Sustainability of Water Cooled Reactors - Energy Balance for Low Grade Uranium Resources

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Abstract. The opponents of nuclear power claim that as uranium resources get exhausted the energy needed to mine low grade uranium ore will be larger than the energy that can be obtained from fission in a nuclear power plant. This would result in loss of sustainability of nuclear power, with the negative energy balance expected within the next 40-60 years. Since the opponents state clearly that the ore containing less than 0.013% U_3O_8 cannot yield positive energy balance, the study of the Institute of Atomic Energy in Poland referenced three mines of decreasing ore grade: Ranger 0.234% U_3O_8, Rossing 0.028% U_3O_8 and Trekkopje 0.00126% U_3O_8, that is with ore grade below the postulated cut off value. The study considered total energy needs for uranium mining, including not only electricity needed for mining and milling, for water treatment and delivery, but also fuel for transportation and ore crushing, explosives for rock blasting, chemicals for uranium leaching and the energy needed for mine reclamation after completed exploitation. It has been shown that the energy estimates of nuclear opponents are wrong for Ranger mine and go off much further for the mines with lower uranium ore grades. The reasons for erroneous reasoning of nuclear opponents have been found. Their errors arise from treating the uranium ore deposits as if their layout and properties were the same as those of uranium ore mined in the US in the 70-ies. This results in an oversimplified formula, which yields large errors when the thickness of the overlayer is less than it was in the US. In addition the energy needs claimed for mine reclamation are much too high. The study showed that the energy needed for very low grade uranium ore mining and milling increases but the overall energy balance of the nuclear fuel cycle remains strongly positive.

1. INTRODUCTION

In October 2007 the European Parliament declared, that nuclear power is indispensable for the European Union for limiting CO2 emissions. Many countries revive their nuclear power programs or start building new nuclear power plants. However, the opponents of nuclear power claim that as uranium resources get exhausted the energy needed to mine low grade uranium ore will be larger than the energy that can be obtained from fission in a nuclear power plant.

When the nuclear experts show that the energy balance is positive [1] [2], the opponents answer that the balance does not include full energy costs of the nuclear fuel cycle, leaving aside the energy incorporated in materials and products bought from other industries and neglecting the energy needed for plant dismantling, mine area reclamation and waste management. This would result in loss of sustainability of nuclear power, with the negative energy balance expected within the next 40-60 years.

The opponents conduct continuously their studies, publish their results in internet and present them at numerous meetings organized by antinuclear organizations. They gain access even to such known universities as Oxford [3], and the publications showing shortage of future uranium supply are being sent to many recipients in various organizations.

In answer to that the Institute of Atomic Energy (IAE) in Poland has performed a study of available uranium resources, energy needed for mining and milling and the CO_2 emissions in the whole uranium fuel cycle with special attention to back-end energy needs [4]. The total energy needs for uranium mining were considered, including not only electricity needed for mining and milling, for water treatment and delivery to the mine and to the neighboring settlements, but also fuel for transportation and ore crushing, explosives for rock blasting, chemicals for uranium leaching and the energy needed for mine reclamation after completed ore exploitation.

2. THE AMOUNT OF URANIUM RESOURCES

2.1 Uranium resources recoverable at current prices

The amount of uranium resources that can be mined at current market price of uranium is growing with every year. According to the Red Book published in 2008, the identified amount of conventional uranium resources which can be mined for less than USD 130/kg are estimated to be about 5.5 million tonnes, up from the 4.7 million tonnes reported in 2005. Undiscovered resources, i.e. uranium deposits that can be expected to be found based on the geological characteristics of already discovered resources, have also risen to 10.5 million tonnes [5]. This is an increase of 0.5 million tonnes compared to the previous edition of the report. The period for which known uranium resources recoverable below USD 130/kg U will be sufficient for present type of reactors with open fuel cycle at present capacity of nuclear power plants is estimated at 100 years. If fast breeder reactors with full recycling closed fuel cycle and thorium utilization are considered, then this period is extended to 24 000 years. On the other hand, if we consider only LWRs with present open fuel cycle, without recycling or other technological improvements, then the identified and estimated uranium resources recoverable below USD 130/kgU will last for 300 years, and considering all conventional and non-conventional resources, including phosphorites, gives the period of 1690 years.

Further exploration and increases of uranium price will undoubtedly lead to further discoveries. Based on analogy with other resources it can be expected that doubling the uranium price will result in tenfold increase of its identified resources. In the time horizon of some 20-30 years, the introduction of IV generation fast breeder reactors being presently developed will provide possibilities of using spent fuel from generation II reactors and the depleted uranium left over from the enrichment process. This will extend the time of sustainable operation of nuclear power to thousands of years..

