Vol. 53, No. 4 October 2024

PHYSICS & SOCIETY

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

From the Editor

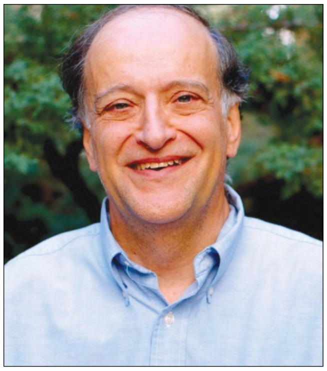
We have three articles in this issue. The first is by Roohi Dalal, on the weapons potential of enriched Uranium, a subject that was dealt with in recent APS meeting forum sponsored sessions. On a related topic we have an article by Jassby on the current status of the tritium stockpile. A third article, by Moynihan, continues the ongoing discussion we have been having on fusion and its potential for energy generation.

It is more than a little depressing to consider the need for articles on nuclear proliferation and the reason why this has become a topic of so much current interest. The inescapable fact is that the danger of a nuclear conflict has drastically increased in the last few years: the end of the traditional cold war did not put an end to it, but merely induced a pause which has turned out to be very temporary.

This is a newsletter and we do publish news. Warren Buck, the Chair elect of this Forum has provided a very informative news item on planned Forum activities at the huge March/April 2025 APS meeting.

As usual, we have a couple of topical Book reviews, provided by our Book Review Editor Quinn Campagna.

We are still looking for a Media Editor. This is a great opportunity for somebody up to date on everything related to social media, and who wants to get more involved in Forum activities. Please apply or get somebody to apply. Just send me an email.



Oriol T. Valls, the current Physics and Society Newsletter Editor, is a Condensed Matter theorist at the University of Minnesota.

This newsletter and its contents are largely reader driven. All topics related to Physics and Society are acceptable, excluding only undiluted politics and anything containing invective, particularly of the ad hominem variety. Manuscripts should be sent to me, preferably in .docx format, except Book Reviews which should be sent directly to book reviews editor Quinn Campagna (qcampagn@go.olemiss.edu). Content is **not peer reviewed and opinions given are the author's only, not necessarily mine, nor the Forum's nor, a *fortiori*, the APS's either**. But subject to the mild restrictions mentioned above no **pertinent subject needs to be avoided on the grounds that it might be controversial. On the contrary, controversy is welcome.**

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

IN THIS ISSUE

Brief Program Report

Warren W. Buck, wbuck@uw.edu
Committee Chair and FPS Chair-elect

The FPS invited speaker sessions have been determined for the APS 2025 March/April Joint meeting March 16 - 21, 2025; and we are excited with the quality of speakers presenting.

Though the meetings are now joint, the FPS topics are divided into March meeting sessions and April meeting sessions.

March FPS Sessions:

1. Intersections of quantum science and society
2. Science communication in an age of misinformation and disinformation/defending the culture of science
3. Fusion energy, Lab to grid commercial development and climate impacts/ramifications

April FPS Sessions:

1. History and physics of the Manhattan Project and the bombings of Hiroshima and Nagasaki
2. International scientific collaboration amidst current geo political conflicts
3. Awards Session: Joseph A Burton Forum Award & Leo Szilard Lectureship Award, overview of FPS followed by a light reception.
4. A possibility of a fourth session on Climate Impacts under development.

Session co-sponsorships include FHPP (Forum on History and Philosophy of Physics), DQI (Division of Quantum Information), DNP (Division of Nuclear Physics) and FIP (Forum on International Physics). Additional co-sponsorship sought with FDI (Forum on Diversity and Inclusion).

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, letters (500 words), commentary, reviews 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 aps.org/units/fps.**

Reevaluating nuclear security standards: The modern-day weapons potential of high assay low enriched uranium

Roohi Dalal, Outer Space Institute and University of British Columbia, rdalal@outerspaceinstitute.ca

Strict international restrictions have been placed on the use and transfer of Highly Enriched Uranium (HEU), because of its direct usability in nuclear weapons. Today, these controls exist on uranium enriched to contain 20% or over of the isotope uranium-235 by mass. However, a recent paper, titled 'The weapons potential of high-assay low enriched uranium' (Kemp et al. 2024)[1] points out that this threshold is meaningless without accompanying limitations on the mass of uranium at a given site, and insufficient given the increasing use of uranium enriched to 10-20% ^{235}U (high assay low enriched uranium, or HALEU). With ever-growing plans to use large quantities of HALEU in civilian power reactors both for terrestrial and outer space applications, it is essential that the United States and other countries reevaluate their security standards.

The weapons potential of uranium depends on both its level of enrichment and the total mass. Above 6% ^{235}U enrichment, uranium fuel can sustain an explosive fast chain reaction that produces the massive amount of energy released by a nuclear weapon. However, for a given configuration (e.g. material density and neutron reflector), the lower the level of enrichment, the more uranium that is needed for a fast critical mass, and, in general, for a weapon.

Based on analysis conducted at Los Alamos in 1954, the U.S. Atomic Energy Commission (AEC) concluded that fuels below a 10% enrichment level could not be used to make a practicable nuclear weapon, regardless of quantity,[2] but fuel enriched to 10-20% ^{235}U had "weapons significance", meaning that it could be used to make a nuclear weapon if available in sufficient quantity, which was defined as ($2/E^{1.7}$) kilograms, where E is the enrichment percentage. Nevertheless, the AEC allowed exports of uranium, through the Atoms for Peace program, up to 20% enrichment in quantities below the threshold of weapons significance.

The AEC's allowance of HALEU exports was in large part a cost-saving measure – operating reactors with lower enrichment uranium is more expensive, due to the lower ^{235}U density of the fuel. Additionally, HALEU was used primarily to fuel research reactors in small enough quantities that making a weapon from the fuel of a single reactor would have been impractical. It also seems that the decision was influenced by an expectation that future reactors would rely primarily on plutonium for their fuel – a material with far greater weapons potential than HALEU.[3] Over time, the 20% threshold became accepted as the norm for both domestic and international purposes, with both the AEC and U.S. Nuclear Regulatory Commission allowing less strict security rules for domestic users working with uranium enriched below 20%.[4]

Yet today, rather than plutonium, a growing number of reactors are being designed to use HALEU as a fuel. These are largely small modular reactors and microreactors, which are much smaller in size than conventional reactors.[5] Because of their smaller sizes and greater surface to volume ratios, these reactors are generally neutron inefficient, requiring fuel enriched above the 3-5% level that is standard for commercial reactors, and large quantities of it. In fact, many proposed designs for these reactors require hundreds to thousands of kilograms of 19.75% ^{235}U HALEU. Estimates indicate that several hundred to about 1000 kg of HALEU could produce explosive yields similar to or greater than the bomb that the United States dropped on Hiroshima, equivalent to 15 kilotons of TNT[1] (note that 1000 kg of uranium represents a sphere with a radius slightly less than 25 cm). It is clear that such reactors using HALEU would have serious implications for the potential to produce nuclear weapons.

