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On the Future of Fission and Solar Energy

SUMMARY

Our attitudes towards the risks of climate change must be reconsidered. We must recognise that the consequences will be huge and inevitable if we do not act now. Better to accept a few false alarms rather than be unprepared for a climate catastrophe. An outstanding example is the calculation by groups from Germany and the UK in 2009 (1) of the allowable emissions of CO_2 before a 2°C increase in global temperature is exceeded. This leaves very little time, only 4 to 8 years, for mitigation measures.

Nuclear fission now presents a formidable fleet of some 450 reactors benefitting from over 50 years of operational experience. Throughout decades of development, they reached outstanding safety standards, exceeding those of most renewable sources. However, the threat of climate change is calling this perspective into question as nuclear technology requires long-term stability of institutions. The future of nuclear fission will be determined after the expiration of the next decade with the development of hydro, solar and wind energy as replacements. For Croatia, in view of future climate insecurity, we cannot recommend the construction of a nuclear power plant built to operate from 2043 to 2083 (2) as a replacement for the outgoing NE Krško plant. Instead, we should intensify the development of our renewable resources.

EARLY YEARS OF NUCLEAR ENERGY, START IN WAR TIMES

The effect of the discovery of nuclear fission in 1939, just before World War II, was of tremendous historic importance. It made possible a release of large amounts of energy from a miniscule amount of fuel. Soon, under the threats of war, nuclear scientists produced the first atomic weapon, which ended the second world war in 1945 (3). Nuclear science attained scientific prestige and influence. No doubt that the promise of a new energy source stimulated far-reaching research into its peaceful use. Fission energy benefitted from lavish investments and annual support during its early years when nuclear programs were a matter of national prestige, and, after 1949, regrettably, of military importance (4.). Looking back over the last 50 years, we can see that initially nuclear development was broadly based. Many types of reactor were tried, but over the years that wide selection was narrowed down, leaving us with only a small number of reactor types that satisfy nuclear safety, technical and economic criteria. Dominant now are PWR (Pressurized Water Reactor) reactors. That long period of development produced extremely safe PWR reactors, capable of operating for decades. Indeed, after a working life of forty years, many even obtained life extensions. These reactors, initiated by a group of outstanding scientists and developed over more than 50 years, represent an invaluable and unrepeatable accumulation of financial resources, worldwide scientific and technical knowledge and experience.

NUCLEAR ENERGY IN FORMER YUGOSLAVIA

The Yugoslav nuclear program was initiated with the building of five nuclear institutes from 1947 to 1950. Details can be found in the 2015 HAZU publication (5). In its early years, the program was mainly dictated by political motives - fear of the Soviet Union. Indeed, from 1948 until Stalin's death in 1953, some politicians, fearing Soviet Union aggression against Yugoslavia, pretended to be working on nuclear weapons. However, later developments had a strong influence on Yugoslavia's nuclear program. A large hydroelectric plant was under construction at Đerdap in Serbia. Serbian ambition thus satisfied, the time was ripe with the completion of Đerdap I scheduled for 1971 (1081 MW for Serbia) and the abandonment of nuclear ambitions in FCNE (Federal Commission for Nuclear Energy), for the initiation of a program to build a nuclear power station in the west of Yugoslavia, where, it was argued that the region lacked coal deposits. The decision in 1970 by the two western republics of Slovenia and Croatia to embark jointly on construction (7) of a nuclear reactor, using foreign investment, was based on sound economic arguments. At that time a second joint Croatian-Slovenian nuclear power plant was prepared for construction in Croatia. Following the break with the Soviet Union, the non-alignment policy had become the main driving force behind Yugoslav external political activity. Work on nuclear weapons was incompatible with Tito›s leading position in the non-alignment movement. When, in 1974, Tito laid the foundation stone on the site of the future nuclear power station to be built under IAEA supervision and approval, he was sending a clear political message. Moreover, the location of the power plant at Krško, in Slovenia, provided the American- Yugoslav project with additional international security, as was proven by NP Krško operating without interruption throughout the 1990-95 war, when reliable production of electricity was essential (8). The reactor for Slovenia and Croatia, of the Pressurized Water Reactor (PWR) type, was built by American industry with Westinghouse as the main contractor. It started commercial production in 1983. The Krško plant proved to be one of the best.

