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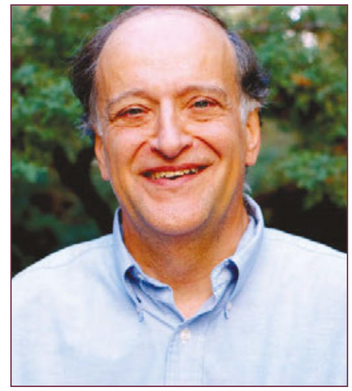
Note from the Editor

We are sending this issue out a little early because we are including the list of talks for the Forum sponsored sessions in the April meeting, which this year is in January. For those who cannot attend, I hope to persuade several of the speakers, if not all, to submit a newsletter article for a future issue.

In addition to the news items, we have several articles. That from Steve Pierson on how to interact with politicians may prove to be timely. The article by Jassby on fusion in the last issue has generated a reply. I am delighted: as I said in the October issue controversy is good and, besides, it makes my task easier. When an article produces a response I am getting two articles for the effort that it takes me to obtain one. We have also an article on modular reactors.

Laura Berzak Hopkins (the Assistant Editor) and myself have decided to start publishing interviews, in addition to the regular articles. Please remember that the contents of the newsletter are very largely determined by the interests of the readership. Please send suggestions for article topics and authors and also for persons to be interviewed. Better yet, send your own contributions: they are reviewed for style and appropriateness, but I am very open as to what is appropriate, as I explained in the previous issue. Please see the Editor's note in the October issue at https://www.aps.org/units/fps/newsletters/201610/editor.cfm for details.

Oriol



Oriol T. Valls, a Condensed Matter Theorist at the University of Minnesota, is the new P&S newsletter editor.

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LETTERS

Fusion instead of pure fusion

Wallace Manheimer

The recent resignation of Stewart Prager as head of the Princeton Plasma Physics Lab highlights the difficulties of the American magnetic fusion project. I believe the fusion program is too ambitious in attempting pure fusion, that is the use of the 14 MeV fusion neutron's kinetic energy to boil water. A much better plan is to use its kinetic, AND what, for want of a better term, I'll call its potential energy to breed nuclear fuel for separate thermal nuclear reactors. The optimum next step for the American magnetic fusion program would then be to build what I have called 'The Scientific Prototype' which is a steady state Q~1 tokamak approximately the size of TFTR, but which runs in DT, breeds its own tritium, and perhaps 233U also. It would answer the major issues not addressed by ITER. Realistically, there is nothing else for us to do. This would put America back in fusion's major league, where we have not played since the disassembly of TFTR. The advantage of this plan is that from a success in the scientific prototype and ITER, there is almost certainly a straightforward path to mid century economical fusion breeding. There is almost certainly NO straightforward path from such a success to economical pure fusion; this would require additional scientific breakthroughs of a fundamental nature, breakthroughs, which might or might not be possible to achieve.

Fusion breeding envisions a sustainable, carbon free, economically affordable, and environmentally sound energy architecture, with no proliferation risk. It consists of a single fusion breeder which fuels at least 5 light water, or more advanced thermal nuclear reactors, and a single fast neutron reactor such as an integral fast reactor (IFR), which burns the actinide wastes.

I have written a review article on this, which fleshes out these assertions. It is available open access, so anyone can see it, anywhere, any time. Here is the reference and link:

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Wallace Manheimer, Fusion Breeding for Midcentury Sustainable Power, Journal of Fusion Energy, vol 33, p 199, 2014,
http://link.springer.com/article/10.1007/s10894-014-9690-9

ARTICLES

Communicating Scientific Evidence to Someone with a View Contrary to Yours: Respecting Cultural Values

S.W. Pierson

Not accepting your scientific evidence ≠ not appreciating science

As scientists, we like to think the scientific evidence we present will be readily accepted, particularly when it is the consensus or established view. Having worked the past 15 years for a scientific society—six years in the APS Physics Washington Office under the expert guidance of Michael Lubell and Francis Slakey and almost nine years with the American Statistical Association—it is particularly disappointing when the scientific position of such a society isn't accepted as valid. After all, the position of a science society necessarily represents a balanced view of the science. For years I struggled to grapple with this reticence to accept a scientific society's position as authoritative. A 2010 paper in *Nature* magazine—Fixing the Communications Failure by Dan Kahan of the Yale Law School—provided to me by a Capitol Hill staffer helped me to better understand the phenomena and how to try to address it.

In this piece, I will discuss this work of Kahan and his colleagues because I think it is so insightful and—even seven years after its publication—is not as well known as I think it should be. I will also mention some of Kahan's subsequent work and possible ramifications for scientific societies and scientists on current topics.

KAHAN ET AL. CULTURAL COGNITION WORK

Kahan's central point in his 2010 article is that how people receive scientific information depends upon their cultural values, a process they call cultural cognition. Their work seems to hold over a variety of topics—from the safety of nuclear waste storage and climate change to nanotechnology and vaccines—and is symmetric by cultural group (which I'll explain more below.) To frame his discussion, Kahan starts his article recapping a 1950's psychology experiment in which students from separate universities are asked to assess the referee calls of a football game between their two universities. Not surprisingly, how students viewed a controversial call depended to a great extent on whether the call benefitted or hurt their team.

In the context of scientific debates, Kahan and coworkers identify two groups: (i) "People with individualistic values, who prize personal initiative, and those with hierarchical values, who respect authority, tend to dismiss evidence of environmental risks, because the widespread acceptance of such evidence would lead to restrictions on commerce and industry, activities they admire"; (ii) "people who subscribe to more egalitarian and communitarian values are suspicious of commerce and industry, which they see as sources of unjust disparity. They are thus more inclined to believe that such activities pose unacceptable risks and should be restricted."

A key finding of their work is that "groups with opposing values often become more polarized, not less, when exposed to scientifically sound information." Yes, you read that correctly: providing scientific evidence contrary to a person's standing can be counter productive. Before any of us jump too soon to conclusions about being above this phenomenon, Kahan's group found this to be true not only for the egalitarian/communitarian group when it comes to nuclear waste but also the hierarchical individualistic group when it comes to anthropogenic climate change.