The technological improvements being presently implemented, such as increase of burnup of nuclear fuel, allow for more efficient utilization of uranium. Further possibility of increasing the amount of fissionable materials consists in using thorium, which is threefold more abundant than uranium. Considering all conventional and non-conventional resources and fast breeder reactors with full recycling of uranium and thorium will yield resources sufficient for 472 000 years – so practically for an infinite time, because long before that other sources of energy will certainly be available.

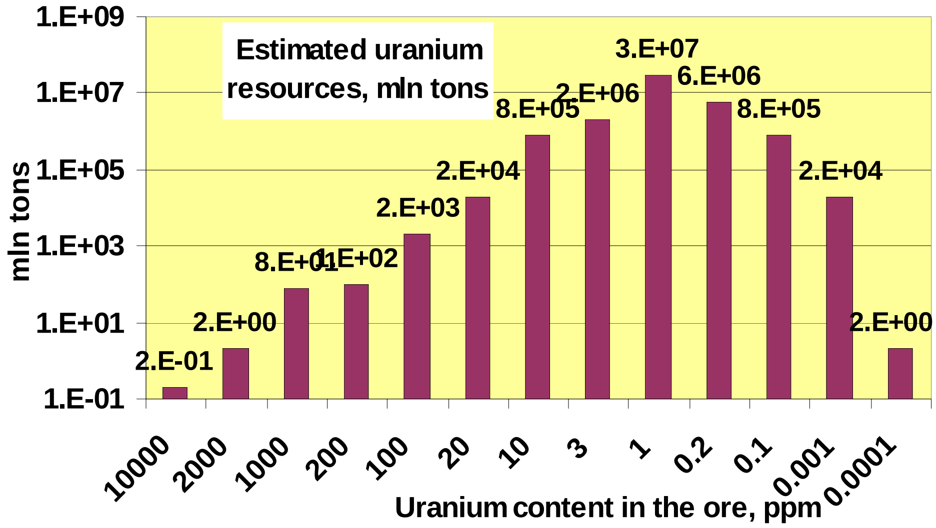

Fig. 1. Uranium resources at various uranium ore grades
(the drawing shows the lower limit of each range, i.e. for the range 100-200 the number 100 is shown)
Figure drawn by the author according to the data from Deffeye&MacGregor [6]

Fig. 1 shows that as we consider ore of lower grade, the amount of uranium available for mining increases. Within the range of 1% do 0.0001% U_3O_8 a decrease of uranium grade by 10 times results in the increase of its quantity from 50 to 100 times. Thus, there is no problem of absolute quantity of uranium available in middle term or in the long term. The problem consists in finding out, at what ore grade it is still profitable to mine uranium. Profitable from the standpoint of energy balance – that is what is the lowest ore grade at which the energy balance will still be positive.

2.2. Shall we have enough energy to mine low grade uranium ore?

It is logical, that as the ore grade decreases the costs and amount of energy needed for uranium mining will go up. However, according to the nuclear industry, there will be no long term shortage of uranium, while the opponents claim that the uranium resources are too small even for the existing fleet of nuclear reactors. What is the basis for such claims?

The amount of energy needed for uranium mining and milling is presently a small part of the energy obtained from this uranium in a nuclear power reactor. But already in the 70-ies it was claimed that the shortage of uranium must come [7] and for the last two decades Storm van Leeuven and Smith, whose work will be shown in abbrevation as SLS [8] have claimed, that at low ore grade there is an energy cliff, below which the amount of energy obtainable in the whole uranium cycle abruptly falls down. They state specifically that below the grade of 0.013% more energy is needed to mine and mill uranium than can be obtained in thermal reactors with open fuel cycle, without reprocessing. Let us check therefore, what energy is needed to get uranium from low grade ores.

2.3 The energy obtained in the nuclear power plant

In order to have a common reference point with the nuclear power opponents, let us consider a nuclear power plant (NPP) of 1000 MWe power, operated at load factor of 82% over 40 years. Such parameters correspond to the values that used to be obtained some 20 years ago, at fuel burnup equal to 30 000 MWd/t(U). Presently fuel burnup is much higher, e.g. in EPR the average burnup is to be 50 000 MWD/t(U). The assumption of the low parameters chosen by the SLS is therefore a very pessimistic assumption.

