Nuclear Energy: Status And Future Limitations

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ABSTRACT:
Discussions about the origin of energy in a post fossil fuel world are quickly dominated by a general exchange of mostly fruitless arguments about the future contribution of nuclear energy. In this paper we discuss the status of nuclear energy today and analyze its potential evolution during the next 10-20 years. The facts are that nuclear energy contributes only about 14% of the world's electric energy mix today, and as electric energy contributes itself only about 16% to the end energy use, its contribution is essentially negligible. Still, nuclear energy is plagued already with a long list of unsolved problems. Among the less known problems one finds the difficulties that nuclear plants can not provide power according to needs, but have to be operated at full power also during times of low demand. As a result, regions with large contributions from nuclear power need some backup hydropower storage systems. Without sufficient storage capacity, cheap electric energy is suggested during low demand times, which obviously results in wasteful applications. The better known problems, without solutions since at least 40 years, are the final safe storage of the accumulated highly radioactive nuclear waste, that uranium itself is a very limited and non renewable energy resource and that enormous amounts of human resources, urgently needed to find a still unknown path towards a low energy future, are blocked by useless research on fusion energy. Thus, nuclear energy is not a solution to our energy worries but part of the problem.

Keywords: Limits of Nuclear Energy, Fusion Illusions, Uranium Peak and shortages

1. Introduction

Commercial nuclear fission energy started during the cold war period in the 1950ies. The nuclear energy sector has always been plagued with its dual role in building up a huge overkill nuclear weapon capacity for a few countries and as being praised for its final solution to the energy problem. More than 50 years later, and about 20 years after the cold war has ended, the promised nuclear solutions to the energy problems are further away than ever imagined and the nuclear weapon sword of Damocles (a final solution) is still above us. During the last few years the energy debate started to heat up again and so did the question about the future of nuclear fission energy. Perhaps one of the most remarkable observations by the International Energy Agency (IEA) at the end of 2008 was that the current world energy system is unsustainable. This statement was made in connection to the presentation of their annual world energy outlook up to the year 2030 [IEA08] and with respect to the use of fossil energies. According to the counting scheme of the IEA, used by many other organizations, energy data are presented in units of the required amount of oil equivalent. Unfortunately, this scheme leads to an overall distortion in the non fossil energy sector, favoring nuclear power by an unjustified factor of three. As a result, the contribution from nuclear energy to the world energy sector is accounted for as about 7%, while hydropower is presented with a contribution of only about 3%. However, a more careful analysis of electric energy data reveals that during the year 2009 hydropower contributed about 3000 TWhe, while nuclear fission power contributed only 2560 TWhe. A more accurate world energy accounting system would perhaps be slightly more complicated, but it would allow to make more realistic estimates of the impacts from the coming decline of oil and gas. One would thus first separate electric energy, which makes 16% of the current world energy mix, from

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the other demanded forms of energy for transport, heating and other uses and secondly argue about the possibility to transform electric energy efficiently back into the other required forms. Furthermore, a realistic analysis of the contribution of nuclear energy should also mention the problem that nuclear power plants can provide essentially only base load power, while electric energy coming from hydropower and gas fired power plants has a much higher value, as production can follow the huge demand variations for electric energy. Thus, in fact nuclear produced electric energy should receive some kind of penalty factor in comparison with hydropower. Ignoring such details, one calculates easily that nuclear energy contributes currently only an almost negligible amount of about 2.3% to the worlds useful end energy. Taking the European Union as an example of an industrialized area, one finds that the contribution of electric energy is about 23% from which nuclear power plants contributed about one 25% in 2009. It follows that even with a relatively large density of nuclear power plants, they hardly contribute 6% to the European energy system. These sobering facts about today's small contribution of nuclear fission energy indicate already that nuclear energy cannot contribute in any significant way during the next decades to compensate for the coming decline of fossil fuels.

Still, it is important to determine, with some realism, an upper limit for the contribution of nuclear energy during the coming decades. Such limits come from the technological and political constraints to construct new nuclear power plants and from the limits to extract uranium fuel. In the following we present some details about the current and near future situation with nuclear power and describe why one should not count on technological miracles with respect to future fission and fusion reactors. We conclude this paper with some arguments, which demonstrate that nuclear energy should be considered as an integral part of our energy problem and not as a possible solution. It turns out that, even if the Nuclear Armageddon can be avoided, many potential problems with the existing nuclear energy infrastructure, starting from the fuel production to the final waste deposal might soon become important regional and essentially unsolvable nightmares for the concerned future generations.