Kahan provides a couple recommendations for how scientists can deal with a limitation of not being able to lead with or even emphasize the science. Building on the work of Stanford Psychologist Geoffrey Cohen, one approach is "to present information in a manner that affirms rather than threatens people's values." "For instance," Kahan writes,

> people with individualistic values resist scientific evidence that climate change is a serious threat because they have come to assume that industry-constraining carbon-emission limits are the main solution. They would probably look at the evidence more favourably, however, if made aware that the possible responses to climate change include nuclear power and geoengineering, enterprises that to them symbolize human resourcefulness. Similarly, people with an egalitarian outlooks are less likely to reflexively dismiss evidence of the safety of nanotechnology if they are made aware of the part that nanotechnology might play in environmental protection, and not just its usefulness in the manufacture of consumer goods.

Kahan continues, "The second technique for mitigating public conflict over scientific evidence is to make sure that sound information is vouched for by a diverse set of experts."

IMPLICATIONS FOR KAHAN'S WORK FOR SCIENTISTS AND SCIENTIFIC SOCIETIES

The work of Kahan and many others doing science communications research on how people receive scientific information provides many insights that we can use and learn from. An obvious one is not to assume people holding a view contrary to ours do not appreciate science. In retrospect, I saw this firsthand as a guest to a black-tie celebration of a libertarian think tank's anniversary. The honored guest was Norman Borlaug, the late plant geneticist whose work in bringing high-yield wheat varieties—along with improved agricultural production techniques—vastly improved the food security of countries like India, Mexico, and Pakistan. While praising Borlaug's scientific advances, the group roasted the scientific work of climate researchers. (For full disclosure, I believe I am more of an egalitarian/communitarian thinker and hold the view of the APS statement "Earth's Changing Climate", i.e., it "is a critical issue and poses the risk of significant environmental, social and economic disruptions around the globe… multiple lines of evidence indicate that human influences have had an increasingly dominant effect on global climate. The potential consequences of climate change are great and the actions taken over the next few decades will determine human influences on the climate for centuries. ") At the time, I felt the group was trying to have it two ways, praising some scientific work and rejecting other scientific evidence. Looking at the apparent pick-and-choose approach

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through the lens of Kahan's work, Borlaug's scientific accomplishments resonate with the hierarchical individualist themes of technological advances that contribute to commerce and industry—as opposed to restricting it—while addressing a global challenge. For climate change, I believe the group saw—and perhaps still do—steps to address climate change as being more restrictive of commerce and industry.

I also value Kahan's advice to take the approach of affirming—rather than threatening—people's values when discussing the scientific evidence relevant to issues of the day. Implicit in this I believe is establishing a relationship to learn each other's values. This will take time but, as Kahan also says in his *Nature* article, "citizens who hold opposing cultural outlooks are in fact rooting for the same outcome: the health, safety and economic well-being of their society." A December 2015 *Washington Post* article—Their 1996 clash shaped the gun debate for years. Now they want to reshape it—is a fascinating example of this. The article tells the story of the Arkansas Congressman whose 1996 clash with a Center for Disease Control (CDC) gun violence researcher led to the CDC's decision to stop its gun-violence research. A few weeks later after their tense encounter, Congressman Jay Dickey (R-Ark.) had his staff invite Dr. Mark Rosenberg into his office to review some data. After meeting with staff, Dr. Rosenberg was invited to speak with the congressman. Saying in the 2015 *Post* piece that he "knew the value of not letting divisions exist," Congressman Dickey didn't talk about gun violence research that day. Instead the two talked about their children and other such topics. A friendship ensued and it was only after they became trusted friends that they could talk about gun violence. Sixteen years later, in 2012, they coauthored an op-ed in the Washington Post saying they are "are in strong agreement now that scientific research should be conducted into preventing firearm injuries and that ways to prevent firearm deaths can be found without encroaching on the rights of legitimate gun owners."

The circumstances leading to the Dickey-Rosenberg friendship are quite different than meetings scientists request with Members of Congress or their staff to discuss climate change. We can't wait for the Member or staffer to ask us about our children but must make the most of their limited time and to get to our point quickly. Nevertheless, I believe such meetings are constructive when their purpose is to start or continue the conversation (preferably with the Member) and to develop rapport and trust. Annually for six years I have accompanied Leonard Smith (London School of Economicsand Pembroke College, Oxford)—who is both a member of the ASA and the APS—into his Republican U.S. Representative's office to talk about climate science. Through three different staffers and mixed reactions (from skeptical to indifferent) to the discussions of wilderness, residential, commercial, and military areas in the district threatened by climate and/or sea level rise, we were gratified—not to mention pleasantly surprised—when this year they said they'd be willing to consider cosponsoring the "Gibson Resolution", a non-binding House Resolution (H.Res. 424) on environmental stewardship that acknowledges a "changing climate" and it being a "conservative principle to protect, conserve, and be good stewards of our environment." Only an anecdote of a small victory to be sure but it demonstrates the potential of regularly and earnestly engaging and listening to policymakers on topics we may not agree. It also leads one to ask what could be achieved through a more concerted and organized long-term effort to have scientists working to build trusting relationships with their policymakers.

In my lead paragraph I say scientific societies must necessarily present a balanced view of the science of a given topic. I believe this because scientific societies represent scientists holding a broad range of views on a given scientific topic. To take the diverse views of its members into account when developing their position statements, I have only seen societies present a balanced view of the membership of its societies. Further, because it is imperative scientific societies protect their reputations as objective entities, I believe scientific societies tend to be conservative in presenting what they see as the scientific position.

With our unique capability to present a balanced view on a scientific topic, scientific societies have an important role to play in informing policymaking and the public on matters of national importance. The APS is a leader in this regard through its "POPA Reports", the in-depth studies on topics ranging from energy and environment to national security issues from the Panel on Public Affairs (POPA). Indeed, I think the experts assembled for the POPA reports embody Kahan's second suggestion that sound information be vouched for by a diverse set of experts.

In addition to more societies issuing such reports and perhaps issuing joint reports (the ASA would be pleased to suggest statisticians for future POPA reports), we must educate policymakers and the public about the scientific authority we bring to a topic. Last year I was with representatives of two other scientific bodies in a meeting with a Senate committee staffer that was likely a case of us trying to present a scientific view contrary to the staffer's position. After our best efforts of presenting the science, her reply was that she had a letter signed by 78 scientists supporting her position. I tried to explain our view represented the middle of a bell-curve of scientific views while her 78 were on one of the extremes but I knew we had lost the day with no trust or rapport on which to go. (Professor Smith and I were also told early in our six annual visits by a congressional staffer that, when it comes to climate change, "we have our experts and you have your experts" reinforcing their appreciation for science but illustrating the large divide on the topic.) I maintain however that it comes back to scientific societies also building and maintaining the trusting relationships I suggested earlier for individual scientists.