According to the opponents [8] such a reactor would use 162.35 tonnes of natural uranium equivalent per year and deliver electric energy 7.1 TWh/year. Assuming the ratio of thermal (t) energy to electrical (e) energy equal to 3, which is a normal assumption in power balance analyses, we can find that the thermal energy provided by the NPP operation is 478 TJ(t)/t(Unat)

Since in the future the majority of uranium will be provided from low grade ores, let us check the amount of energy needed for mining and milling uranium from the mines exploiting uranium ore of various contents of U_3O_8, from the values close to the actual world mean value down to the ore as poor as that threshold value below which SLS claim that a positive energy balance is impossible.

3. THE ENERGY NEEDED FOR URANIUM MINING AND MILLING IN THE MINE RANGER

3.1. Energy needed for uranium mining and milling

Let us start with the mine Ranger, which in 2004 exploited the ore of comparatively high grade, equal to 0,234 % U_3O_8. According to the data from WNA [9] the energy used locally (in the mine and around the mine, including production of sulfur acid but without counting the energy included in materials bought for the mine) for uranium mining and milling was 195 GJ(t)/t(U). According to the

rules of life cycle analysis, we should add also the energy contained in the explosives and chemicals bought by the mine, whose production had required some energy earlier, before they were delivered to the mine.
The data concerning the quantities of these chemicals and their energy content are shown in Table I
.

Table 1. Energy contained in chemicals (Data from SLS) [10]

Material	Contained energy	Quantity	Electric energy	Thermal energy
	GJ(t)/t	Thou. tonne	TJ_{th}	TJ_{el}
Explosives	72	2300	2	160
Sulphur S	40.26	29.8		1200
Natrium chlorate NaClO3	87	2.75	58	66
Ammonia NH3	158	1.08	39	54
Calcium oxide CaO	8.6	26.04	1.8	219
Total			101	1699

Annual production of U_3O_8 in Ranger was 5910 tonnes. The additional energy of explosives and chemicals brought to the mine Ranger per tonne U_3O_8 was then (recalculating the electric energy into thermal energy) (101 x 3 + 1699) TJ(t)/5910 tonnes(U_3O_8) = 338 GJ(t)/t(U_3O_8)

Total energy used locally and contained in the materials bought by the mine was therefore 165 + 338 = 503 GJ(t)/t(U_3O_8). After introducing the coefficient for the amount of uranium in U_3O_8 equal to 0.848 we obtain unit energy consumption of 503 GJ(T)/t(U_3O_8) / 0.848 t(U)/t(U_3O_8) = 593 GJ(t)/t(U)

Altogether the amount of energy used locally and imported with purchased materials is 593 GJ(t)/t(U).

The ratio of energy used in the phase of uranium mining and milling to the energy obtained in a NPP is therefore 593 GJ(t)/478 TJ(t) = 0,00125. But since we conduct analysis in the whole life cycle, it is necessary to consider not only the energy needed for uranium exploitation, but also the energy needed for mine reclamation after the ore has been mined.

3.2. The energy for mine reclamation

It should be observed, that the waste rock and the tailings from the process of ore separation contain the same minerals that have been originally in the mine before ore mining. The difference consists only in the fact that we have removed uranium, so the radioactivity has been decreased. If the waste rock is placed again in the ground and covered with a layer of rock and soil, then it will not be more hazardous to the environment than it had been originally, before the uranium mining was started. In the mine Ranger the tailings and waste rock will be put back into the excavations left after ore mining and will be covered with a layer of soil, stabilized by means of cultivation of grass and trees. This will prevent erosion processes on the surface of reclaimed area.

How much energy is needed for this purpose? We know how much energy was needed to get the whole overburden¸ waste rock and ore upwards, from the mine to the ore pile where stripping process was realized. We can assume conservatively that the same energy will be needed to get those materials back into the mine excavations, although of course the amount of gas for trucks will be lower for transport downwards than it has been for the transport upwards. No explosives will be needed, because the rock has been already milled, and no chemicals, since the uranium has been already removed. The needs of electrical energy per unit of transported mass will be lower than they were when that mass was extracted, but we shall again assume conservatively that they are as large as for extraction.

Thus we can estimate the amount of energy needed for mine reclamation. It is equal to the electric energy used in ore extraction plus the fuel needed for material transport. This will be a value lower than in the normal mine operation, but we shall assume conservatively the same value, namely 195 GJ(t)/t(U) for Ranger mine.

