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# PHYSICS & SOCIETY

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## From the Editor

Are things finally clearing up with the pandemic? It seems as if it has evolved to an endemic thing that we will have to learn to live with. We have an article by R. Wiener, a member of our board of Editors, related to what has happened so far. Unfortunatley, a threat of nuclear war, much more deadly than the epidemic, has now materialized when we thought such threats had receeded into the past.

We also have an article on new events in the fusion field. And my predecessor in the Editor position has contributed an article on his experience as a member of the New Jersey Legislature. On this I can only reiterate that whatever may at one point lead me to quit my Editor position it will not be to join the Minnesota Legislature. The New Jersey one might be corrupt, but Minnesota's is (as Pauli would have said if he had been acquainted with that body) "not even corrupt." As usual, we have some news, and a couple of book reviews for which we have to thank our Reviews editor.

The contents of this newsletter are reader driven. Please send your contributions and your suggestions. All topics related to Physics and Society, broadly understood, are appropriate. Controversy is welcome: content is not peer reviewed and opinions given are the author's only, not necessarily mine, nor the Forum's nor, a fortiori, the APS's either. Letters to the Editor for publication are also accepted. Book reviews should be sent to the reviews editor directly (ahobson@uark.edu). Everything else goes to me.

And now something you have not seen for a while: an actual opinion Editorial!

*Oriol T. Valls, the current P&S newsletter editor, is a Condensed Matter theorist at the University of Minnesota.*

**Trouble at arXiv?**

I am one of the very earliest adopters of the arXiv preprint system, having posted everything I do since 1992. It is therefore with deep concern that I have watched its recent troubles. These are well exemplified by a case that has led to mass emails around the Condensed Matter community.

To briefly inform everybody else: there has been a raging controversy about superconductivity at very high pressure in certain materials. The experiments are extremely difficult and contentious arguments have swelled on their interpretation. In response to criticism, some published papers have been withdrawn, (see https://link.aps.org/doi/10.1103/PhysRevLett.102.197002) but in general authors are sticking to their

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guns, on either side of the question: are the materials superconducting or is the signal an artifact? Preprints advocating on either side of the question have been flying around arXiv. I am not in that subfield, but I have been following the arguments just for fun.

Nobody should be afraid of controversy: I have inserted the words "controversy is good" in nearly all my editorials since I have been Editor of this publication. It is what science needs. In the old days, such arguments were the private domain of people that were in the right mailing list. ArXiv made such preprints available equally to all.

It is therefore distressing that arXiv is withdrawing posted papers (on both sides) of this controversy. These are by well-known people who are participating in the argument. The papers thus censored used vigorous but by no means inappropriate or offensive, language. This is a loss to all of us.

Now, a recent example for which I have specifics: a set of authors on the Yes it is side posted a preprint (arXiv2201.11883). A few days after it was canceled by arXiv "moderators", who included a public notice labeling the language in the posting "unprofessional" and its language "inflammatory". The preprint in question (I had downloaded it before it was canceled) attacked a particular previous posting by a notorious naysayer, but not in a way that I would consider inappropriate, much less "unprofessional" and certainly not "inflammatory". Indeed the attacked naysayer (one of whose papers had also previously been canceled) made it known in a widely diffused email that he objected strongly to his own opponents' posting being canceled, arguing that the posting was within the bounds of scientific controversy. That should have been the end of it. It was not: the self appointed moderators refused to reinstate the posting until changes had been made (I believe they eventually were). When this was made public the explosion of emails (some by distinguished people, including at least one Nobel prize) ensued.

Such withdrawings (this is far from the only case, and it seems that even people have been banned from submitting anything) are made by anonymous "moderators". They then replace the contents of the posting with a notice (in the 2201.11883 case, and others) that "moderators" have canceled the paper "due to inflammatory content and unprofessional language". Having myself read several such postings, before they were canceled, I found that there was nothing particularly outrageous about the language used. Indeed, the language used by the moderators is itself more inflammatory ("unprofessional" being deeply insulting), than the original language in the submissions. As a referee (and I am an APS "Best Referee" awardee) if I found a report calling other people "unprofessional" and their language "inflammatory" without some very good reason, I would flag them for violation of APS journal policies.

The emergence of censorship in arXiv is not just a perversion of the original arXiv intent, but a deep loss to the Physics community, and indeed to society at large. Society has a stake in the freedom of exchanges among scientists so that scientific truth may emerge.

ArXiv uses only volunteers, many of whom do praiseworthy work. But "volunteers" can sometimes mean "self-appointed" and unsupervised. It is like the word "nonprofit" which sometimes serves as a cover for very profitable activities. As it sometimes happens to volunteer-run organizations, arXiv may have been infiltrated by the wrong kind of people. I was contacted with a senior person involved in the" moderation" and while I am grateful to him for trying to explain things, it is clear to me that he does not see anything wrong with the situation, on the contrary, he is angry that people are complaining.

There used to be no 'moderation' in arXiv, and when it started it was only to weed out non-physics (e.g. political or advertising ) postings. It should be eliminated. Yes, that would result on the occasional "the Earth is flat" posting. So what? The Earth would remain round. The APS allows all members their ten minute talk at meetings: very kooky things are occasionally said, and nothing happens. Physics has a tradition of Swiss patent office clerks and uneducated bookbinder's assistants publishing and contributing. Our journals, to this day, do not include titles such as PhD or whatever, in article bylines.