The Department of Energy (DOE) and Department of Defense are currently funding at least 10 reactor concepts that would each use hundreds to thousands of kilograms of HALEU.[6] Despite its weapons potential, the Nuclear Energy Institute urged the U.S. government to make over 100 tons of HALEU available each year, starting by 2030.[7] This fuel will be shared by the DOE with private companies, per the Energy Act of 2020,[8] and the 2024 Congressional Appropriations Act makes $2.72 billion available to subsidize the private production of low enriched uranium, including HALEU.[9] NASA and DARPA are also developing a Demonstration Rocket for Agile Cislunar Operations (DRACO), that will use 300 kilograms of HALEU, and will be launched into Earth orbit in 2027.[10] Other countries including the United Kingdom,[11] and France,[12] have also indicated an interest in HALEU production for terrestrial small modular reactors, and the United States,[13] Russia, and China,[14] have all announced plans to build nuclear power plants on the moon, likely using large amounts of HALEU[15] or HEU.

Despite the flurry of global activities involving HALEU, there has been no recent reevaluation of the risks that this fuel poses to international security. Any country operating HALEU reactors could be days away from building a nuclear weapon, while the use of HALEU in cooperative space missions poses an additional threat to the nonproliferation regime. Rockets and other space missions powered by HALEU are not contained to the borders of their launching states, making it more likely that others could get their hands on this weapons-usable fuel, for example if a rocket suffers a failure during launch and lands in another country. While the 20% enrichment threshold for additional security measures was acceptable before HALEU began to be used in such large quantities, these plans mean that a reassessment of security protocols for HALEU is urgently needed.

The authors of the HALEU study urge the U.S. Congress to direct the DOE's National Nuclear Security Administration to commission a new review of HALEU proliferation and security risks, that takes into consideration the changes in nuclear design software since the 1966 study by the AEC. They further recommend that such a study be peer reviewed by an independent body organized by the National Academies of Sciences, Engineering and Medicine, or JASON, an independent scientific advisory group which consults for the U.S. government on issues related to defense science and technology. Ideally, such a study would set a new, technically justified lower enrichment limit for weapons-usable uranium, such that uranium enriched above 10 to 12% ^{235}U is protected with similar security measures as HEU. This would enable reactor programs to continue with modest additional security costs or perhaps result in different design choices, while also safeguarding the nonproliferation regime.

References

[1] R. S. Kemp et al., "The weapons potential of high-assay low-enriched uranium" *Science*, 384, 600, pp. 1071-1073 (2024) https://www.science.org/doi/10.1126/science.ado8693.

[2] U.S. AEC, "Research Reactors for Foreign Application: Report to the General Manager by the Director of Reactor Development" (1954); https://fissilematerials. org/library/haf54.pdf

[3] U.S. AEC, Study of Strategic Importance of Nuclear Materials, (5 December 1966), as cited in "Report of the Advisory Panel on Safeguarding Special Nuclear Material" (1967); https://www.osti.gov/servlets/ purl/4264753.

[4] U.S. NRC, "Rulemaking for Enhanced Security of Special Nuclear Material" (2015); https://www.nrc.gov/docs/ ML1432/ML14321A007.pdf.

[5] Joanne Liou, "What are Small Modular Reactors (SMRs)?", IAEA Office of Public Information and Communication, 13 Sept 2023 https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs

[6] NASEM, Merits and Viability of Different Nuclear Fuel Cycles and Technology Options and the Waste Aspects of Advanced Nuclear Reactors (National Academy Press, 2023).

[7] Nuclear Energy Institute to Secretary of Energy Rick Perry, "Need for High-Assay Low Enriched Uranium" (5 July 2018); https://www.nei.org/CorporateSite/media/ filefolder/resources/letters-filings-comments/letterperry-haleu-20180705.pdf.

[8] U.S. Congress, "Energy Act of 2020" https://science.house.gov/2020/12/energy-act-of-2020

[9] U.S. Congress, "Consolidated Appropriations Act, 2024," Public Law no. 118-42; https://www.congress.gov/ bill/118th-congress/house-bill/4366/text.

[10] Defense Advanced Research Projects Agency, "Environmental Assessment for the Demonstration Rocket for Agile Cislunar Operations (DRACO) Mission" 23 Oct 2023, https://www.nasa.gov/wp-content/uploads/2024/01/draco-final-ea-oct2023.pdf

[11] UK Department for Energy Security and Net Zero, "UK invests in high-tech nuclear fuel to push Putin out of global energy market," (Press Release, 7 Jan 2024); https://www.gov.uk/government/news/ uk-invests-in-high-tech-nuclear-fuel-to-push-putinout-of-global-energy-market.

[12] European Commission, "Commission approves €300 million French State aid measure to support Nuward in researching and developing small modular nuclear reactors," (Press Release, 26 April 2024); https://ec.europa.eu/commission/presscorner/detail/en/ip_24_2228

[13] NASA, "NASA's Fission Surface Power Project Energizes Lunar Exploration," (Press Release, 31 Jan 2024); https://www.nasa.gov/centers-and-facilities/glenn/nasas-fission-surface-power-project-energizes-lunar-exploration/

[14] Reuters, "Russia says it is considering putting a nuclear power plant on the moon with China," 5 March 2024, https://www.reuters.com/technology/space/russia-china-are-considering-putting-nuclear-power-unit-moon-ria-2024-03-05/

[15] Jeff Foust, "NASA plans for lunar fission power systems face fiscal challenges," 20 July 2023, https://spacenews.com/nasa-plans-for-lunar-fission-power-systems-face-fiscal-challenges/

Fusion is not hindered by the science, but everything else.

Matthew Moynihan, moynihan.matthew@gmail.com

Introduction:

What is limited the development of fusion power in the United States is not the science or technology but factors like funding, organization and political support. Fortunately, these conditions are starting to shift. Fusion energy offers Mankind an abundant, zero-carbon energy source; a technology that will become increasingly valuable in a hotter, more energy insecure world. Other governments are starting to realize this. In the Fall of 2023 Germany announced 370 million euros [32] and the UK announced 650 million pounds in fresh funding for fusion [31]. The recent COP28 was all abuzz [33] around the progress made by Commonwealth Fusion Systems; the company intends to start up their SPARC reactor by the end of 2026 [34]. These governments are being dragged along by a private sector that is increasingly bullish on this technology. The fusion startup community has now raised over 6.1 billion dollars in private funding across several dozen (mostly US-based) firms [35]. From a technical prospective, these firms range from the utterly foolish to the technically rigorous, but many share a common theme: they are tackling research that the US government was traditionally unable or unwilling to fund. There are several good examples of this from the past 25 years:

- **REBCO Tokamaks**. More than a decade ago, the Plasma Fusion Science Center at MIT was evolving a concept for a compact, REBCO-magnet based superconducting tokamak. Director Dennis Whyte assigned his class - with many future fusion luminaries like Bob Mummgraad, Derek Sutherland and others – the task of designing this Tokamak using a REBCO superconductor [30]. What emerged, were a series of papers spelling out a concept called the VULCAN reactor and touting the clear advantages of a 10-13 tesla compact tokamak [25]. Such magnets were not new, but building a compact tokamak from them had not been conceived. After the Alcator-CMOD tokamak was shut down in 2012 [26-28], Dr. Whyte went on a lecture circuit [28-29] trying to drum up government funding for this new reactor. But the Department of Energy was unwilling to build this new machine, which ultimately lead a team of six MIT staff to form Commonwealth Fusion Systems in 2017.
- **Dynomaks**. For several decades, Dr. Thomas Jarboe at Los Alamos and later at the University of Washington was working on a concept now known as the Dynomak [17, 18,19-23]. This device is based on a plasma theory developed by John Taylor in 1974 that if a loop of plasma minimized its' energy but conserved its' helicity, it would self-structure into a twisted loop similar to the plasma shape inside a stellarator [19]. Over a large body of literature, Dr. Jarboe argued that such a reactor would have fundamental advantages (easier heating, better stability, lower engineering requirements, etc..) than alternative fusion reactor designs [20-24]. Dr. Jarboe and his group built a series of prototype spheromak devices (HITS, HIT-SI, etc.) at the University of Washington to explore this idea. In 2012, the team developed a way to stably and inductively heat the plasma inside this device, by injecting magnetic helicity [24]. In the 2014, Dr. Jarboe - and his hand-picked successor Dr. Derek Sutherland - attempted to drum government funding for developing this into a fusion reactor. But the Office of Fusion Energy Sciences was unwilling to fund this work, leading the University of Washington spinning out the fusion startup known as CT Fusion [11, 22, 18].
- **Excimer IFE**. Roughly a decade ago, the NIKE and Electra lasers at the Naval Research Laboratory demonstrated the high-repetition shot rate needed for an Inertial Fusion Energy (IFE) power plant. The NIKE laser was able to fire more than 90,000 shots in ten hours and Electra pulsed power hardware was able to fire more than 3 million times over 3 weeks [10, 12]. This extraordinary technical achievement was enabled by a laser architecture that was fundamentally different than the one used at National Ignition Facility [12-14]. To progress further, NRL would require NIF-level funding to build out the supporting technology (optics, etc.) for this novel laser architecture. Director Dr. Stephen Obenschain and the NRL team argued in literature [9] that these achievements should be championed and advanced with more government funding. But the US National Nuclear Security Administration (NNSA) did not see this as aligning with their strategic goals of stockpile stewardship and ultimately cut the NIKE and Electra budgets. Dr. Obenschain had to ultimately form his own company [15] and this year, the Naval Research Laboratory shuttered the NIKE laser program [16].
- **Flowing Pinches**. In the mid-nineties, Dr. Uri Shumlak developed a concept known as a shear-flowed stabilized (SFS) pinch [5]. By that time, shear-flow-stabilization was a common technique used by the tokamak community to improve device performance [6]. Shumlak reasoned that if this technique was applied to a pinch a fundamentally small fusion reactor could be realized. Over two decades, Dr. Shumlak group at the University of Washington built a series of machines (FuZe, etc.) that demonstrated beautiful

pinch behavior over increasingly longer run-times [2-4]. Shumlak sought government funding to further develop the idea but the Office of Fusion Energy Sciences refused to increase funding for this research. This ultimately led Dr. Shumlak, Dr. Brian Nelson and Mr. Benjamin Conway to form the fusion startup Zap Energy in 2015 [7-8].

There are many additional examples of this trend – it can be convincingly argued that General Fusion, TAE Technologies, Renaissance Fusion and Thea Energy were all started because these teams could not garner government support. But if fusion power could do so much to decarbonize our civilization, then why it is so hard to get US government funding?

Current Funding:

At present, researchers have four sources of money within the US government: the National Nuclear Security Administration, the Office of Fusion Energy Sciences (OFES), the Advanced Research Projects Agency–Energy (ARPA-E) and the DOE Milestone Program. There has also been a small program called INFUSE that lets fusion startups leverage national laboratory resources to address scope-limited problems. Taken together, the total funding dispensed was roughly 1.4 billion in 2023 [36-38] but, roughly half this funding is allocated to nuclear weapons related research and is not geared around energy. This is a huge improvement from just five years ago when both INFUSE and the Milestone programs did not exist, but it is worth pointing out that the United States spent more money on the B-21 Bomber in 2024 [49]. Clearly, fusion energy is not as high a priority for the US government as many other challenges.

But beyond this relatively low funding, these US agencies often have competing and disconnected positions which are not well-coordinated. A good example is in the conflicting positions of the OFES and ARPA-E. ARPA-E started funding fusion research in 2014 under the leadership of Dr. Patrick McGrath [40]. That agency supported innovative research that had previously been dropped by the Department of Energy, seeding many of the fusion startups we see today. At that time, there was an internal debate within the department about who should fund fusion, OFES arguing it should be their office [39]. But, the focus of OFES during this period was not on alternative fusion concepts at all, but rather on the US-ITER program. Everyone in fusion has an opinion about the ITER project - but is worth pointing out that the program puts all the funding into just one approach and just one reactor design. The reality was that ARPA-E involvement in fusion put the ITER project in a bad position politically. It is hard to convince hundreds of politicians in Washington that the ITER project is the best way to advance fusion energy – while acknowledging that alternative (and potentially cheaper) approaches existed. In fact, it was in the US-ITER program's interest to ensure that alternative fusion technologies were not funded. It could even be argued that the OFES deliberately attempted to kill off alternative fusion approaches to maintain their focus on the US ITER program.

A Billion For Fusion:

Ultimately, Congress and the White House have the ability to fund and control all of this, and fortunately, this political landscape has shifted over the last five years. For about a generation – from the late 1980's until the late 2010's – the fusion program was presented to members of Congress as science or defense initiative. We funded it because it was great science - which was critical to maintaining American exceptionalism. Framing fusion as an *energy* program was always a fraught political position. The world spends ten trillion dollars each year on energy [41] and lots of jobs and money are tied up in maintaining the status quo. Industries like wind, solar and electric cars have already gone through long-term political fights with Big Oil and Big Auto to get the funding that they now enjoy. Fortunately, fusion energy has made great progress within both Congress and the White House. In the Fall of 2021, the House of Representatives formed the Fusion Caucus, which today can claim at least 70 members [42]. Over the Summer of 2022, this caucus was able to authorize 1.023 billion dollars for fusion within the CHIPS and Science Act [43]. Fusion also got support within the White House – with a White House Summit organized in 2022 and a billion requested for fusion in the 2024 Presidential Budget Request [44, 45]. But getting change in Washington is never that simple. Any new fusion funding will require Congressional (1) authorization, (2) appropriation and (3) passage by the President. As of this writing, only two of these three boxes are checked. The 2024 "billion dollars for fusion" failed in the House Appropriations committee over the Summer of 2023 - although advocates have not stopped lobbying. It was four members of the House Freedom Caucus on this committee who opposed this funding. For those of us who had been advocating for fusion funding for years - this defeat was a gut punch.