3.3. Total energy needs for Ranger mining

In total, the overall energy needs for uranium mining and milling and for mine reclamation counted with a large safety margin will be
593 GJ(t)/t(U) + 195 GJ(t)/tU = 788 GJ(t)/t(U)

This is only 0.0016, i.e. 0.16% of energy obtained from one tonne of natural uranium equal to 478 TJ(t)/t(U)

3.4. Comparison of real and estimated by SLS energy for the mine Ranger.

On the other hand, the evaluation according to the approach of Storm van Leeuven yields the energy needed for uranium mining and milling in Ranger equal to 1280 GJ(t)/t(U). Moreover SLS claim that the energy «*needed for reclamation is estimated to be fourfold larger than the energy needed for uranium mining*». This energy needed for mining is equal according to Storm van Leeuven :

E (mining) = 1.06 GJ(t)/t(ore)

The mass of waste, including limestone and bentonite which according to SLS should be added to stabilize the waste, is estimated by SLS as "*twice larger than the mass of excavated ore*" [10]. Such an assumption leads to the result that the energy needed for reclamation is 8 times larger than the energy needed initially for ore mining, which yields energy outlay 8.4 GJ(t)/t(ore).

Together with the energy needed according to SLS for ore mining and milling this would give 4920 GJ(t)/t(U). This is much more than the total value of 788 GJ(t)/t(U), which has been determined in our considerations above. It shows that already for the ore containing 0.234% uranium the estimates of SLS are more than 6 time higher than the real data. With decreasing ore grade the errors of SLS estimates grow.

4. URANIUM MINE ROSSING – ORE GRADE BELOW 0.03% U_3O_8

In order to get closer to the postulated „*cliff effect*" which is so spectacular in SLS drawings, let us consider real operational data for uranium mine Rossing in Namibia, where the ore grade is 0.0276% U_3O_8 [11] or 0,0234% U. The annual report of the mine indicates [12] that in 2006 the mine Rossing produced 3617 tonnes of U_3O_8 , and the energy use in the mine was 1366 TJ(t) (without chemicals). Unit energy expenditure per tonne of ore was 113.7 MJ/t. This corresponds to the expenditure of thermal energy per tonne of uranium equal to 113.6 MJ(t)/t(ore)/0.000234 t(U)/t(ore) = 484 GJ/t(U) (without chemicals).

This is twice more than in Ranger, where the energy expenditure in the mine (without chemicals) was 195 GJ(t)/t(U). Twice more - but why is it not ten times more, in spite of the ore containing 10 times less uranium?

Evidently, the value of needed energy depends strongly on local conditions, and a decisive parameter is the stripping ratio S of the mass of overburden to the mass of uranium ore. In Ranger this ratio was S =3. In Rossing the ratio S is in the range from 0.7 to 1.43, and in 2006 it was 0.71. This low mass of overburden results in comparatively low energy expenditure. It should be observed, that with decreasing ore grade the ratio of overburden to ore mass naturally decreases, so this phenomenon of reduced ratio S is typical for low grade ores.

According to SLS, the energy needed for uranium mining and milling (without mine reclamation) for low grade ore of 0.023% uranium should be 17 TJ(t)/t(U). If it were true, then with annual production of 3 617 tonnes of U_3O_8 the mine Rossing would consume energy equal to 3617 x 0.848 x 17 TJ/t(U) = 52142 TJ/a, ie. 52.1 PJ per annum. As shown by Sevior [1], taking even the cheapest source of energy, namely diesel oil at the price of $1 per litre, with energy content 43 MJ/kg and density 0.848 kg/litre, the amount of energy to be bought per 1 USD would be only 43 x 0.848 = 36 MJ.

The energy claimed by SLS as necessary for Rossing is 17 TJ/t(U), so its cost would be 472 000 USD/t(U). If SLS were right, then with the uranium price which for many years has been 40 000 USD/t(U), the extraction of each tonne of uranium from the mine Rossing would involve LOSSES in the amount of 430 000 USD!

Now let us check the data for a mine where the uranium content in the ore is very close to 0.01%.

5. ENERGY NEEDS FOR TREKKOPJE, NAMIBIA

5.1. Energy needed for mining and milling uranium ore at Trekkopje

SLS claim, 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*. [3]" In the most recent work of SLS presented in internet on their own website the value of 0,013 % is shown as the value at which the uranium fuel cycle brings **net energy losses** both for hard ore (table G.32) and for soft ore (table G 35 – net energy output full system – 40 GJ/kg U nat) [10].

Let us look at the energy balance for Trekkopje mine in Namibia, which received license in February 2009 and has produced the first batch of uranium. The balance was made for shareholders and its veracity was checked by independent financial organizations. The average content of U_3O_8 in the ore in Trekkopje is 0.0126%. According to SLS, the extraction of such ore should result in negative energy balance – and of course in financial losses. What is the truth?

Ore extraction from Trekkopje will be 100 000 tonnes per day, the average ratio of overburden to ore is 0,3:1 and the thresholod of ore separation from the barren rock has been set at 0,0046%, so threefold lower than the threshold of the "energy cliff" postulated by SLS.