There is another lesson here and a troubling one: arXiv's code of conduct includes the usual statements on inclusivity and respect, concluding with: "All communication between arXiv community members should be respectful". (See https://arxiv.org/help/policies/code_of_conduct). Yet the "moderators" think nothing of themselves using insulting language ("unprofessional" is a very strong insult indeed) when a simple note politely saying "we believe this posting is in violation of arXiv policy" Or "the moderators have requested changes in the wording" would more than suffice. They exclude good controversy, they apparently fear it. They do not live by their own rules. I pointed this out to the person that contacted me . No reaction.

Unfortunately this problem is not limited to arXiv: people that speak loudly of inclusivity often exclude those that do not agree with them in some way. People that speak of 'respect' often think nothing of insulting those that do not toe their line.

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## April Meeting Forum-sponsored sessions

**Session E06: Climate Mitigation, Nuclear Energy and Proliferation**

E06.00001: An Infeasible Solution: Prospects for Nuclear Energy and its Potential Contribution to Climate Change Mitigation.
*Invited Speaker: M.V. Ramana.*

E06.00002: The role of nuclear energy in a decarbonized world: Examining and addressing equity, environmental justice, and governance constraints in the reactor design process.
*Invited Speaker: Aditi Verma.*

E06.00003: "Advanced" Isn't Always Better: Assessing the Safety, Security, and Environmental Impacts of Non-Light-Water Nuclear Reactors.
*Invited Speaker: Edwin S Lyman.*

**Session H06: Fighting Climate Change: Overcoming hurdles to implement non-carbon technologies.**

H06.00001: Leo Szilard Lectureship Award: The Right Path to Decarbonization.
*Invited Speaker: Michael E Mann.*

H06.00002: Global Rare Earth Supply Chains: Persistent Myths and Possible Pathways Forward.
*Invited Speaker: Julie Klinger.*

H06.00003: Making Power Markets Designed for Fossil Generation Fit for Purpose When Renewables and Storage Dominate.
*Invited Speaker: Benjamin Hobbs.*

**Session Q06: Artificial Photosynthesis**

Q06.00001: Making Fuels with Sunlight and Hybrid Photoelectrodes.
*Invited Speaker: Jillian Dempsey.*

Q06.00002: Conversion of Solar Energy into Chemical Energy by Artificial Photosynthesis.
*Invited Speaker: Frances A Houle.*

Q06.00003: Learning from Nature How to Make Solar Fuels.
*Invited Speaker: Gary Brudvig.*

**Session X06: Climate Change and International Security**

X06.00001: Climate Change and National Security: People not Polar Bears.
*Invited Speaker: David Titley.*

X06.00002: Climate and Conflict: Towards a Global Green Economy and a World of Societal Change.
*Invited Speaker: Tegan Blaine.*

X06.00003: Climate Change and Water Weaponization in the Middle East and Africa.
*Invited Speaker: Marcus King.*

**Session Y06: Physics Education Can Spark Unusual and Creative Careers Outside of Academia**

Y06.00001: Joseph A. Burton Forum Award (2022): No Simple Trajectory: Navigating between Research in Theoretical Physics and the Civic Responsibility of a Scientist.
*Invited Speaker: Robert L Jaffe.*

Y06.00002: Responsible AI: Combatting Blind Faith in Machine Learning.
*Invited Speaker: Scott Zoldi.*

Y06.00003: The Gravity of Leaving Science for the Circus.
*Invited Speaker: Julia Ruth.*

*Physics and Society* is the non-peer-reviewed quarterly newsletter of the Forum on Physics and Society, a division of the American Physical Society. It presents letters, commentary, book reviews and articles on the relations of physics and the physics community to government and society. It also carries news of the Forum and provides a medium for Forum members to exchange ideas. ***Opinions expressed are those of the authors alone and do not necessarily reflect the views of the APS or of the Forum. Articles are not peer reviewed.*** Contributed articles (up to 2500 words), letters (500 words), commentary (1000 words), reviews (1000 words) and brief news articles are welcome. Send them to the relevant editor by e-mail (preferred) or regular mail.



***Physics and Society* can be found on the web at www.aps.org/units/fps.**

## Consider a Spherical Virus

*Richard Wiener*

A simple dynamical model for the spread of an infectious disease is a gas of well-mixed particles that can be in one of three states: susceptible, infectious, or removed, the latter state so-named because particles in that state are removed from the disease transmission process. The particles change states due to their interactions. Susceptible particles irreversibly turn into infectious particles at a rate proportional to the fraction of susceptible particles times the fraction of infectious particles. Infectious particles irreversibly turn into removed particles at a rate proportional to the fraction of infectious particles. If the system begins evolving from an initial condition in which almost all particles are susceptible and a handful are infectious, the relationship between the fraction of infectious particles $I$ and the fraction of susceptible particles $S$ is given by

$$I = 1 - S + R_0^{-1} \ln S$$

where $R_0$, referred to as the reproduction number, is the ratio of the rate constants. (1) For $R_0 = 2$ (a reasonable guess for COVID in March 2020), 80% of the susceptible particles turn into infectious particles before all the infectious particles turn into removed particles. For a mortality rate of 0.5% (also a reasonable guess in March 2020), the model yields an order of magnitude estimate of one million COVID deaths in the US. The model contains no genomics, no virology, no immunology, no variability in susceptibility, no infection rate heterogeneity, no re-infections, no therapies, no vaccines, and no variants. Neither does it contain government mandates, changes in individual behavior or masking. Particles don't experience racism or lose their jobs, and they are not heroes on the frontlines or villains spreading disinformation. They don't have partisan politics. Nonetheless, tragically, the order of magnitude estimate based on the model is all too accurate two years later. It's a powerful illustration of how an extraordinarily simplified model can nonetheless illuminate the essential dynamics of a process, and in the case of disease spread provide a red flag warning. The myriad factors, which made the disease deadlier than it had to be and less terrible than it might have been, canceled out. The balance could've been different, resulting in many fewer deaths. Let's hope some collective wisdom emerges from this pandemic and next time is different.