1.1 Nuclear Energy today

The commercial use of nuclear fission energy started some 50 years ago. Today 441 nuclear power plants in 30 countries with a total electric capacity of 374.6 GWe are considered as operational. These reactors provided 2560 TWhe of electric energy in 2009, about 1.6% lower than in 2008 and about 100 TWhe lower than in the record year 2006. About 84% of these nuclear produced electric energy comes from 344 reactors, with a capacity of about 315 GWe, operated in the relatively rich and highly industrialized OECD countries in Western Europe, North-America, Japan and the Republic of Korea.

Some nuclear energy saturation effects and even declines due to their aging reactors are observed for the OECD regions and still no real replacement policy for the relatively important amount of nuclear produced electric energy has been found. The existing reactors have an average age of about 25 years and about 100 reactors are expected to reach the retirement age during the next 10-15 years. Many of them will certainly be terminated during that period.

The picture is drastically different when one looks in which countries the 60 reactors, currently under construction, are located. Most of them are found outside of the OECD block and in the larger so called emerging countries, e.g. countries with a predicted continued fast economic growth.

Thus, on one hand a stagnation of nuclear power in OECD countries is observed and on the other hand one finds very ambitious plans for new nuclear reactors in China, Russia and India. These plans seem to have some parallels with similar past aggressive nuclear growth scenarios in the OECD countries, following the political oil crisis during 1973. The fact that not even 50% of these aggressive nuclear growth scenarios were realized in the past is a warning for those who believe in today's predictions about strong nuclear growth scenarios. Thus, and independently of the realization of the ambitious plans of China, Russia and India, a further slow decline of nuclear energy during the coming decades and in the rich OECD countries, appears to be essentially unavoidable.

2. Limiting factors for nuclear fission energy during the next decades

As presented above, the often mentioned coming nuclear renaissance, can only come from China, Russia and India. Taking China as an example one finds that nuclear power currently plays an almost negligible role: the 12 nuclear power plants in China with a capacity of 9.6 GWe produced 65.7 TWhe in 2009, about 1.9% of the total electric energy. Following its economic success and the accumulation of up to about 1000 billion dollars, China is now in a position to simply buy -- in the ``free market" --many high tech items like nuclear power plants, large amounts of uranium and many other vital resources. Since China now faces enormous environmental problems created by their extensive use of dirty coal, the option of increasing nuclear power production appears to be logical. In addition the operation of nuclear energy is still considered as one of the most obvious signs for a successful transition to a modern society. The result is that out of the 60 nuclear power plants currently under construction 24 are found in China. If their construction proceeds according to plans about 2-3 GWe of new capacity will be added per year up to 2012 and another 6-7 GWe per year from 2013 to 2015. Plans exist to continue this growth with 33 more reactors by 2020 and another 120 reactors for the years 2020 to 2030. According to the latest plans, the nuclear power capacity should reach about 35 GWe by 2015, 80 GWe by 2020, 200 GWe by 2030,roughly twice the number in the USA today, and perhaps even 400 GWe by 2050. These plans require corresponding large amounts of uranium, starting with a demand of 2875 tons in 2010 to perhaps 6000 tons by 2015, 14000 tons by 2020 and 30000 tons by 2030. However, the 2009 uranium mining in China produced only 750 tons and without any significant uranium deposits of its own, China investigates aggressively in existing and planned uranium mines all around the world.

This situation raises the question about uranium resources and uranium mining: will these mines be capable to double the current uranium mining from about 51 000 tons in 2009 to more than 100 000 tons during the next 10 to 15 years?