5.1.1. Water consumption at Trekkopje and electric energy needs

The mine will use water at the rate of 20 million $m^{3/}$a, what allows separating milled ore at the rate of 2083 m^3/h at full height of crushed ore pile equal to 9 m. After washing the amount of uranium oxide obtained daily is 16 tonne U_3O_8 [13].

At the end of March 2009, the first production of sodium diuranate was achieved at Areva's Trekkopje uranium mine's minipilot plant, proving the heap-leaching treatment process a success [14].

Table 2. Electric energy needed for Trekkopje Mine

Sea water desalination	Pumping station for water transport	Pumps of water tank	Permanent power supply for the mine	Total
10 MVA	6 MVA	2,5 MVA	15 MVA	33.5 MVA

Sea water desalination station provides water not only for the mine, but also delivers additionally 25 mln m^3 of potable water for the local population. In the course of public discussion of these umbers the representative of Namwater company stated [15] that the station producing 6 million tonnes of potable water per year and the pumps transporting that water of will need the total installed power of 4,3 MWe. The table shows 10 MWe. This shows that the numbers estimating the energy needs for

Trekkopje have been chosen with a large reserve. They can be taken as the basis for further considerations

The annual uranium production from Trekkopje at full capacity over 360 days/year is evaluated at 4884 t(U)/a [13]. Electric energy per unit of uranium mass is then 1040 TJ(el)/a / 4884 t(U)/a = 213 GJ/t(U)

5.1.2. Diesel oil consumption

Estimated diesel oil consumption for excavations and ore transport from the mine to the uranium ore pile is 0.3 litre per tonne of rock. At full production of 100,000 tonne per day, the amount needed is 30,000 litre of diesel oil per day.

Taking into account the density of diesel oil equal to 0.848 kg/litre we get the annual consumption equal to 30.000 x 0.88 x 360 = 9 504 tonnes/a.

The calorific value of diesel oil is 43 MJ/kg, so that the energy consumption of the whole diesel fuel is 408 TJ(t)/a. This corresponds to the energy consumption per unit mass of uranium equal to 408 TJ(t)/a / 4884 t(U)/a = 83.6 GJ(t)/t(U)

5.1.3. Explosives

The amount of needed explosives is 0.30 kg/t. Taking the energy content of explosives according to the data of Storm van Leeuwen [10] as 71 GJ/t we get the total energy in explosives delivered to the mine equal to 71 GJ/t x 0.3 kg/t x (26 + 11) 10^6 tonne/a = 788 TJ(t)/a.

5.1.4. Chemicals

According to Trekkopje project data the quantity of chemicals needed for uranium extraction from the pile is

- Natrium carbonate - 7.5 kg/t ore
- Natrium bicarbonate 1.5 kg/t ore.

The thermal energy in natrium carbonate is -2550 cal/gm [16].= 10.7 kJ/gm, and taking the same value for natrium bicarbonate we obtain the total energy content of the main chemicals equal to

0.009 t(ch)/ tonne of ore x 10.7 GJ(t)/t(ch) = 0.096 GJ(t)/tonne of ore.

At the ore grade 0.013% U_3O_8, the energy of chemicals per 1 tonne of uranium oxide is

0.096 GJ(t)/tonne of ore / 0.00013 t(U_3O_8)/tonne of ore = 740 GJ(t)/t (U_3O_8)

The annual energy needs are then
740 GJ(t)/t (U_3O_8) x 5760 t(U_3O_8)/a = 4262.4 TJ(t)/a

5.1.5. Energy needs for uranium mining and milling at Trekkopje

Finally the whole energy needed for uranium mining and milling in Trekkopje is
Electricity + diesel oil + explosives + chemicals = 1040 TJ/a (el) + (408 + 788 + 4262.4) TJ(t)/a

Or, using the coefficient 3 to calculate equivalent thermal energy from electricity we get 8578.4 TJ(t)/a

The energy per tonne of uranium is then 8578.4 TJ(t)/a / 4884 t(U)/y = 1.76 TJ(t)/t(U)

5.1.6. Energy needs for mine reclamation

Assuming similarly as above that the energy needed for mine reclamation equals the energy needed for keeping the mine in operation and energy in diesel fuel needed for rock transport back to the mine we shall get the additional energy for mine reclamation equal to 240.8 GJ(el)/t(U) = 722 GJ(t)/t(U).

