8th SESSION of AER Working Group < f > "Transmutations"
Trest, Czech Republic, April 16-21, 2006

Workshop on application of INPRO methodology for assessment of innovative nuclear energy systems
International Atomic Energy Agency, June 26-30, 2006, Vienna, Austria

16th Symposium of AER on VVER Reactor Physics and Reactor Safety,
Bratislava, Slovakia, September 25-29, 2006

Uranium
as raw material for nuclear energy.

Vladimir Lelek
Nuclear Research Institute Rez, Czech Republic
lelek@nri.cz

Uranium as raw material for nuclear energy.

- if we want to analyze future behavior of the energy market and how supply it specially by nuclear energy we need prices estimations of future investment and operation and maintenance (OM) prices

- for the whole power station lifetime we need guaranty of uranium supply

?? how understand future OM prices for something like 60 years (projected lifetime) if prices of uranium are growing about three times during several years ???

answer is that forecast price must be different from the simple approximation of the spot (just now market price) prices development

That is why we are trying to understand more deeply
what is the price and what were the uranium prices in the past period and
based on it we shall try to build up concept of prices for the far future.

free consideration following

Reflection on the Uranium Market by Phillip Crowson

from the conference World Nuclear Association

Annual Symposium 7-9 September 2005 – London

http://www.world-nuclear.org/sym/subindex.htm

basic description of the uranium mining:

1. looking for the future uranium mine
2. if we find the place we shall start mining planning
3. if planning is OK we shall start to build up mine
4. if we have mine we start mining and uranium selling

   time for the realization of points 1 $\Rightarrow$ 4 is about ten years
5. we are mining and selling uranium in order to

   make money and cover expenses of 1 $\Rightarrow$ 4 points

   (which are giving no money and are very expensive)

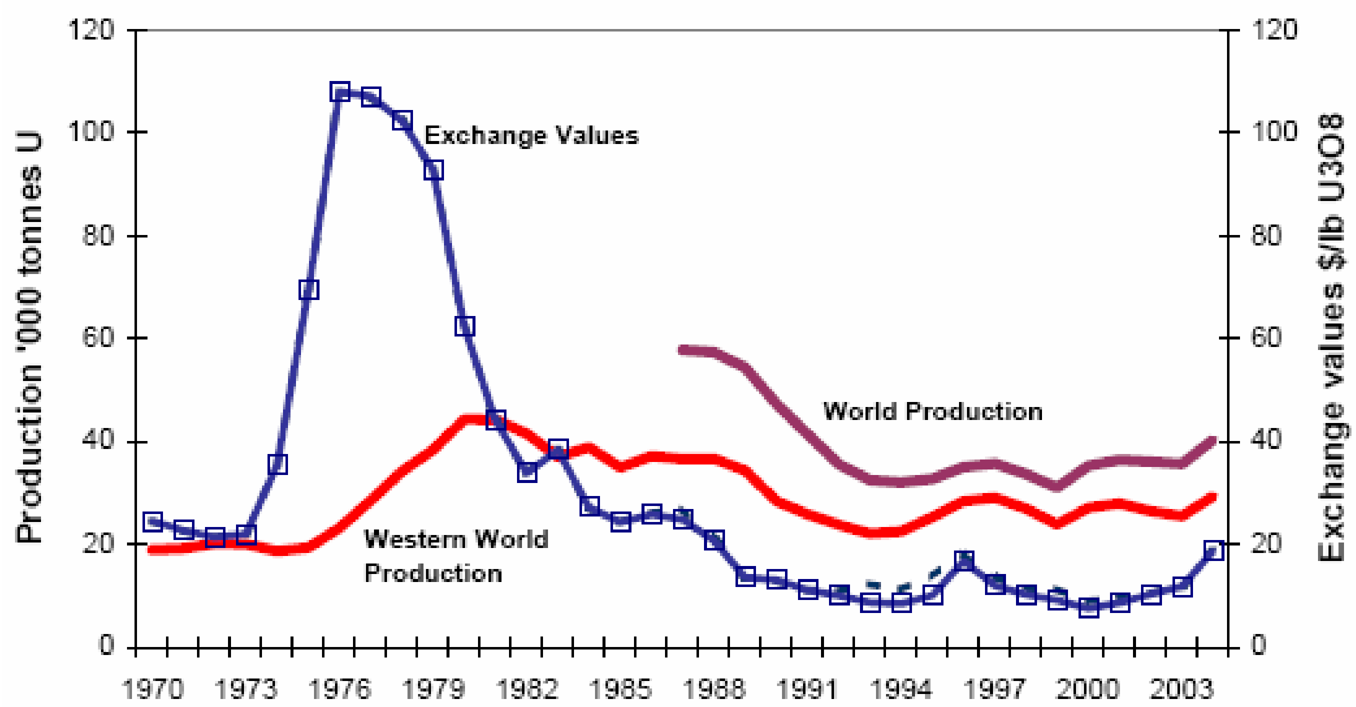
over all this points there are market influences –