By stressing the balanced view that we can present from a bell-curve of scientific judgments, scientific societies can counteract the often slanted view a congressional panel too often presents on a heated topic. With the minority only usually allowed one witness and the majority the rest, it has been my observation the last couple years that hearings on climate change have not presented a balanced view on climate change, largely due to the majority witnesses being mostly from one of the extremes. While I understand that hearings in non-science committees will take more political positions, I believe the science committees have a responsibility to the American people to present a more balanced view on a topic as important as climate change.

While progress on climate change—as characterized by bipartisan recognition of the problem and bipartisan resolve to address it—will be slow and consensus is lacking about how to achieve such progress, I would be happy with the small step of bipartisan acknowledgement that the changing climate is a problem and that humans are a primary cause. Perhaps to achieve or at least gauge such bipartisan agreement, Democrats in recent years have offered "Sense of Congress" amendments saying, in effect, climate change is occurring and humans are the primary driver. During a January, 2015 Senate debate on the Keystone XL pipeline, five Republicans voted to support an amendment saying "climate change is real" and that "human activity significantly contributes to climate change". (As an aside but informative of the political dynamics, two of the five Republican Senators lost their reelection bids in November: Senator Mark Kirk of Illinois and Senator Kelly Ayotte of New Hampshire.) In the House science committee later that winter, a similar amendment was amended to remove the line about humans being the primary cause and then passed.

I have not followed Kahan's work closely since his 2010 *Nature* paper but did see a May 2015 presentation where a theme was, "Don't make reasoning, free people choose between knowing what's known and being who they are." Applying this to the "Sense-of-Congress" efforts, it seems like Democrats are trying to force Republicans to choose between knowing what's known and being true to their constituents. After all, one of the factors identified in the 2010 primary loss of South Carolina's Republican U.S. Representative Bob Inglis was his acknowledgement that climate change is caused by human activities and poses significant risks. As a thought experiment, what if the Sense of Congress were to read as follows?

It is the sense of Congress that the overwhelming majority of scientists with expertise in climate science agree that—

(1) climate change is occurring; and

(2) human activity significantly contributes to climate change.

By inserting "the overwhelming majority of scientists with expertise in climate science agree that," the language is no longer asking Members of Congress to say what they believe regarding anthropogenic climate change per se but is asking them to acknowledge where the majority of scientists and scientific societies are regarding anthropogenicclimate change.

Whether or not a vote on such a "Sense of Congress" would move the ball forward in some small way I'll leave to others. Regardless, it's imperative we listen to what science communication researchers are telling us and merely impose our scientific knowledge upon policymakers and the public.

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Small modular reactorsand the challenges of nuclear power

M.V. Ramana and Zia Mian, Princeton University

Nuclear energy is on the decline, certainly as a share of global electricity generation. Between 1996 and 2016, this share has come down from 17.6 percent to 10.7 percent (BP 2016). Future prospects don't seem any better either: the International Atomic Energy Agency's projections for 2030 and 2050 see nuclear energy maintaining market share under the high scenarios, and declining under low scenarios (Ramana 2016a).

The influential 2003 study on the future of nuclear power from the Massachusetts Institute of Technology attributed the "limited prospects for nuclear power" to "four unresolved problems": costs of generating electricity at nuclear reactors, safety of reactors and nuclear fuel cycle facilities; proliferation and the possible misuse of commercial or associated nuclear facilities and operations to acquire technology or materials as a precursor to the acquisition of a nuclear weapons capability"; and "unresolved challenges in long-term management of radioactive wastes" (Deutch et al. 2003, 2).

One particular problem that has become even more of a challenge in the last decade or more has been increasing costs of construction. Reactors classified as Generation III or III+ have typically costed 6 to 10 billion dollars (for 1100 to

1600 MW of generating capacity), and have taken close to a decade or more to construct; practically all have experienced time and cost overruns in comparison with initial estimates (Schneider and Froggatt 2015). In response, nuclear reactor developers and vendors in several countries have been pursuing the development of Small Modular Reactors (SMRs), with power levels between 10 and 300 MWe, much smaller than the 1000–1600 MWe reactor designs that have become the industry standard.

Proponents of SMRs suggest that these reactors can resolve the four key challenges confronting nuclear power today. In turn, many countries, including the United States, Russia, China, France, Japan, South Korea, India, and Argentina, are investing large amounts of money to support such development. What are the prospects of SMRs solving the problems confronting nuclear power?

Any attempt to deal with the problems identified above—safety enhancement, proliferation resistance, decreased generation of waste, and cost reduction—has to be reflected in some fashion in the design of specific nuclear reactors. But it turns out that each of these priorities can drive the requirements on the reactor design in different, sometimes opposing, directions (Ramana and Mian 2014). Leading SMR designs under development involve choices and trade-offs between desired features and focusing on any one goal might make other goals more difficult to achieve.

Because a number of SMR designs are under development, it is not possible to examine each of them to demonstrate these trade-offs. SMR designs vary by power output, physical size, fuel geometry, fuel type and enrichment level (and resulting spent fuel isotopic composition), refueling frequency, site location, and status of development. However, the many different kinds of SMRs can be classified into a few families, which share common characteristics.

SMR FAMILIES

One way to categorize SMRs is to look at their primary purpose, or stated aim (Glaser et al. 2015).

Ready to Build

The first family of SMRs involves reactor designs intended to demonstrate the technical and commercial viability of these designs as early as possible. These are essentially scaled-down standard light water reactors, usually with steam generators located within the same pressure vessel as the reactor itself (integral Pressure Water Reactor or iPWR). Integration of the primary system has been assessed by some analysts to be "the biggest challenge to SMR development".

These reactors are typically fueled with low-enriched uranium, with enrichment levels of 5% or less. Not only is the enrichment of fuel in the same ballpark as conventional light water reactors, but even the fuel assembly designs are intended to be almost identical to existing designs (although scaled down in height). Because of the similarity of the fuel design, the spent fuel can be reprocessed using traditional and widely understood techniques.

Succeeding the Second Time Around

A second family of SMRs involves reactor designs that were studied in the past but that lost out to the light water reactor design that has dominated nuclear power deployment since the 1970s. Two leading types are the molten-salt reactor (MSR) and the high temperature gas-cooled reactor (HTGR) concept.

MSR designs, as the name suggests, involve nuclear fuel dissolved in salts and that is continuously circulated in and out of the reactor itself. When out of the reactor, the fuel has to be processed, to remove the build-up of various fission products. But handling the highly radioactive molten-salt stream and ensuring that various structural components of the reactor core can tolerate high levels of irradiation as well as corrosion from the highly corrosive salts remain formidable challenges before these designs can be commercialized. These designs have so far not been subjected to independent evaluation of safety by nuclear regulators.