5.1.7. Total energy needs at Trekkopje

Altogether the energy needed for uranium mining, milling and mine reclamation is
E(m,m,r)= (1760 + 722) GJ(t)/t(U) = 2482 GJ(t)/t(U)

The ratio of the energy needed for mining and milling and for mine reclamation for ore grade 0.0126% to the energy obtained in an NPP is in Trekkopje equal to 0.519%. In other words, the energy obtained from uranium is 192 times larger than the energy needed for its mining and milling, together with mine reclamation. On the other hand, according to the formulae given by SLS, the energy needed just for mining and milling should be 29.3 TJ(t) /t(U). Together with mine reclamation there would be 154.1 TJ(t)/t(U).

5.2. Formula of SLS applied to Trekkopje case

The formula adopted by SLS has the form:
E(G)= = C/(Y x G) [GJ(t)/kgU]

where

[G] – is the content of uranium oxide given in % U_3O_8 in the ore.

Constant C = E_o /8.48
- where the coefficient 8.48 reflects that the uranium mass in 1 kg of U_3O_8 is 0.848 kg and that the uranium content in the ore is given in percent of U_3O_8.
- E_o – energy needed for mining and milling one tonne of ore. After introducing a division of uranium ore into hard and soft, SLS defined the value of E_o as follows:
  - E_o = 5.55 GJ/t of hard ore
  - E_o = 2,33 GJ/t of soft ore

Y is the yield of uranium from uranium ore. SLS have proposed a formula describing the decrease of efficiency of uranium recovery from the ore in function of its grade
$Y = 0.98 - 0.0723 (\log (G))^2$

Let us observe, that this relationship is inherently flawed, because at uranium content in the ore at the level of 2 ppm the yield Y would be zero, while it should be possible to recover a finite amount of uranium even for very low grades. Moreover, the formula yields Y values much lower than those already obtained in practice for uranium content in the ore below 0.03% U_3O_8.

However, let us check the amount of energy which would be obtained from SLS formula for soft ore containing 0.013 % U_3O_8.

$Y = 0.98 – 0.0723 (-1.886)^2 = 0.98 – 0.257 = 0.722$

E(0.013)= 2.33 GJ(t)/kg(U) /8.48 GJ/kgU /(0.722 x 0.013) [GJ/kgU] = 29.3 TJ/tU

According to another estimate given by Storm van Leeuwen in [10], the energy needed to get uranium from soft ore of uranium content 0.013% is even more, namely 44.8 TJ/tU, of which thermal energy

39.5 TJ/tU, and electric energy 5.3 TJ/tU. This is the estimate for soft ore, for hard ore it would be much more.

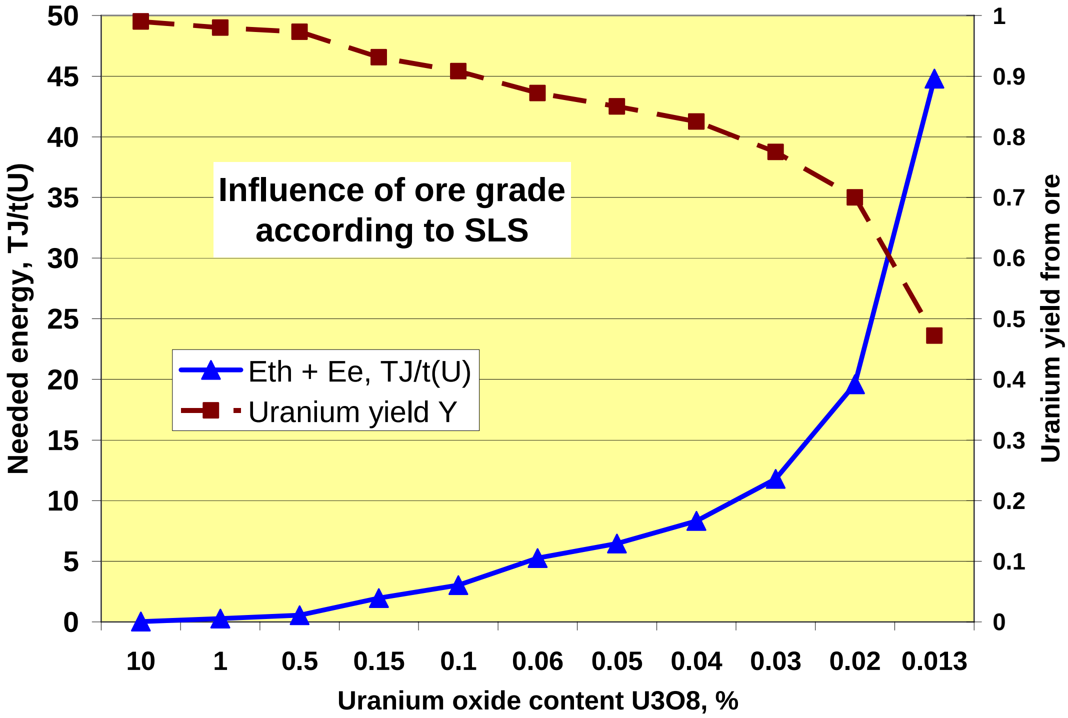

Fig. 2. Claims of nuclear opponents concerning the energy needed for mining and milling low grade uranium ores (*Curves drawn by the author on the basis of numerical data from table D6 in [10]*)