The UK:

All of this sharply contrasts with conditions inside the United Kingdom, where private fusion is being well-supported by the government and well-led by their Atomic Energy Agency (UKAEA). The UK has grown multiple fusion startups (Tokamak Energy, First Light Fusion, etc..) as well as multiple supporting companies (Oxford Sigma, etc..) out of anchor institutions like Imperial College and Culham. These organizations are actually physically clustered close together around Oxford, giving them inherent advantages. They are also being well led; under Sir. Dr. Ian Chapman, the UKAEA has done everything it can to fund fusion. Using public money, the agency has built a superconducting magnetic test stand, established the largest tritium handling facility in the world, and built a center to prototype robotic maintenance of fusion reactors [1]. The UKAEA is also decommissioning the Joint European Torus - and using it to show industry what the unique challenges are for dismantling fusion reactors. The government has also invested 248 million pounds into a new national fusion device called STEP and has encouraged heavy industry to get involved [50]. The agency sponsors an internship program, where university students receive a stipend to work at fusion startups on scope-limited projects. All of this will build the workforce and industrial base needed to build fusion reactors within the UK. The UKAEA has also done all it can to build public-private partnerships: establishing the fusion cluster - an umbrella organization that connects private and public groups. The fusion cluster organizes investor events, posts fusion jobs, facilitates communication, funnels the workforce and enables government to stay on-top of the needs of industry. All of this support has inadvertently led to breakthroughs on the technical-side including breakthroughs in superconducting magnets [46], advanced particle physics code, costing analysis [47], heating using magnetic reconnection [48] and other advances. The bottom-line is that technology is not the limiting factor in fusion power's development – money, organization and support is what is killing this field.

Conclusion:

Despite the near-term setbacks in developing fusion, it is a safe bet that we will see increasingly more activity and interest around this field going forward. The fundamentals have never changed: energy is still a multi-trillion-dollar cash cow [41], fossil fuels are still a finite resource, climate change will continue to become increasingly dire, and the military implications of fusion power are too huge to ignore. Right now, fossil fuels are finite resources that nations use to weld immense political power on the world stage; energy resources warp the economics, military and political landscape to suit some nations. But fusion power changes energy from a fixed resource to something that can be engineered by a country and that represents a significant shift in the world order. That reality is starting to dawn on world leaders around the world and when they realize that the technology is not the limiting factor – but rather the funding, organization and workforce – the pace and tenor of fusion research will dramatically shift.

References:

[1] Ian Chapman. "UKAEA Fusion activities in the UK". Presentation to the 2021 Fusion Power Associates Meeting. December 2021.

[2] Shumlak, Uri. "Z-pinch fusion." Journal of Applied Physics 127.20 (2020): 200901.

[3] Shumlak, U., et al. "Evidence of stabilization in the Z-pinch." Physical review letters 87.20 (2001): 205005

[4] Shumlak, Uri, et al. "Increasing plasma parameters using sheared flow stabilization of a Z-pinch." Physics of Plasmas 24.5 (2017): 055702.

[5] Shumlak, U., and C. W. Hartman. "Sheared flow stabilization of the m= 1 kink mode in Z pinches." Physical review letters 75.18 (1995): 3285.

[6] Shear flow stabilization of Z -pinches Paraschiv, Ioana. University of Nevada, Reno ProQuest Dissertations Publishing, Degree Year 2007. 3264527.

[7] FuZE (Fusion Z-Pinch Experiment). Fusionenergybase.com. Published 2015. Accessed July 19, 2022.

[8] Strong Atomics investment in the University of Washington. Fusionenergybase.com. Published 2017.

[9] Obenschain, S. P., et al. "Direct drive with the argon fluoride laser as a path to high fusion gain with sub-megajoule laser energy." Philosophical Transactions of the Royal Society A 378.2184 (2020): 20200031.

[10] Wolford, Matthew F., et al. "Krypton fluoride (KrF) laser driver for inertial fusion energy." Fusion Science and Technology 64.2 (2013): 179-186.

[11] "Dynomak Fusion Energy Technology" Poster, Derek Sutherland and Chris Hansen, Advanced Research Projects Agency - Energy (ARPA-E) Contracts #DE-AR0001098 and #DE-AR0001266. 2022 ARPA-E Energy Innovation Summit. May 25, 2022.

[12] "Perspectives on Inertial Fusion Energy-Opportunities and Challenges" Presentation to University of Reno-Nevada, Seminar, November 4th 2022. Campbell, Michael.

[13] Lindl, John. "Development of the indirect-drive approach to inertial confinement fusion and the target physics basis for ignition and gain." Physics of plasmas 2.11 (1995): 3933-4024.

[14] Hurricane, O. A., et al. "Physics principles of inertial confinement fusion and US program overview." Reviews of Modern Physics 95.2 (2023): 025005.

[15] Start-Ups With Laser Beams: The Companies Trying to Ignite Fusion Energy. The New York Times. Published 2023. Accessed January 1, 2024.

[16] M Moynihan. Private Conversation with Dr. Richard Hubbard. December 2023.

[17] Sieck, P. E., et al. "First Plasma Results from the HIT-SI Spheromak." APS Division of Plasma Physics Meeting Abstracts. Vol. 45. 2003.

[18] "Steady-state spheromaks for the pursuit of economical fusion power" Presented by CT Fusion, Sutherland, Presentation at ARPA-E conference, August 30th, 2017.

[19] Taylor, J. Brian. "Relaxation of toroidal plasma and generation of reverse magnetic fields." Physical Review Letters 33.19 (1974): 1139.

[20] Jarboe, T. R., et al. "Recent results from the HIT-SI experiment." Nuclear Fusion 51.6 (2011): 063029.

[21] Jarboe, T. R., B. A. Nelson, and D. A. Sutherland. "A mechanism for the dynamo terms to sustain closed-flux current, including helicity balance, by driving current which crosses the magnetic field." Physics of Plasmas 22.7 (2015):072503.

[22] Sutherland, D. A., et al. "The dynomak: An advanced fusion reactor concept with imposed-dynamo current drive and next-generation nuclear power technologies."

[23] Jarboe, T. R., et al. "Spheromak formation by steady inductive helicity injection." Physical review letters 97.11 (2006): 115003.

[24] Jarboe, T. R., et al. "Imposed-dynamo current drive." *Nuclear Fusion* 52.8 (2012): 083017.

[25] Olynyk, G. M., et al. "Vulcan: a steady-state tokamak for reactor-relevant plasma–material interaction science." Fusion Engineering and Design 87.3 (2012): 224-233.

[26] Rivenberg P. Warren, Clark join in restarting of Alcator C-Mod tokamak. MIT News | Massachusetts Institute of Technology. Published February 2014.

[27] Alcator C-Mod may lose funds | The Tech. The Tech. Published 2012. Accessed July 19, 2022. https://thetech.com/2012/09/07/alcator-v132-n353.3.2 Tokamak Energy.

[28] Energy researchers seek new directions after Alcator C-mod decommissioned | The Tech. The Tech. Published 2016.