OUR WORK ON NPP KRŠKO

I am presenting my personal view here, as I consider it to be relevant to the future of fission energy and solar energy. I was the founder member of the Croatian nuclear society in 1992, having been active in nuclear physics and nuclear energy from the late fifties to the present day. My memories range from meetings of the Federal Nuclear Commission (Savezna komisija za nuklearnu energiju) to recent days when the main topic has become global warming and climate change. With the construction of the first joint nuclear power station at Krško in Slovenia, Croatian and Slovenian scienti-

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sts, engineers and technicians gained invaluable experience in top science and technology from leading experts in nuclear technology. Many attained the highest level of knowledge in nuclear science. We are all proud of our contributions to nuclear technology and we are grateful for the technical help we received over more than half a century.

A COMMENT ON THE SAFETY OF PWR REACTORS

With about 450 reactors now in operation, the last major nuclear accident was at the US

Three Mile Island power station in 1979 (9), on a PWR reactor with a containment building to stop radiation escaping into the surroundings. Even at an early stage of development, prior to the many improvements made in later years, containment buildings proved to be very effective. Nuclear fission is, according to most surveys, amongst the safest sources of production of large amounts of energy, as was recently admitted even by the usually very critical Union of Concerned Scientists (10). The accident at Chernobyl in 1986 in the former Soviet Union took place with an entirely different type of reactor, without containment, that would never have received an operating license in the West (11). The last nuclear accident happened at Fukushima, Japan, initiated by the devastating earthquake in 2011 (12), causing loss of human life in the tens of thousands, but none that could be ascribed to the effects of radiation (13).

WORK ON GLOBAL WARMING BY THE ZAGREB GROUP

I remember ironic smiles at my mention of global warming, sometime in the early nineties, when the problem with fossil energy was being discussed and the argument for nuclear energy was formulated. I was an early bird, with a chapter on global warming in my book on nuclear energy, published in 1993 (14), introducing the main concepts. After a pause of a few years (1994-2005) devoted to the problems of demining, investigating nuclear methods of mine detection, I returned to energy problems. Ten years on, global warming was recognized as the most dangerous long-term environmental threat. Our own research on the topic began in about 2007. First, working with scientists from the University of Zagreb and the Academy of Sciences, we showed, for the first time, that nuclear fission had the potential on a worldwide scale to effectively contribute towards the mitigation of global warming by replacement of fossil fuels (15). This was confirmed by published research in the years 2010-2019 (16,17,18,19). These publications were important as they demonstrated the possibility of using fission energy to combat global warming at an earlier phase, before solar energy could make a significant contribution. The technical reason for delay was that efficiency of solar photovoltaic energy required time to reach economically interesting values for large-scale electricity production. Some twenty years ago, solar energy was not capable of large energy production, but we witnessed fast progress during the twenties, when the production of wind and solar energy, as predicted by world surveys (21) and (22), overtook nuclear.