5.3. Checking opposing data against objective reality for Trekkopje

We see that the amounts of energy needed for Trekkopje postulated by SLS are in sharp contrast to the published data. This data is checked and carefully verified, because it is used for marketing purposes and any discrepancies with reality would have very severe economic consequences. However, the opponents can still claim that the nuclear industry hides the real energy needs.

Let us check therefore, ***whether SLS can be right***. If getting one tonne of U_3O_8 from a low grade ore (0,01% of U_3O_8) should really require 29.3 TJ(t)/t(U), then at Trekkopje mine productivity of 4884 t(U)/year [13] the energy needed would be 29.3 TJ(t)/t(U) x 4884 t(U) = **143 PJ(t) .**

However, the whole electricity being used in Namibia with all uranium mines and mines for other minerals is 9.97 PJ [17], and the total energy needed for the whole country is 59.7 PJ(t).

The energy needs postulated by SLS for just one uranium mine are therefore 2.5 times larger than the actual energy consumption in the whole country! Besides, the mining industry provides only 12% of gross national product in Namibia. It is evident, that so large a consumption of energy in Trekkopje would be impossible to hide – and would be anyway physically impossible.

A graphic comparison of SLS claims and reality is shown in Fig. 3.

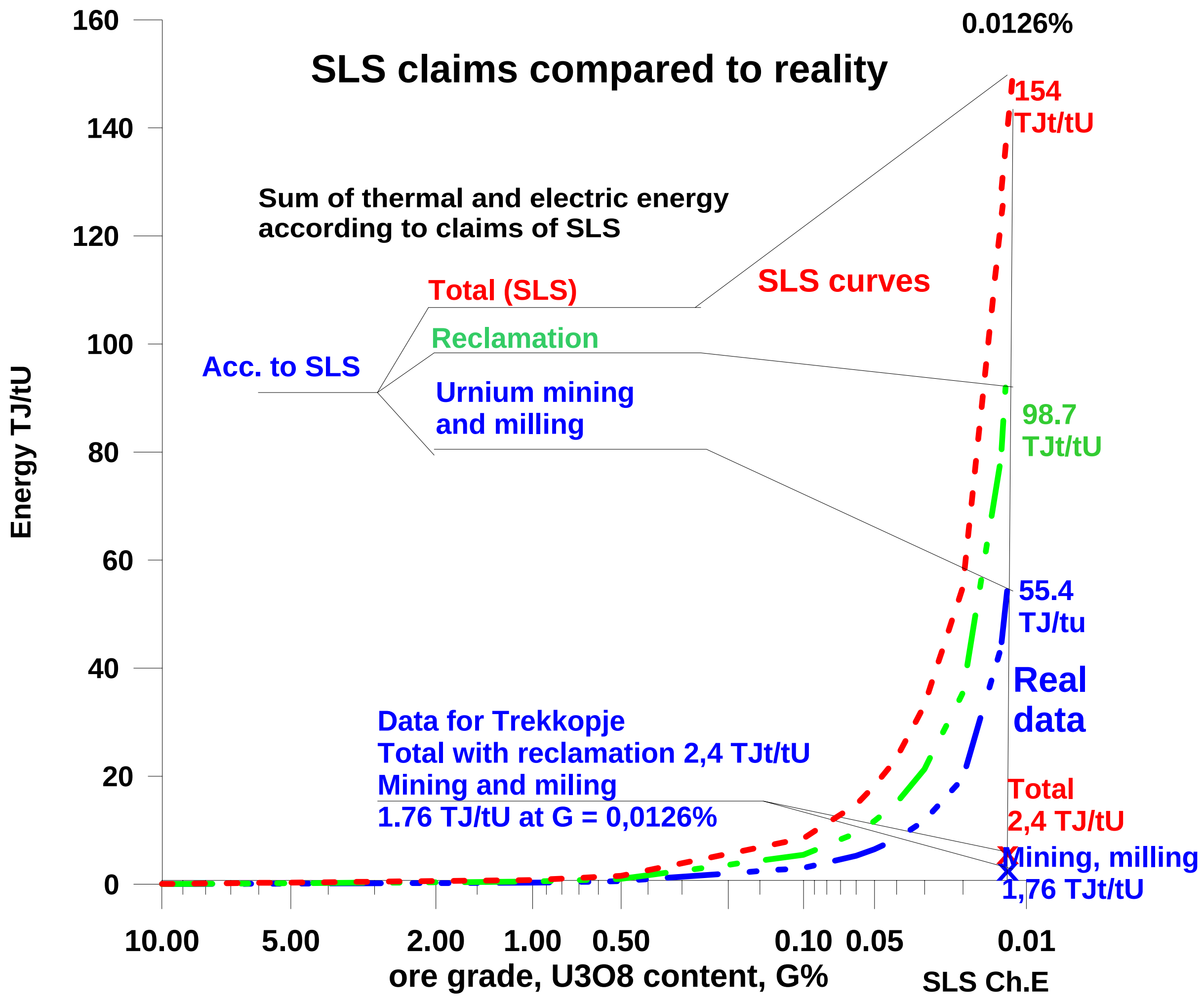

Fig. 3. Comparison of energy needs for uranium mining claimed by Storm van Leeuven and Smith with real data for low grade uranium ore mining in some presently operating mines.

Fig. 3. shows that the real data are orders of magnitude lower than the claims of SLS. SLS give the value of needed energy as the sum of electrical and thermal energy, directly added without considering that the electrical energy is usually multiplied by 3 to get the equivalent thermal energy. The value of energy really needed for Trekkopje mine takes all kinds of energy into account and includes the coefficient E= E(t) + 3 E(el). In spite of that, the real value for the mine is 64 times LOWER than the value claimed by SLS.

6. SOURCES OF ERRORS OF SLS

The estimates given by SLS are based on an old study from 1975 [18] in which the data for mining and milling were taken from US practice with high grade ore, containing about 0.22% of U_3O_8. SLS have not considered technological progress which has taken place since then. Moreover, they have assumed an erroneous formula describing the energy needed for mining in function of uranium content in the ore. In particular, they have tacitly assumed that the thick overlayer of barren waste typical for the US ore mined in the 70-ies is a permanent feature in all mines.