Before going into some details, we would like to remind the reader that already the small contribution from nuclear power plants to the world electric energy of 14% requires an amount of about 68 000 tons of natural uranium equivalent per year. However, during the last 10 years only between 65-75% of this uranium was provided from uranium mines and the rest came from so called secondary resources, accumulated mainly during the cold war period between 1950-1990 and a smaller contribution from expensive nuclear fuel recycling and depleted uranium tails. All available data about uranium mining, collected in a bi-annual publication, the Red Book[RB09], from the International Atomic Energy Agency (IAEA), indicate that the so called civilian part of the secondary resources has essentially been exhausted. In contrast, about 200 000 tons and 300 000 tons remain in the military reserves of the USA and Russia respectively. Some rough estimates allow to assign an amount of about 100 000 per country, fixed in the remaining 20 000 nuclear warheads. Most likely another up to 100 000 tons per country is considered to be in weapon ready highly enriched weapon grade uranium, not directly useful for the existing nuclear reactors. It might thus be possible that especially Russia controls some relatively large amount of uranium, ready to be injected into the international uranium market.

According to the 2009 edition of the Red Book (RB09), new large uranium mines with a production capacity of more than 2 000 tons are supposed to start during the next 5 years in

Kazakhstan (plus 10 000 tons), Namibia (plus 9 200 tons), Niger (plus 5 000 tons), Canada (plus 6 900 tons) and Jordan (plus 2 000 tons). The total production capacity of the 9 larger mines adds up to 33 000 tons by 2015. In addition, many smaller mines with capacities between a few hundred to 2 000 tons will open in several countries, adding perhaps another 16 000 tons of capacity by 2015. Assuming that the existing capacity, given for 2010 as 70-75 000 tons, will not be subject to significant declines, the authors of the Red Book 2009 estimated the total maximum uranium mining capacity for 2015 to be between 96 000 tons and 122 000 tons. The predicted spread indicates large uncertainties about the new projects and the date when full capacity can be reached.

When looking further into the future, one finds an interesting prediction made by the authors of the Red Book. It is stated that the worldwide uranium mining capacity is expected to reach a peak with a maximum between 98 000-141 000 tons around the year 2020, followed by decline to 80 000-129 000 tons (2025), 75 000-119 000 tons (2030) and 68 000-109 000 tons (2035). As if these numbers would not be surprising enough, the ones given for Kazakhstan can perhaps be called alarming. A peak production of 28 000 tons is expected already around the year 2015, followed by a decline to 24 000 (2020), 14 000 tons (2025), 12 000 tons (2030) and to only 5 000-6 000 tons by 2035.

The authors of the Red Book acknowledge that the uranium mining capacity numbers are very different and always much higher than the real production from mining. In order to quantify the difference, one can confront the predicted mining capacity numbers from past editions for the year 2010 with the almost known mining result. Accordingly, past capacity predictions for the year 2010, were 69 000-83 000 tons (RB05) and 81 000-96 000 tons (RB07). In comparison the latest and naturally more accurate RB09 estimate for 2010 presents a capacity between 70 000-75 000 tons, about 11 000-21 000 tons smaller than the RB07 prediction. It follows that roughly 50% of the new projects have been delayed or ``evaporated" between these two editions. In addition and according to the latest estimates, uranium mining in 2010 is expected to reach about 55 000 tons. The real mining is thus 15 000-20 000 tons, or 20-30%, smaller than the mining capacity figure given in the just published RB09 report.

In chapter I of ``The future of nuclear energy" from 2009 [Dittmar09], we had presented two scenarios, A and B, to guess the future evolution from past trends. According to scenario A, which assumes that about 75% of the Red Book 07 capacity can be realized, a 2010 estimate of 60 500-65 000 tons was obtained. For scenario B it was assumed that the existing mines continue their annual production of 40 000 tons (roughly the 2005 result) and that only 50% of the new mines can be realized in time and a forecast for 2010 of 53 000-55 000 tons was obtained. Scenario B is thus in agreement with the 2009 and most likely also with the 2010 result. Following the same procedure to estimate the uranium production for the year 2015, using the RB07 capacity estimates, the predictions were 72 000-88 000 tons (scenario A) and 61 500-70 000 tons (scenario B). If one uses the RB09 capacity estimates for the year 2015 and takes the 2009 mining result of 50 000 tons as an updated baseline, the expected 2015 mining would be 72 000-91 000 tons (Scenario A) or 68 000-78 000 tons (Scenario B).

