Vol. 50, No. 3 July 2021

PHYSICS & SOCIETY

A Publication of The Forum on Physics and Society A Forum of The American Physical Society

From the Editor

It is really nice that things are getting back to normal in many countries. This is undoubtedly thanks to the unexpectedly fast discovery and implementation of effective vaccines. Unfortunately, some irrational fears of 'side effects' remain. It is puzzling to me that some people worry more about the "side effects" of the vaccine than about the "front and center" effects of not taking it.

Elements of the bureacracy remain of course in the "I am scared", "abundance of caution" mode. This is unavoidable, given the low level of principles and of personal courage of the people that staff the bloated bureaucracies at governments and universities.

In this issue I continue implementing the policy of publishing articles written by recent winners of Forum awards and by other invited speakers at APS meeting forum-sponsored sessions. Micah Lowentahl's article on ethics and science policy and Steve Fetter's (2021 Szilard award wnner) delayed article on the technological challenges for our future are in this category. We also have an article on the economics of fusion power and our usual complement of book reviews.

Oriol T. Valls, the current P&S newsletter editor, is a Condensed Matter theorist.

But the newsletter is nearly entirely dependent on readers' contributions. Articles and suggestions for articles should be sent to me, and also letters to the editor. Book reviews should be sent to the reviews editor directly (ahobson@uark.edu). All topics related to Physics and Society, broadly understood, are welcome. Controversy is fine: **content is not peer reviewed and opinions given are the author's only, not necessarily mine, nor the Forum's or, a fortiori, not the APS's either.**

Oriol T. Valls
University of Minnesota
otvalls@umn.edu

IN THIS ISSUE

EDITOR'S COMMENTS

ARTICLES

REVIEWS

Ethics in Policy Advice: Risk Assessment, Nuclear Energy, and Nuclear Weapons

Micah Lowenthal mlowenth@nas.edu

This paper is from a session at the APS April meeting honoring John Ahearne, a physicist, policy maker, and policy advisor. John worked for the Air Force, the Department of Defense, and the Department of Energy, and he served on and then chaired the Nuclear Regulatory Commission. After his government service, he focused on policy advice. John had an extraordinary combination of intellect, judgment, leadership skills, and ethical underpinnings that led him to devote an almost unfathomable amount of time to volunteer advisory activities through the National Academies of Sciences, Engineering, and Medicine, Sigma Xi, the American Academy of Arts and Sciences, the American Association for the Advancement of Science, the UC Office of the President, Duke University, and other organizations. He also mentored a generation of early- and mid-career scientists working on policy advice. He did this work out of a sense of civic responsibility, and because he enjoyed it. When some of us were sitting around marveling at how busy he was with these activities, one colleague asked John what he does for fun. John answered "Physics is fun." I had the good fortune to work with John on several activities and in multiple countries, all with the aim to provide the best advice we could.

Ethics in policy advising is about integrity, and I will use the Academies as an example, although they insist that I note that the opinions expressed here are mine and do not necessarily represent positions of the Academies.

At the Academies, we conduct our work as what I call a high-integrity organization. The defining feature of a high-integrity organization is that the more you know about the organization's processes, decisions, and actions, the more confidence you have in that work and the organization. Although John never articulated his approach to policy advice this way, he lived it and led by example.

This paper addresses ethics in policy advice, particularly regarding risk assessment, nuclear energy, and national weapons. I begin by articulating some general principles of policy advice and then proceed to examine a few ways in which those principles manifest in these three topic areas. In particular, I discuss how biases can affect our advice, and how context factors into what may seem like a narrow question.

So, ten principles

1. *Biases exist, so they must be aired and balanced, and conflicts of interest must be managed or removed.* Everyone has biases. They needn't be disqualifying, but people giving science advice need to make those biases explicit so that they're known and, if possible, balanced. Bias becomes a problem if there's no way to overcome it. To give honest advice, one has to be susceptible to evidence—if contrary evidence doesn't make an advisor question their position, then they aren't fit to advise. Conflicts of interest need to be managed to protect the integrity of the process and to maintain confidence in the advice.
2. *Question the question.* The question itself may be structured to bias the result. It may contain implicit assumptions, such as that action must be taken, that inaction is the default option, or that one problem is more important than another. It may reflect a particular perspective or priority. Generally, the question should inform the decision and consider all of the options, and important benefits, consequences, and uncertainties.
3. *Insist on evidence.* We may think we know the answer, but evidence can be uncooperative. We should seek evidence on all relevant aspects of the question and, of course, must subject that evidence to careful scrutiny.
4. *Analyze the analysis.* Much of the work of science policy advice is reviewing decisions or analyses that support decisions. Some analyses contain unsound reasoning, invalid or narrowly applicable assumptions, erroneous methods, or questionable evidence. We can't assume that the analysts are right. We also can't assume that they're wrong.
5. *Direct the advice at the need.* If the question is technically narrow then the advice can be similarly narrow and focused. But a policy maker might need a broader examination to include the larger system and consideration of policy options and their potential.
6. *State findings accurately but clearly.* We scientists have a tendency to phrase our findings in the same way that we would state the results of research in a journal, with complex language only understood by colleagues in our own subfield. In the policy domain, we sometimes try to build in all of our qualifications, assumptions, and caveats to avoid criticism that the finding is not 100% accurate. Advice communicated poorly is advice not given. It is generally possible to be both accurate and clear, even if it requires us to relegate some qualifications and assumptions to an appendix. Now there's definitely a lot of error on the other side, too: findings that overgeneralize or overstep. We have to be careful of both.
7. *Be constructive.* Policymaking is difficult and criti-

cism is easy. Our objective is good decisions, so we should try to help rather than just tear down. This also means that we should point out what is working in addition to what is not.

8. *Make recommendations when you can; explain why when you can't.* Recommendations might not be recommendations on the decision; that might require value judgments that advisors are not empowered to make, and overstepping can undermine the credibility of the analysis. Advisors can examine the implications of those different approaches. What do evidence and analysis tell you? Should steps be taken to better inform the decision, and if so then what are they? But when possible, recommendations are valuable: policymakers on the Hill and in the executive branch tell us this. Even conditional recommendations can help—if the government believes X then action Z should be taken. The honest, balanced use of evidence, the transparency, and all of the other principles listed here make the advice more than just advocacy.
9. *Subject advice to peer review.* This is essential to good work. Even the smartest people, the best scientists and groups of scientists, make unconscious implicit assumptions, use flawed data, make mistakes, and get stuck in group think. A hard scrub by peer reviewers is usually a net positive, although we all know of exceptions.
10. *Act in private as if every step would be seen by all.* I believe that there's enormous value in both transparency and private discussion and deliberation, especially in the current environment of scrutiny, distortion, and pillory. Consideration of controversial views is part of the job and needs to be protected, but we need integrity to pervade our work, regardless of how much transparency is applied, so we should act ethically throughout the process.

I will add one more point, which is that we can add real value if we remain open to the possibility of creative solutions that are outside of the defined option set. When we assemble smart, knowledgeable, creative people to examine issues in depth, they sometimes identify opportunities we didn't consider in framing the issue. Sometimes the best ideas come from smart people from outside the field, what a mentor of mine Kevin Crowley calls orthogonalists. Sometimes the idea requires that we drop a constraint to solve the problem at hand. Sometimes they come up with solutions to other related problems. These ideas can be valuable, even if not immediately.

ETHICS AND NUCLEAR ISSUES

Physicists have a special duty related to nuclear issues because our modern history has been intertwined with these issues, and even a physicist who has no direct interaction with work on nuclear topics has benefitted from the investments in physics that trace back to nuclear motivations. This does not, however, mean that we are somehow innately endowed with knowledge of these issues by our mastery of the Standard Model. Being a physicist means that you are smart (and probably confident in your intelligence), but it does not mean that you know what you are talking about. We have a duty to ask the naïve questions but also a duty to do the work to ensure that we do not give naïve answers. Furthermore, the issues are multidimensional, not just information and analysis. Anyone can make important contributions.