if the demand is too high, prices are increasing and

miners are trying to increase mining, but their possibilities are limited

as a result prices are increasing

Figure 8. Uranium prices and mine production, 1970-2004



As with most mineral commodities, the collapse of the Soviet Union and the progressive integration of centrally planned economies into the global economy has created discontinuities in the data. *Figure* shows global output annually from 1987, and the production of Western world mines for the entire period. Changes in mine output tend to lag behind those of prices, but production clearly responds. In due course the price rises of the 1970s led to a 137% rise in output between 1974 and 1980, but output then declined with the weakening of prices, the exhaustion of some older deposits and the closure of higher cost mines. The nadir was reached in 1993, when Western output was down to roughly half its 1980 peak level. The price rises of 1996-97 had a discernible impact on mine output, but it was almost as temporary as the rise in prices. Production rose by 32% between 1993 and 1997, and then declined by 18% during the next two years.

Even so, uranium has not been immune from the general political and economic conditions that affect all commodities.

Since the commencement of civil applications of nuclear power the uranium market has witnessed three complete price cycles and is now into its fourth.

The first occurred largely in the 1960s when the industry was adjusting from military to civil procurement. Prices rose by up to 60% in the late 1960s, only to subside in 1969-71 because of delays in reactor construction, the disposal of government stocks and general economic malaise.

The second surge was partly triggered by the oil price rises of 1973-74 and the speculative furore that affected the prices of all commodities. Prices were forced up dramatically in the scramble for assured supplies of fuel for reactors that were often merely projected, let alone planned or under construction. The reaction during the early 1980s was almost as pronounced as the earlier surge. Delays and cancellations of nuclear power programmes coincided with increased mine supplies and the build-up of excess inventories. To a considerable extent the earlier price rise had carried the seeds of its own decline, a common result of surging prices in commodity markets.

The third price cycle, of the 1990s, was relatively brief and only subdued by the standard of the previous cycle. Prices rose to a peak in 1996-97 from their 1993-94 trough, with Nuexco's exchange value rising by 125% between July 1993 and July 1996, but soon subsided to new lows by the end of the decade. The rise was prompted by a production shortfall and a steady rundown of commercial inventories, and the fall by the mobilisation of military stockpiles for civil use.

Are we able to withdraw uranium cost from the data in figure 8?

directly no, because there is interference among the various phases of the cycle;

we can imagine that we shall try to decompose curve into the models of cycles, if we have formulas with parameters – but this is complicated task with unsure result, but then we can calculate mean value over cycle and conclude about the coming period