[1] *Richard Wiener, "Lessons from Epidemiological Models," Physics and Society Newsletter, A Forum of the American Physical Society,* **49** *(3), 2-5 (2020).*

## I dare you to try it - part 2

*Andrew Zwicker*

On January 11, 2022 I took my oath of office to become a New Jersey state senator. The book that I put my hand on was a copy from 1822 of Principia, Vol. 1 by Sir Isaac Newton, one of the greatest books ever written. Tucked inside this grand book of science was the first page of the US Constitution, the NJ Constitution, and the Universal Declaration of Human Rights. Resting my hand on this book, with these documents inside, as I took my solemn oath surrounded by much of my family, was my way of acknowledging the path that had taken me to that very moment.

This path is full of moments, some planned, some unknown at the time that they were deeply consequential. As the author Robert Pirsig wrote, "You look at where you're going and where you are and it never makes sense, but then you look back at where you've been and a pattern seems to emerge. And if you project forward from that pattern, then sometimes you can come up with something."

Twenty years ago, I wrote about one of those moments in an opinion piece called "I dare you to try it," where I told the story of my experience mentoring a young person one summer. I helped change someone's life without realizing that my career trajectory had also fundamentally shifted. I used that mentoring story to write about my belief that the scientific community needs to do more outreach, not just monitoring, but in ways that improve the public's understanding of the scientific process, increase scientific literacy, and fight against the increasingly partisan pushback on public investment in basic research.

Today, while all those concerns certainly remain, our community has embraced the need for strategic and focused outreach and we've seen significant efforts, both individually and formally in places like the Forum on Outreach and Engaging the Public (FOEP).

Four years ago, I wrote a piece called Dr. Zwicker goes to Trenton about another one of those moments. In 2016, I became the first physicist in the New Jersey's legislature after I won my election to the General Assembly by 78 votes out of more than 34,000 cast.

Growing up in Englewood, NJ with a mother that talked politics every day until the day she died, I never in my wildest dreams imagined I would one day become an elected official. In that piece, I focused on the need for the scientific community to get more involved in the political process, whether it was running for elected office or providing expertise to government officials at any level.

Belief in science (trust?) has never been more partisan and that makes me both sad and angry because it shouldn't be that way. The Washington Post did a recent poll and found that 95 percent of Democrats believe climate change is a serious issue, compared to 81 percent in 2015. For Republicans, the numbers have actually declined: 39 percent say global warming is a serious issue, compared to 43 percent in 2015. According to a 2021 General Social Survey, 48% of Americans say they have "a great deal" of confidence in the scientific community, Democrats 64%, Republicans 34%.

This is not a partisan piece against a political party that has too often attacked science (and at times the scientist) simply because it does not fit a specific political narrative. I really couldn't care what political party you belong to or if you belong to one at all. But I do care desperately if you voted in your last election.

We are living during a critical time in our country's history, when science and public policy have never been more connected, coming out of the end of a global pandemic with an Earth that is warming and skepticism towards science permeating our daily lives. All of us have to decide, as scientists, how (not if) we are going to act.

Yes, I'm talking about running for elected office if you've ever thought about the possibility. I'm also talking about advising a local elected official, giving a general public talk about your research, or writing a letter lobbying for more funding for science.

None of this is easy, I get it. Science is supposed to be apolitical and we have the next conference coming up, a paper to write, tenure to worry about, students to advise. And as scientists we are supposed to rise above politics for the integrity of our profession. But as I look around me, I see a country ripping itself apart at the seams, people needlessly dying because they don't trust "the science" of vaccines, and extreme weather events increasing. If the scientific community doesn't speak up in greater numbers and with a louder voice, who will?

A few years ago, I was getting ready to speak on a panel about K-12 education and a person came up to me clearly wanting to speak, opening by identifying as a professional engineer and then launching into a diatribe about why climate change was pseudo-science. I distinctly recall listening politely for a few minutes before cutting off the conversation and walking away somewhat dismissively. I regret that.

As a friend and colleague so wisely stated in an email exchange on this topic, *"To me, the problem is not our ineffectiveness in conveying "scientific truth." Rather it is our lack of empathy for those whose fears we don't take seriously. This makes us too quick to ascribe these fears to ignorance, and it isn't surprising that we aren't heard."*

Let me be clear. I'm not pointing fingers, nor am I blaming anyone. But I'm asking for more of us to take action and to do so with a genuine desire to start a conversation *with* a person and not just lecture *at* a person.

Will all of this fix everything? Of course not. But I know it will help and I dare you to try it.

I've always wanted to end a piece this way, in memory of physics professor Bob Park and his column "What's New," *The views expressed here are my own and not necessarily shared by any institution or person, but they should be.*

*Andrew Zwicker*
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# Fostering a New Era in Inertial Confinement Fusion Research

*Tammy Ma*

Despite multiple recent articles in earlier editions of this newsletter decrying the slow progress in fusion research, the recent game-changing results on the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in Inertial Confinement Fusion (ICF), and technical progress in multiple areas of enabling technologies position us for a new and very exciting era in ICF. These results now place us on the threshold of fusion ignition where energy gain from nuclear fusion in the capsule exceeds the laser energy delivered, opening up future avenues and applications including high neutron yield for stockpile stewardship experiments and inertial fusion energy.