Risk assessment

There is abundant literature on risk analysis, risk assessment, risk acceptance, risk perception, and other ways of addressing nuclear issues. At the National Academies, studies that involve risk assessment have a separate set of guidelines. Many of those guidelines have echoes or substantively rhyme with the 10 principles that I cited at the beginning of this paper. Advisors on risk usually trip up in four ways: Going beyond the data and understanding; excluding misunderstood or inconvenient data; deferring to eminence over evidence; or not handling the problem of the unforeseen, including unforeseen but foreseeable interdependencies. The Great Tōhoku Earthquake, the tsunami, and consequent major nuclear accident that began on March 11, 2011 and unfolded over weeks that followed illustrated all of these. Several expert studies have examined those failures, so I won't recount them here, but I'll note that the Fukushima accident is not unique in illustrating those failures. Visiting the exclusion zone around the power plant, seeing the traces of communities scraped from the landscape by the tsunami and seeing the untouched rows of dwellings made ghost towns by the radioactive clouds and contamination, seeing those drives home how consequential the work of risk assessment can be.

Advisors on nuclear risk encounter a recurring set of epistemological and methodological questions. Are we looking at the right risks, or what are the values that dictate what to measure? Can the system be described quantitatively and are the risks better characterized qualitatively? Are the elements of the system independent or interdependent? Are the underlying assumptions about the system and its components valid? Have we considered the full set of conditions of the system and the environment in which it operates? Are human interactions with the system accounted for or factored in?

As an aside, I'll note that we sometimes find ourselves in reprises of discussions about scientism and the fallacy of objectivity. It may be strictly accurate to say that true objectivity is impossible in examining and analyzing social phenomena, but it is useful to try to be objective and it is only useful to point out its impossibility to remind ourselves that there are value-laden assumptions in what we choose to observe and measure, how we choose to describe those, and

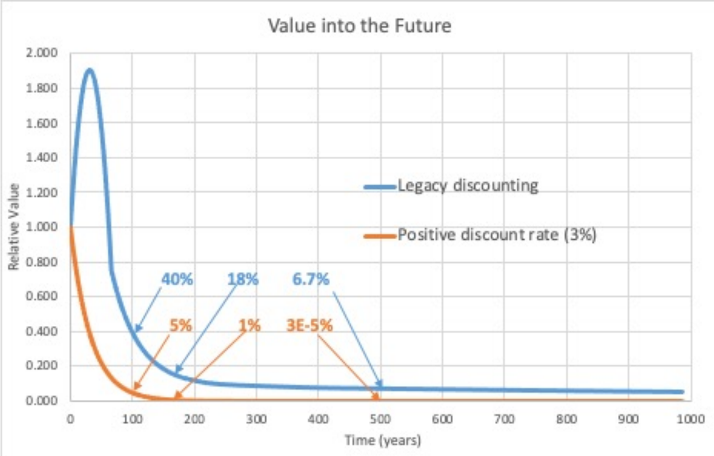

Figure 1: Illustration of relative value over time using a standard positive discount rate and a notional legacy discount rate.

how we interpret what we see. If we recognize these facts, we can expose implicit or hidden judgments that are embedded in our analyses and may have unrecognized implications.

We face a special problem in the 2020s. It is legitimate to have differences of perspective on how to interpret facts or their implications and what should be done about them, but not to purvey clearly false information as facts.

Nuclear Energy

Discussions about ethics and nuclear energy usually focus on safety, security, safeguards, economic, and environmental issues. I will say a few words about environmental issues and intergenerational equity, but first I want to address why we focus so much on nuclear energy. Many of us are drawn to nuclear energy by its enormous promise, by the promise of a technical fix. Nuclear reactors produce more energy per unit mass of fuel than any other source. Some of us work more tenaciously to realize that promise of nuclear energy because it should be a good, efficient solution, the problems with it are solvable, and people who oppose it are uninformed and irrational. Neither the assumption that reason will support nuclear energy nor the idea that technology can solve all of the problems is correct. They might be the right answers in some cases and not in others. Which means that there's a lot of hard work in advising on nuclear energy issues.

Physics education trains us that we draw a diagram, work some equations, draw conclusions about how the world works, and even make predictions. Speaking as someone trained in physics, I like the idea that we might be able to find universal solutions, that we develop a technology, an approach that works everywhere. Little in society and the environment works this way. Many of these challenges resemble ecology more than physics. Each ecosystem is different and we're lucky if we understand it well enough to describe it. Predictions about social systems, economic systems, environmental systems, and the energy systems that we deploy in them require substantial humility.

Of the many ethical issues associated with nuclear waste, I'll address one aspect of its longevity. For many years, critics of nuclear power emphasized the persistence of nuclear waste as a unique liability, and it has indeed been profoundly difficult to site and build nuclear waste repositories. It is valid to worry about the displacement of harms from those who benefit to those who don't, whether that means laying burdens on people in poorer areas or on future generations. But more important than the duration of the hazard is exposure. How should we compare discharges of toxins into the air and water or poorly disposed in the ground now and for the next 100 years versus exposures 10,000 or 100,000 years from now. Is the future less important than the present? The future is long, and we can neither weigh it equally nor totally discount it.

Economists generally apply discount rates to the future. Although they argue about what the value of that discount rate should be, they generally agree that we have to value future benefits less than the same benefits enjoyed today (a positive discount rate), often using 3 percent. I have written before that I think that this applies to monetizable benefits, but not to non-monetizable benefits, such as health and many aspects of the environment. My argument is that if we have to quantify those benefits in an economic analysis, we should value them based on what people value, and that a legacy effect would result in a negative discount rate. By this I mean that I am willing to sacrifice my present wellbeing to benefit my children's future; to the extent that these benefits are decoupled, I value their future more than my present, which is a negative discount rate. There may be an individual limit to this: Is there a difference in how you value your descendants' benefits 1,000 years from now versus the same benefits 2,000 years from now? Maybe not, but probably you value both far less than the next 50 to 100 years. Figure 1 shows an illustration of the relative value over time using a standard positive discount rate and a notional legacy discount rate. Uncertainties about the future make projections on the longer timeframes harder to value: New developments in health sciences or unrelated negative developments might make the projected harms irrelevant, or not.

There are important debates to be had about these issues, not just for nuclear waste and contaminated sites, but perhaps most crucially for climate change because economic discount rates applied in that domain can skew policy decisions in ways that do not reflect the values I just articulated. Our children and grandchildren are already destined to feel the effects, so our actions are to avert catastrophic changes in their lifetimes.

Nuclear Weapons: Narratives of scientists about work on nuclear weapons issues

In advising on nuclear weapons, there is work on the weapons themselves, ranging from design, safety, security of nuclear explosives, and their delivery systems, to ways to counter them, thinking about humans in the systems, terrorism, war, accidental war, and catalyzed war, and how to counter these. There is work on nuclear forensics, monitoring and verification of nuclear weapons, on nonproliferation, detection, and safeguards, and more. I have been asked by some to sign a pledge to never work on nuclear weapons and told by another that I am a parasite if I don't work on them.

In trying to understand competing arguments, I find it useful to understand the larger frames of the arguments. Since the Manhattan Project, there have been competing narratives about nuclear weapons, how they affect the world order, and scientists' role with respect to those weapons. Each is internally logically consistent and I believe that there are people working based on their ethical principles associated with each narrative.

Peace through strength

The potential for major conflict does not exist because of nuclear weapons; nuclear weapons exist because of the potential for conflict. The goal should be promotion of security. Nuclear weapons have played an important role in reducing major conflict and more useable weapons could do even more. We cannot trust that current and future adversaries will not possess or develop nuclear weapons or other comparably horrific or strategic weapons. If nuclear deterrence prevents war then we need to keep nuclear weapons.

Next steps: Work to increase nuclear weapons' ability to increase stability and ensure security over the long term. This includes better understanding nuclear weapons and preventing their spread to other countries and groups. It could include developing new weapons, although arms race stability may dictate against that approach.

Realism

Nuclear weapons are woven into the fabric of the international security system. As long as we have them, they should be safe and secure.

