Future yet to begin: Now Nuclear?

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When the million times denser nuclear energy than any other fuel was discovered, people were dreaming of the Golden Age. But there were shocks as Chernobyl and the story of bombs with bad or positive (deterrence!) views. Nevertheless France produces electricity nearly independently from fossil fuels automatically avoiding effects of the climatic catastrophe. But was this enough? Looking into the present and future problems and uncertainties, a lot of chances are still being missed as shown with the example of. Edward Teller's safe and long lasting fission reactor. Further, the new petawatt lasers may open a very easy way of controlled fuision by ignition of frozen hydrogen isotopes. This very low cost energy production may change the whole scenario on earth.

Numerous books and articles discuss the future, what will be and what will have grandiosely been solved. Definitely there are so many exciting views and arguments how life will be so much better and what problems will have been overcome. Details of solutions and their next steps are overwhelming, only looking what the 7700 physicists offered at the Einstein conference of the German Physical Society in Berlin March 2005. But there are trivial facts which are continuously missed sometimes leading to fateful results. For example, the large number of boats on the oceans mostly for serving the huge international trade are built to withstand waves up to 14 meters height. Only recently it was clarified that the monster waves (freak waves) up to 28 m height very probably are the main reason that nearly every week one ship disappears. The insurance companies are paying compensations in the assumption that the boat was too rusty or otherwise defect. Despite all the long available techniques with satellite measurements, it was discovered only very recently by ESA satellites that there were more than 10 waves of 25 heigth within 3 weeks [1].

We have so many sophisticated means and techniques for testing, to correct and to predict – and we shall need very many more - but we just are not fully aware to what of all problems we have to look for. What we in the following are going to look for is indeed especially restricted to clean and very low cost large scale energy generation, but we are well aware that there are enormously more problems than these which have to be solved. It is not only the problem of cutting the carbon dioxide emission what is a problem. The desire of the population in India – having now 500 Million people under 25 years of age - or China for individual mobility with motor cars is fully justified, their aim to have a spacious home too but in knowing now what a very high increase of water consumption this all will involve is enormous. We should not stress the point that many people in Australia use to take at least two showers per day, but where will this go within the few years of growing standards of living in China. This will result in a further decrease of the ground water level that up to present is 1.5 m lowered, a dangerous value for farming and a problem for the growing need of water for industrial production. The implications are an international question. If China takes more water for own use or transports it away from the rivers at the south side of the Himalaya, the problems for India are then more dramatic. With the Mekong river the difficulties are visible.

How easily problems can be overlooked

But there may be many more problems which are nearly fully overlooked. There are the trade deficits between countries which in some cases exceed the rational value of debiting per person. Budget deficits of administrations are threatening the following generations or will cause chaotic migration where no rational control may be possible in a civilized way. Necessary restrictions by policing, by administrative means up to interference with defence organisations may be a consequence and if it is not excluded very carefully by international arrangements, even nuclear weapons or other weapons of mass destruction may be a thread - not to talk what terrorists and similar organisations may cause. This all is mentioned to appreciate what dramatic problems are waiting for a solution for which not enough is done to solve them nor even the awareness of these problems can be noticed. Without calls of Cassandra but for sharpening our consciences we should recall the black Friday of 1929 where a very minor mistake in the monetary loan system was destroying the economy of the

whole world for years with wide spread suffering of whole populations and with subsequent political disasters.

Early February 2005 was a gathering under the leadership and moderation of Karina Kelly from the ABC-TV at the Australian Einstein Congress of Physics in Canberra, where with prize presentations by the Australian Governor General. A panel discussion with 6 prominent physicists was arranged for questions of the awardees from high schools. Two Nobel Prize winners, Dr. Helen Quinn, the Australia born President of the American Physical Society and others gave their views what will be the status of physics 100 years later. Indeed energy was one point including nuclear energy but also communication and biophysics problems were mentioned. One of the 16-year awardees asked what the experts could say which of the present developments may have the importance as e.g. 100 years ago the discovery of the electronic amplifier triode valve did have. Not one clear answer was heard. The worst was that nobody expressed the hope that physics should have contributed within 100 years from now to provide all necessary innovations, inventions and technological means that all individual crimes and conflicts will be eliminated then and all the human problems and conflicts will be solved in a civilized and legally best possible way at the highest possible individual freedom.