In the present dangerous climate of uncertainty, it is time to rethink the future of fission energy. For Croatia, it is a question of whether or not to rely on nuclear energy after the year 2043 (on the assumption that Croatia will be sharing 50% of Krško's power production) when the existing agreements between the two owners expire. NP Krško should be closed no later than 2043, by which time we will already be deep into the climate change years. In my opinion, it would not be wise to build a nuclear power plant that would operate from about 2043 to 2083 or longer. We must be sure to be able to fulfil all our obligations as owners of the nuclear plant, including decommission and taking care of spent fuel. Our commitments would extend into the next century. That is not a good idea in the unpredictable times we are facing. Owing to the present lack of adequate carbon-free energy sources, other than hydroelectricity, we are currently in a position of being dependent on fission as our main source of carbon-free energy. But the wisdom of using nuclear fission energy, despite its successful development, is debatable. The main problem is the long-term safety of radioactive nuclear materials. If their security cannot be ensured long-term in the wild weather conditions we expect to prevail after about 2053, with all the ensuing repercussions, then the long-term future of fission is dubious. There are examples of safe storage of spent fuel by Finland and Sweden (23) but the question is the unit costs of low capacity storage is open. We must be sure that highly radioactive materials can be safely stored for a long time. But we cannot even be sure that in 50 years' time organizations to ensure the long-term safety of radioactive waste will exist. Surveys and controls will be needed for many decades, even centuries. Should this be impossible to guarantee under future climatic and social conditions, then we have to think very seriously about the wisdom of continuing with fission energy in our country after 2043. This opinion should be independent of European attitudes to nuclear energy, as many political considerations and obligations are to be respected. However, as nuclear fission problems can be expected to emerge from countries outside the Non Proliferation Treaty regime, we are not optimistic.

LATE INVESTMENT IN RENEWABLE ENERGY

While it is true that nuclear energy was privileged in its early years, it also true that photovoltaics were slow to develop. Initial investments in solar and wind energy were much smaller. Production of solar and wind energy is now modest relative to nuclear energy. However, solar energy plans are much more ambitious for the future, as presented in IRENA (20) and in IEA reports (21), (22). Present annual production of solar and wind energy is nominally at some 750 GW in average power, but in reality about 11 %, of that. Figures for wind power with average annual value of 550 GW are similar, except for higher efficiency (about 20%). There is a fleet of about 450 nuclear power reactors now in operation. They produce about 10% of the world's electric energy. This is currently about 285 GW of average power on the annual level. About 1600 further nuclear power stations of about 1000 GW would be needed to replace all coal power stations (24). Future decisions on fission energy on a world-wide scale will require very careful consideration (25). At the moment, important discussions are in progress. The European Union has asked the TEG (Technical Expert Group) of the EU to assess the nuclear contribution to the mitigation of global warming. The TEG mandated the European Joint Research Council to prepare the study. Over the coming months, JRC will prepare to give a technical assessment of the question "whether corresponding economic activity qualifies as contributing substantially to climate mitigation or climate adaptation". The result will influence the financing of European nuclear projects.

Whatever the results of the JRC may be, they cannot ignore the drive and inertia of large nuclear industries and projects, as shown by ITER project. Croatia is not a country for a large nuclear projects, however, Croatia is well positioned for solar and wind energy and possess good backing of hydro energy. With nuclear energy available up to 2043, it can use the years up to 2043 to expand its solar and wind potentials, to cover the end of nuclear contribution by 2043.

THE FUTURE OF NUCLEAR FISSION VERSUS PHOTOVOLTAIC ENERGY

However, climate changes also force us to take a new look at the future of electricity production. We now have two outstandingly advanced technologies, nuclear and photovoltaic, capable of producing large amounts of carbon-free energy, but they have very different long-term prospects in these times of climate change. Nuclear energy requires an extensive supporting infrastructure, from nuclear legislation to the production of massive components such as pressure vessels and heat exchangers and to small but technically challenging fuel rods. Operational nuclear safety imposes many limitations on the reactor design. Highly radioactive spent fuel needs storage and supervision for decades and even centuries. Owing to high initial investment costs, nuclear power plants must have long lifetimes to be profitable. Nuclear power stations have controls and regulations, the cost of which does not vary with the size of the plant. This discourages the building of small plants and explains why a typical plant is of 1000 MW in electric power. Photovoltaic cell units, on the other hand, are small and can be multiplied without limitation. The unit cost is high, but steadily decreasing. The cell units are ubiquitous, offering countless uses, thus reducing the cost. However, the prime advantage of photovoltaic relative to nuclear energy is that it avoids dealing with radioactivity. The principal disadvantage is the low energy density of stored energy. There is no replacement for petrol in sight but there is scope for development, perhaps hydrogen if production becomes cheaper. Countries with a good proportion of hydro-electric power will be at an advantage. Croatia is in a relatively good position.