A nuclear war cannot be won and must never be fought. Nuclear weapons are horrific and should never be used, but the only path to zero is through incremental, verifiable reductions that preserve both stability and each party's security, a kind of isentropic change. In ratifying the NPT (Nuclear Proliferation Treaty), nuclear weapon states made a commitment to work toward disarmament. Efforts like TPNW (Treaty on the Prohibition of Nuclear Weapons) are counterproductive because they undermine or distract from measures that can make real progress on arms control, reductions, and disarmament.

Next steps: Work to reduce the dangers of a world with nuclear weapons, even as we work to solve the obstacles to eliminating the dangers of these weapons' existence. The challenges range from maintaining stability and containing proliferation to securing, monitoring and verifying arms-control regimes.

Humanitarian

Nuclear weapons are immoral and must be banned. They violate humanitarian principles and laws and they impose unacceptable risks.

The use and even possession of nuclear weapons is immoral. Use violates all principles of use of force. Possessing them enables the possibility of an accident, an unintended or unwanted use, or use caused by a person's madness. These all have grave consequences for people who do not wish to be part of a conflict but also those who have nothing to do with the conflict. Nuclear deterrence is the standing threat of violence imposed upon the world, and there is a harm from even the threat. Nuclear weapons are used to preserve a power structure as much as they are used for security.

Next steps: Establish a norm and a legal obligation to eliminate nuclear weapons, de-alert, remove from operational deployment, irreversibly disable, and irreversibly dispose. The more sophisticated adherents to this position recognize that these steps will not happen immediately and must be done carefully, in coordination, etc., but they believe that we must establish the norm as a first step.

It has long been a commitment under the Nuclear Nonproliferation Treaty and a goal of many states, including both states that do and do not possess nuclear weapons, to eliminate nuclear weapons. In 2017, 122 countries voted to approve the Treaty on the Prohibition of Nuclear Weapons (TPNW), also known as the nuclear "Ban Treaty." The United States and other nuclear weapon states (and 35 other countries) did not participate in the negotiations. 12 more countries have signed on and the treaty will enter into force on January 22, 2021. In 2017, the Nobel Peace Prize was awarded to the International Campaign to Abolish Nuclear Weapons (ICAN) for its role in making the treaty happen.

Advising on nuclear weapons

In providing advice on nuclear weapons, one need not represent one of these positions, nor do we need to balance all of them, but it is valuable to understand all of them. Some of us see real value in having people and groups with diverse interests express their perspectives—pushing for nuclear disarmament, prioritizing international security and stability over disarmament, promoting nuclear safety, security, and non-proliferation now as we work toward a longer term goal of disarmament—as all of these are important aspects of the problem that must be considered. Multiple advocates making the best arguments for the different considerations in a societal debate, in a healthy debate, is good for the country and the world. Can we establish a healthy debate?

Physicists organized through the Science and Global Security Program at Princeton University have launched the Physicists Coalition for Nuclear Threat Reduction. The focus is on reestablishing a community of physicists who are informed, engaged advocates for reducing the dangers, the threats, and the risks of nuclear weapons. This is one step toward a healthy debate.

Conclusion

In discussing risk and nuclear energy, I observed that seeing the effects of the tsunami in Sendai and the additional effects of the Fukushima nuclear accidents invested me with the gravity of the consequences of decisions about nuclear safety. Seeing the scale of uranium mill tailings in Colorado and Utah or contaminated sites at Hanford and Mayak give the beginnings of a feel for the effects of mismanagement of waste from the nuclear fuel cycle.

It is harder to feel the immediate connection between nuclear energy and climate change, but it is there and unfortunately we will see more and more tragic events that make us feel the effects viscerally.

Advising on nuclear weapons is important and the bad outcomes can be both devastating and far reaching, both physically in terms of the direct effects of the weapons and the after effects, and in terms of nuclear weapons' role in international relations.

No one person is endowed with the knowledge, wisdom, and judgment to establish good nuclear weapons policies, manage the existing nuclear stockpile, and navigate through crises that may involve nuclear weapons, but in the United States we endow a person in one position with the authority to do all of those actions, and use nuclear weapons if he or she chooses. Whole agencies support the President's efforts. They can use good help. Not lazy, gut-reaction advice, but thoughtful, reasoned, informed, and even impassioned advice from many perspectives. If we, the advisors, hold civil discussion about the issues, the reasoning, and the evidence, we may be able to see the value in each other's thinking and identify common ground, approaches that work from multiple perspectives. It's what John Ahearne dedicated his professional life to doing. That work can only help those charged with some of the weightiest responsibilities in our society, and I can tell you that they can use all the good help they can get.

Anticipating Our Technological Future

Steve Fetter, University of Maryland, sfetter@umd.edu, 2021 Recipient, Leo Szilard Lectureship Award

It is an honor to receive an award named in memory of Leo Szilard. Szilard was a visionary with deep concern about the social consequences of physics. He was able to peer around the corner of established science to see what might come next and anticipate the possible impacts of those developments for society.

For many years I taught a course on nuclear weapons. The first required reading was The Making of the Atomic Bomb by Richard Rhodes. The book begins with a recounting of Szilard's epiphany in 1933, just a year after the discovery of the neutron, that a chain reaction might be possible. Rhodes quotes Szilard recalling that it "suddenly occurred to me that if we could find an element which is split by neutrons and which would emit two neutrons when it absorbs one neutron, such an element, if assembled in sufficiently large mass, could sustain a nuclear chain reaction. I didn't see at the moment just how one would go about finding such an element, or what experiments would be needed, but the idea never left me. In certain circumstances it might be possible to set up a nuclear chain reaction, liberate energy on an industrial scale, and construct atomic bombs."(1)

Szilard patented the idea of a nuclear reactor shortly thereafter. When uranium fission was discovered five years later, Szilard helped draft a letter from Albert Einstein to President Roosevelt warning that Germany might develop nuclear weapons. This led to the Manhattan Project, which produced the first nuclear reactors and nuclear weapons. When the war was coming to an end in 1945 and it was clear Germany had not developed nuclear weapons, Szilard helped draft the Franck report, which warned of an inevitable arms race and argued for international control of nuclear weapons.

Szilard alerted U.S. political leaders to the dangers of nuclear weapons but was unable to persuade them to surrender the short-lived advantages of a nuclear monopoly for the longer-term gains of international control. The arms race he predicted happened and fundamentally changed warfare and international relations. After the Soviet Union and China acquired nuclear weapons, total war among great powers was generally recognized as self-defeating because it would result in total destruction for all. Political and military leaders came to understand that no preemptive or preventive attack could prevent devastating retaliation, and that no potential military gain could justify the destruction of their society. And so great powers have been deterred not only from using nuclear weapons, but from engaging in conflicts that might lead to the use of nuclear weapons. But this deterrence comes at a high price: the constant risk that nuclear weapons might be used by miscalculation or mistake, through escalation of conventional conflicts or as a result of false warnings or cyberattacks, or by deranged leaders, officers without authorization, or terrorists who have stolen nuclear weapons or nuclear materials.

Niels Bohr famously said, "prediction is very difficult, especially about the future." But Szilard showed that prediction is not only possible, but essential. It is vital to anticipate what scientific and technological discoveries may lurk around the corner, consider what the possible consequences of these developments may be for society, and identify steps to avoid or minimize the negative impacts while maximizing the positive.

I had the good fortune to serve for five years in the White House Office of Science and Technology Policy during the Obama administration. During that time it became apparent that we were entering a new industrial revolution characterized by emerging technologies in various domains:

- Microelectronics and software: cyberattack; blockchain; virtual and augmented reality; artificial intelligence and machine learning for computer speech and vision, robotics, autonomy, synthetic media (e.g., deep fakes and misinformation); sensors; storage, retrieval, and movement of massive amounts of information;
- Advanced manufacturing: additive manufacture, nanotechnology, microfluidics, microreactors, fiber lasers;
- Space: microsatellites for visual and radar imagery and global wireless communication;
- Biotechnology: genome sequencing, bioinformatics, synthetic biology, genome editing;
- Neuroscience: neuroimaging, human-machine interfaces, cognition enhancement; and
- Quantum: sensors, communications, computers.