In addition to these two scenarios my own 2009 guesstimates, assumed that uranium mining will be strongly affected by the financial crisis and by the increasing troubles to exploit lower and lower grade. My scenario was wrong for Kazakhstan during 2009 and 2010. However, the almost too perfectly matching of the yearly mining in Kazakhstan with the plans from the past years, remind a critical observer about the ``false" success stories of some historical 5-year plans in the Soviet Union. One might thus remain a little ``uneasy" about the mining reports from this area. In contrast to this particular country, my last year guesstimate was in rough agreement with the mining results from all other countries in 2009 and presumably also with the one in 2010. Therefore, and despite the fact that my 2009 uranium mining estimate was 7000 tons too low, my 2010 updated guesstimate for the next years is that uranium production from all countries, other than Kazakhstan, will not increase significantly above

40000 tons during the coming five years. I thus continue to predict problems with uranium supply and assume that shortages after 2013 can only be avoided if new ``miracles" (at least for me) will happen. Examples of such ``miracles" are that uranium mining in Kazakhstan can really be further increased to the claimed 24000 tons by 2015 or that a new deal concerning the military uranium reserves between Russia and the USA will be made in time.

Whether and how the future uranium needs of China and India can be satisfied -- even if almost all future production went to these countries -- remains to be seen. If these needs can not be satisfied, perhaps their dreams of becoming rich industrialized countries, thanks to billions of dollars spent on nuclear power plants, will end in nightmares with unfinished or unfueled plants lying in ruins.

One should also reflect about the possible consequences from the unavoidable decline of oil on uranium mining. For example one could think about the impact of a deep economic crisis on many essential parts of the uranium fuel chain. If history can be of any guidance in such a situation, one might conclude that uranium mining will decline in all the affected countries. Furthermore one could guess that the ``best" nearby friends will be served first. Thus one could imagine that uranium from Canada might go to the USA and the one from Australia and Kazakhstan to Russia, Japan, Korea and China. It is of course uncertain if sufficient amounts can be extracted and delivered even for the nearby countries. Such a situation would look especially difficult for the requirements of Western Europe. Most likely only a tiny fraction of the required uranium would reach Europe under such a scenario and the results would be that the stability European electric grid would quickly end.

3. Why we should not count on miracles from future fission and fusion reactors

While it is acknowledged in general that fossil fuels are finite, most people think that potential problems are still a few generations away and that nuclear fission and fusion energy, following some decades of research and technology, will be the solution. Following the often expressed idea that known conventional uranium resources can satisfy the current yearly requirements for up to about 100 years the situation seems to be under control. However, it has not gone totally unnoticed that the current real nuclear contribution to the final energy mix is tiny and that some nuclear growth scenario needs to be taken into account.

Taking for example the current maximal nuclear growth scenario from the RB09 of perhaps 2% as a guideline, by 2030 nuclear energy would still provide only about 20% compared to the world electric energy supplied in 2009. Taking a more aggressive growth scenario of 5%/year, e.g. a doubling time of roughly 14 years, nuclear energy would reach today's total electric energy numbers by roughly 2050, thus about 1/4th of today's total amount of energy. With today's type of reactors about 500 000 tons of uranium would be required on an annual basis. As a result the claimed to be known exploitable uranium resources in the ground would of 6.3 million tons [RB09] would already be exploited at latest around 2046 in the 5% growth scenario. Still, even with the moderate 2% growth scenario the resources would be terminated quickly and uranium mining would end around the year 2065.

Of course such scenarios are totally unrealistic as uranium mining like any other mineral will follow some kind of Hubbert exploration curve. Nevertheless, the problem of limited uranium resources is in general being accepted by the nuclear energy lobby and has been summarized in the so called Generation IV nuclear power plant road map towards the development of safe fast breeder reactors [GenIV]. According to the roadmap from the year 2001 the new reactors should be ready for commercial construction around the year 2030.

Fast reactors are operated with the prompt neutrons from the nuclear fission and can be considered as prototypes for future Generation IV reactors. Among them is the French Phenix reactor, originally a 0.2 GWe prototype breeder reactor, which started operation in 1974. This reactor was finally closed in October 2009 and officially terminated in February 2010. One might hope that a detailed review of its past operation, allowing verification of the so-far unsubstantiated claims about nuclear fuel breeding, will be published eventually. Another fast reactor is the Russian BN 600, a 0.56 GWe reactor, operated since 1981. This reactor has just received the permission to continue its operation for 10 more years. The construction of its newer and slightly larger version, the BN 800, was started during 2006 and following some delays is currently expected to begin operation in 2014 at earliest. According to the WNA document [WNA1], both Russian reactors are now called ``fast reactors" instead of ``fast breeder reactors". The last ``just functioning" fast breeder prototype is now the Japanese Monju reactor with a capacity of 0.28 GWe. It has, after a 15-year-long stop, officially begun to operate under test conditions this spring and is supposed to reach its normal operation only by 2014. According to the Japanese nuclear agency the date for the operation of commercial fast breeders is now given as 2050. This is not very different from statements of French government officials claiming that the next commercial breeder reactor will not be operational before the year 2040. Thus, the original timeline of 2030 for the Generation IV reactors appears to be totally outdated.