The Energy Problem

For the problem of the energy production without environmental destruction, the general awareness is rather developed that it is absolutely impossible to continue - or even to increase - with burning fossil fuels (coal and petrol) on the present level. Since the scientific revolution by Isaac Newton and its subsequent technological application with the steam engine by James Watt and the electromotor and -generator by Werner von Siemens, the well appreciated modern life in the developed countries was based on the use of the fossil fuels. And this has to be accepted with thanks. The only present limit is that we have to find alternatives in energy production since the present emission of carbon dioxide from burning coal and oil is about three to fife times higher than can be tolerated. There are numerous indications about this situation and several criticisms against the critics with reference of the rising or not rising of the sea level, reduction of glaziers or not, melting of Antarctic ice or not.

A convincing result is the very precise measurement of the thickness of the tree rings of the up to two thousand years old huon pines in Tasmania as carefully evaluated by American researchers [3]. For one thousand years the annual change was fully within the 21% limit up and down depending on the cycle of solar irradiation where warmer years caused thicker tree rings against the thinner rings at less solar activity with its 10.4 years period as known for at least one million years. A deviation was measured only since 1950 until 1994 where an increase of the rings towards warmer climate with more assimilation of the now available higher carbon dioxide level, was showing an increase up to 41%! This very simply shows that any carbon dioxide emission until 1950 was rather tolerated but that the more than 3.5 higher emission since is beyond the limits. This is the reason that the environmentalists request a reduction of the carbon dioxide emission at least down to the level of 1950 worldwide.

It has to be mentioned that a serious step against natural balance during the last two hundred years is the large amount of black coal and of the petrol used, superimposed well by other disasters like the rather criminal logging of tropic forests in Brazil or in Indonesia and other areas without observing a systematic re-forestation as it is mandatory use since hundreds of years in Europe. The natural way of climatic changes during the last million years with ice ages and warm periods in between obviously was the excessive growth of forests in the warm periods taking out the carbon dioxide from the atmosphere with a reduction of the greenhouse warming, leading to cooling, reduced vegetation and growing of ice until the ice covered former forests. This degraded to brown coal and then methane and other gases were released which again produced greenhouse warming,, melting ice and growing of new forests. This cycle definitely was influenced since 200 years by adding the burnt carbon from black coal and oil which was in huge amounts buried permanently 500 and more million years ago. 500 million years ago with all this carbon dioxide in the air, the earth atmosphere was extremely hostile and most of the animal life could develop in water only before the carbon deposits were built. It is

remarkable that now the manmade disturbance by harvesting and burning black coal and petrol is not strongly included in the numerous environmental considerations with even more serious results than usually assumed.

Energy without climatic catastrophe

The wealth of modern life is based on the generation of energy from coal and oil where at present per year about 20 billion tons of carbon dioxide, 3.5 time more than 50 years ago are added to the atmosphere and the increase from industrial expansion in the developing countries may hardly be compensated by reductions in developed countries. Alternatives from solar energy, wind power, water power and similar are growing very profitably, but their costs are far too high and the net capacities are too low for the large scale energy generation to reach a serious compensation against the energy production from fossil fuels.

The 1972 oil crisis led to the decision in France to base electrical power generation on nuclear fission reactors. Their safe and low cost energy generation today covers 80%, showing that in this sector the reduction of carbon dioxide emission has reached the level below that of 1950 in France. The contrary happened in Germany. It was known that between Cologne and Aachen there was a large deposit of brown coal, however buried below nearly 50 meters of soil. Under usual economic conditions the mining of this brown coal would never have been economic, only under the desperate pressure of the energy crisis 1972, the very expensive project was pushed through permanently costing the German tax payer billions of dollars of coal subsidy; but on top it produces enormous pollution of the atmosphere for which later the compensation payments for carbon dioxide emission will cost additional sums.