## THE NATIONAL IGNITION FACILITY (NIF) ACHIEVES THE THRESHOLD OF IGNITION

This past August, a breakthrough fusion experiment achieved a yield of 1.35 megajoules on the NIF, more than two-thirds of the 1.9 megajoules of laser energy deposited on the target, and eight times more than the previous record (see Figure 1). This result places NIF on the threshold of fusion ignition for the first time, and demonstrates the feasibility of laboratory-scale laser driven inertial confinement fusion to achieve high-yield conditions.

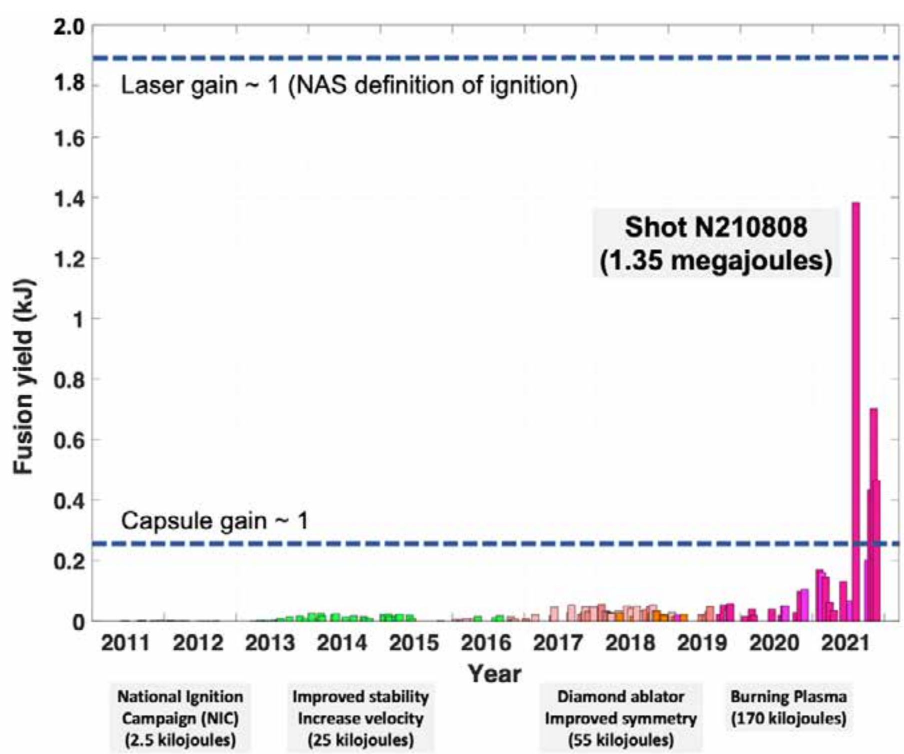


*Figure 1. Shot N210808 on NIF produced more than 1.35 megajoules of fusion yield and marks a significant advance in ICF research. The histogram shows the progress over a decade of dedicated research and development on the NIF.*

The NIF is a football-stadium-sized facility that houses the world's largest, most energetic laser (approximately 60 times more energetic than any other laser in the world when it was completed in 2009, and currently still 10-20x the energy of the next most energetic laser, which is in China). The precision and repeatability of this laser system are unprecedented in the world. NIF's 192 laser beams are guided and amplified through thousands of optical elements and then focused onto a miniature, highly engineered target the size of a BB. Inside this target is a spherical capsule containing the fusion fuel. The result is a hotspot the diameter of a human hair that creates conditions hotter and denser than those found at the center of the sun.

The central mission of the NIF is to provide experimental insight and data for the National Nuclear Security Administration (NNSA)'s science-based Stockpile Stewardship Program (SSP). Experiments in pursuit of fusion ignition are a vital part of this effort. They provide data in an important experimental regime that is extremely difficult to access, furthering our understanding of the fundamental processes of fusion ignition and burn, and enhancing the simulation tools that support our stockpile stewardship mission. Fusion ignition is the gateway toward even higher fusion yields in the future.

While full scientific interpretation of these latest results is still ongoing and will be vetted through the scientific peer-reviewed process, initial analysis shows that this experiment generated more than 10 quadrillion watts of fusion power for 100 trillionths of a second from a 50 micron-size burning plasma. This equates to an improvement of eight times over experiments conducted in the spring of 2021 and a 25-fold increase over the yield from a year previous. This shot also achieved capsule gain (defined as the ratio of energy released over the energy absorbed by the capsule) exceeding a factor of five. By the National Academy of Sciences 1997 definition of ignition (wherein the energy out of the target is equal to the total laser energy incident on it), the gain was 70% of that needed for ignition.

The experiment built on several advances gained from insights developed over the last few years by the NIF team, including new diagnostics; fabrication improvements in the target that include the hohlraum, capsule shell (which contains the deuterium and tritium fuel), and fill tube (by which the capsule is filled with the fusion fuel); improved laser precision; and design changes to increase the energy coupled to the implosion and the compression of the implosion.

Three repeat shots have now been undertaken to assess the sensitivity of that highest performing implosion to variability in the system and degradation mechanisms. In each of those cases, however, small differences in the number and size of particulates on the capsule surface, laser delivery, fill tube size, and target assembly meant that either more hydrodynamic mix or relative mode 1 asymmetry, or both, was recorded, resulting in lower total fusion yield. This variability in yield, however, is to be expected, as we are currently sitting on a performance cliff, where even small fluctuations can lead to large differences in the amount of alpha heating or burn propagation.