Not much experimentation with respect to thorium reactors has been reported during the past years. However, the program to develop a high temperature high efficiency pebble bed thorium reactor project in South-Africa has been stopped. It follows that those who hope for future TH232 breeder reactors are left with nothing but modeling to support their hopes. Taking the current financial world crisis into account, the construction and realization of thorium prototype reactors during the coming years does not look very promising. Finally, newspaper reports about future "small" scale wonder nuclear reactors appeared during the past months, claiming that such projects are supported by some rich private promoters and also by the US and Russian governments. However, looking at similar claims and plans from past decades one might give them not much more credibility than most people give to snake oil medicine.

Having seen that even the most optimistic hopes for a nuclear fission renaissance are faced with enormous fundamental problems and that such hopes are still fall far below any realistic replacement for the coming decline of fossil fuels and especially of oil, expected to decline during the next 5-10 years. The last hope, for an economic growth based society, is thus put on nuclear fusion energy and its flagship ITER, currently under construction in Southern France. The 2009 and 2010 news about the ITER project, known also as the path to commercial nuclear fusion energy, a multi billion dollar/euro dream project of all larger countries, demonstrate that it is becoming nothing short of a financial nightmare for high level powerful bureaucrats and politicians in Brussels and elsewhere. Reasons for this nightmare are many:

The exploding cost of the project now admitted to have increased, even before real construction has started, by almost a factor of three. Claims are made, and even transmitted by project officials that ITER became so expensive because it has been set up as an international project. Certainly not a good start for a project defined to pave the path towards fusion energy.

(Doubtful) Statements by scientists and politicians that alternative and much more promising directions need to be taken towards mastering nuclear fusion. Examples are the multi billion euro laser fusion projects in the USA, the UK, France and elsewhere as well as special agreements like the one between Russia and Italy on alternative costly fusion projects. Obviously such projects raise doubts about the scientific foundations of the ITER project.

The distribution of the knowledge that the ITER project has absolutely nothing to do with commercial energy production and that, even if realized according to plans, not even some of the most basic tests required for a future even bigger fusion project can be performed. Among these tests one finds the demonstration that the tritium breeding chain can function and that a neutron radiation resisting material, which at the same time can survive the always occurring plasma eruptions, can be found. These and other fundamental problems have been explained in detail in the article ``Fusion Illusions”[Dittmar08] and in Chapter IV [Dittmar09]. As explained, enough knowledge about the imagined tritium breeding process, required for a future commercial power plant, has already been accumulated. It is thus understand that nobody within the fusion community has even the slightest idea on how this problem can be solved. One can be sure that once this still-well-hidden problem becomes common knowledge, the enthusiasm from the entire scientific community will disappear quickly.

The recent statement from French physics Nobel laureat G. Charpak and other scientists, asking for an end of the ITER project and for the transfer of the money to more down-to-earth nuclear fission projects, must hit extremely hard in the country where most of the money has to come from.

The year 2010 might not be the termination year of the ITER project, but perhaps it can be defined as the year when the ``false dawn" of nuclear fusion was realized. We can thus safely predict that the belief in commercial nuclear fusion on our planet will end once the younger generation of scientists sees that plasma fusion research is a dead end career path and turns its talents to other research projects.

4. Can we understand nuclear energy as part of the energy problem before potential nuclear nightmares turn into the greatest disaster ever.