The French example of nuclear power generation is indeed very impressive, the whole cycle from uranium using modest enrichment for the standard light water reactors is under rather save operation and the waste handling seems well to be under control. The new design of reactors by Framatom, a French cooperation with the German Siemens experts looks very positive. New reactor designs as that of Siemens large research reactor Garching II realizes a new type of safety working undercritcial and adding the final amount of neutrons form a Californium 252 isotope. Even the next better solution for this by using a cylindrical fusion neutron source IEC with quick electric switching is at hand. The normal reactor buildings have such a strong dome that a jumbo-jet will not break it and a catastrophe due to the bad building as in Chernobyl is impossible. This case and that of the three miles island melt-down (with not one single human loss) was due to irresponsible shut-down of the otherwise very sophisticated control systems. Whole Lithuania is getting electricity from Chernobyl type reactors but the Russian operators are now very carefully watching the control systems.

But is this all we can expect from nuclear fission power stations? Putting the unqualified critics on nuclear energy by militant greens aside, the light water reactors cannot substitute the present days need for electricity generation. Alone China considered 700 nuclear power stations. For the whole world the light water reactors could produce electricity only for estimated 10 years, then the needed uranium would be exhausted. The alternative of breeder reactors for about hundred times longer operation are not without safety problems as was underlined 1972 by Edward Teller who was an expert with nuclear reactor technology from the very beginning. What is missing is that only very little was done to develop and consider very advanced new reactor concepts. The only excuse may be that the anti-nuclear media conformism has poisoned any necessary movement into this direction.

Edward Teller said 1993 in a lecture [2, p.51] “in France, I do not know why…the French have a really unjustifiable advantage over everyone: they are logical! And that logic tells them that the nuclear way is the way to go…”. Only as one example, Teller envisions an advanced type of nuclear power station using breeding to have the scheme for long duration, avoiding any environmental damage in case of a failure and fully excluding any problem of nuclear waste handling nor any danger of misuse for nuclear weapons preparations.

The first point is to eliminate any human error. This requires eliminating humans from the reactor cycle, e.g. to built the reactor 200 meters below ground in very solid rock. Even if there would be a disastrous explosion, this would not influence life on earth as known from underground tests. The design needs an automatic control with a gaseous

coolant and a reactor using an inherently large negative temperature coefficient. This has been established such that when the temperature would rise that the reactivity goes down. “Then with a strong negative temperature coefficient, the power goes down. This tends to shut down the reactor, thus providing power control on demand. The key to this approach is that a strong negative temperature coefficient must exist, but that can be designed into the reactor core if the importance of this goal is realized. The next point about this reactor I envision is: I don’t want to change the fuel during the plant life-time – elimination of refuelling would be the second key design goal”. For a thirty years run, the first ten years could use existing technology but the thirty years requires a new fuel-rod metallurgy which should be possible. The advantage is that lengthy shut shutdown times and exact safety procedures with refuelling are eliminated and no costs for operators are needed. If more electricity is requested, the coolant temperature has to decrease and the reactor will respond without manipulating control-rod positions. Reduction of reactivity by fission products built-up can be overcome by using burnable poisons. In addition to the uranium/plutonium fuel, thorium can be used for breeding U233 . This is an answer to the question that the reactor begins with plenty of fuel and put in a breeding-like thorium component. This thorium balances the reactivity as the burn-up proceeds.

At the end of the reactor the coolant could be switched off and the reactor will melt down in a desired and controlled way into the rock. Putting metal into the fuel, this will absorb enough energy to melt and mix with the fuel and fission products upon shutdown. The meltdown will be stopped in a volume like a million cubic meters (100 meters to the cube) which is the region for absorbing the heat of the meltdown. The fission products are captured in a metallic, very radioactive substance. Any mining of this would be very difficult and would become obvious to the world.

