Ranger mine the barren rock and the waste from uranium milling will be placed in the excavations and covered with a layer of soil

Let us assume that the energy needed during ore exploitation i.e. 0,195 TJ/t(U) will be also needed during mine reclamation.

Finally the total energy needed for uranium mining, milling and mine reclamation with a large safety margin will be

- 0,593 TJ(t)/t(U) + 0,195 TJ(t)/tU = 0,788 TJ(t)/t(U)

This is only 0,0016, or 0,16% of the energy obtained from 1 ton of natural uranium in the NPP, namely 478 TJ(t)/t(U)

According to SLS, the energy for uranium mining and milling in Ranger would be 1,080 TJ(t)/t(U), for reclamation 3.840 TJ/t(U, and total energy needed 4.9 TJ(t)/t(U).

This is 6 times more than in reality. When the ore grade gets loower, the errors of SLS get larger- much larger.

Rossing mine – ore grade **0.0276%U**

- In 2006 the mine Rossing produced 3 617 ton of U_3O_8 , while the energy locally used in the mine was 1366 TJ(t). The unit energy needs were then 0,411 TJ/t(U).
- This is twice as much as in Ranger. But ... why not 10 times more, although the ore grade is 10 times lower?
- The energy needed in a mine depends strongly from local conditions.
- The ratio of overburden to ore mass in Ranger was S =3, while in Rossing it is 0.7 to 1,43, and in 2006 it was 0.71.
- The total energy including chemicals would be more - let us assume twice more, as in Ranger.
- But according to SLS the energy needs in Rossing should have been much, much larger!

Contradictions in SLS evaluation of energy needed for Rossing

- According to SLS the energy needed for ore mining and milling (without mine reclamation) for ore grade 0,023% U_3O_8 should be 17 TJ/t(U).
- At the price of $1 per liter of fuel, at energy content 43 MJ/kg and fuel density 0,848 kg/litr, the amount of the cheapest energy to be obtained per dolar would be

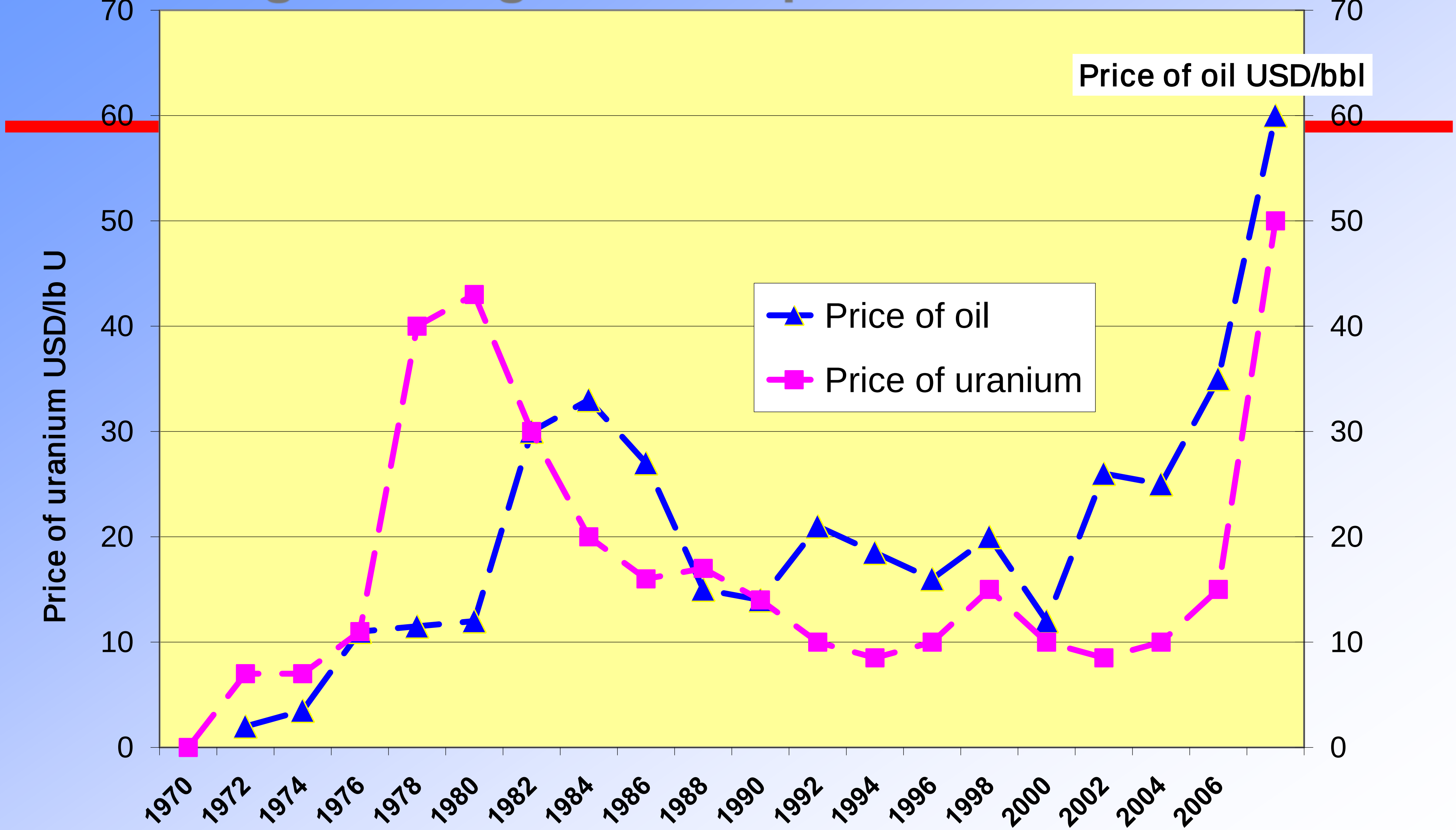
$$43 \times 0.848 = 36 \text{ MJ/USD.}$$