As we have explained above, commercial nuclear energy is currently contributing only a tiny fraction of about 14% (and only 2.3% to the final useful energy mix) to the worldwide electric energy mix. Still the nuclear reality in many rich countries of the OECD block demonstrates that it will be essentially impossible to keep their current nuclear energy capacity from slowly declining during the next decade. Current hopes from nuclear energy believers, often expressed in our Western media, are thus based on plans in China, India and Russia. Could it perhaps be possible that such statements about the nuclear renaissance are made with the hope that a few Western companies, with the nuclear power plant construction know how, can sell such nuclear power plants in exchange for hundreds of billions of dollars accumulated by China (and soon India and Russia) during its past years of economic boom? While this idea might be too far fetched, it would at least explain why the acknowledged stressed uranium supply situation during the coming years is almost never discussed in the corresponding articles.

This idea might remind us, in the richer countries, about the legacy of past and still ongoing mega-projects, which are all based on the assumption that a continuous growth of oil, gas and energy in general supply will be possible during the coming decades.

In contrary to such ``growth based” illusions, one observes that more and more people start to think about the problems related to the limits of exponential growth on a finite sized planet. While it is already very late to start planning for the coming unavoidable contraction of economic activities and the subsequent collapse of vital infrastructures, it is certainly a better option to try some planning instead of just waiting for the coming chaos resulting possibly into some future resource wars.

In summary of the current nuclear energy situation and with respect to the unavoidable decline of oil we conclude that:

1) Nuclear energy, with its current contribution of about 14% to the world electric energy, cannot be increased in such a way that it would compensate for the decline of fossil fuels at any significant level.
2) The average reactor age of above 25 years will result in the termination of up to 100 reactors during the coming 10-15 years, mostly in Western Europe, North-America and Japan. As most of the future reactors, currently under construction or in the planning phase, are found in China, Russia and India, nuclear energy in the richer OECD countries will decline.
3) Problems with the coming more and more limited supply of oil will lead to price explosions and suspensions of all kind of future mega projects. Unfortunately this will also affect heavily the necessary, but not even started, deep underground project needed for a safe storage of the highly radioactive nuclear waste and for a safe decommissioning of retired nuclear power plants. Even though little is known today about how and where to construct final nuclear waste deposits, the problem can not expected to disappear magically during the coming years. One can expect that the current situation will lead most likely to a nightmare scenario. Such a scenario would mean that future low energy societies will not be able to deal with the problem anymore and that the radioactive material will slowly be mixed to the surroundings, resulting into some heavily contaminated areas for hundreds to thousands of years.
4) Thus, even under the unlikely situation that from tomorrow onwards one would be able to plan and act for a ``power down" path in our societies, one will be faced with a dual problem of bad options: (a) keeping the electric grid functioning as long as possible requires the further running of the still reliable functioning nuclear power plants. Thus one could imagine that the huge amount of accumulated nuclear weapon arsenal could be eliminated in such a way. Unfortunately this burning would produce even more nuclear waste for future generations. The alternative (b) would be to degrade the highly enriched uranium back to natural levels, followed by its burying together with the already accumulated nuclear waste and as quickly as possible. Unfortunately this is a very costly option and one without a guarantee that the deep mines will be sufficiently safe.
   Both options are not perfect but certainly much better than the final ultimate use of the Nuclear Weapon arsenal, still ready to solve the problem, that the homo sapiens was perhaps an evolutionary mistake. Of course such a final solution would result in a huge ``collateral damage" and would eliminate certainly a countless number of other species for ever.

In summary we have presented hard and unpleasant facts about nuclear energy, which demonstrate that nuclear fission power is an integral part of our energy problem. Unfortunately the false hopes in a solution coming from the mastering of the nuclear fission and fusion energy technology, especially within the scientific community, are still large. These false hopes are still hiding very efficiently the view towards urgent plans and the necessary first steps into the unavoidable end of our energy growth addicted way of living.

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Thus, the author hopes, with the ideas expressed in the quote from Gustave Le Bon below, that this report will contribute to the realization of some kind of ``telescope'', which will help others to observe that some objects are moving around the Jupiter.

``Science promised us truth, or at least a knowledge of such relations as our intelligence can seize: it never promised us peace or happiness''

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[WNA1] The statements that the Russian Fast Reactors are not breeder reactors but simply burners with fast neutrons can be found in the WNA article about Russia at http://www.world-nuclear.org/info/inf45.html.

[Dittmar08] The original article "Fusion Illusions" is published in the second edition of the The Final Energy Crisis edited by S. Newman. For more details and many other articles about the coming energy crisis, cf. http://candobetter.org/TFEC/.