The fuel for HTGRs, on the other hand, is usually in the form of TRISO (tristructural-isotropic) particles, which consist of uranium coated with multiple layers of different materials that can withstand high temperatures and are hard – but not impossible – to reprocess. For use as fuel, the uranium has to be enriched to well above 5 percent as fuel, and graphite as a moderator. Helium is often used as the coolant fluid. Earlier attempts at commercializing similar designs failed (Ramana 2016b).

Reducing the Burden of Nuclear Waste

The next reactor family involves designs that seek to extend uranium resources by using uranium much more efficiently and so lessen the problem of legacy waste. This requires these reactors to be based on the use of fast (energetic) neutrons without any moderator, because fast neutrons are more efficient at fissioning all isotopes of uranium and transuranic elements. The coolant used in these reactors is typically a molten metal, often molten sodium, although some designs involve helium as a coolant.

Comes with Fuel for a Lifetime

Lastly, there are designs intended as "nuclear batteries," with long-lived cores that are designed for possibly unattended operation. They are generally targeted at "newcomer" nations with small electric grids interested in developing nuclear power systems or for remote locations in developed countries. These reactors tend to be liquid metal-cooled fast reactors with fresh fuel having high uranium enrichment levels.

CHOICES AND CONFLICTS

Evaluating all the different SMR designs, even when they are organized in families, against the desired criteria of costs, safety, waste, and proliferation is not straightforward. Each of these criteria has several dimensions, and multiple technical characteristics are needed to effectively implement each criterion. At the same time, the different designs do have some shared technical characteristics, and these characteristics affect how these reactors might score on different desirable criteria.

Cost

The economics of nuclear power is a challenge because of both the high cost of constructing each facility and the high cost of generating each unit of electrical energy relative to other options for meeting the same demand. The two are related but distinct. The attraction of SMRs comes from the fact that they are expected to have lower initial expenditures. But this feature will likely make the latter challenge even harder to meet because they miss out on what are called economies of scale: the advantages that come with costs scaling more slowly than output power. For example, a 1000 MW reactor does not require four times as much concrete as a 250 MW reactor. Designers hope that this negative effect possibly could be offset somewhat through economies of mass manufacture. But even with optimistic assumptions about learning rates, hundreds, if not thousands, of reactor units would have to be built in order for mass manufacture effects to counteract the loss of economies of scale (Glaser et al. 2015). There are but 450 reactors operating today around the world after roughly six decades of nuclear power plant construction. Expert elicitation studies also project higher costs for SMRs (Abdulla, Azevedo, and Morgan 2013; Anadón et al. 2012). Thus, the smaller power capacity of SMRs has a largely negative effect on costs of electricity generation, and is unlikely to make nuclear power economically competitive.

There are also specific features of each of these SMR types that would tend to increase costs. For example, the lower fuel burnup in iPWRs means that fueling costs would be higher whereas the special materials used to coat the fuel particles in HTGRs and non-conventional manufacturing techniques also lead to higher fueling costs. In the case of nuclear batteries, the increased cost is a result of needing to fuel the reactor for its entire lifetime up front, that too with fuel with higher enrichment levels.

Safety

The small physical size and smaller fissile inventories of SMRs benefit safety. However, in the case of fast reactors, there are other characteristics that affect safety negatively. These include the potential in the core for accidents involving disassembly and reactivity increase as well as the risks from using molten metals as coolants (IPFM 2010; Kumar and Ramana 2008). Proponents of these reactors argue, not surprisingly, that they are safe, but many others view the use of fast spectrum neutrons and molten metal coolants as a significant disadvantage from a safety perspective.

One disturbing trend has been attempts by SMR proponents to emphasize the safety aspects of these reactors to use those features as reasons to get existing licensing requirements diluted (Ramana, Hopkins, and Glaser 2013). The primary motivation for these attempts has been to compensate for higher costs of electricity generation and the consequent inability to compete economically in power markets.

Waste

SMRS based on fast neutrons produce a lower amount of radioactive waste per unit of electricity generated. The significance of the lower rate of waste generation, however, is debatable. The problem with siting geological repositories for waste disposal has been local and public resistance. The level of resistance is not particularly sensitive to the amount of waste that might be disposed of in the repository. In other words, even if the repository were to be designed to deal with a significantly smaller volume of spent fuel, there may not be a corresponding decrease in opposition to siting the facility.

Linkage with nuclear weapons

The linkages of nuclear power to the potential for weapon proliferation stems mainly from the front end (uranium enrichment) and the back end (plutonium in spent fuel, and possible processing of spent fuel) of the nuclear fuel chain (Feiveson et al. 2014). All else being equal, the use of fuel with higher levels of uranium enrichment would be a greater proliferation risk, and is the reason why so much international attention has been given to converting highly enriched uranium fueled research reactors to low enriched uranium fuel or shutting them down. Likewise, the chemical processing of fuel allows easier access to the plutonium (or uranium-233, in the case of reactors using thorium), which facilitates proliferation. Practically any mixture of plutonium isotopes could be used for making weapons (DoE 1997; Mark 1993). In the case of both iPWRs and fast reactors, the proliferation risk is enhanced relative to current generation light water reactors primarily because greater quantities of plutonium are produced per unit of electricity generated (Glaser, Hopkins, and Ramana 2013).

Proliferation resistance imposes sometimes contradictory requirements. One way to lower the risk of diversion of fuel from nuclear reactors is to minimize the frequency of refueling because these are the periods when the fuel is out of the reactor and most vulnerable to diversion, and so many SMR designers seek longer periods between refueling. This is the case for SMRs belonging to the fourth family. However, in order for the reactor to maintain reactivity for the longer period between refuelings, it would require starting with fresh fuel with higher uranium enrichment or mixing in plutonium. Therefore, any reduction of proliferation risk at the reactor site by reducing refueling frequency, will be accompanied by an increase in the proliferation risk elsewhere.

SMRs belonging to other families have different impacts on proliferation. In the case of HTGRs, proliferation risk is increased because of the use of fuel with higher levels of uranium enrichment, but is diminished because the spent fuel is in a form that is difficult to reprocess.With MSRs, the continuous processing of fuel, which is integral to reactor operation, could facilitate the extraction of weapon-usable materials (plutonium or uranium-233) from the fuel.