An exploration of these technologies and their possible social consequences would require several volumes. I will mention just a few examples to hint at the magnitude of the technological revolution currently underway.

One of the most impressive examples of the advance in microelectronics is the most commonplace: the smart phone. Today's smart phones have computing power equal to the fastest supercomputers in the 1990s, along with high-resolution cameras, microphones, GPS receivers and accelerometers for precision location, navigation and timing, high-speed wireless communication, and power consumption so low they can operate for a day on a single battery charge—all in a package weighing as little as 100 grams. Smartphones are so capable that they can power small satellites, such as the hundreds of shoebox-sized Doves produced and launched by Planet, which now image the entire Earth every day (see figure 1) (2). The enormous advances in microelectronics make possible the deep neural networks that underlie machine learning and enable speech recognition, computer vision, and self-driving vehicles.

Figure 1. Planet CEO Will Marshall with a 5-kg Dove satellite. Planet currently has 180 Doves in orbit, imaging the entire Earth daily.

Emerging technologies in each of these domains has tremendous potential for social benefit. Autonomous vehicles will reduce pollution and traffic deaths while increasing leisure and productivity. AI may be able to prevent medical errors and improve the accuracy of diagnosis and treatment, and improve reliability of software by finding bugs and malicious code. Virtual reality will bring a wide range of experiences and learning opportunities to people everywhere, regardless of income, and reduce the need to travel. Human-machine interfaces will restore functions to the disabled. Small satellites may bring affordable Internet access to people around the globe, free of State censorship. Genome editing will result in cures for terrible diseases and crops that are resistant to climate change. Quantum computers promise to solve some of the most difficult problems, leading to the development of new drugs and materials, devices that will allow us to produce, transmit, and store carbon-free energy, and processes to cheaply remove carbon and nitrogen from the air.

But these emerging technologies also have a darker side and the potential to harm individuals and societies. The advance in microelectronics that makes possible the smartphone has made commercially available rifles with digital fire control systems that allow anyone to hit a target within a centimeter at a distance of 1000 meters—better than an expert sniper (figure

Figure 2. A rifle available for $8,995 with a digital fire control system that corrects for elevation, range, wind, temperature, humidity, and rifle position, allowing 1 cm accuracy at distances of 1000 m.

2) (3). Image recognition technology can allow autonomous drones to search for particular individuals or critical infrastructure targets—and attack them. Self-organizing swarms of autonomous vehicles might be developed to defeat conventional armies, navies, and air forces—or fight the opposing swarms of an adversary. Synthetic media could make it impossible for ordinary citizens, or even experts, to distinguish fact and fiction, persuading millions to believe a false narrative. Authoritarian governments could use synthetic media, ubiquitous sensors, facial recognition, and neuroscience to impose a degree of social control beyond that imagined by George Orwell, continuously monitoring the activities—and even the thoughts—of citizens. Genome editing and synthetic biology might be used to enhance the performance of a nation's soldiers or to develop new bioweapons. AI and quantum sensors could upset strategic stability by making mobile missiles or submarines vulnerable to attack.

Unlike nuclear fission, it is difficult to foresee the consequences of these emerging technologies. They certainly will change the balance of power between states, and between states and non-state actors, but the nature of these changes is unclear. Will they benefit the United States and its allies, make aggression easier or more difficult, make us more or less secure? Some speculate that the United States or China will become dominant in artificial intelligence or quantum computing and will move quickly to capture enduring military, political, and economic benefits from this dominance. Others believe emerging technologies will diffuse rapidly through commercial channels and will empower smaller states and subnational groups.

Many of these emerging technologies make new and powerful capabilities available to individuals with little or no specialized knowledge or skill. Anyone with $9000 can buy and use the sniper rifle described above. Anyone with a credit card can buy a commercial drone with a remote video link and follow instructions on YouTube to outfit it with a grenade or rifle that can be triggered remotely. Anyone with a computer can make a deepfake video or download the malware to launch a cyber attack. Someone with no engineering or manufacturing knowledge can buy an industrial 3D printer and use it to make the most metal objects or parts by downloading a blueprint from the web; for much less, they can use a cheap 3D printer to make a plastic handgun that can evade metal detectors. Do-it-yourself CRISPR gene editing kits are available for less than $200 (figure 3), (4) and gene sequences can be mail-ordered from a gene synthesis service by someone with no scientific credentials.

Prediction is difficult, but we should not leave the field to science fiction writers. We should engage experts in a systematic effort to understand what applications of emerging technologies are likely to be possible, what the societal consequences may be, and what steps can and should be taken by government to ensure the benefits for society are maximized

Figure 3. A do-it-yourself bacteria CRISPR genome editing kit, available for $160

and the risks are minimized. In doing so, we must recognize a fundamental difference in the nature of the currently emerging technologies. The technologies of the 20th century—nuclear weapons, chemical and biological weapons, manned aircraft and cruise missiles, ballistic missiles and rockets, supercomputers, and large communication, navigation, and early warning satellites—required the resources and support of a nation state. The important discoveries and developments were made by scientists with government funding, often in government laboratories. This allowed government to control, and often classify, essential information, slowing the diffusion of the technology to other countries and non-state actors. The fact that these technologies were being developed by government, often in classified environments, allowed government to recruit the best and brightest scientists and engineers, who were attracted by the opportunity to work on problems that were at the cutting edge of science and technology.

In contrast, the emerging technologies of the 21st century are being developed by private firms motivated largely or entirely by commercial applications, without government funding or involvement. This creates special challenges because multinational firms have enormous economic power and can move operations to another country when faced with government regulation. The technologies they are developing and deploying have a product cycle measured in months rather than years and are evolving too rapidly for government to keep pace, as is illustrated by the battle over encryption. Top graduates are increasingly choosing to work for Google, Apple, Amazon, Microsoft, Tesla, and SpaceX, rather than for Los Alamos, the National Security Agency, or NASA. During the Cold War, a major issue was "spin off": how to transfer the fruits of government research to benefit the civilian economy. Today, the challenge increasingly is how to harness the creativity and rapid progress of commercial firms for intelligence and defense. This was the motivation for the creation of In-Q-Tel by the intelligence agencies and the Defense Innovation Unit by the Department of Defense.(5)

What would a systematic effort to assess emerging technologies look like? It would not be a single, dedicated agency, like the former Office of Technology Assessment. It would have to be an all-of-government effort, led by the Office of Science and Technology Policy and the National Security Council in the White House, to empower all science and technology agencies to understand new technologies, assess the potential for misuse, and consider ways to mitigate those risks. That will require increasing the capacity of government to stay at the forefront of science and technology. Because these new technologies are being developed by industry and the best talent will always be drawn to the cutting edge, government should take advantage and tap into industry talent in addition to career government scientists. The Obama Administration promoted a "tour of duty" model and created programs to bring world-class talent into government for 6 to 12 months. Examples include the 18F program, the U.S. Digital Service, and the Presidential Innovation Fellows, which added to existing fellowship and other programs to attract scientific talent into government.(6) Firms could embrace and promote this as a service opportunity for their staff and a demonstration of the company's commitment to the responsible use of the technologies they are developing.

The flow should go in the other direction, too. The Central Intelligence Agency might be able to recruit a new PhD microbiologist or computer scientist to follow and assess technological trends, but those analysts will not be able to stay at the cutting edge by reading journal articles. Agencies should create sabbatical programs to allow their scientists and engineers to periodically work in university or industry labs for a year to keep their skills sharp and learn first-hand about new developments.

In all of this, partnerships between government and industry and universities are essential. The developers of new techniques, machines, and algorithms are in a good position to assess the potential for misuse and suggest ways risks could be mitigated without diminishing benefits. They will appreciate that if their discoveries and inventions are used for destructive purposes, it could lead to burdensome (and perhaps ineffective or counterproductive) regulation and even the destruction of commercial opportunities. Agencies could use independent scientific advisory bodies, like the JASON defense advisory group, to explore the potential for the misuse of new technologies like CRISPR. And this must be a truly interdisciplinary effort involving information and computer science, biology and neuroscience, and social science, in addition to physics.