- So the energy needed for Rossing would cost

17 TJ/t(U)/36 MJ/USD = **472 000 USD/t(U).**

- But the price of uranium has been for a long time about 40 000 USD/t(U)...

If SLS were right, the production of every t(U) would bring Rossing losses equal to 430 000 USD!



Can we get positive energy balance for the nuclear cycle using low grade ore of 0.013% U?

Trekkopje in Namibia, 0.0126% U_3O_8

According to SLS mining and milling such ore should result in negative energy balance – and evidently in financial losses. What is the truth?

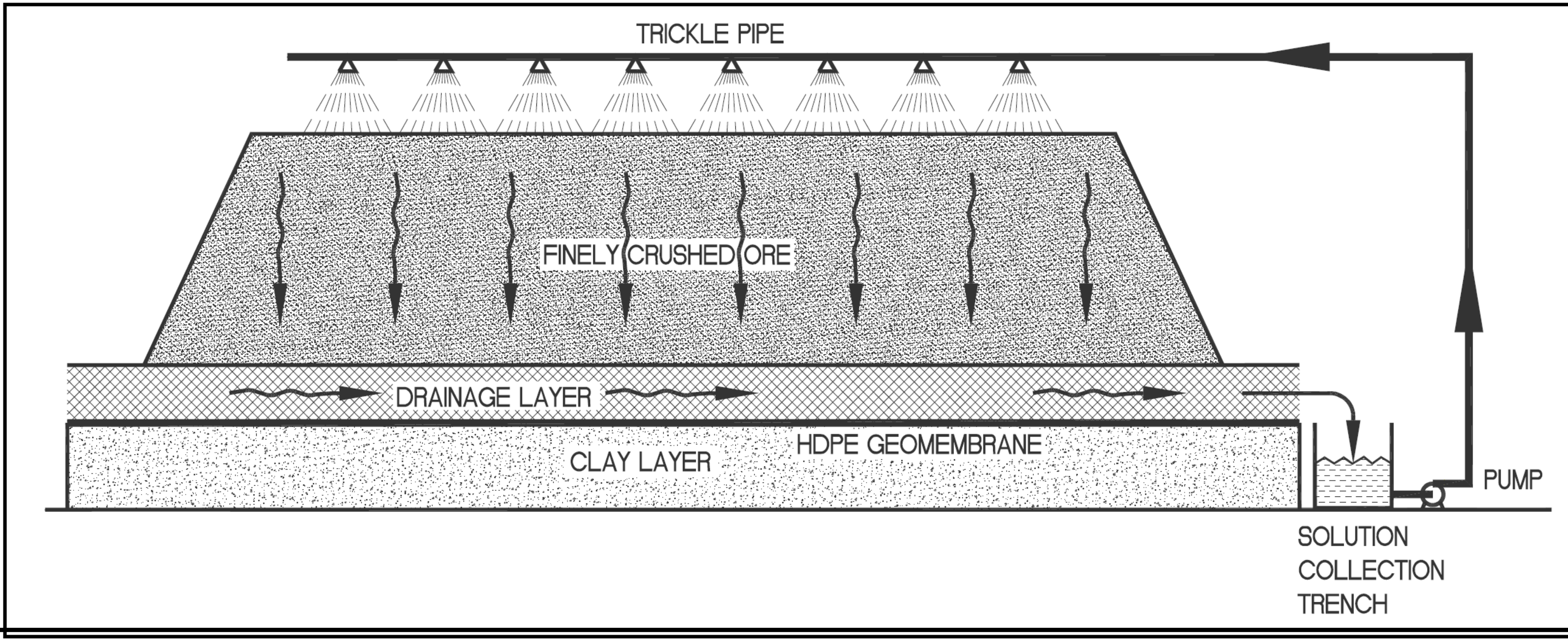
Ore mined - 100 000 tons/day.