CONCLUSION

Of the different major SMR designs under development, it seems none meets simultaneously the key challenges of costs, safety, waste, and proliferation facing nuclear power today and constraining its future growth. In most, if not all designs, it is likely that addressing one or more of these four problems will involve choices that make one or more of the other problems worse.

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SMR Type	Technical characteristics	Cost	Safety	Waste volume	Proliferation risk
iPWR	Smaller size, lower fuel burnup	Higher	Increased	Larger	Increased
HTGR	Lower power density and higher enrichment level	Higher	Increased	Mixed impact	Mixed impact
MSR	Molten fuel, continuous processing	Uncertain	Uncertain	Mixed impact	Increased
Fast reactors	Higher power density and higher fissile content, molten metal coolants	Higher	Decreased	Smaller	Increased
Nuclear batteries	Higher fissile loading, small size, possibly unmonitored operations	Higher	Lower	Smaller	Increased

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Fission and Fusion: a Path to Energy Security

In a recent Forum article (October 2016) Dr. Jassby identifies seven technical issues that a commercial fission and a future fusion reactor have in common. The theme of his argument is that as a result of these issues commercial fission is failing in the energy marketplace, and because these issues are shared it is likely that fusion will also fail.

WHY IS FISSION BECOMING LESS COMPETITIVE?

Fission reactors have been adversely affected by the dramatic drop in the price of natural gas, largely due to fracking. The relatively low-risk premium for the financing and building of natural gas power plants, the very high efficiency of combined cycle natural gas plants (63%), and the substantial subsidies and government priorities afforded to electricity produced by renewables, have reduced the competitiveness of nuclear power. Fission has also relied on a technology whose efficiency (33%) has not changed over 60 years. Its demise is in large part a result of incremental improvements on 60-year-old concept and a poor investment strategy to improve its performance.

ADVANCED FISSION REACTOR INITIATIVES

The goals of advanced fission concepts are to reduce the price of electricity, improve safety, reduce waste production and increase proliferation resistance. The vast majority of advanced fission reactor concepts involve higher operating temperatures, as high as 850 C, higher thermal conversion efficiencies, and fuel burnups 3 times that of current reactors. Research on new high temperature and radiation resistant materials, such as ceramic materials, for cladding, heat exchangers, and vessels, can have significant impacts on conversion efficiency, fuel burnup, safety margins, and waste production. Other concepts involve different coolants to increase operating temperatures, and still others offer unique core designs that enable higher fuel burnups[1]. To reduce the risk premium of fission reactors, there are now several modular designs that allow manufacturing and assembly at a factory and then shipment by ground or barge to a reactor site for installation. Much of this is also relevant to the future of fusion reactors.

WHY DO WE NEED FISSION AND FUSION?

Abundant supplies of low cost energy are critical to coping with the challenges of world population growth and the demands that will be placed on a broad range of resources such water, food, materials, healthcare, communications, and transportation. The world cannot grow and the quality of life improved without abundant, affordable and reliable amounts of energy.

Utilities, taking advantage of the low costs of natural gas, are replacing aging coal plants at a higher than expected rate, resulting in electricity production from natural gas now surpassing coal. This will very likely continue as long as future government policies do not adversely affect the natural gas industry or the price of natural gas does not significantly increase.

If you now add to this, the aging of approximately100 U.S. fission power plants, whose licenses are scheduled to end on a timetable from now until 2050, natural gas is again the likely replacement option.

The elimination of coal and fission plants amounts to a 53% reduction in our current total national electricity production. If electricity demand increased by just 1% per year from now to 2050, then that would require an additional increase in electricity production capacity by over 40%.

From now until 2050 the gradual shortfall of electricity capacity, whether 53% or 90% or if demand increases significantly, would have to come from only two sources, natural gas, which is an exhaustible resource, and renewables, which have significant scalability and operating capacity issues given the potential magnitude of the shortfall. This is not a viable energy security strategy for a major economic power like the U.S., because it could make our nation dependent upon others for our energy needs.

There are two scalable clean-energy options to consider, namely fission and fusion power. Nuclear fission and fusion power both have a common strategic advantage, large fuel reserves. For properly designed advanced nuclear reactors, proven uranium reserves (those reserves that today can be affordably extracted from the earth) have enough energy content to last the entire world well over 10,000 years based upon total world electricity consumption per year. Unfortunately, current nuclear reactors severely under-utilize the usable energy out of uranium fuel, which contributes to the larger nuclear waste volume.

For fusion energy, lithium is the key energy resource, which based upon proven reserves, could last well over 20,000 years assuming the same world electricity consumption rate per year. Such enormous amounts of energy do not include all known reserves of uranium and lithium, such as those that today are not economically extractable in the oceans.

COMMENTS ON JASSBY'S POINTS

1) Radiation Damage imperils reactor integrity.

The only accessible fusion nuclear reaction is the combination of deuterium (D) and tritium (T) to produce a neutron and a helium nucleus, because there are ways to confine plasmas and heat them so that they generate thousands of mega-watts of energy to ultimately convert heat into electricity. For the D + T reaction, the neutrons stream out of the hot plasma and into the surrounding structures, heating them and providing the dominant part of the energy to make electricity. The differences between fission and fusion neutron exposure of materials has been recognized and addressed for some time now [2]. In response to a desire to reduce the radioactivity of materials exposed to neutrons in fusion, alloy elements were replaced/minimized with much lower activity elements (e.g. Mo by W or V, Nb by Ta), creating the reduced activation ferritic-martinsitic (RAFM) steels, which are now the basis for all worldwide efforts to pursue fusion power plants. In addition, the materials community has identified and verified that precipitates in solids can be used to enhance strength and operating temperatures, and to trap the helium produced by fusion neutrons, thereby mitigating the degradation mechanisms associated with this gas produced in solids. Advanced RAFM steels are being developed at the laboratory level and activities to pursue industrial level production are being explored. Extending the lifetime and reducing the radioactivity of these materials in the harsh fusion nuclear environment is a task that the fusion research community is tackling. The issue is how long can these materials last in a fusion reactor designed for commercial use until they have to be replaced.

2) Radioactive Waste

Fusion power plants will generate radioactive waste. However, all of this waste can be classified as low level waste (LLW), allowing its disposal in shallow burial repositories. In contrast, fission power plants generate LLW, intermediate level waste (ILW) and high level waste (HLW). Fission waste as spent fuel assemblies must be disposed of in deep geological repositories to guarantee no contact with the biosphere for many hundreds of thousands of years (e.g. Yucca Mountain). The volume of LLW and ILW generated per year from a PWR is ~ 200-350 m^3 [3]. For a 40 year plant life, the HLW volume is ~ 800 m^3 and LLW/ILW volume is ~ 8000-14000 m^3. Here we are quoting World Nuclear Association data [3] for operating fission power plants.