Because the pace of change is so rapid, partnerships and voluntary action by university and industry are essential. We can no longer afford to be reactive—to wait until a product is on the market and then develop government regulation. We must anticipate future developments and the potential for misuse, and to include this sort of thinking in the training of scientists and engineers so they view it as a professional obligation and civic duty. Universities should embrace this thinking and encourage faculty and doctoral students to consider the societal implications of their research, and reward faculty who make significant contributions to understanding and addressing societal impacts of emerging science and technology.

Part of the answer will be using emerging technologies to mitigate the risks they generate. For example, using AI to find and fix security vulnerabilities or malicious code in software or to detect suspicious patterns of behavior (e.g., an individual ordering gene sequences that could be assembled to create a pathogen). The United States is fortunate to be leading the development of many of the technologies; we should also lead in identifying and mitigating the risks they may pose.

1 *Richard Rhodes, The Making of the Atomic Bomb (New York: Simon and Schuster, 1986), p. 28.*

2 *https://www.planet.com/*

3 *https://talonprecisionoptics.com/*

4 *https://www.scientificamerican.com/article/mail-order-crispr-kits-allow-absolutely-anyone-to-hack-dna/*

5 *https://www.iqt.org/, https://www.diu.mil/*

6 *https://18f.gsa.gov/, https://www.usds.gov/, https://presidentialinnovationfellows.gov/*

Magnetic Fusion is tough – if not impossible – fusion breeding is much easier

Wallace Manheimer, Retired from the US Naval Research Laboratory (NRL), wallymanheimer@yahoo.com

The magnetic fusion energy (MFE) effort worldwide is now centered around the ITER project, a large tokamak in France, set up by an international consortium of 7 partners, the European Union, United States, Russia, China, Japan, South Korea and India (1). Current estimates of ITER's cost are ~\$25B, up a factor of ~5 from the original estimate of ~\$5B in 2005, and possibly much more. Its time line has also slipped from 2016 to 2025 for the start of plasma experiments and to 2035 for DT experiments (2,3). ITER's hope is to achieve ten times more neutron power than is injected into the machine with neutral beams and microwaves, i.e., Q=10 by 2040. Specifically, it hopes that with 50 megawatts (MW) of injected power, it will produce 500MW of fusion power, for a 400 second pulse. See Figure (1).

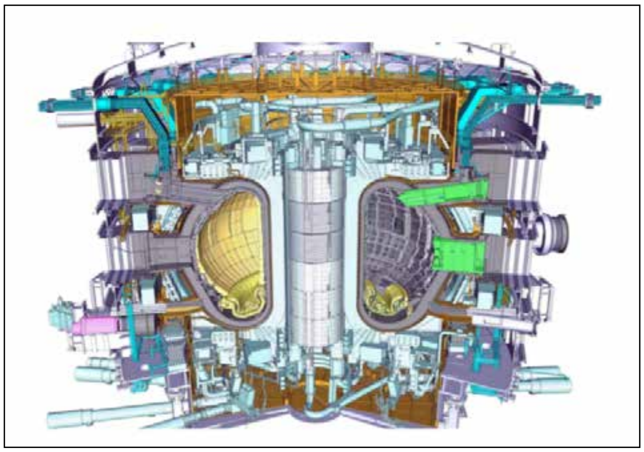

Figure 1: An artist's conception of the ITER tokamak, from the ITER web site. The major radius from the center of the torus to the center of the vacuum chamber is 6 meters and the toroidal magnetic field is about 5 Teslas.

What is not generally publicized is that after a success with ITER, there are enormous obstacles to producing economic power from what the ITER web site calls its follow on, the DEMO (1,4). Note that electric power is produced with an efficiency of ~ 1/3, so the 500 MW of power means ~170MW sent to the grid. However, beams and microwaves are not produced with 100% efficiency either, once again 1/3 is a typical number. Hence the 50 MW of input power would take ~150MW of wall plug power, leaving virtually nothing for the grid. There have been speculations of more efficient generators, and in fact these, mostly gas-powered generators, have been developed on a small scale. How well they would match with a fusion source is unknown. However, relying on a special generator just to make fusion relevant, does not sound like a very good argument for either fusion or the special generator. Better if fusion can fit in with existing infrastructure.

To make ITER an economical machine, first the gain would have to increase by at least a factor of 3 or 4, so that the circulating power is a much smaller fraction of the total power. Second, the power would have to be increased by a factor of about 5 or 6 to make it comparable to current power stations. Third the size and cost would have to be reduced substantially. But with larger power and a smaller size, the wall and divertor loading would increase by at least an order of magnitude. These are not minor details! Assuming they could be accomplished at all, they would take decades and additional \$10B's. Realistically, pure fusion, at least on the ITER pathway, is at best a 22nd century possibility. Shortly we will make the case that even this is very unlikely, given current understanding of tokamak physics.

However, fusion breeding, using an ITER like device, is an alternative which is likely achievable not too long after midcentury, and it would fit in with existing nuclear infrastructure. This is the use of 14 MeV fusion neutrons not only to boil water with their kinetic energy, but also to breed 10 times more nuclear fuel, for separate, nuclear reactors. Fusion breeding could produce ~150 MeV of ^{233}U from each 14 MeV neutron. Hence an ITER like device could be an end, not a means.

The author's initial work was published in 1999 (5). This work also suggested a path forward for the American program, a tokamak called 'The Scientific Prototype', which would, on as small a scale as possible, address two of the issues ITER will not and cannot address; true steady state operation in a DT plasma, here with Q~1, and tritium breeding (6). He has subsequently published several open access articles on the subject in prestigious and rigorously reviewed journals (7-10). Reference (7) is addressed principally to the fusion community, (8) to the general technically astute community, (9) to the physics community, and (10) to those mostly concerned with sustainable development. These works, as does this, all concluded with a proposed fusion breeding-based energy infrastructure, "The Energy Park". It is economically and environmentally viable, and has extremely little or no proliferation risk.

This essay hopes to present the case for fusion breeding in a simple and clear enough way, so as to be useful to anyone from a congressman to a plasma or nuclear science expert. *Specifically, an ITER type machine would be fine for fusion breeding, but not for pure fusion. There would be no need to develop who knows what DEMO, who knows how many decades later, who know for how many more tens of billions.*

The amount of ^{235}U is quite limited (11), so some sort of breeding will ultimately be necessary for sustainable, carbon free nuclear power. Fusion breeding could provide significant power not too long after midcentury. We will see that it has certain enormous advantages over fission breeding. While the MFE effort has been reluctant to partner with the nuclear

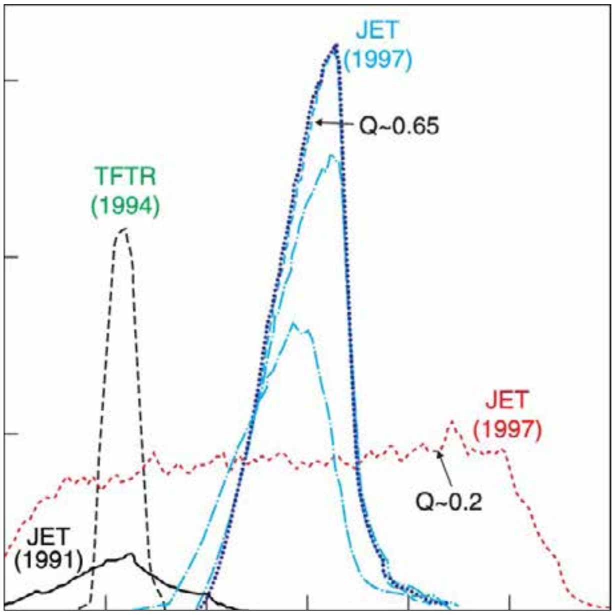

Figure 2: A plot of the neutron production rate, taken from Ref 19, expressed in terms of the Q at the maximum of the curve, for a variety of shots on TFTR and JET. The horizontal time axis covers about 6 seconds. There are two modes of operation, hot ion, observed in both TFTR and JET, which gives Q~0.65, but which could not be maintained; and thermal, observed only in JET, which gives Q~0.2 and lasts for the entire pulse.

industry, which might not even want it, one should consider realities.