Evidently the amount of energy needed for mining and milling uranium ore increases with the decrease of the uranium content in the ore. This is due to the fact that the amount of ore to be mined and cleaned increases as the grade goes down. The correct formula should be:

E (mining) = C_s (1+S) /G

where

- C_s – indicator of energy needed to mine one tonne of ore or barren rock
- S – stripping ratio, i.e. the amount of tonnes of overlayer to tonnes of ore

SLS assumed, that the value of stripping ratio S = 50 typical for US ore 30 years ago [10] is representative for all uranium ore layers in the world and have used formulae in which instead of variable value C_s (1+S) changing in function of stripping ratio S a constant value C is used, determined for the value of S = 50.

Evidently, when the value of S in a mine is lower than 50, the formula of SLS yields wrong results. For example in mine Trekkopje S= 0.3, so the estimates of SLS can be up to 150 times too high.

Prof. Prasser remarked that when the graded of the ore decreases, there is a natural tendency to decrease the ratio of barren waste to the ore [19]. This is why in the mines exploiting low grade ore the value of S is many times lower than in old US mines which were exploiting high grade ore.

7. CONCLUSIONS

Neither Storm Van Leeuwen and Smith nor antinuclear organizations repeating the claim of coming uranium shortage have checked this claim against actual data on uranium mining. They preferred to keep to the extrapolations of data from the early period of nuclear power development and use a simplified and wrong formula. If their claims were right, then both Rossing and Trekkopje would bring enormous losses to the owners. If the evaluation of energy costs made above for Rossing is repeated for Trekkopje at the energy expenditure claimed by SLS (29.3 TJ(t)/t(U)), then the energy cost would be 810 000 USD/t(U).

Assuming that Trekkopje will operate while the uranium price is 130 USD/kg (U), each tonne of uranium would involve the loss of **680 000 USD**! Who would like to build such a mine? And for what purpose?

This simple check is enough to prove that the formula of SLS is wrong.

The considerations above show that even for the mine using the uranium ore of very low grade, namely 0.0126% U_3O_8 in Trekkopje mine, the energy obtained at the NPP is about 190 times larger than that needed for the uranium mining, milling and mine reclamation. Thus the claims of nuclear opponents are shown to be wrong. What is more, the countries having low grade uranium ore can develop nuclear power industry without fear that in the long term the uranium resources will run out.

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