then mean values over cycles will express

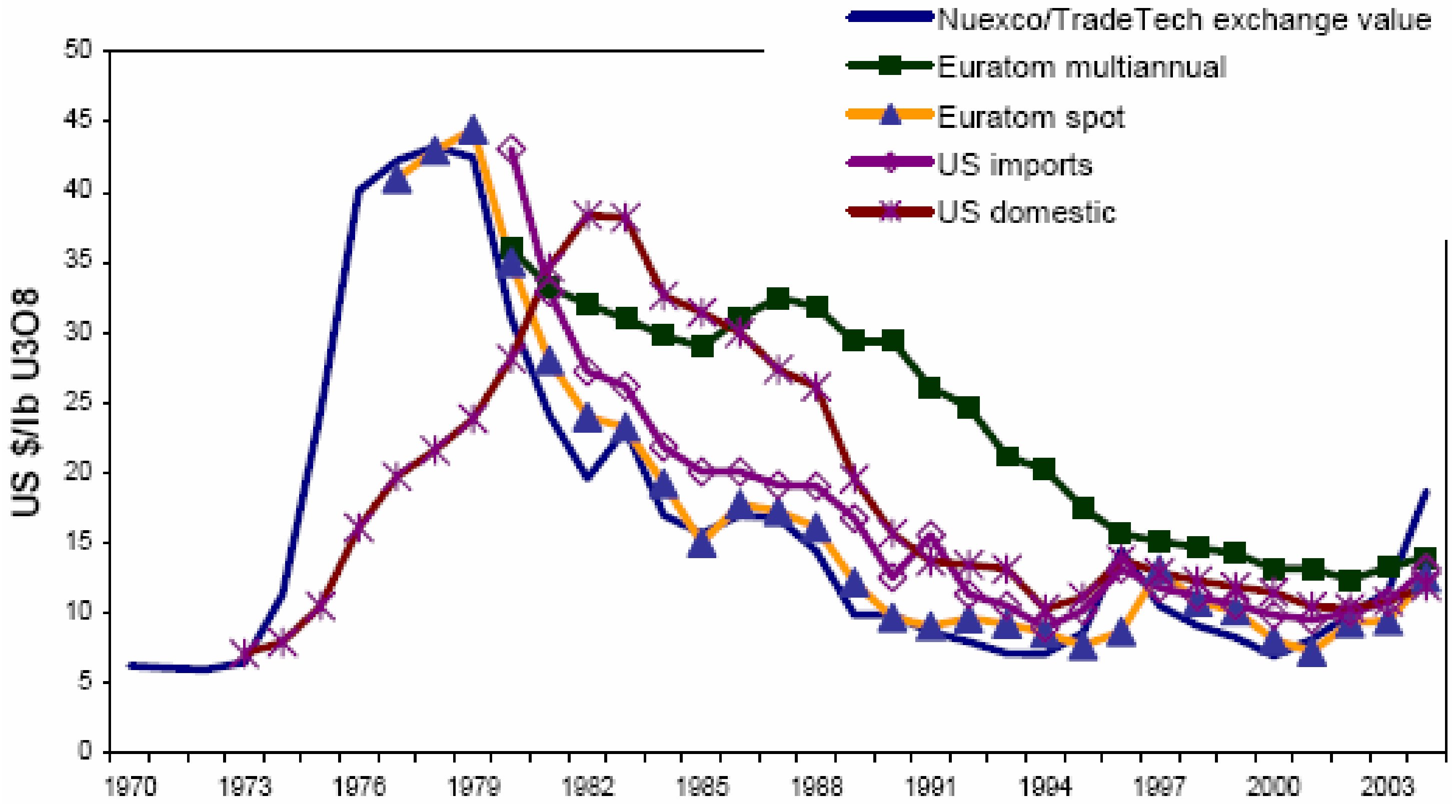
growing cost of mining due to worse raw material …

this should be something like price expectation

for the long time period

Let us look, what are the prices

Figure 3. Measures of uranium prices, 1970-2004



Here we must explain that there are various prices:

– spot price (just now price on the market)
– long term contract price,
– short time contract,
– price for domestic suppliers,
– …

Prices are flowing and mutually changing and the differences are used to play in the market to gain financial effect (here we can remark that Czech uranium reserves were sold out in the period of low prices).

End of the graphs (contemporary data) is not in the work and growing prices now are expected.

!!! attention !!!

This is not the full picture. There is so called secondary supply.