The estimated fusion waste volumes range from 1500-8000 m^3 [4] including the multiple fusion core blankets required during the plant's lifetime, assumed to be about 50 years. These waste volumes are not significantly different from fission waste volumes, however efforts continue in the fusion community to minimize this waste [5] by 1) choosing/developing low activation materials, 2) controlling impurities in materials, 3) recycling/clearing plant materials with little to no induced radioactivity, 4) controlling the material choices where possible to allow recycling/clearance after short periods of time (1-10 years), and 5) guaranteeing that the highest radioactivity wastes will decay to low levels in a few decades after they are removed from the fusion core.

Nuclear analysis has shown how strongly the radioactivity of materials can be reduced when specific elements are controlled, and this is the reason the fusion program is pursuing improved materials so aggressively. These materials are not phantasm.

Contrary to the Jassby's claim, there is a private company in West Texas, WCS Corporation, supported by its surrounding community, that already operates two LLW waste facilities, and has applied for NRC licenses to operate a consolidated interim storage facility to prepare used nuclear fuel for long term disposal at a geologic repository.

3) Radiation shielding.

Radiation shielding is required in fusion power plants, and remote handling of all operations inside of the bio-shield (the barrier separating where humans can work with no impact on their exposure) in a fusion power plant is mandatory. We have a great deal of experience shielding, monitoring and handling of radiation sources through the use of neutron absorbing materials and remote handling equipment. The experience of remote handling on fission power plants, and at research hot cell facilities (going on for nearly 5 decades) is considered a very strong basis for fusion's needs. A good example of our existing remote-handling capability is the fact that no human being has ever entered the H-Canyon facility at the Savannah River Site [6] over the 60-year span of its use in the handling, processing and disposal of special nuclear materials. The development of systems relevant to fusion is an important part of the fusion program.

4) Tritium release

Since tritium is not naturally occurring, a fusion power plant must generate its own tritium, by taking advantage of the neutrons produced through their interaction with lithium-based compounds in the blanket. Detailed calculations of the neutron behavior show that breeding enough tritium is achievable, and a recent JASON study [7] independently confirmed this conclusion.

Tritium WILL NOT BE RELEASED to the atmosphere in a fusion power plant from breaches in reactor vacuum ducts, heat exchangers, etc. Tritium permeation is NOT a critical unsolved problem in fact complex situations have been studied including tritium behavior in neutron irradiated samples while exposed to tritium plasma. Predicted total tritium levels in a fusion power plant can range from ~ 1-10 kg, which is much higher than the tritium levels produced in a fission power plant. For comparison, the Savannah River National Laboratory, which is the primary tritium and nuclear material handling laboratory for U.S. defense (and many other functions), has an inventory limit of 7 kg of tritium, and a processing rate of 2-3 kg of tritium per year. For ITER, the on-site inventory limit for tritium is 4 kg, and the targeted maximum loss is ~ 27 Ci/day. The containment and control of tritium is a fundamental design aspect of a fusion power plant, involving identifying all sources/inventories, all migration pathways, all forms (e.g. gas, water, dust), all materials interfaced, all environmental parameters both normal and off-normal (e.g. temperatures, pressures), all interfacing equipment (e.g. pumps, extraction, heat exchanger, purification, storage), and establishing a plant wide series of isolation rooms, regions, and buildings. Multiple barriers are utilized throughout the plant. All appropriate forms of de-tritiation will be present in a fusion power plant from the fusion core to the turbine building.

Tritium releases from fission power plants vary widely. For 2004-2005 [8] gaseous releases range from 1 to 972 Ci (1 Ci = 10^{-4} grams of tritium), and the liquid effluent releases ranged from 142-2951 Ci. Comparing the fusion targeted limit of 3650 Ci/year, the releases would be similar, albeit the fusion power plant would have an extensive tritium sequestering and control system in place since its plant tritium inventory is much higher than fission. Tritium is one of the most critical quantities in a D-T fusion power plant, and this guides the fusion community's emphasis on all tritium aspects.

5) Nuclear proliferation.

Using a fusion reactor for proliferation is at least as impractical as using a commercial fission reactor to produce weapon grade plutonium. Proliferation cannot be described in any depth in a letter such as this, and so we refer to the several journals, papers and workshops on the topic [9,10]. The need for IAEA standards and safeguards for a fusion power plant does not appear to us to present a barrier to fusion power production, or even a discouragement, particularly since the IAEA has been involved in a wide range of fusion development activities for over 40 years already.

6) Coolant demands

Fusion power plant designs over the last 30 years have generally moved away from water as a coolant due to its limitations in the operating temperature (< 330C), high required pressures to avoid boiling (20 MPa), safety issue of water-lithium interactions, possibility of hydrogen explosion when water is dissociated during accidents (like Fukushima), and limitations in thermal conversion efficiency to make electricity. Helium is most often used as the coolant, and water is even eliminated as the secondary coolant in order to keep thermal conversion efficiency high (~45-60%) including the use of a bottoming cycle to utilize the waste heat to further improve efficiency. A great deal can be done to minimize water usage, these techniques are known, and they will not limit fusion's potential.

7) Outsized operating expenses.

Jassby's reference to ITER electricity consumption whether during plasma operation or not, is not a relevant benchmark to judge fusion power plants. ITER's mission is to demonstrate the sustained burning plasma for times long compared to plasma time scales and with sufficient gain (fusion energy produced by the plasma per energy injected into the plasma). It has no mission whatsoever to produce electricity, to minimize recirculating power, or to demonstrate efficient subsystems, all relevant goals of a power plant. The factors mentioned, recirculating power and replacement of fusion core components, have been included in conceptual power plant studies and viable power balance and net electricity production have been found.

ENERGY SECURITY IS A FUNDAMENTAL PART OF NATIONAL SECURITY

The path we are on in eventually eliminating coal and nuclear fission reactors raises serious national security concerns. The real challenge we face is to create technically and economically feasible options over the next 35 years. This will require strong dynamic leadership with vision, serious efforts in long-term planning and sustained investment in high-risk/high-payoff R&D. The annual expenditure on energy in the US is ~ 1.2 trillion dollars, which comprises about 8.5% of the gross domestic product, and the 5 billion dollars spent on energy research per year appears to be utterly inadequate. Given the shortfall in electricity described above by 2050 and the limited options afforded by the current path we are on, more funding should be devoted to a portfolio of credible options for our long-term energy needs such as advanced fission reactors and fusion. Since we do not know what the future will bring, this would be a sensible hedging strategy to provide us with energy security options to adapt to a highly uncertain future.