[29] Northern. Breakthrough in Nuclear Fusion? - Prof. Dennis Whyte. YouTube. Published online February 25, 2016. Accessed January 1, 2024. https://www.youtube.com/watch?v=KkpqA8yG9T4

[30] M Moynihan. Private Conversation with Dr. Derek Sutherland at the 2021 APS DPP Meeting. November 2021. Pittsburgh PA.

[31] Team H. Towards Fusion Energy: UK announces over half a billion pounds in funding. Energy Advice Hub. Published October 20, 2023. Accessed January 1, 2024.

[32] Germany announces new fusion program. Fusionenergyinsights.com. Published 2023. Accessed January 1, 2024.

[33] M Moynihan. Private conversation with Mr. James Tu on visit to COP28. Thursday December 21th 2023.

[34] Harris M. 2023 Climate Tech Companies to Watch: Commonwealth and its compact tokamak. MIT Technology Review. Published October 4, 2023. Accessed January 1, 2024.

[35] International Partnerships in a New Era of Fusion Energy Development | OSTP | The White House. The White House. Published December 3, 2023. Accessed January 1, 2024.

[36] "Us Fusion Budget". Qedfusion.org. Published 2014. Accessed January 1, 2024.

[37] DOE Announces $46 Million for Commercial Fusion Energy Development. Energy.gov. Published 2023. Accessed January 1, 2024.

[38] DOE Announces $42 Million for Inertial Fusion Energy Hubs. Energy.gov. Published 2023. Accessed January 1, 2024.

[39] M Moynihan. Private conversation with Dr. Patrick McGarth. Fusion Power Associates Meeting. December 2017. Washington DC.

[40] Nehl, C. L., et al. "Retrospective of the ARPA-E ALPHA fusion program." Journal of Fusion Energy 38 (2019): 506-521.

[41] Tim De Chant. With $10T on the line, 6 fusion investors explain why they're all in | TechCrunch. TechCrunch. Published June 21, 2023. Accessed January 1, 2024.

[42] Caroline Anderson. Bipartisan Congressional letters urge increased fusion funding - Fusion Industry Association. Fusion Industry Association. Published October 31, 2023. Accessed January 1, 2024.

[43] CHIPS and Science Act Supports Advanced Nuclear and Fusion Industries. Pillsbury Law. Published 2022. Accessed January 1, 2024.

[44] FACT SHEET: The President's Budget for Fiscal Year 2024 | OMB | The White House. The White House. Published March 9, 2023. Accessed January 1, 2024.

[45] Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy | OSTP | The White House. The White House. Published April 19, 2022. Accessed January 1, 2024.

[46] Tokamak Energy. Ten years of Tokamak Energy: the rapid progress of a private fusion company. YouTube. Published online June 17, 2020. Accessed July 19, 2022.

[47] Woodruff Scientific Inc. Systems Analysis | Woodruff Scientific, Inc. Woodruffscientific.com. Published 2017. Accessed January 1, 2024.

[48] Tokamak Energy. Tour of the Tokamak Energy development facility. YouTube. Published online March 25, 2020. Accessed January 1, 2024.

[49] Karan R. Revealed: 15 Most Expensive Future Weapons of the United States Military - CEOWORLD magazine. CEOWORLD magazine. Published December 26, 2023. Accessed January 1, 2024.

[50] Gibney E. UK hatches plan to build world's first fusion power plant. Nature. Published online October 11, 2019.

Bio: *Dr. Matt Moynihan has been involved in fusion since 2006; he is the author of "Fusions' Promise" (Nature-Springier, 2023). He holds a PhD focused on targets from the Laboratory for Laser Energetics at the University of Rochester and was a Senior Nuclear Engineer for the Nuclear Navy at the Bettis Atomic Power Laboratory in Pittsburgh. For five years, he worked as a private consultant helping investors navigate the fusion investment landscape and has worked firms such as Honda Innovations, Westinghouse, Naval Research Laboratory, National High Magnetic Field Laboratory, Shine Medical Technologies and Utah Retirement Systems.*

On the reduction of weapons tritium inventory

by Daniel L. Jassby (retired from Princeton Plasma Physics Lab)

"Fission loves fusion and fusion loves fission"
— the weaponeers' maxim

While journalists, bureaucrats, and anti-nuclear activists make a fuss about the radioactivity of tritium and create a holler when a few curies are released, tritium's radioactivity is a trivial health hazard compared with the role it plays in nuclear weapons. As we shall relate, tritium is indispensable for "boosting" the yield of almost all modern *fission* (not fusion) explosives, a role that accounts for as much as 90% of the annual demand for tritium. But tritium's radioactivity is an Achilles heel for its weapons application. Tritium's short half-life (12.3 yr) lends itself to the gradual and effortless crippling of entire nuclear arsenals, simply by not replenishing decayed tritium.

The DT-boosted nuclear explosive

Nuclear weapons can be a single-stage fission device, or may also have a secondary thermonuclear stage. The discussion herein applies only to the fission-based stage, called the primary, that's found in all nuclear weapons. The configuration in Fig. 1 is the basis of the primary, according to unclassified sources [1, 2, 3]. The fissile material can be plutonium isotopes, principally Pu-239, or U-235 or a mixture thereof.

The following is the sequence of events in a boosted fission primary, such as depicted in Fig. 1.

1. Detonation of chemical high explosives (H.E.).
2. A compression wave implodes the shell of fissile material in 10 μs and increases the density of the DT gas (typically 5 g) by a factor of 100, while neutrons are initiated.
3. Fissions multiply neutrons some 70 times in 400 ns, producing nearly 1,000 GJ and heating most of the assembly, including the 5 g of DT, to 3 keV.
4. At least 3/4 of the D and T nuclides fuse in 10 ns, producing 1,500 GJ and 5×10^{23} neutrons, about 30 times the number of existing fission neutrons. The 10 ns time for DT burnup is of the order of one fission doubling time, while the 14-MeV fusion neutrons have 3 times the speed of typical fission neutrons and the fission cross section is 50% larger. Hence essentially all subsequent fissions are generational descendants of the D-T neutrons, especially since each fusion neutron produces at least 4 fission neutrons in Pu or U-235 compared with just 3 for slower fission neutrons in Pu and 2.5 in U-235.
5. D-T neutrons fission nearly 5×10^{23} nuclides, producing 2×10^{24} neutrons and 16 TJ of energy, or 4 ktons TNT-equiv.
6. Before the primary totally disassembles, about half of the fission neutrons from event #5 cause further fission, producing another 8 ktons.

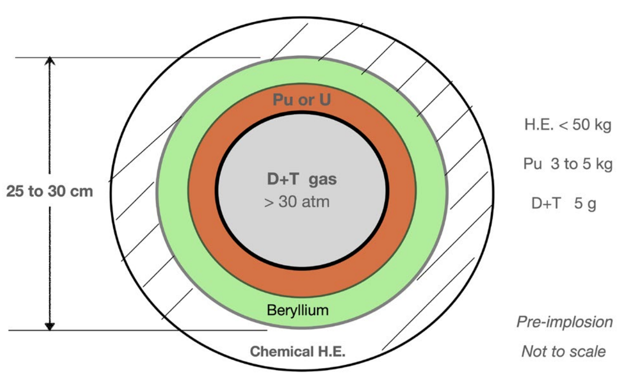


Fig. 1. Typical configuration for the boosted primary of a nuclear weapon.