ON HISTORIC MISTAKES MADE WITH NUCLEAR FISSION IN THE PAST

Looking back over the history of nuclear fission energy we can register two mega blunders, which have compromised the benefits to human society of the discovery of nuclear fission. They are even more regrettable in these uncertain times of climate problems. The first monumental blunder was committed by the Soviet Union in its rejection of the generous Western offer to unilaterally ban nuclear weapons and to establish international authority (International Atomic Developments Authority) over the use and development of peaceful nuclear energy, presented as the “Baruch plan” to the UN by the US delegation in 1946 (26). This generous Western offer, backed by most of the top scientists of the time, including Robert Oppenheimer, was rejected by the Soviet Union which was working on its own nuclear weapon that exploded in 1949. The significance of this wrong turn cannot be overestimated. It was the most fateful one in centuries. The history of the arms race is detailed in a book by Nobel prize winner Noel-Baker (27). As a result, a deadly dangerous arms race started and eventually developed by the eighties into ludicrous “overkill” stock-piling of nuclear arms. We were lucky to escape annihilation when targeted by over 50 000 nuclear weapons, most of them stronger than those thrown on Hiroshima and Nagasaki. The second blunder, with a similar negative effect, occurred later, at the end of the Cold War, in the nineties. With the disappearance of one side from the arms race following the breakdown of the Soviet Union, there was a good chance of removing and banning all nuclear weapons. But the USA were revelling in their unique position as the only nuclear superpower. As a result of their short-sighted, egoistic policy, shortly afterwards several new nuclear countries emerged. New, illegal nuclear weapons countries appeared in addition to the five acknowledged nuclear countries (USA, UK, France, Soviet Union and China). Political control over these newcomers (Israel, Pakistan, India and North Korea) is very problematic and can only become more so in the political anarchy that is expected to follow the climate crisis. How can this situation be regarded as a positive development? Thanks to these two fatal faults, the idea of stopping the proliferation of nuclear weapons was compromised beyond repair. The result is a dangerous negative effect on the future of fission energy. With four nuclear states rampaging out of control, we shall need a nuclear policeman to protect the rest of the world. And this (international) police force would need an overwhelming nuclear force. Not a nice prospect! Let us hope for better solutions.

ON SOME LONG-TERM PREDICTIONS AFTER 2040.

But for the short-sighted USA policy at the end of the era of confrontation between the two blocks, the chances of nuclear disarmament would have been real. Being an old Pugwash member (28), for me this was a colossal blunder on top of which we now have the problem of global warming. This is the reason why we should be suspicious of any long-term predictions for our future. We can predict floods in the regions of the Mekong and Bangladesh deltas, because they have already started. Draughts in North Africa are spreading, climate change is already here. Surprising positive feedback processes are starting. However, predictions for 2050 can only be extrapolations from what is already happening, plus a pinch of imagination. The pictures of the future by Tong et al. (29) or from Millar et al. (30) are wishful thinking at best. In our present world situation it is impossible to predict main world events for more then 15-20 years ahead. There will be many repercussions when the temperature increase exceeds 3°C. We are on the cusp of disaster. Melting of permafrost is expected and will release methane, a very active greenhouse gas. Without the use of force, the authorities will not be able to stop mass movements of millions of migrants coming from areas made uninhabitable by climate changes. That means mass murders and would spell the end of democracy. Those millions would not even know that we, the rich people of Europe and the US, the initial cause of their sufferings, are to blame. This is the basic reason why we cannot predict the future with any certainty, certainly not after the years 2030-2035. As consolation, may I recall the definition of an optimist by a great physicist, Rudolf Peirls, at that time in Birmingham: “An optimist is a person who believes that the future is uncertain”. We must be prepared for climate emergencies, sooner rather than later.