The advantages with this uncomplicated arrangement avoiding refuelling, reprocessing or terminal radioactive waste management are evident. The reactors could be located in areas of high populations, especially in the Third World having reactors safe and untouchable. No nuclear weapons could be produced from this energy production.

Some costs as mentioned may be higher than in the existing reactors, but the overall costs may be so strongly reduced by eliminating operational and handling costs that it may not be impossible to produce energy below the present days lowest costs of energy generation from nuclear power station. Teller was cautious with any prediction for lowering the costs, but it may be estimated for the very large scale of reactor series that the cost of electricity may well at least become a little bit lower than the present day’s lowest costs.

Is the Ultimate Goal of Fusion Energy by Lasers Near?

The just mentioned vision about the fission reactors is still more realistic than what may be mentioned now as a further possible alternative in the future. This is the fusion energy. Since 1934 it is known from an experiment by Oliphant, Harteck and Lord Rutherford that the nuclear reaction of heavy hydrogen is a real exception compared with all the usual nuclear reactions. The usual ones occur only if the nuclei are smashed against each other after acceleration by electric fields of more than million volts. As a real contrast to this, the light nuclei as the isotopes of hydrogen up to nuclei of boron need only hundred thousand volts or even only less than ten thousand volts to react. This permits them to react at temperatures of few ten million degrees only as shown in the sun and in most of all the myriads of stars. This also was reproduced on earth with the H-bomb as an uncontrolled explosion.

Even before the nuclear fission - the splitting of heavy nuclei under enormous energy release - was discovered by Otto Hahn end of 1938, Oliphant was trying to study how the energy from the fusion – to combine light nuclei - could be used for energy production. This research has absorbed enormous funds since it was most attractive to find an energy source like the sun for a controlled process in power stations. Most of the funds were invested to confine the nuclear fuel at the necessary temperature of several ten million degrees by magnetic fields. It took much longer time than expected to overcome many of the problems involved but even the most optimistic experts share the view that it will not be before 2050 to know whether the concept to use magnetic

fields for confining the fuel as high temperature plasma may be an economic solution.

An alternative impact for hope for the fusion reactor came with the advent of the laser. It was evident that the possible extreme high concentration of energy within very small volumes during a very short time should provide a new tool to for solving the problem. At the moment, lasers have an intensity which is 10^{23} times higher than the sun light at the earth surface. Laser powers of 2 Petawatts have been produced for pulses of a picoseconds (one millionth of a millionth of a second) duration. One Petawatt (thousand million times million watts) is thousand times higher power than all power stations of the USA are producing. Two Petawatt is the power of 6 billion motor cars, for all living persons one car of the Mercedes S-class, however only for the mentioned picoseconds duration [4].

What the laser introduced is a completely new dimension of physics, the nonlinear physics. It is not possible that all what one can dream can be realized, but in the future of the next thousands of years, nonlinear physics will be able to systematically derive effects which could not be suggested by the wildest dream and which will change the world and the life style in any economic, social and political way. This is the reason how the linear physics thinking on which magnetic confinement fusion was based and on which any beam fusion appeared impossible, became wrong and obsolete.

Indeed with the first lasers after 1960, not much could be gained for fusion energy. The new nonlinear phenomena appeared and had to be explored and solved step by step taking a much longer development than expected. Nevertheless after the first fusion reactions were detected by laser irradiation of targets in 1968/69 their number per laser shot was increased by more than ten billions nearly reaching break-even in energy production. After one had to learn so much new physics, laser systems costing few billion dollars are now being built with the aim to prove the ignition of nuclear fuel (heavy hydrogen deuterium D and super-heavy hydrogen tritium T) with very sophisticated laser pulses of the classical duration of about 1000 picoseconds. It has been proved [2, p. 6] that these classical techniques using fuel compression to few thousand times the solid state density and using laser pulses of few Megajoule energy by applying the safe volume ignition produce energy gains just sufficient for a power station. However for practical means these big laser systems will have to be reduced in size and costs enormously for which the physics will provide all possibilities similar to the transistor when it was reduced from its initial size to the microscopic nano-size we have now on computer chips. This at least is possible in principle as solution for a laser fusion power station.