These recent results now open a vast new frontier for scientific exploration and exploitation. The same fusion plasmas that we create for ICF national security applications can also be exploited to become the basis of a future clean nuclear power source, which will also contribute to domestic energy independence and security.

## PROGRESS IN INERTIAL CONFINEMENT FUSION (ICF) LAYS THE GROUNDWORK FOR INERTIAL FUSION ENERGY (IFE)

As we approach inertial confinement fusion (ICF) ignition on the NIF, this will represent the first time in the laboratory that a fusion reaction will release more energy than was used to generate the reaction. This breakthrough forms the basis of a possible path to fusion energy that has significantly different technological and engineering risk portfolios than the concepts being pursued for magnetic fusion energy. To be clear, however, NNSA does not have an energy mission and, therefore, no NNSA resources are being used for inertial fusion energy (IFE) research at LLNL.

It must be acknowledged that, like all approaches to fusion energy, there are many scientific, technological, and engineering challenges to IFE. An IFE system would work by using a driver (such as a laser) to implode an injected target to fusion ignition and high energy gain conditions many times per second. Net electrical energy gain should be possible when the ratio of fusion energy released to input driver energy is on the order of 100 times the input energy. To make this possible, significant technological hurdles need to be overcome: ignition schemes with high yield and robust margin must be developed; drivers must be matured that have high efficiency and that can be operated at repetition rates of several times per second; ignition-quality targets must be economically mass produced, efficiently driven, and stably imploded at the rate of many times per second; optics and hardware produced that can withstand continual exposure to both high optical irradiance and fusion radiation; and reactor chambers must be designed to contain the micro-explosion products and adequately protect the driver. Furthermore, each of these systems will have to be engineered with cost, operability, and maintainability in mind required for economical energy production.

The National Academy of Sciences studied this problem and released an excellent report in 2013 entitled “An Assessment of the Prospects for Inertial Fusion Energy.” A number of findings and conclusions were made, including one that “The potential benefits of energy from inertial confinement fusion (abundant fuel, minimal greenhouse gas emissions, and limited high-level radioactive waste requiring long-term disposal) also provide a compelling rationale for including inertial fusion energy R&D as part of the long-term R&D portfolio for U.S. energy. A portfolio strategy hedges against uncertainties in the future availability of alternatives such as those that arise from unforeseen circumstances.” The report was also clear in concluding that “The appropriate time for the establishment of a national, coordinated, broad-based inertial fusion energy program within DOE would be when ignition is achieved.”[1] This is the time to begin as we stand at the threshold of ignition.

Fusion energy research is a high-stakes endeavor, and as such, technological diversity is always a good strategy. NNSA has made a significant investment in ICF, NIF, and other ICF-relevant facilities such as the Z Pulse Power Facility at Sandia National Laboratories, and the Omega Laser Facility at the University of Rochester. The DOE Office of Science Fusion Energy Sciences program can and should leverage this to help establish the IFE path forward. In 2022, a number of community-driven workshops are being held to assess research opportunities in inertial fusion energy, to be followed by a DOE Basic Research Needs Workshop.

## THE SYNERGIES BETWEEN IFE AND ICF ARE MANY AND MUTUALLY BENEFICIAL

The NIF is a marvel of science and engineering, allowing for research at the cutting edge of the most extreme conditions in the universe. However, it is exactly that – a scientific exploration facility, and very different from what would be needed for an inertial fusion energy power plant. As briefly touched on above, an electricity-producing IFE power plant would also require, for example, a more robust, high-yield ignition scheme likely different from what is pursued as part of the SSP; a driver, target injection, and tracking system, all operating at high repetition rates; an energy conversion system; robust first walls and blankets for wall protection, tritium processing and recovery, remote maintenance systems, and more.

The development of IFE towards the goal of a clean en-

1 *An Assessment of the Prospects for Inertial Fusion Energy, Committee on the Prospects for Inertial Confinement Fusion Energy Systems; NAS (National Academies Press, Washington, D.C., 2013).*

ergy source, is distinct yet highly compatible with NNSA's SSP mission through the ICF program. The synergies between IFE and ICF are many and mutually beneficial; for example, advanced targets that could yield high gain for IFE could similarly produce high neutron yield for ICF applications, while improvements in driver cost and repetition rate for IFE could similarly mean more HED experiments for SSP. Furthermore, IFE offers a long-term solution for climate change and energy security – important factors in the overall national security landscape.

The exciting vision of IFE also serves as an important recruitment and training tool for our field. Generations of laser and plasma physicists, scientists and engineers, have been drawn to the opportunity to be involved with the big science and challenging problem of fusion. The current U.S. leadership in HED/ICF research stems, in part, from the historical pursuit of IFE and as such, we must continue to take a leading role in IFE to maintain preeminence in this arena. The U.S. has an opportunity now to grow the national program by nourishing and leveraging our leadership in ICF with unique and world-leading competencies in the underlying science and technology that underpins IFE.

## THE TIME IS RIGHT TO RESTART AN IFE PROGRAM IN THE U.S.

We're now in an excellent position to make rapid progress in this area by leveraging the large investment being made in many emerging technologies and by the NNSA in ICF research. Many institutions already active in HED research would be well-positioned to contribute to this activity.