A WARNING FROM A GROUP OF OXFORD AND POTSDAM SCIENTISTS

A group of serious scientists has issued a warning. On reading the paper by the Potsdam and Oxford groups, published in Nature in 2009 (1), it became clear to me, should their results be correct, that there is much less time to stop global warming than was previously thought. We respect this serious and well-argued work, but we do not know how crossing the limit will manifest itself, or where. That would require more knowledge of meteorology. The Mekong delta, Bangladesh, Florida, the Arctic region, the Antarctic ice sheet? According to their calculations, up to the year 2000 we would emit 1000 Gt of CO_2 before breaching the commitment of not exceeding an increase of 2°C in global temperature. But by now we have already spent a considerable part of this “emission capital” - around 770 Gt - so we have only 230 Gt left to keep emissions below the 2°C rise in global temperature. Now, in 2021, we have about four years left before we cross over into the region where the temperature increase will exceed 2°C. Our annual carbon dioxide emissions at present from all sources amount to about 43-45 Gt. Ironically, there has been a slight decrease due to a reduction in carbon use as a consequence of the Corona virus pandemic having slowed down the world economy!

FALSE HOPES IN NUCLEAR FUSION AND CARBON CAPTURE AND STORAGE (CCS)

Unfortunately, we cannot expect to be saved by fusion energy in the earliest climate emergencies. According to the 2018 report by the Director General of ITER (31), laser installation could be completed by 2035. This refers only to the experimental ITER device and does not take into account that at least 10 to 15 more years will be required to complete and test the following DEMO (32) installation and to use it as a thermonuclear power plant. The basic laws of physics dictate that future fusion devices would have to be of a similar size to ITER. Creating the outer wall of a fusion chamber remains an outstanding and unsolved problem. To build a fleet of plants capable of having an impact on carbon emissions would demand advanced technology and thus could not engage a large circle of countries. Technical and material problems would be serious and could take us well into the sixties. As plans to use CCS are only at the stage of discussion about technologies, whilst there is no-one with any serious idea of how to store at least several Gt of CO_2 ,some thousand times more than current annual storage would need. So, we cannot expect a serious contribution from CCS. Paper by Biello is a serious evaluation, independent of the short-term interests of the coal industry (33). Meanwhile, there is bluster from the coal industry and so-called scientists working on impossible projects paid by coal business.

Faced with such serious warnings about what could happen in the next ten years, we would be foolish to ignore them. We must be prepared for the likely future. Should it give us a miss, we will be grateful, but we must not count on it. As stated previously, we have grave misgivings about investing all our efforts to stop global warming in CCS and nuclear fusion, both likely to fail, whilst neglecting more imminent dangers. On the basis of the prediction by Meinshausen et al, (1), we should be prepared for much earlier emergencies. Unlikely success with fusion will come too late, in the sixties. In the meantime, we must develop solar energy to the point where it can first replace electricity production from coal and gas, and thereafter when it could also replace power from nuclear fission.

IN CONCLUSION

My life was in fission energy, as can be seen from most of my earlier work, but the future of humanity lies in solar energy. Use it, curtail wastage and abuse, and it should provide enough energy for everybody, without entailing unpredictable and dangerous geo-engineering experiments.

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[3.] World war II ended with capitulation of Japan following two atomic bombs thrown on Hiroshima and Nagasaki on 6. and 9. August 1945

[4.] Soviet Union explodes its first atomic device in 1949. I can be taken as start of nuclear arms race. The exgsictence of many thousends of atomic bomb ever since present a permanent possibilty of destroying all life on the planet. There are reports many case of close escapes and there are some irresponsible nuclear weapon countries.

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[6.] Death of Stalin in 1953 marks a reversal point of confrontation with countries of Eaistern block

[7.] Decision to build the first nuclear power plant was reached by Yugoslav Eletricity Industry (Jugoslovenska elektoprivreda), a top joint authority of federal adminstration

[8.] An uninterupted electicity supply from nuclear power Krško was very important in the early war days of Serbian agresion on Croatia

[9.] Most serious accident on PWR plant occured on the reactor from the Three Mile Island in 1979. Pressure vessel suffered heavy damage from partly molten reactor core but only very small part of radioactivity ascaped beyond the border of power station. In years later many improvement on contaiment have additionaly increased safety.

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