While only 5% of the total energy release is from fusion during event #4, essentially all of the fission energy release can be traced to fusion neutrons. With this extra neutron source, compression requirements can be relaxed, thus greatly reducing the mass of chemical explosives needed. Much higher explosive yields are possible, but the numbers herein reflect minimal fissile content and modest compression by H.E., and the yield is adequate to ignite the weapon's secondary stage, if there is one.

The advantages of boosting are that 1) the Pu or U-235 charge can be smaller than with no boosting, 2) the mass of chemical H.E. can be greatly reduced, shrinking the warhead size so that it is small enough to be deliverable by missile, 3) reactor-grade Pu (high Pu-240 content) is perfectly usable, and 4) safety advantages against unwanted detonation are realized when the DT gas is stored separately from the weapon before use.

Some of the so-called "H-bomb" tests of India, Pakistan and No. Korea were probably tritium-boosted fission explosions, as distinct from the more difficult Teller-Ulam configuration requiring an elaborate secondary stage.

Proposals to ban tritium production

Tritium is radioactive with a half-life of 12.3 years. If the decayed tritium is not restored periodically, weapons' primaries would provide only fizzle yields if detonated, a few hundred tons TNT-equivalent, and could not ignite the thermonuclear secondary.

Of course D is equally as important as T in the boosting process, but D does not decay and is easily extracted from ordinary water, being 1 part in 6,500 of natural hydrogen. In contrast there are no natural resources of tritium, which must be manufactured in fission reactors or particle accelerators. The tritium content of each weapon must be replenished after a few years, so that allowing it to decay indefinitely is a splendid target for arms control. Hence proposals have appeared for a freeze on tritium production.

The boosting technique was declassified in the 1970's. The first published suggestion to implement a tritium production freeze that would effectively draw down weapons inventories was apparently made by Wilkie in 1984 [4]. Shortly after the last tritium-producing reactors in the US had been shuttered in the 1980's, a worldwide ban on tritium production was proposed by Leventhal and Hoenig [5] and by J. Carson Mark, et al [6]. With a freeze on new tritium supply, the number of viable weapons would decrease monotonically as remnant tritium is transferred from retired weapons to replenish those in the active stockpile.

In the 1990's Kalinowski and Colchen (K&C) made by far the most elaborate and complete study and recommendations for the cutoff of tritium supply and usage [7]. K&C went beyond reduction of arsenals by mere natural decay of tritium, and urged the active removal of tritium from weapons. K&C estimated that without tritium and no change to weapons composition or design the total yield of nuclear arsenals would decrease by two orders of magnitude, principally because the thermonuclear secondary could not be ignited by the greatly reduced yield of the primary. Rebuilding the primaries without tritium but with more Pu and vastly more chemical explosives for compression would make the weapons too large for delivery by missile, and both their fission and fusion yields might be drastically reduced.

Unplanned reduction of weapons tritium inventory

No international freeze agreement was ever negotiated. However, the end of tritium production in the US conveniently occurred a few years before the USSR unraveled and led to the START agreement between the US and USSR to reduce their nuclear stockpiles by a factor of five. For at least 15 years, the US simply transferred remnant tritium from retired weapons to replenish the stocks of those in active service, as the freeze proposals advocated. The US has lately resumed small-scale production using TVA reactors.

Nuclear stockpiles have always been dominated by the US and Soviet Union. Although the US stockpile peaked around 1965, the total size of the global arsenal peaked in 1986 at about 62,000 weapons, so that year is an appropriate starting point to monitor the decay of the original deployed tritium inventory.

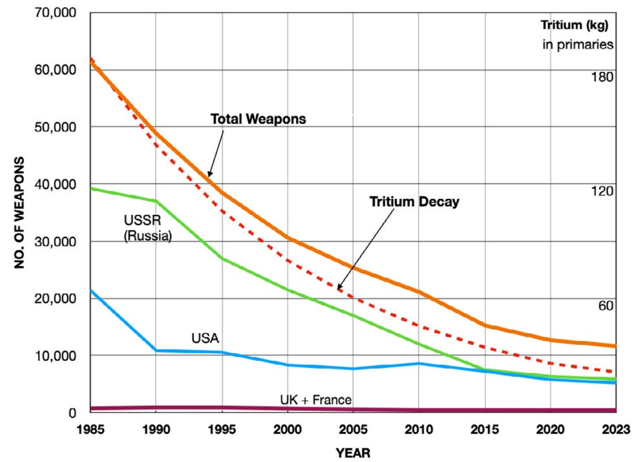


Fig. 2. Nuclear arsenal strength vs year, and decay of initial tritium inventory.

Figure 2 shows the decay of the 1985 tritium inventory compared with the actual reduction in nuclear stockpiles [8] of the four nations that purposely reduced their inventories. The UK and France cut their peak strength nearly in half, a much smaller factor than effected by the US and Russia. The UK and French arsenals together amounted to only 1% of the total in 1985, but make up 4% of the total today.

The tritium scale in Figure 2 assumes that all the weapons in the 1985 stockpiles used tritium boosting in the first stage (the primary) and assumes a charge of 3 g per weapon, While that is probably incorrect, some weapons such as the "neutron bomb" reportedly each used tens of grams of tritium, which would compensate for those using none. Many two-stage weapons also use tritium boosting in the fission "spark plug" in the secondary. That use would increase the actual tritium inventory to as much as twice that indicated in the figure labeling, but does not affect the normalized decay curve. Actual tritium inventory has always been secret information in every country.

For any year there is some variability in the arsenal numbers given by different sources, because of different estimates about the actual number held by nations other than the US, and because of the uncertainty in distributing weapons among the deployed, stockpiled and to-be-dismantled categories.

Figure 2 shows that the global stockpile dropped by a factor of 5 from 62,000 to about 12,000, while the 1985 tritium inventory dropped by a factor of 9. The stockpile in 2005 was only 20% higher than would have been produced simply by tritium decay, but it was 65% higher in 2023. The US and Russia each have about 1,500 retired, non-deployed nuclear warheads included

Fig. 2. Nuclear arsenal strength vs year, and decay of initial tritium inventory

in this tally. If these weapons contain no tritium, the 2023 stockpile is only 20% higher than allowed by tritium decay.

If a tritium freeze had actually been implemented in 1988, then the number of tritium-boosted weapons would have been reduced, without international agreement, to about 60 to 80% of the number available for use today. Nevertheless, what the 1980's proponents wanted to accomplish with a tritium freeze has essentially happened, but for other reasons.

Figure 2 omits the five nuclear powers that have never reduced their nuclear arsenals. Those arsenals were relatively insignificant in 1986, but expanded to a total of 900 weapons by 2023, and now add nearly 10% to the number shown in Fig. 2.

Prospects for a tritium freeze agreement

Nine-tenths of the annual global demand for tritium, both military and civilian, is used to maintain the effectiveness of nuclear arsenals by replenishing the boosting component.