A number of promising technologies key to eventual IFE systems are making steady progress. In particular, exciting advances in repetition-rated high-energy laser technology and repetition-rated pulsed power technology in the U.S. over the last few years potentially lower the cost of a future driver for an IFE system (see Figure 2). Additive manufacturing and other automated manufacturing techniques are becoming more cost-effective and are being used as part of the current target fabrication effort on NIF. Artificial intelligence and machine learning are being deployed to train large-scale, high-performance, high-speed models, improve predictive simulation models, and quantify uncertainties.

Many countries are ramping up efforts in IFE alongside magnetic fusion energy. EUROFusion, a consortium of nine European nations, is working on a Roadmap for an Inertial Fusion European Demonstration Reactor, and China and Russia are already building "NIF-like" lasers. The fusion energy industry is rapidly growing, already seeded by nearly $5 billion of investment. The competition is substantial, but significant potential for productive partnerships and progress in fusion energy abound. For example, while public and private strategies differ in technical focus and deliverables, significant overlaps exist that are beneficial to both parties. Strategically partnering the public and private sectors can result in rapid enhancements in scientific and technological capabilities.

IFE is a multi-decadal endeavor and will require innovation to enable an economical energy source. This is an opportune time to move aggressively toward developing fusion energy as the world pushes toward decarbonization to mitigate the effects of climate change. Unlike other renewable

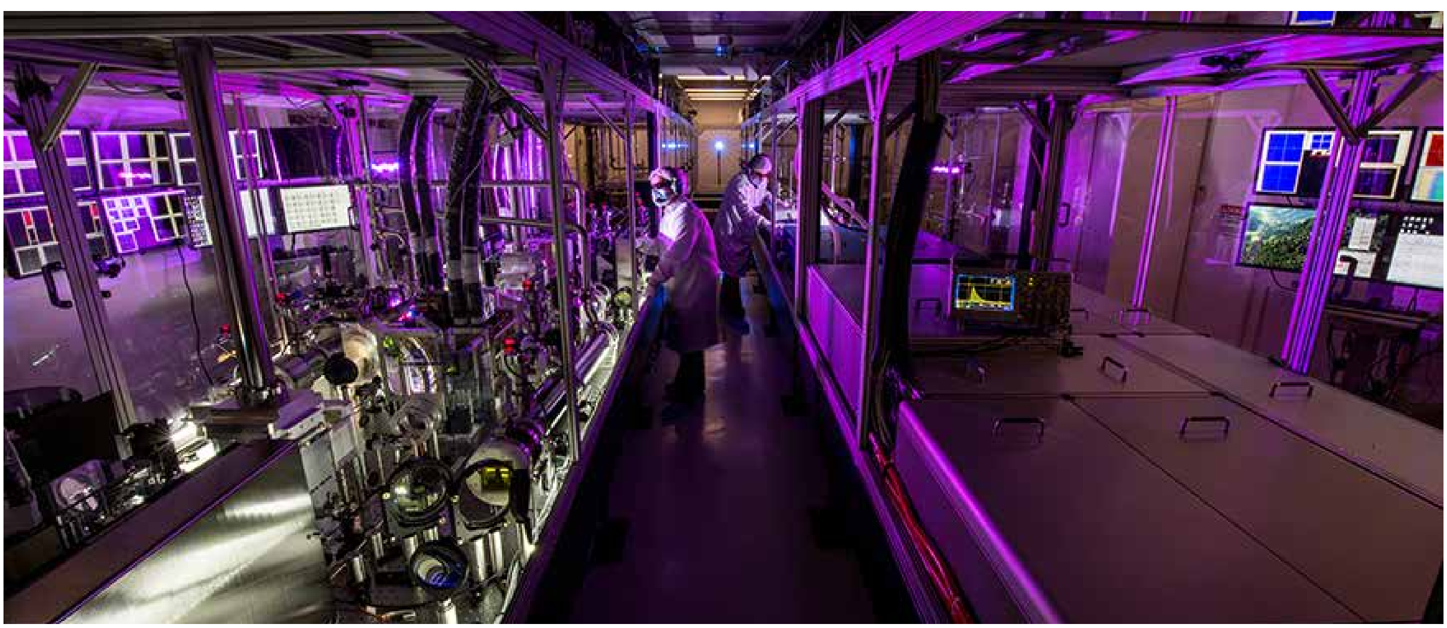

*Figure 2. The ultracompact High-repetition-rate Advanced Petawatt Laser System (HAPLS) is the world's most advanced, highest average power, diode-pumped laser system. It was designed, developed, and built by LLNL for the Extreme Light Infrastructure Beamlines (ELI-Beamlines) in the Czech Republic. HAPLS is designed to fire 10 times per second, which represents a major advancement over existing petawatt lasers and lays the groundwork for high-rep-rate laser drivers for IFE.*

energy sources, IFE would be both high-yield and extremely reliable, not susceptible to variables such as the weather or extended supply-chains. Future energy sources such as IFE will help make the nation more robust to potential geopolitical complications and alleviate our dependency on foreign energy providers. Now is the time to reestablish a vibrant national inertial fusion energy program and ignite a credible development path towards clean fusion energy.

For more details on the IFE Science & Technology Community Strategic Planning Workshop, see: https://lasers.llnl.gov/nif-workshops/ife-workshop-2022/. Information and links to the follow-on DOE Basic Research Needs will also be posted there when available. Wide community engagement is encouraged!