Secondary Supplies: Future Friend or Foe? by James C. Cornell
from the conference World Nuclear Association
Annual Symposium 7-9 September 2005 – London
http://www.world-nuclear.org/sym/subindex.htm

Secondary supply :

tail (former rests of U^{235} after the enrichment process was about 0.4%, contemporary praxis is about 0.3%, growing prices of U on the market are influencing to have in the tail only 0.2% U^{235}) It is estimated that only in Russia there is about one year world uranium production which could be produced from the old tails.

> There is discussion about the future availability of enrichment capacities. There is general statement that there will be lack of it.
>
> On the contrary there were open information from Russia that they are using their enrichment possibilities only for about 30%.
>
> How is enrichment capacity measure is in the enclosure (SWU – separation work unit).

HEU from weapon programs: market expectation that contemporary supply of the HEU diluted to 4% or to 5% will be up to 2012 (amount is equivalent to half of the US yearly needs). It is under question mark how much will be still on the stockpile and how it will be given to the market.

uranium from the reprocessed fuel: spent fuel contain about 1% of Pu isotopes and uranium is still also about 1%. Pu is supposed to be used for fast reactors, but amount of U was not up to now taken into the balance. So called, “one through recycled uranium” contains also U^{236} and as a result you need slightly higher enrichment (about 0.1%) to have equivalent material as from the natural uranium.

Supposing that original enrichment was 4.4% and now you have 1%, tail will be 0.2%, you can reach 0.7% from the material – the whole amount would be about 1/7. So that seventy years of nuclear energy would give you about ten additional years from one through cycle reprocessed uranium. Process could be repeated, even if U^{236} will be growing and we can maybe save altogether with such option 20 years supply for the contemporary LWR. Such fuel is already now offered by Russia's suppliers.

This potential source of fuel was not taken into account into the existing balance considerations (al least by my opinion).

Markets don't like surprises, especially surprises that are inflicted on them by government whims that disregard such private sector requirements as return on investment and reasonably predictable requirements. This is particularly true in the uranium sector, where discovery and development risks are high, and lead times extraordinarily long. If governments really want to be a friend to the market, transparency and true market neutrality must be the name of the game. Only when secondary supplies are viewed as a friend to all, and a foe to none, will fuel suppliers be in position to make the necessary investment decisions that will assure adequate supplies to meet expanding demand.

We can only conclude that is not easy to estimate price development.

There is work specially devoted to the price problem.

The True Cost of Uranium Production by Ken Seitz
from the conference World Nuclear Association
Annual Symposium 7-9 September 2005 – London
http://www.world-nuclear.org/sym/subindex.htm

But there is only discussion without formulas and direct indications how to proceed.

long time scaling in the uranium mining is discussed in the work

Challenging or Easy? Natural Uranium Availability to Fuel a Nuclear Renaissance by Tim Gitzel
from the conference World Nuclear Association
Annual Symposium 7-9 September 2005 – London
http://www.world-nuclear.org/sym/subindex.htm

categories of resources are introduced and comparison with Red Book is done.

Red Book is book about uranium resources published each two years by IAEA giving the world overview and situation description state by state.

New categories which will be used in the Red Book 2005.

- **"Identified Resources"** (replacing previous "Known Conventional Resources") refers to resources that are precisely positioned geographically (between the meter to the hectometer scale or at the shovel scale!). In the Red Book, this category is reported **as tonnes of recoverable uranium**, instead of *in situ* uranium. This category covers
- the **"Reasonably Assured Resources"** that have a high assurance of existence according to the tonnages, grades, recoverability of the uranium and cost assessment.
- The **"Inferred Resources"** (previously Estimated Additional 1) that are basically geometrically less known extensions (larger drilling patterns) of the previous (RAR) but are likely to have similar geological, technical and economic characteristics.
- **"Undiscovered Resources"** refers to resources that are not necessarily positioned at a mine scale (at the kilometer scale or even larger). Because of the uncertainty of potential mining and ore processing methods, Undiscovered Resources are reported as in situ uranium. This category covers
- **"Hypothetical Resources"** that are evaluated on the basis of indirect evidences within known uranium bearing areas, and
- **"Speculative Resources"** that are thought to exist in geologically documented but poorly explored areas with respect to uranium "on the basis of indirect evidence and geological extrapolations".