- Average overburden to ore ratio S = 0.3:1.
- Annual ore production 36 mln ton, overburden 11 mln ton.
- After milling we get 16 ton U_3O_8 per day

Energy consumption is:

- Electric energy 1040 TJ(el)/a
- Thermal energy in diesel oil 408 TJ/(t)/a
- Thermal energy in explosives 788 TJ(t) /a.
- Thermal energy in chemicals 4 262 TJ(t)/a

Total thermal energy in reality 8578.4 TJ(th)/a



Schematics of uranium milling from ore in Trekkopje

Annual production of U in Trekkopje is to be 4884 t(U)/a equivalent to the thermal energy production in an NPP

2 358 872 TJ(t)/a

Since the thermal energy needed for uranium mining and milling is **8578.4 TJ(th)/a, the ratio of energy used to energy obtained is 0.0036.**

The low grade ore uranium (0.013% U) will yield 275 times the energy needed for ore mining and milling

Even if the energy for mine reclamation is equal to that for uranium mining, the balance remains strongly positive.

Low grade ore can be mined and milled with success!

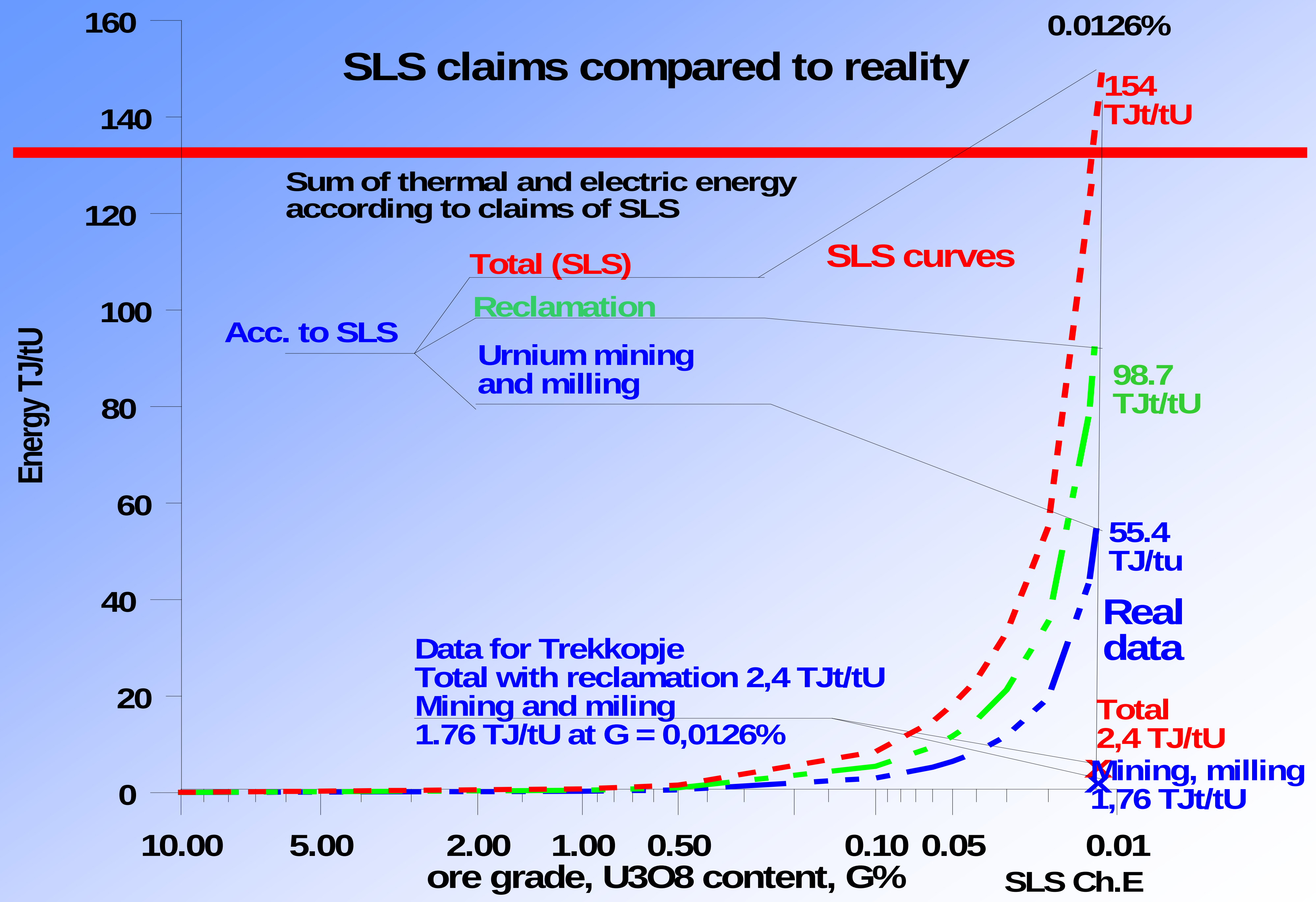
Can SLS be right?