Pure economical MFE on the ITER pathway may well be out of reach. Economical Fusion breeding most likely is not.

Breeding is a perfectly acceptable, and possibly even a better outcome for the fusion effort. There are fission breeding possibilities, for instance fast neutron reactors. Russian and Indian nuclear scientists and engineers are actively pursuing these, and Russia now has two operating sodium cooled fast reactors, their BN-600 and BN-800. However, the breeding options are few, and fusion breeding should be considered. This author believes that if fuel supply were no problem, any fission reactor designer would choose a thermal over a fast neutron reactor. The thermal neutron reaction cross section is a few thousand times greater, and there is a wide choice of coolants, not just liquid sodium or lead. Fusion breeding gives this choice to the reactor designer. Also, it would provide a raw fuel with minimal proliferation risks and which fits in with current nuclear infrastructure.

Even in a best-case scenario, where pure fusion does prove to be possible for the 22nd century, fusion breeding could provide an intermediate product, of real economic value, a product which might be desperately needed by midcentury. By then the world will have a population of ~10 billion, all of whom will demand a middle class life style; namely a life style which uses 4-6 kW per capita as we in the west do; i.e. at least ~40 Terawatts (TW) worldwide, well over the ~14TW now. Furthermore, it is extremely unlikely that wind and solar can come anywhere near filling this gap (8, 10, 12, 13, 14). Even its proponents admit that a transition to wind and solar would cost $50-100T (15), and of course the skeptics, even if they admitted it were possible, would surely come up with a much, much higher figure; real money!

But first let us briefly digress and debunk a cottage industry that developed over the past decade or so, namely a variety of private sector companies, supported by billionaires, that claim to have a fusion shortcut. As Jassby (16) noted, these companies have not produced a single 14 MeV neutron. A commercial fusion reactor would need to produce in excess of 10^{21} fusion neutrons per second. Tokamaks JET (Joint European Tokamak in Culham lab in England) and TFTR (Tokamak fusion test reactor, in Princeton Plasma Physics Lab in Princeton, NJ) have produced ~ 10^{19} n/s (i.e. Q~0.5) in bursts of a few seconds (17,18,19) as shown in Figure 2. They have gotten to where they are after a 50-year, worldwide research effort, costing billions. Nevertheless, this does not stop these companies from making preposterous promises. For instance, General Fusion Company made the following assertion. Using magnetized target fusion, a concept that was studied over the past 35 years at NRL and the Los Alamos National Laboratory (LANL), in 2013 (16) they promised break-even by 2015 and a commercial reactor *last year*! Meanwhile, let's get back to reality.

In addition to the technical obstacles just addressed, there are significant additional scientific obstacles. The author has discussed these fully in Refs (7-10) and has called them 'Conservative Design Rules' (CDR). Tokamaks are limited in electron density, current, and plasma pressure (or more precisely the plasma beta, the ratio of plasma to magnetic pressure). These limits are not controversial; they have a solid base in theory and have been confirmed in a wide variety of experiments. They are individually well known, but taken together their implications are both astounding and ignored. They almost certainly prevent a tokamak from becoming an economical pure fusion device. Yet the MFE community refuses to recognize this reality. But as Richard Feynman said after the Challenger disaster, "Reality must take precedence over public relations, for nature cannot be fooled".

Conservative design rules and their implications for economical tokamak fusion have been in the literature in a variety of publications (7-10,20) starting in 2009. Freidberg also derived similar constraints (21). This author has given seminars on them at MIT, University of Maryland, NRL, University of Rochester Laboratory for Laser Energetics, and The American Physical Society Headquarters. Also, he has presented posters on them at numerous Friday morning APS DPP sessions, which many have attended over the years. With all this exposure, nobody, not a single individual, in print or in person, has ever disputed CDR'S or their implication.

References (7-10, 20) compared maximum powers predicted by CDR with actual powers achieved by TFTR (17) and JET (18). In each case, the CDR predictions were well above the actual power produced, at least by a factor of 2. Furthermore, comparing CDR predictions of power with projected power of fusion devices on the drawing board, ITER (22) and ARC, a high field tokamak, B=9T, proposed by MIT (23), CDR's predicts considerably more power than the designers think they can get from the machine.

For a pressure limited plasma, the maximum fusion rate is at a temperature of ~16 keV. Once the temperature and maximum pressure are known, one has the density and hence the fusion rate. Then there is a lesser dependence on electron to ion temperature ratio and profiles, so there are slight differences in formulas depending on these assumptions. The most optimistic formula for maximum fusion power is given in Eq. (6) of Ref. (9). This assumes the highest beta that CDR's would allow for any tokamak examined, 4%. It assumes a uniform temperature and density profile all the way out to the separatrix, as seen roughly in the super H mode shots (24), where a nearly uniform profile extends to ~80% of the separatrix. Equation (1) below corrects this and multiplies Eq. (6) of Ref. (9) by 0.64.

$$P(MW) \leq 2x10^{-3}\pi^2 KR(m)a^2(m)B^4(T) \qquad (1)$$

Here a is the minor radius to the separatrix or limiter in the horizontal plane, B is the magnetic field in Teslas, R is the major radius, and K is the vertical elongation of the assumed elliptical cross plasma cross section.

To get a more pessimistic, and likely more realistic formula, we use that from Eq. (1) of Ref. (8). This assumes a parabolic profile of density and temperature, an approximate maximum beta derived for the particular tokamak, and the ion temperature equal to twice the electron temperature, as is often measured in initial beam heated plasmas experiments. Assuming equal temperatures, as is more reasonable for a large reactor plasma, this fusion power is reduced by a factor of 9/16 as some of the ion pressure (which reacts), is replaced with electron pressure (which does not react). Then the formula for maximum fusion power becomes:

$$P \leq 0.06K^2[aB]^4/R \qquad (2)$$

Let us consider typical values for tokamaks, K=1.7, a = R/3, and set the maximum power equal to 3 GW, as is produced by a standard conventional power station. The Eqs. (1 and 2) become formulas for the minimum radius R, as a function of the magnetic field. These are summarized in Table 1. The left-hand column specifies the magnetic field, 5 or 9 T, the top row, R, from Eqs. (1 and 2). The Table entries are the minimum radii in meters (rounded to the nearest whole number).

	R[Eq. (1)]	R[Eq. (2)]
B(5T)	11	12
B(9T)	5	6

Notice that for a given field, the calculated minimum radii do not vary very much on the assumptions. Adding the minor radius and shielding, the device would extend from the goal line to somewhere around the 30-40-yard line of an American football field for a 5 T tokamak reactor. This does not sound inexpensive!

However, a tokamak breeder like ITER, while expensive, provides fuel for as many as 5 thermal reactors of equal power, as well as power for the grid (the breeding reactions are exothermic, so the total produced power is now ~ double the neutron power). A very rough estimate of the cost of fusion bred fuel, based on the current cost of ITER, comes to about 1-3 cents per kwhr (7-10). Mined uranium fuel, while it lasts, currently costs about 0.5-1 cent per kwhr.