This recently-proposed distinction introduces a very sharp limit between the Identified and Undiscovered Resources categories. It is to be implemented for the 2005 Red Book issue, and will require from a few countries some work to adapt their data to this new system.

The second axis of the classification is the economic attractiveness defined through cost categories limits. To allow gathering the data in single tables, all the costs are converted in US dollars at a fixed date. The costs are typically "forward marginal cost" (mezní náklady), not taking into account sunk (?) costs nor any profit margin and return on invested capital.

The costs limits considered in the Red Book are

- less than $40/kgU (about $15/lbU3O8)
- $40 to $80/kgU (about $30/lbU3O8)
- $80 to $130/kgU (about $50/lbU3O8)

Information from older analyses is saying that the use of sea water (generally categories over the limit $130/kgU) will need more energy than you can obtain. Analyses are not complete but this is probably the way, how to admit further uranium or thorium deposits.

My personal conviction is that it will not be needed because fast reactors and reprocessing will be cheaper.

Alternative work formulation instead of :

shall we have enough uranium –

WHEN REPROCESSING WILL GIVE CHEAPER FUEL

???????????

There were old studies of the analogical situation, which were not fully performed.

- great studies done in IIASA (International Institute for Applied System Analyses);
- the impulse to do it was first oil crisis.

ENERGY IN A FINITE WORLD

A Global System Analyses

Report by the Energy Systems Program Group of the IIASA

Wolf Häfele, Program leader
Ballinger Publishing Company, Cambridge, Massachusetts, 1981

There were attempts to estimate amount of work to mine uranium and if the work is subdivided into the people work and energy, there could be possibility to construct formulas and use expected acceleration in prices. But we have no information about such study from that times.

Recommendation as conclusion: use formula for uranium mining work, which will have separated people work and energy and try to find parameters of such formula either based of consultation with mining specialists or by various integration of old curves expressing prices etc.

Mean values are needed to separate pure market waves.

Work cannot be done without experts
for uranium resources and uranium mining.

Enclosure 1.

What's a SWU?

A SWU (separative work unit) is a unit of measurement used in the nuclear power industry, just as unit measurements such as calorie, watt, decibel, ampere, volt, etc., are used in other industries.

A SWU pertains to the process of enriching uranium so it can be used as fuel for nuclear power plants.

Most commercial nuclear reactors cannot use uranium in its natural form. More than 99% of natural uranium is composed of uranium-238 (U-238) atoms. The majority of the balance—less than 1%—consists of slightly lighter U-235 atoms. Most reactors need uranium fuel with a U-235 content of between 4% and 5%. Uranium enrichment is the process that increases that U-235 content.

A SWU is a unit of measurement of the effort needed to separate the U-235 and U-238 atoms in natural uranium in order to create a final product that is richer in U-235 atoms. Material enriched to between 4% and 5% U-235 is called low-enriched uranium (LEU). SWUs are measured using a standard formula derived from the physics of uranium enrichment.