In 2004 Kalinowski published an even more elaborate and detailed discussion of tritium inventories and proposed methods to reduce them, as well as methods to control the distribution and use of tritium [9]. Despite Kalinowski's detailed and persuasive arguments, it seems that none of these recommendations has been adopted, as the continual production and extraction of tritium has apparently alarmed few. But with China and other Asian nations continuing to increase their stockpiles, there have been more recent calls for a tritium freeze [10].

Two dozen CANDU reactors around the world as well as many heavy water reactors in India unavoidably produce tritium in their D2O moderators by neutron absorption in deuterium, analogous to the inescapable production of plutonium in every uranium-fueled reactor by neutron absorption in U-238. Hence it's not feasible to ban all production of tritium any more than to ban production of plutonium. It may be possible to ban the *extraction* of tritium from heavy water or lithium compounds, analogous to the de facto ban on reprocessing plutonium from spent fuel rods that's tacitly observed in many countries including the US.

Meanwhile, the US has been producing tritium for weapons in one or more TVA reactors for nearly 20 years [11]. As for the other nuclear powers, Russia has two dedicated tritium production reactors named Lyudmila and Ruslan. France intends to produce weapons tritium from LWR's at the Civaux nuclear power plant. India plans on building still more heavy-water moderated reactors, from which it extracts tritium for weapons. Israel, North Korea and Pakistan continue to produce tritium from small special-purpose fission reactors.

Summary and Conclusions

Tritium is an irreplaceable component of the primary of virtually all modern nuclear weapons, and thereby works hand-in-glove with plutonium to maintain the most dire threat to civilization. In principle this threat could be decisively curtailed by an international agreement simply to allow all tritium inventory to decay without replenishment. As it happened, a factor-of-5 reduction in deployed tritium occurred between 1988 and 2020 because of the negotiated reduction in nuclear arms that accompanied the demise of the Soviet Union. It is not realistic that a ban on tritium production itself can be negotiated, and a second inventory reduction may have to await another monumental geopolitical event that prunes nuclear arsenals.

Nevertheless, those who seek nuclear disarmament should look for opportunities to restrict tritium extraction and trafficking and not just maintain exclusive obsession with safeguarding plutonium and enriched uranium. After all, if a different practical method could be found to heat the DT package in the primary, the extremely challenging Pu or U-235 component could be replaced by widely available depleted or natural uranium, or even thorium, all of which can be fissioned by D-T neutrons.

References:

[1] Wikipedia entry for "Boosted fission weapon," and references therein.

[2] "Boosted Weapons," GlobalSecurity.org (online).

[3] André Gsponer and Jean-Pierre Hurni, "The physical principles of thermonuclear explosives," *Independent Scientific Research Institute*, Geneva, Switzerland (1997) and 2009, online.

[4] Tom Wilkie, " Old Age Can kill the Bomb," New Scientist, Feb. 6, 1984.

[5] P. Leventhal & M. Hoenig, "The Tritium Factor," New York Times, Aug. 4, 1987.

[6] J. Carson Mark, T. D. Davies, M. M. Hoenig, and P. L. Leventhal. "The Tritium Factor as a Forcing Function in Nuclear Arms Reduction Talks." Science 241, (September 2, 1988), 1166–68.

[7] Martin Kalinowski and Lars Colschen, "International Control of Tritium to Prevent Horizontal Proliferation and to Foster Nuclear Disarmament," Science and Global Security, 1995, Vol. 5, p. 131 ff.

[8] Wikipedia entry for "Historical nuclear weapons stockpiles by country," and references therein.

[9] Martin Kalinowski, "International Control of Tritium for Nuclear Nonproliferation and Disarmament," Science and Global Security Monograph Series, v. 4. Boca Raton: CRC Press, 2004.

[10] Robert E. Kelley, "Starve nuclear weapons to death with a tritium freeze," SIPRI report (August 2020), online.

[11] "Production of Tritium in Commercial Light-Water Reactors," NNSA-USDOE report, June 2016, energy.gov (online).

Daniel L. Jassby
Retired from Princeton Plasma Physics Lab.
dljenterp@aol.com

The Great Displacement: Climate Change and the Next American Migration

Jake Bittle (Simon & Schuster, 2023) ISBN 978-1-9821-7825-3. $18.99

This just in, Houston is flooding again, "more flooding expected with 2.1 million people under a flood warning" (NYT May 2024). Jake Brittle's book *The Great Displacement* tells personal stories that are the direct result of destructive climate change in the United States. The book has eight chapters. The first few chapters deal with sudden events such as fire and floods due to hurricanes, the next few chapters focus on the slower changes such as drought and flooding due to sinking earth and rising sea levels. The final few chapters address the problems of people who are displaced by climate disasters.

The book opens in the Florida Keys, "the first flock of canaries in the coal mine of climate change." This chapter shows the extent of "climate migration" that has already taken place. The author uses "displacement" in the title of the book arguing that migration is "not quite the right word" because it "implies an intentional, one-directional action, but the movement on the ground is more diffuse". Bittle thinks displacement "conveys the reality: these movements will be unpredictable, chaotic, and life-changing". In the case of the Keys, many people will stay after the initial disaster and new people move into the empty spaces, but then comes a second and a third disaster. Somewhere along the way most decide to leave permanently. Local and national politicians must sometimes determine which areas are worth saving and which are not. In the case of one area in the Keys, the local government decided to raise all the roads.

The second chapter looks at Lincoln City in North Carolina, an area the government deemed not worth saving. Hurricane Floyd in 1999 swelled the Neuse River drowning Lincoln City under five feet of water. FEMA purchased the riverside neighborhood of Lincoln City, "giving each homeowner a check for the value of their home as long as they moved someplace else." FEMA was trying to break the "vicious cycle of construction, destruction, reconstruction, and re-destruction". Unlike the area in the Keys, FEMA decided that Lincoln City was not worth saving.

Chapter three examines the wildfires in Santa Rosa, California. It also looks at the consequences that fires have on insurance and housing prices. The chapter is a good example of what the author means by displacement versus migration. In covering these disasters through the lives of families, he considers their decision-making process: why some stay, why some move a short distance away (still in the line of fire), and why some move far away.

Chapters four and five cover the more gradual changes that are occurring using the examples of Point-au-Chien an Indigenous fishing village on the coast of Louisiana and the attempt at flood control in Houston Texas. In both cases it has become more difficult to live in the area, which was attractive because it was close to work, unless you have the means to move to higher ground and a more expensive area. These two chapters clearly show that the life-quality disparity between the haves and have-nots is disproportionately amplified after a displacement resulting from a climate disaster. Attention to the increase of social injustice as a result of climate change is an important theme indicated throughout this book.