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*Tammy Ma is the Program Element Leader for High-Intensity Laser High Energy Density Science within the NIF & Photon Science directorate at LLNL. This article was largely taken from her written testimony to the Committee on Science, Space, and Technology Subcommittee on Energy, United States House of Representatives, Hearing on "Fostering a New Era of Fusion Energy Research and Technology Development," November 17, 2021.*

## Rethinking Land-Based Nuclear Missiles: Sensible Risk-Reduction Practices for US ICBMs

*by David Wright, William D. Hartung, and Lisbeth Gronlund (Union of Concerned Scientists, 2020). 44 pages.*

In this report from the Union of Concerned Scientists, David Wright, William Hurting, and Lisbeth Gronlund put forth their recommendations for the future of the US Intercontinental Ballistic Missile (ICBM) program. In the process, they provide explanations for the development of current nuclear policy, arguments from and counterarguments to the proponents of ICBMs, and several courses of action that would achieve the goals they recommend.

Right from the start, the authors state that ICBMs represent an unnecessary risk to the US and the world, especially given the fact that any benefits they have are also present in the much less risky submarine launched ballistic missiles (SLBMs). As it currently stands, the US ICBM force is kept on high alert at all times, meaning that they can be launched on command. Military policy is such that a maximum of 30 minutes is allowed to elapse between the detection of an enemy missile launch and the president's decision to order a nuclear strike. This is clearly not enough time to fully review the available information, and therefore needlessly creates the opportunity for unnecessary nuclear attacks.

The usual defense for this state of affairs is that if another nuclear power were to attack the US, they would need to destroy existing ICBM sites first in order to prevent a massive counterattack, and therefore would have fewer missiles to attack other targets, or indeed be dissuaded from attacking in the first place. As the authors point out, however, this would be the case even if the ICBM fleet were taken off high alert, since in the case of a nuclear attack they could simply be re-alerted and launched. Proponents of ICBMs at this point would argue that if the missiles are taken off high alert, they could be destroyed before they can be re-alerted and launched, removing the threat of a nuclear counterstrike. This is where the authors say that SLBMs can fill in the gap. Submarines, they say, are effectively invulnerable to attack when at sea, meaning that they are not at risk of being destroyed in an initial attack. Military leadership would then be able to order a counterstrike from the submarines, fulfilling the same role that keeping the ICBMs on high alert provides.

Taking the ICBM fleet off of high alert is not the final goal of the authors, however. Ultimately, they argue that the US should retire all its ICBMs and replace them with SLBMs. When the Cold War was at its height, ICBMs were much more accurate than SLBMs, and communication with submarines was unreliable when they were at sea. Over time, with technological advancements, these problems have been resolved. Today, SLBMs are just as accurate as ICBMs, communications have become more reliable, and, as previously mentioned, they are effectively invulnerable at sea. This means that SLBMs offer the same deterrent to aggressive nuclear strikes as ICBMs while also being much more secure.

So the question remains: why has the state of nuclear policy remained static despite the radical change in technology and circumstances? In addition to the defenses mentioned above, the authors state that politics and rivalries between service branches have kept these outdated protocols in place. When nuclear weapons were first being developed, the Army, Navy, and Air Force competed amongst themselves for control over the new program, and therefore the funding that came with it. In the end, this resulted in the so called nuclear triad of ICBMs, SLBMs, and strategic bomber aircraft. Today, although service rivalries aren't as intense as they were in the 1940s, competition for funding is still a driving force for the maintenance of the triad. On top of this, the political will to change the status quo in nuclear policy is very weak.

Because nuclear weapons are, rightfully, treated very seriously, many politicians assume that there are well-founded reasons to keep policies the same. Additionally, there are several states that benefit immensely from the continued existence of the ICBM fleet, namely Montana, North Dakota, Wyoming, and Utah. Each of these states houses an ICBM base or facilities used for the maintenance of ICBMs, which bring many jobs to those states. The senators and representatives of these states form the ICBM Coalition, and have blocked several attempts to reduce the ICBM fleet that have been introduced to Congress over the years. Defense contractors like Boeing and Northrop Grumman have a financial interest in the continuation of the ICBM fleet. Currently, the Air Force is developing a new generation of ICBMs known as the Ground-Based Strategic Deterrent, or GBSD. This program is expected to cost \$100 billion, and therefore represents a significant opportunity for the companies who will be contracted to build these missiles. As such, the defense industry has spent more than \$1 million dollars in campaign contributions to the ICBM Coalition alone between 2007 and 2018. The consistent campaign contributions, coupled with the economic benefits for their states, keeps these elected officials fighting against any change in nuclear policy.

Wright, Hartung, and Gronlund make an excellent case for phasing out the US ICBM fleet and replacing it with SLBMs, both on its own merits and in opposition to points often made by proponents of ICBMs. Each chapter is presented as a complete picture of the evidence, counterarguments, and defenses that are relevant for each subtopic of the report. Because many of the topics overlap, this does lead to a somewhat repetitive feeling when reading the report from beginning to end. In addition, due to the nature of the subject matter, the article can be a bit dry at times. There is no question, however, that the article presents an important argument for a change in policy that has the potential to save lives, and I look forward to it being taken into consideration in future policy changes.

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## The Fairy Tale of Nuclear Fusion

*L. J. Reinders, Springer Nature Switzerland AG, 2021, 621 pages, ISBN 978-3-030-64344-7, $125.*

This 600-page tome actually comprises 3 books in one: a detailed history of fusion energy research, covering the scientific, technological and political aspects; a textbook of virtually all fusion concepts and related plasma phenomena and technologies, assisted by an unusually instructive 12-page glossary; and a critical analysis and comments on each step in the erratic development of fusion systems, supporting the conclusion that a viable fusion power plant is a "fairy tale" for the foreseeable future.