SLS formulae would yield the needed energy of 29,3 TJ/tU

If it were true, then with Trekkopje capacity of 4884 t(U)/a the energy needed for the mine would be **143 PJ(t)/a .**

But the whole electric energy used in Namibia is 9.97 PJ, and the total energy - electric and thermal - in the whole country is **59,7 PJ(t)/a**

The energy needs postulated by SLS are 2 times larger than the real energy needs for the whole country!


SLS claims compared to reality
0.0126%
154
TJt/tU
Sum of thermal and electric energy
according to claims of SLS
SLS curves
Total (SLS)
Reclamation
Acc. to SLS
Urnium mining
and milling
98.7
TJt/tU
55.4
TJ/tu
Real
data
Data for Trekkopje
Total with reclamation 2,4 TJt/tU
Mining and miling
1.76 TJ/tU at G = 0,0126%
Total
2,4 TJ/tU
Mining, milling
1,76 TJt/tU
Energy TJ/tU
160
140
120
100
80
60
40
20
0
10.00
5.00
2.00
1.00
0.50
0.10
0.05
0.01
ore grade, U3O8 content, G%
SLS Ch.E

SLS claims are quoted by many opponents of nuclear power

Anti-nuclear warriors quote SLS with enthousiasm:

John Busby **"*At uranium content in the ore below*** *0.01% for soft ore and 0.02% for hard ore, the fuel cycle will consume more energy than can be produced"*

Friends of the Earth (*Nuclear power not a solution for global warming*), Jim Green (*Global warming: Nuclear power no solution*) " ***uranium resources will be exhausted within 50 years***",

Oxford Research Group "***it is impossible to get net energy from uraniumj ore containing below 0.02-0.01% U_3O_8".***

Energy Watch Group „***Full calculation ...proves that for the ore below 0.02–0.01% uranium content the net energy balance is negative***"

None of them thinks it advisable to check the facts!

Nuclear power – the key to sustainable developement

The claims of SLS and their followers are so blatantly wrong, that in Sept. 2008 the scientific committee of Swiss Symposium Physor 08 rejected a paper containing similar claims as being in clear conflict with the facts.

Several eminent experts, e.g. Prof. Sevior from Australia, Dr Dones and prof. Prasser from Switzerland, and others have shown the fallacy of the claims of SLS.

The European Parliament on 24,10.2007 adopted with overwhelming majority of votes the resolution saying that „*known world resources of uranium will last for over 200 years*" and that „*nuclear power has a long future...till thousands of years*"

This is also the opinion of large countries like USA, Russia, France, UK, Japan, China, India, and of many small countries such as Finland, Czech or Slovak Republic, which cannot be suspected of military ambitions. These countries simply make investments in their future.

This should be the guidance for others. There is enough uranium in longterm and the promise of recycling and fast breeder reactors will assure that the fissionable fuel will really last for thousands of years.