We show here why fusion breeding is in many ways superior to fission breeding. Whether the reaction is a fission or fusion reaction, each reaction produces 2–3 neutrons (in the fusion reaction this is after neutron multiplication, which is possible because the fusion neutron has a much higher energy than the fission neutron). In fission, one of these neutrons is needed to continue the chain reaction and one is needed to replace the fuel atom; in fusion one is needed to breed the tritium from lithium, so in either case one or two neutrons are available for other purposes. Of course, in either case there are losses, so probably somewhere between half and one neutron per reaction is available for breeding ^{233}U from ^{232}Th,

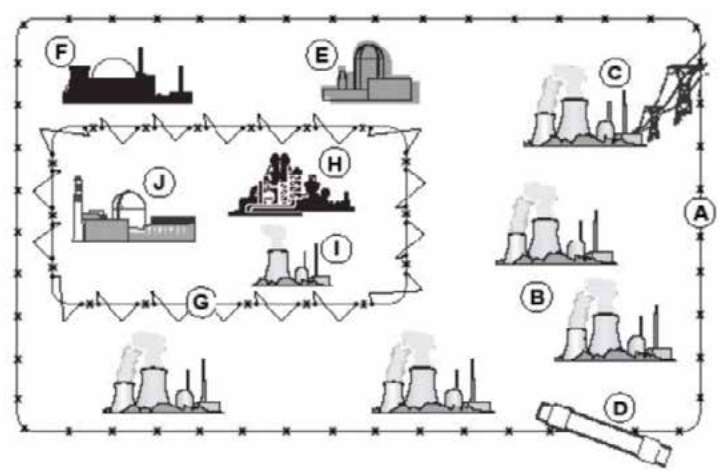

Figure 3: The energy park: A. low security fence; B. 5 thermal 1GWe nuclear reactors, LWRs or more advanced reactors; C. output electricity; D. manufactured fuel pipeline, E. cooling pool for storage of highly radioactive fission products for 300–500 years necessary for them to become inert; F. liquid or gaseous fuel factory; G. high security fence, everything with proliferation risk, during the short time before it is diluted or burned, is behind this high security fence; H. separation plant. This separates the material discharged from the reactors (B) into fission products and transuranic elements. Fission products go to storage (E), transuranic elements got to (I); I, the 1GWe integral fast reactor (IFR) or other fast neutron reactor where actinides like plutonium are burned; J. the fusion breeder, producing 1GWe itself and also producing the fuel (ultimately enriched to ~4% ^{233}U in ^{238}U) for the 5 thermal nuclear reactors for a total of 7 GWe produced in the energy park. It could be a sustainable, economically and environmentally viable carbon free power source with no proliferation risk. These could supply 10's of TW to power civilization as far into the future as the dawn of civilization was in the past.

or ^{239}Pu from ^{238}U. However, the fission reaction produces about 200 MeV, while the DT fusion reaction produces only about 20. Hence for reactors of equal power, a fusion reactor generates about 10 times more neutrons, and therefore breeds about 10 times more nuclear fuel than a fission reactor does. In other words, a fusion reactor is neutron rich and energy poor, while a fission reaction is energy rich and neutron poor, a perfect match.

"The Energy Park" uses the fact that a fusion breeder can breed fuel for about 5 light water reactors (LWR's) of equal power, and each year an LWR discharges about 1/5 of its fuel as plutonium and higher actinides. Hence one envisions an energy infrastructure where there is one fusion breeder to supply fuel, and one fast neutron reactor to burn the 'waste' actinides (7-10). A schematic, which appeared in Refs. (7-10) is shown in Figure 3. Most of the elements of the energy park are available today, only the fusion breeder needs full development.

So, if not breeding, what are the options for ITER and magnetic fusion? Could one prove, with solid theoretical and experimental evidence, that CDR's are not correct or one has a way around them? This has not happened in 50 years of tokamak research. If so, could one handle the enormous wall loading? Would a sponsor sign on to the concept of a very expensive DEMO with $R \geq 12M$ and $B \sim 5T$, or $R \geq 6M$ with $B \sim 9$ T? It seems that a fission breeder would be a better, and less expensive choice. Russia and India are already champing at the bit.

While it is not impossible that ITER will lead directly to economic pure fusion power, it is very unlikely, based on 50 years of experience with tokamaks, and the best science at this point. Most likely the largest MFE flagship is now cruising top speed, right toward the iceberg. However, there is still time to steer the ship. Fusion breeding seems to be both possible and necessary. At least for the American program, the time to prepare to lay the groundwork for fusion breeding is NOW.

Acknowledgement: This work was not sponsored by any agency public or private.

References

1. *www.iter.org*
2. *ITER article in Wikipedia: https://en.wikipedia.org/wiki/ITER#:~:text=The%20expected%20cost%20of%20ITER,estimate%20of%202016%20to%202025.*
3. *David Kramer, ITER disputes DoE's cost estimate of fusion project, Physics Today (in politics and policy), April 16, 2018 https://physicstoday.scitation.org/do/10.1063/PT.6.2.20180416a/full/#disqus_thread*
4. *Stuart Nathan, Beyond ITER – next steps in fusion power, The Engineer, Jan 3, 2019, https://www.theengineer.co.uk/beyond-iter-next-steps-in-fusion-power/*
5. *Wallace Manheimer, Back to the future, the historical, scientific, naval and environmental case for fission fusion. Fusion Technol. 36, 1 (1999)*
6. *Wallace Manheimer, The Scientific Prototype, a Proposed Next Step for the American MFE Program, J. Fusion Energy, (2013) vol 32: p 419–421*
7. *Wallace Manheimer, Fusion Breeding for Midcentury Sustainable Power, Journal of Fusion Energy, June 2014 (open access) vol 33, p 199 https://link.springer.com/article/10.1007/s10894-014-9690-9*
8. *Wallace Manheimer, Midcentury carbon free sustainable energy development based on fusion breeding, IEEE Access, December 2018, Vol 6, issue 1, p 64954-64969, https://ieeexplore.ieee.org/document/8502757*
9. *WallaceManheimer, Fusion breeding for mid-century, sustainable, carbon free power, Heliyon (Cell Press), Volume 6, Issue 9, September 2020, e04923 https://www.sciencedirect.com/science/article/pii/S2405844020317667#!*
10. *Wallace Manheimer, Fusion breeding as an approach to sustainable energy. Discover Sustainability 1, 4 (2020).*

    https://doi.org/10.1007/s43621-020-00004-9
11. *Martin I. Hoffert et al., "Advanced technology paths to global climate stability: Energy for a greenhouse planet," Science, vol. 298, pp. 981–987, Nov. 2002.*
12. *Mark Mills, "The new energy economy, an exercise in magical thinking" Manhattan Institute Report, March 2019, https://media4.manhattan-institute.org/sites/default/files/R-0319-MM.pdf*
13. *BP Energy Outlook, 2019 edition, p 15, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf*
14. *Wallace Manheimer, German green energy compares poorly to French nukes, Business and Politics BPR, March 12, 2021 https://www.bizpacreview.com/2021/03/12/german-green-energy-compares-poorly-to-french-nukes-1042200/*
15. *Barbara Bushner et al , Landscape of global climate finance 2019, Climate policy initiative, November, 2019 https://climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-2019/*
16. *Daniel Jassby, Voodoo Fusion Energy, Forum on Physics and Society, April 2019, https://www.aps.org/units/fps/newsletters/201904/voodoo.cfm*
17. *Richard Hawryluk et al., "Fusion plasma experiments on TFTR: A 20 year retrospective," Phys. Plasmas, vol. 5, pp. 1577–1592, May 1998.*
18. *A. Gibson and The JET team. "Deuterium–tritium plasmas in the joint European torus (JET): Behavior and implications," Phys. Plasmas, vol. 5, p. 1839–1847, May 1998*
19. *Jean Jacquinot, Martin Keilhacker & Paul Henri Rebut (2008), Chapter 2: Mission and Highlights of the JET Joint Undertaking: 1978-1999, Fusion Science and Technology, 53:4, 866-890, DOI: 10.13182/FST08-A1742*
20. *Wallace Manheimer, Hybrid fusion: the only viable development path for tokamaks? J. Fusion Energy, 28 (1) (2009), p. 60*
21. *J.P. Freidberg, F.J. Mangiarotti, J. Minervini, Designing a tokamak fusion reactor—how does plasma physics fit in? Phys. Plasmas, 22 (7) (2015), p. 70901*
22. *D. J. Campbell, "The physics of the international thermonuclear experimental reactor FEAT," Phys. Plasmas, vol. 8, no. 5, pp. 2041–2049, 2001*
23. *B. N. Sorbom et al., "ARC: A compact, high-field, fusion nuclear science facility and demonstration power plant with demountable magnets," Fusion Eng. Des., vol. 100, pp. 378–405, Nov. 2015.*
24. *P.B. Snyder et al, High fusion performance in Super_H-mode experiments on Alcator C-Mod and DIII-D, Nucl. Fusion, vol 59, number 8, 2019.*

The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump

by William J. Perry and Tom Z. Collina, Ben Bella Books Inc., Dallas.