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[2] S. J. Zinkle and J. T. Busby, Materials Today, http://www.sciencedirect.com/science/article/pii/S1369702109702949

[3] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx

[4] L. El-Guebaly, et al, Fusion Science and Technology, vol 67, (2015), 179.

[5] N. P. Taylor, et al, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.135.1187&rep=rep1&type=pdf

[6] Savannah River National Laboratory (F-Canyon and H-Canyon) http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.558.7021&rep=rep1&type=pdf

[7] JASON report on Tritium, http://fire.pppl.gov/jason_tritium_fusion_2011.pdf

[8] http://www.ieer.org/sdafiles/16-1/tritium_releases.html

[9] The Nonproliferation Journal, http://www.tandfonline.com/doi/full/10.1080/10736700.2013.852876?src=recsys

[10] A. Glaser and R. J. Goldston, Nuclear Fusion, vol 52, (2012), 043004.

FORUM NEWS

Forum Sponsored "April" Meeting (January 28-31 2017) Sessions

8:30 AM SATURDAY INVITED

PLENARY SESSION I: Science Policy in the 21st Century

Room: Ballroom Salon 2/3
Chair: Daniel Holz, University of Chicago
Invited Speakers: John Holdren
Cherry Murray
Rush Holt Jr.
Bill Foster

1:30 PM SATURDAY

Nuclear Testing Limitations and Monitoring Low Level Radioactivity

Room: Delaware A Sponsor: FPS
Chair: Thomas Cochran, Natural Resources Defense Council
Invited Speakers: Pierce S. Corden
CharlesCarrigan
LassinaZerbo

10:45 A.M. SUNDAY FPS AWARDS SESSION

Room TBD

3:30 PM SUNDAY INVITED

The Social Legacy of the Manhattan Project

Room: Delaware A Sponsor: FPS FHP DNP
Chair: Allen Sessoms, Georgetown University
Invited Speakers: Daniel Kevles,
Kelsey Davenport
Carlton Stoiber

JAN 29 2017 5:45PM, SUNDAY

APS Prizes and Awards Ceremonial Session

Room: TBD

8:00PM, SUNDAY

Staged Reading of the Play: Reykjavik

Room: TBD

1:30 MONDAY

The Roles of Physicists in International and Nonprofit Organizations

Room: Delaware A Sponsor: FPS FIP
Chair: Allen Sessoms, Georgetown University
Invited Speakers: Charles D. Massey,
Anne-Marie Mazza

3:30 MONDAY INVITED

Classically Forbidden Transitions: Tunneling Through the Barriers to Advance Women and Minorities in Physics

Room: Maryland B
Sponsor: FPS COM
Chair: Beverly Hartline, Montana Tech of the University of Montana
Invited Speakers: Jocelyn Bell Surnell,
Njema Frazier
KeivanStassun

Short Course on Nuclear Weapon and Related Security Issues

American Physical Society's Forum on Physics/Society, GWU Elliott School, FAS, AAPT

April 21-22, 2017 (Friday/Saturday, GWU, 1957 E St., NW, DC, room 602)

George Washington University, Elliott School of International Affairs, Washington, DC

A popular technical workshop is making a repeat performance. The first three APS/FPS Conferences on Nuclear Weapon and Related Issues were published in the American Institute of Physics Conference Proceedings 104, 178 and 1596. International experts will give the background to understand these issues more completely. We recommend signing up early, as it is limited to 100 conferees. The cost is $120 for 25 talks, 250 pg. book, 2 lunches, coffee/snacks. The organizers are Pierce Corden (AAAS), Tony Fainberg (former DHS), Dave Hafemeister (CalPoly), Allison Macfarlane (GWU). Information/registration at http://www.aps.org/units/fps/meetings/nucwpissues/ Questions, contact dhafemei@calpoly.edu. (12/15)

I. Strategic Nuclear Weapons (9 AM, Friday)

Keynote. *Future of US/Russian Arms Control*: Steven Pifer (Brookings)
US Nuclear Strategy Toward China, Charles Glaser (GWU)
Alert Status of Nuclear Weapons: Hans Kristensen (FAS)
Nuclear Modernization: Amy Woolf (CRS)
Global Strike Hypersonic Weapons: James Acton (CEIP)
Nuclear Warhead Verification: Alex Glaser (Princeton)

Luncheon Speaker: *Richard Garwin's Biography*: Joel Shurkin (shared Pulitzer).

II. Multilateral Arms Control

NAS Nuclear Test-Ban Studies: Raymond Jeanloz (UC-Berkeley)
CTBT On-Site Inspections: J.J. Zucca (LLNL)
Control of Conventional Arms: Bruce Turner (State Dept.)
Space Weapon Technology and Policy: Theresa Hitchens (U. Maryland)
BMD Countermeasures: George Lewis (Cornell)
CW/BW Arms Control: Robert Mikulak (former US Ambassador to OPCW)

III. Nuclear Proliferation (9 AM, Saturday)

North Korea's Nuclear Program: David Albright (ISIS)
Joint Plan of Action with Iran: George Perkovich (CEIP)
Future of NPT, Measures to Reduce Nuclear Dangers: Daryl Kimball (ACA)
Role of Safeguards to Ensure Compliance: Sandy Spector (MIIS)
Quadripartite ABACC; A Model for Others: Togzhan Kassenova (CEIP)
Further Proliferation from Nuclear Power Infrastructure: Sharon Squassoni (CSIS)

IV. Terrorism

General Threat from Terrorists: (DHS Center, Univ. Maryland)
Nuclear Terrorism – Threat or Not: Miles Pomper (MIIS)
Technologies to Counter Aviation Security Threats: Huban Gowadia (TSA)
Drone Warfare: Hugh Gusterson (GWU)
Countering Nuclear Terrorism with Technology: Mike Carter (LLNL)
Summary of Countering Terrorist Threats: Tony Fainberg (IDA)

Dear Professor Dyson: twenty years of correspondence between Freeman Dyson and undergraduate students on science, technology, society and life,

by Dwight E. Neuenschwander, World Scientific, 2016,428 pages, ISBN 9814675857, $36 paperback

This book is based on a correspondence for over 20 years between Freeman Dyson and Dwight Neuenschwander and his students in a general education capstone course "Science, Technology, and Society" (STS) taught at Southern Nazarene University in Bethany, Oklahoma. Neuenschwander, who is listed as the "editor" of this book, but perhaps more accurately should be listed as the author, has taught a section of this STS class for over 20 years. He has used Dyson's semi-autobiographical book *Disturbing the Universe* as the textbook for this class. In 1993 Neuenschwander and his students sent a letter to Dyson along with questions and comments about *Disturbing the Universe*, hoping to get some brief response. In fact within a week of receiving this letter Dyson responded with lengthy replies to six of the students' queries along with copies of some of his talks. Thus began a continuing intellectual and personal dialog between Freeman Dyson and the professor and his STS students. They covered a range of topics involving the impact of science and technology on society and other more general areas often centered on morality and ethics.