The three "books"—actually themes—are closely intertwined, with one theme interrupted by another, but a 30-page index (in small print) enables one to navigate the 600 pages, regardless of which theme one chooses to follow.

The book is basically a history, with presentation of specific experimental devices and plasma phenomena as they turn up chronologically. The history covers some 80 years from the 1940s, before fusion R&D was established in national programs, until 2020. Many other books cover the same historical events up to about 2000, but perhaps not so completely as Reinders, and certainly not as up-to-date. The author has managed to unearth practically everything going on in fusion research since the earliest days, with meticulous referencing throughout, and he comments sharply on every bit of it.

Existing books on fusion R&D cover plasma phenomena and fusion devices explained at various levels of supposed reader background ranging from the general public to the fusion specialist. Reinders began his professional career as a particle physicist, then switched to less technical pursuits, so that he is able to present this material at a level that can be readily understood by the typical reader of *Physics and Society* as well as by those journalists and energy planners who have at least some training in the physical sciences. There are dozens of superb color diagrams clearly illustrating fusion concepts and related plasma phenomena, such as for tokamak magnetic systems and laser-heated hohlraums, as well as many relevant photographs. The pervasive instabilities plaguing confined plasmas are described throughout. The text is almost entirely equation-free, although some simple formulas are actually given in words.

In the universe of fusion books the third theme of critical analysis mentioned above is nearly unique to this volume. Of the hundred or so books on the fusion enterprise that have been published, all are enthusiastic promoters of the feasibility and inevitability of fusion power reactors. Their critical comments are largely limited to perceived political obstacles that they claim prevent the adequate funding of fusion R&D that would ensure the timely realization of fusion power. Not Reinders, who makes the point in dozens of appropriate places that for fundamental scientific and technological reasons—not just available money—a practical fusion reactor cannot be developed in the foreseeable future, and maybe never.

Throughout the text Reinders quotes statements from fusioneers claiming major breakthroughs and predictions of imminent power production and shatters them with irony, satire and sarcasm. These quotations and Reinders' accompanying remarks capture well the hubris, self-deception and ludicrous promises that have characterized the fusion enterprise from the 1950's to this very day.

There are literally ten thousand articles by journalists as well as fusion promoters that glorify the prospects for fusion R&D, but only a handful of articles are seriously critical. Reinders identifies much of the latter and quotes amply from their pages in chapters 18 and 20 and elsewhere. For example, he picks up the argument that adequate breeding of tritium fuel is impossible [1], thus dooming reactors that burn deuterium-tritium and requiring the much more demanding development of reactors fueled by deuterium only. The adverse environmental and economic issues of the ITER tokamak reactor project (ch. 10) as well as putative fusion power reactors are also well covered.

Despite the book's myriad instances of balloon-puncturing, I have to take fault with what I regard as its over-indulgent treatment of so-called fusion concepts that have produced no neutrons or only token amounts [2], a shortcoming that it shares with all texts on fusion research. In chapters 13-15, the author includes the entire zoo of fusion contraptions for the sake of completeness and explains the physical principles that supposedly underlie each one. Many of these schemes are vying for the hotly contested title of most worthless fusion concept, but Reinders has no interest in ranking them on a credibility scale such as by "fusion triple product" or neutron production. While he often expresses reservations, he does little to demolish any "alternative concept," even those that are prime examples of voodoo fusion energy [2]. In one such case, 4 pages with elaborate diagrams are devoted to a Lockheed-Martin assembly based on leaky cusp and mirror plasma confinement schemes that were tried and rejected decades ago. This contraption has insignificant fusion triple product and zero neutron production.

Surprisingly, so-called "cold fusion" is barely mentioned. Given the uproar it caused 3 decades ago and sporadically since then, surely some space could have been devoted to explaining why it violates the well established tenets of nuclear physics, an elucidation that non-specialist readers would welcome.

Also perplexing given Reinders' customary skepticism is that he apparently takes seriously the latest advertised plans for multi-billion-dollar reactor projects (chs. 9, 17) that are proposed to follow operation of the real-world ITER reactor, or even to be contemporary with ITER. These projects include design activities for numerous demonstration reactors in Europe and Asia, engineering test reactors, fusion-fission hybrid reactors and various "pilot plants." In fact none of those pipe dreams will be built or even could be built, much less made to operate. The author does note that two of them, the US's proposed FNSF and LIFE, are moribund, but may not realize that all the other grandiose proposals are headed for oblivion and should be derided as chimeras.

But these criticisms concern minor issues, and this treatise is all the same a monumental tour de force. The book can even be employed as an entertaining and educational "fusion encyclopedia" to be consulted at random or with the Index, as nearly everything fusion-related is at least mentioned somewhere and presented in an engaging matter.

This book can also serve to mitigate the current pandemic of fusion frenzy [3]. For more than 60 years, countless ignorant and foolish journalists have acted as unwitting shills and cheerleaders for government fusion labs and private fusion startups. Energy prognosticators dutifully include fusion reactors in the post-2050 energy scene. Now that Reinders' book is available, journalists and energy planners should be required to read it before writing another word.

## References


*[1] D. Jassby, "Fusion reactors: Not what they're cracked up to be," Bull. Atomic Scientists (online), April 19, 2017.*

*[2] D. Jassby, "Voodoo Fusion Energy", APS Forum on Physics and Society, Vol. 48, No. 2, April 2019, 13-16 (online).*

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