The mentioned Petawatt-picosecond laser pulses, however, may lead to a much easier solution. When the big lasers in Osaka were showing 1991 how carbon polymers could be compressed to 2000 times the solid state density, the result was that the maximum temperature of about 3 Million degrees was much lower than expected. This was very disappointing for reaching a fusion reactor. The result indeed could be used to conclude the just mentioned volume ignition with the very big laser pulses of 1000 picosecond duration. But a much more ingenious solution was introduced by Mike Campbell with the fast ignitor. He knew about the Petawatt-picosecond laser pulses and concluded that after the fuel compression to a few thousand times solid state, the missing temperature should be provided by adding a Petawatt-picosecoond pulse.

The technology of these laser pulses was ingeniously solved but when interacting with a target, all kinds of unexpected relativistic effects were observed, including pair production, nuclear transmutations, very energetic electron and ion beams etc. but just not the initial aim of additional heating for the fusion reaction in the right place. This scenario was changed by a discovery in 2002 [2, p. 14] how to avoid the relativistic effects and how to produce ideal plane [5], fast, and low temperature plasma layers by the nonlinear force based on a skin layer acceleration. The trick is that preheating by the laser has to be suppressed by a very high factor (contrast ratio). This led then to the experimental confirmation that plasma blocks with ion current densities of 100 billion Amperes per square centimeter were produced and the energy flux densities of up to 100 Megajoule per square centimeter are close to be reached. These enormously extreme conditions are known since 30 years how to ignite uncompressed solid DT fuel where e.g. a 10 kilojoule-picosecond laser pulse may produce 10000 times more fusion energy in a

controlled way, but these conditions seemed then to be completely utopian. Now, the Petawatt-picosecond laser pulses with the skin-layer plasma block generation fulfil these conditions with the very high fusion gains by simply using solid state DT fuel without the complicate pre-compression.

A confirmation of this path to a very simply working laser fusion power station was given by one of the very first pioneers of laser fusion, John Nuckolls [6], when he found that under similar conditions very intense electron beams can ignite large amounts of DT fuel with little more than solid state density. Based on his very detailed experience in this field it may be expected subsequently from the just mentioned skin layer mechanism [5] as explained also in the introduction of the Edward Teller lectures ([2] p. 14), that this type of laser fusion power station may produce energy fife times less expensive than any other energy source known on earth.

The golden age

Based on the last statement for lowest cost energy production – though not fully proved in all details – this is at least at a stage that it is possible without fiction to discuss consequences for technology, politics and social changes by such an option. One may imagine only that then any amount of water can be distilled from the oceans to make deserts green. Production of aluminium and similar metals is of very low cost as well as chemical production of polymers from petrol in such quantities that architects and town planners can develop unprecedented designs. For the individual mobility, the modern hybrid cars will be changed into purely electrical energy operation with or without fuel cells, where the basic energy comes from the low cost clean and safe laser fusion power stations with unlimited fuel. Tropical forest would not need to give space for growing grain which can be harvested from the greened deserts and any amount of water could be taken from oceans avoiding regional conflicts about water supply. The only limit is that the total energy production on the earth must not exceed about 50 times of today.

[1]www.spiegel.de./panorama/0,1518,351854,00.html.
[2] Edward Teller Lectures: Lasers and Inertial Fusion Energy, H. Hora and G.H. Miley eds. Imperial College Press, London 2005, ISBN 1-86094-468-X
[3] H. Hora, Innovation, Technologie und Ökonomie, S. Roderer Verlag, Regensburg 2000, p. 163, Fig. 24
[4] Spiegel No. 13/2004, p. 124
[5] R. Sauerbrey (1996), see H. Hora, Laser and Particle Beams 22, 439 (2004)
[6] J. Nuckolls et al., Future of Inertial Fusion Energy, Preprint Lawrence Livermore National Laboratory, UCRL-JC-149860 (September 4, 2002), ICNES2002 Conference Proceedings Sandia National Lab. T.A. Mehlhorn ed., p. 171