This book presents the current status of the U.S. nuclear arsenal. It stresses the danger that a nuclear response on warning of an attack by a foreign power poses. The authors describe several false alarms warning that the U.S. was under nuclear attack. A nuclear exchange between the U.S. and a major nuclear power would probably make Earth unfit for human habitation even in nations not involved in the war. According to Patrick Huber writing in *The Cern Courier*, "A regional nuclear war involving just 1% of the global arsenal would cause a massive loss of life, trigger climate effects leading to crop failures and jeopardize the food supply of a billion people." Although this may not be a reliable number, (the author, a theoretical particle physicist, is Director of the Center for Neutrino Physics at Virginia Tech and interested in using neutrino detection to curtail the production of Pu239), it is one more open acknowledgement of the threat of any exchange of nuclear weapons.

The authors of *The Button* argue that the short times for launch decisions enhance this peril. This book is not comfortable reading since it makes very clear how short the time is for the President to decide if an attack warning is a false alarm or not. They stress that US land-based missiles are powerful weapons, which would probably be destroyed by a surprise attack although the survival of both bomber and submarine-launched missiles would leave the U.S. with considerable ability to retaliate with nuclear weapons after a surprise nuclear attack. All in all, missile defenses don't work well and warning systems have proved unreliable in the past (examples are provided). The computers scheduled to launch nuclear warheads which connect elements of the early warning which, in turn, are connected to the President are very vulnerable to hackers, both home-grown and working for a foreign power.

Part 1 recaps Truman's use of nuclear weapons and the reasons why he decided that only the President could launch the U.S. nuclear arsenal. According to the authors, Truman was chiefly worried about maintaining civilian, not military, control of the destructive power of nuclear weapons. His successors maintained this concern until the Soviet Union became a second nuclear superpower.

Part 2 recounts the history of US decisions about arms control treaties and negotiations as well missile defenses. It stresses the creation of the football, the president's emergency response satchel, which is carried by a military officer who is ALWAYS close to the president and even sleeps in the White House, and The Biscuit, a card carried by the president which contains the codes needed to launch nuclear weapons. The Biscuit has been lost by at least two presidents.

Part 3 summarizes the authors' recommendations for handling our weakness when only the President can press the button to launch nuclear weapons and has very little time to decide to launch or not launch.

The authors are certainly well-qualified to write about nuclear weapons. They both have long and distinguished careers in enforcing nuclear security. Perry is clearly a member of the Washington establishment that controls the U.S. military, particularly when it comes to nuclear policy. He has served as Undersecretary of Defense for Research and Engineering, as Secretary of Defense and as an advisor to Democratic presidents. My reaction to his authorship of *The Button* is not to argue with his knowledge but to wonder what event triggered the concern expressed in this volume when he no longer has power to change policy. Collina comes with a 30-year career in the non-profit sector concerned with preventing a nuclear war. He is currently Director of the Ploughshares Fund and undoubtedly possesses extensive knowledge of nuclear issues before the U.S. government which explains his interest in the issues examined in this volume.

One detail in the authors' recommendations calls for a major study of missile defenses and mentions that the 1987 APS report on the feasibility of directed energy weapons for missile defenses helped to scale back SDI. They suggest, on page 215, that the APS study and report on current missile defenses. Should FPS accept this suggestion as a challenge? Although the report would have to be released through APS via the Panel on Public Affairs, the Forum is now positioned to get a start before an outside panel of experts is appointed.

In summary, *The Button* is an interesting and relatively quick read written by well-qualified experts on nuclear policy. I strongly recommend it.

How to Avoid a Climate Disaster: the Solutions We Have and the Breakthroughs We Need

by Bill Gates (Knopf, New York, 2021). 257 pp. $26.95. ISBN 978-0385546133.

Fifty-one billion tons of greenhouse gases: that's how much planet Earth emits into its atmosphere every year. Avoiding a future climate disaster requires that this be reduced to zero by 2050. In his introduction to this book, Gates relates how he first became aware of this from encountering the problem of energy poverty in conjunction with his foundation's work in global health. He also learned that this means the energy sources used by planet Earth must be "clean."

This realization led him to take some actions on his own. He sold all his investments in fossil fuels, bought sustainable fuel for his jet, and purchased carbon dioxide offsets. In conjunction with COP21 (the Paris Climate Accord) he attracted 28 fellow investors to form the Breakthrough Energy organization. That all the miseries from COVID-19 have reduced greenhouse gas emissions by only 5% shows that reducing them to zero will be hard. But not reducing them to zero, he writes, would be a catastrophe. By using today's technology and the additional breakthroughs we'll need to achieve along the way, Gates believes that we can do it, and he has written this "how to" book to show us how to accomplish it.

Gates categorizes the 51 billion tons of greenhouse gases annually emitted into five groups: manufacturing (accounting for 31%), electricity generation (27%), food (19%), transportation (16%), and indoor climate control (7%). He evaluates the cost of eliminating these greenhouse gas emissions in terms of a Green Premium, which he defines as the percentage cost increase of a non-greenhouse-gas-emitting energy source as compared with its fossil fuel equivalent. Economics would dictate choosing the least expensive Green Premiums and funding reduction in their cost. Achieving a zero-carbon world would require that the whole world be able and willing to pay these Green Premiums.

Electricity can replace the fossil fuels (primarily natural gas) used for indoor climate control with heat pumps--and more efficiently than electric space heaters. In fact, Gates points out that heat pumps can provide both heating and cooling by pumping heat from the outside to the inside during winter and from the inside to the outside during summer. Moreover, for most new installations, depending on climate and the cost of electricity and natural gas, a heat pump can do so with a *negative* Green Premium.

Likewise, electricity offers a way to eliminate emissions from gasoline in most forms of transportation. The only exceptions Gates cites are long-haul trucks, planes, and ships, for which his answer is "advanced biofuels," except for ships, for which he recommends exploring the possible use of nuclear energy.

When it comes to manufacturing, processes can be re-engineered to use electricity except for making cement, which requires very high temperatures. Here Gates's suggestion is to employ carbon capture, although its Green Premium can range up to 140%.

The greenhouse gas emission problem from growing food stems largely from animals, for two reasons: the need to grow food for them, and the emission of an additional greenhouse gas, methane, by ruminants. This occasions what might be Gates's most severe recommendation: switch to plant-based meat.

Gates recognizes that these multiple uses of electricity in a post-carbon world require increasing its generation, by factor of as much as three. This would require adding electrical generation capacity at three times the present rate. And while solar and wind energy are now economically competitive to do this, their intermittency is a problem for customers who want the lights to go on when they flip the switch. Gates feels that it is unwise to attempt to decarbonize the world's energy sources by 2050 without nuclear energy, which he writes is "the only carbon-free energy source that can reliably deliver power day and night, through every season, almost anywhere on earth, that has been proven to work on a large scale."

Having cited innovations needed to reach zero carbon emissions by 2050 in the chapters on greenhouse gas emissions from each of the five sources, Gates' penultimate chapter compiles them into a list in his plan to reach this goal. Similarly to what he did at Microsoft, Gates structures his plan in terms of two stated goals: "expanding the *supply* of innovations" and "accelerating the demand for innovations. He then makes recommendations to achieve each goal.

Although Gates recognizes throughout this book that reaching zero carbon emissions by 2050 will be hard, he closes on an optimistic note because he says he knows what technology and people can accomplish. And he leaves us, in his last chapter, with suggestions of "What Each of Us Can Do." I would add that, in addition to these, each of us should read his book.

John L. Roeder
The Calhoun School
433 West End Avenue
New York, NY 10024
JLRoeder@aol.com