The final three chapters follow the circumstances of families who are currently displaced. Chapter six covers Phoenix suburbs and the water crisis in Arizona along with the collapse of its cotton industry. Chapter seven looks at the coastal city of Norfolk, Virginia, "where rising sea levels have destabilized the flood insurance system and set the stage for a housing crash of epic proportions." The final chapter considers where displaced people move and why they choose their new locations. This chapter consolidates discussions found in earlier portions of the book about the pressures on families who are displaced. Many of the families' reasons for moving have less to do with "escaping climate risk and more to do with finding social and demographic ties that ease the process of relocation."

The book's great interest derives from the author's choice to tell stories from the perspective of families that are affected by climate change. Several key themes emerge as the book unfolds. These include: 1) how flooding and fires affect the lives of the haves and have nots disproportionately; 2) the economic interconnections with climate change that cause feedback loops and downward spirals (for example: drought makes cattle feed less plentiful and more expensive resulting in livestock selloffs that lead to a drop in the price of cattle). Finally, the author points out the obvious: this is just the beginning, and things are going to get worse. Yes, this book can be a distressing read, but the resilience (climate resilience is a growing field of study!) of many families is notable; some people are even able to significantly improve their situations. As the climate and responses to it change, so too the law will have to evolve. Currently, people who experience sudden disasters like fire and flood tend to receive more government assistance than those who suffer from gradual flooding. Expect changes.

I was amazed at both the amount of turmoil people will put up with to stay where they are and how much involvement the government has with both sudden events and long-term areas of concern. People are raising their homes up off the ground and towns are raising the roads. Whole towns have been bought out and the people moved out from areas due to climate change. Flood maps keep getting redrawn, and flood insurance is now a large part of people's budgets. One family in a three-year span paid yearly $3,200, then $10,000, then $13,000 for flood insurance. There is also a growing business for making changes in your home to lower insurance costs including installing flood vents so each time your home floods the water drains out.

People are living in homes where they have installed a device that drains their home each time it floods. It is getting crazy out there, isn't it?

Dr. Jeff Williams
Physics Department
Bridgewater State University
j7williams@bridgew.edu

The Dawn of a Mindful Universe: A Manifesto for Humanity's Future

Marcelo Gleiser (Harper Collins, New York, 2023). 244 p. ISBN 978-0-06-305687-0. $29.99.

Marcelo Gleiser is described on the book jacket as "a theoretical physicist and public intellectual at Dartmouth College." On the first page of his prologue he announces that "It's time to retell the story of who we are under a new mindset. This book is about life on Earth, its cosmic relevance, about humanity's mandate to rise above our past to reshape our collective future." "To keep on going as if nothing is happening is simply not sustainable," he adds (p. 4).

"The premise of this book is that we need to reinvent ourselves as a species," Gleiser then states. "The body of this book is my attempt to explain how." (p. 4) His prescription for the future is "*biocentrism*, the idea that a living planet is a sacred realm that deserves respect and veneration." But he cautions that whether following this prescription "will be sufficient to change our current disastrous course is up to us. . . ." (p. 7)

Noting that Copernicus's dethroning of Earth from its special place in the Universe also took away the uniqueness of life on Earth and held forth the possibility that life could exist anywhere, Gleiser in his first chapter calls for a post-Copernican view that restores recognition of Earth as a unique supporter of life and observes that we are the only species capable of doing this. He reiterates this theme in his second chapter, this time reaching all the way back to Ancient Greece, where the pre-Socratics replaced the myths of the gods by the elements of earth, air, fire, and water to explain the structure of the Universe, then advancing to Einsteinian gravitation, and noting that "the world of modernity was erected from the degraded remains of life buried for millions of years under our feet." (p. 54) Here he adds that the Copernican implication that life is not unique to Earth cheapens it – Gleiser calls this the "mediocrity principle." Though there may be Earth-like exoplanets, he asserts that there is no evidence that they have borne life, not to mention intelligent life.

Gleiser takes one more swipe at this theme in his third chapter, this time from the standpoint of belonging. He traces the human sense of community to our hunting-gathering state, in which we felt we belonged to the land. But this relationship reversed in the agricultural stage, he states, and subsequent stages gave rise to religion, in which the land was irrelevant (in both Aristotelian cosmology and Christian theology imperfection occurred on Earth and perfection above). By challenging Aristotelian cosmology, Copernicus upset Christian theology, and this resulted in demoting Nature to being a commodity.

Gleiser's argument for the respect and veneration of Earth rests on the uniqueness of life, or at least intelligent life, on Earth, and he spends the next several chapters endeavoring to establish this. Exploration of our solar system has yielded no evidence of life on Mars and has held forth the possibility of underground pools of water on Europa and of methane on Enceladus to be investigated, but any life found there is expected to be at a low level. We have not been visited by an extraterrestrial civilization, and we have not detected evidence for one outside our solar system by observing the spectra of exoplanets' atmospheres when they transit their stars.

The laws of physics and chemistry are the same everywhere, Gleiser observes, but he points out that this is not true for the steps by which they enable life to form, because there is an unpredictable element in the passage from one generation of living things to the next. He puts forth nine steps for the formation of intelligent life, but he asserts that their succession is contingent upon events which may be unique to a given planet, like the collision of the asteroid onto the Yucatán peninsula 65 million years ago, which wiped out 75% of then living species, including the dinosaurs.

On the first page of his eighth chapter Gleiser reveals the basis of his book's title: "The dawn of humanity marked the dawn of a mindful Universe." (p. 191) But he cautions that "our inability to build a sustainable relationship with the natural environment that supports us" (p. 196) now presents a challenge. He reminds us that "we alone have the power to preserve or destroy the biosphere" (p. 196) and admonishes us that this "would be the greatest crime humankind could commit against itself" (p. 195).

Gleiser's assessment of the present state of humankind is that we are "an incoherent mass of dissenting tribes, most embracing value systems based on short-term thinking devoid of any deeper reflection of the mid- to long-term consequences of our choices." (pp. 199-200) "There are two major obstacles to change," he goes on. "The first is our current narrative that places humankind above all other forms of life . . . The second obstacle is our fixation on the material at the expense of the spiritual." (p. 202)

This brings Gleiser to his “manifesto for humanity’s future,” which is both the subtitle of his book and the title of his final chapter:

1. Adopt “the core value of *biocentrism*. . . .” (p. 203)
2. Realize “that *life is a rare event in the Universe and that Earth is a rare planet*.” (p. 203)
3. Bring about a reawakening of secular spirituality in humanity.
4. Combine science with secular spirituality; it is “an essential tool for our collective future” (p. 204), but it alone is not enough.
5. Follow “the LESS approach to sustainability,” “the MORE approach to engagement with the natural world,” and “the MINDFUL approach to consumerism.” (p. 205)
6. “*All schools should add the history of the Cosmos and of life on Earth to their curricula at all levels*” (p. 206), and this should be done without any political or religious agenda in mind.

This final element addresses the need for everyone to be aware of this manifesto if it is to do any good. As Gleiser elaborates, “If humankind is to change its relation to the planet and to life, this change needs to be nourished in all classrooms and dining rooms, promoted by teachers and families. The reshaping of our collective future starts with learning the story of life’s past, its unity, and our deep link to the history of the Universe.” (p. 207)

John L. Roeder
The Calhoun School
JLRoeder@aol.com