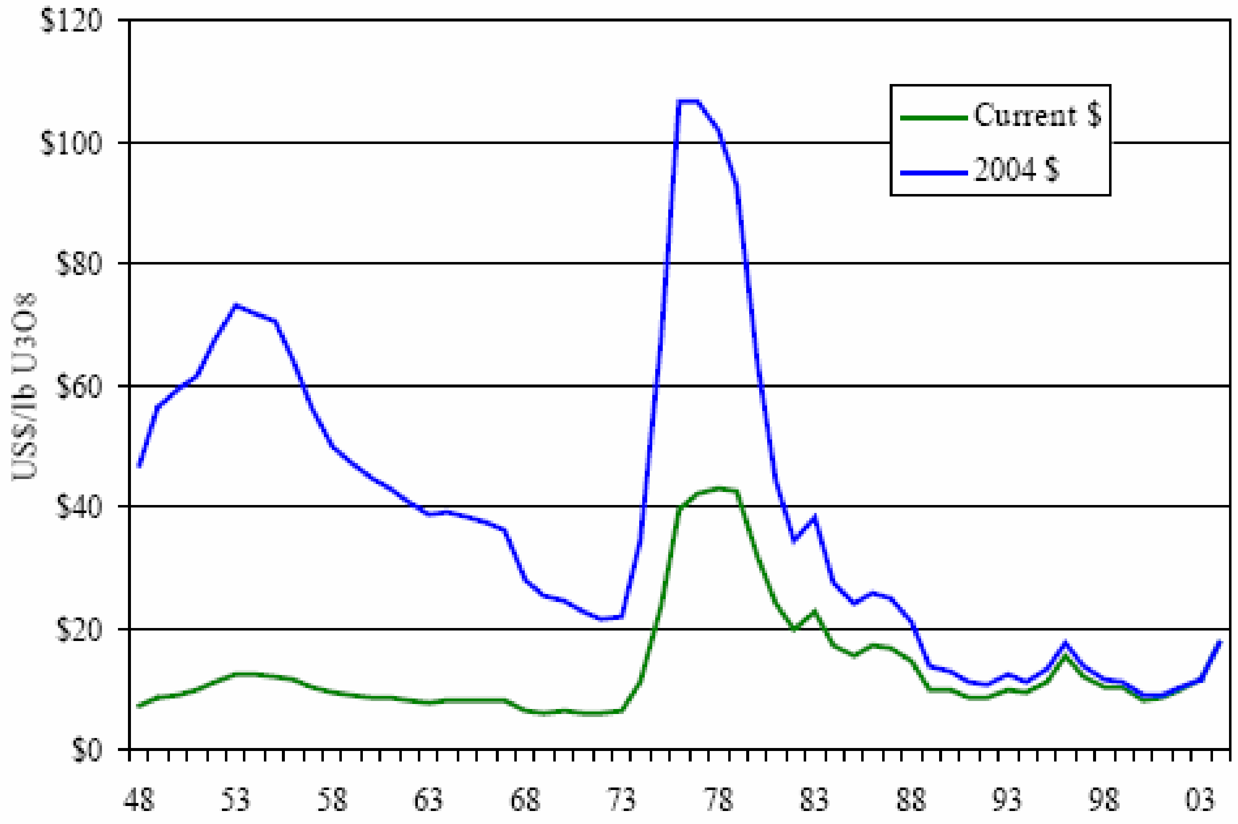
What does a SWU do? Natural uranium, in the form of uranium hexafluoride ("natural UF6"), is fed into an enrichment process. If, for example, you begin with 100 kilograms (220 pounds) of natural uranium, it takes about 60 SWU to produce 10 kilograms (22 pounds) of uranium enriched in U-235 content to 4.5%.

It takes on the order of 100,000 SWU of enriched uranium to fuel a typical 1,000 megawatt (MW) commercial nuclear reactor for a year. A 1,000 MW plant can supply the electricity needs for a city of about 600,000. That's approximately the size of Memphis, Tennessee or El Paso, Texas.

see: www.usec.com

Enclosure 2: from WNA Symposium, 2004,
Fueling the Future: A New Paradigm Assuring Uranium Supplies in an Abnormal Market by Jeff Combs

Figure 4. Historical Prices Expressed in Current and 2004 Dollars



Differences in the curves, demonstrating various position of USD, if curve is recalculated to the current $ at that times and if it is recalculated to the same time $ by inflation rate.
! quite different feature, only basic form is repeated !

Uranium as raw material for nuclear energy.

Vladimir Lelek
Nuclear Research Institute Rez, Czech Republic

Abstract.

There is lot of information bringing our attention to the problem of limited raw material resources. Fortunately uranium for nuclear energy is very concentrated source and that is why its transport brings no problems and could be realized from anywhere.

Second question is if overall resources are available for current nuclear energy development. Data documenting reasons for nowadays price growth is presenting and it is clearly shown that the most probable explanation is that there is gap in new uranium mines preparation and the lot of smaller mines were closed in the period of low uranium prices.

Conclusion is that there is at least for the first half of this century even for thermal reactors enough uranium. Situation cold be changed if there will massive production of