Their discussions include topics on: how best to live a good and ethical life; how to choose one's life's work; how to reconcile the teachings of religion and science; Dyson's predictions about the future of human civilization beyond our solar system and his involvement with project Orion; Dyson's interactions with famous scientists like Oppenheimer, Teller and Feynman; our relationship with machines; the differences and similarities between artistic and scientific endeavors; the efficacy and ethics of aerial bombing; the development and use of nuclear weapons; nuclear disarmament; genetic engineering doubt and faith; and ending with a chapter titled "Family First: Letters on Priorities".

In many ways this book is a narrative about how Neuenschwander runs his STS class. About half of the actual text is written directly by the author where he describes how he runs the class, summarizes some of the scientific topics discussed in class, such as big bang cosmology, and presents his opinions on the topics discussed. About 20% to 25% of the text consists of Dyson's responses to the letters written to him by Neuenschwander and his students and some of this consists of comments like where Dyson was when he wrote a particular letter. The remainder consists of excerpts from written material by the students and brief quotes from a variety of sources including *Disturbing the Universe*. These different types of material are distinguished from one another by the use of different fonts. Each chapter discusses one or more related topics without any precise chronological ordering of the exchanges between the STS classes and Dyson.

Some of Dyson's letters are particularly interesting such as his discussion on the nature of scientists and their work and creative methods compared to those in other areas like the arts, and one in which he writes about the difficulty of acting in a war-time setting in what in hindsight he realizes could have been a more correct and moral manner. Here he discusses his work with the British Bomber Command whose efforts he eventually saw as futile and also deadly to both the British pilots and German civilians and compares his experiences to the work of the scientists at Los Alamos who built the A bomb. He explains how difficult it was for him or them to disengage from their efforts during wartime to reflect on what they were doing and he appreciates how the Los Alamos scientists could have been so caught up in their potentially deadly work that some of them said they enjoyed it. There are a few of Dyson's replies that talk about his childhood and about his family, his parents, his sister, his children and his grandchildren. We also learn of some of Dyson's iconoclastic views on topics like global warming, the 9/11 attacks on the U.S., and how best to respond to North Korea's nuclear weapons program.

Dyson is an excellent writer and a brilliant scientist. His writings on science and religion make him an exceptional person to study in an STS class at a faith-based university like the author's; this is evident when he writes that "science and religion are two windows that people look through, trying to understand the big universe outside, trying to understand why we are here… to me religion is not a matter of belief but a way of life. I go to church to be part of a community of caring people. I consider myself a Christian, but I don't believe in the resurrection." But throughout this book Dyson is regarded as the "Wise Grandfather" or spirit guide and his responses to the students' questions are always accepted without challenge or comparison with opposing views while often being used to guide and validate the personal choices and opinions of the author and his students. Much interesting material is presented in the book. However, considering the amount of space actually devoted to Dyson's writings, if one wants to learn more about Dyson and his wide-ranging and interesting thoughts on almost any topic it is more efficient to read Dyson's books and articles directly.

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Building the H Bomb: A Personal History

by Kenneth W. Ford (2015, 221 pages, World Scientific, Hackensack, NJ), ISBN 978-9814632072 ($47 hardback, $17 paperback)

The invention of hydrogen bombs was a major, page-changing event. An increase by a factor of one thousand (ten doublings) from kilotons to megatons is a big deal. Such an increase in prowess can easily overwhelm arms control efforts to constrain the beast. Ken Ford lived these events as a Princeton graduate student, doing his pure physics thesis in parallel with his calculations of fission-fusion-fission for the 10.4-megaton Mike test of 1 November 1952. Ford's historical treatment of nuclear events is timely since we do not have solid plans for stronger nuclear controls in 2016, only principles and hand wringing. It is my hope this book will force us to go to the well, once more, to seek a solution beyond "deterrence seems to work."

Let's place Ford's book in context. Richard Rhodes' book *Dark Sun:The Making of the Hydrogen Bomb* is an excellent historical document by a historian. [1] Ford's book, written by a physics–insider, makes a significant contribution to the history of the science, as well as to the history of the political conflicts around the H-Bomb program. Ford combines excellent descriptions of the nuclear learning process, along with humorous and illuminating discussions about the designer physicists. He does a nice comparison/contrast on the nuclear rivals, Stan Ulam and Edward Teller, concluding that they both were a bit on the lazy side, with Ulam too laid–back and Teller too tense.[2]

Ken Ford entered the H bomb workforce in June 1950 for two years as part of the Matterhorn Project at Princeton and Los Alamos under Professor John Wheeler. This was a time of uncertainty for the H-bomb, as the "classic superbomb," having a boosted primary to ignite a deuterium secondary had been shown to fail by Stan Ulam and Cornelius Everett. Ford was a member of the Matterhorn Project in February 1951 when Stan Ulam showed that the radiation–implosion mechanism could raise temperatures and pressures sufficiently to fission nuclear deuterium. Ford then used desk calculators and IBM cards to show definitively that the Mike's deuterium fusion would propagate and succeed when its Teller-Ulam radiation pressures were taken into account.

The basic physics is straightforward:

- A ten–kiloton primary exploded over 100 nanoseconds has an average power of 4×10^{20} watts.
- The radiant flux developed over a 10 cm radius primary sphere is 0.3×10^{22} W/m^2.
- The black body temperature to develop this flux is 15 million kelvin.
- The average x-rays from this black body have an energy of 6 keV and a wavelength of 0.5 micron.
- Radiation channels direct the x-rays perpendicularly to the secondary surface, which evaporates, carrying momentum and compressing the secondary inward.

As it turns out Teller didn't believe this was true until Ulam reported his results to him. They co-authored Los Alamos Manuscript (LAMS) 1225 on 9 March 1951. The issue of what to do with H bombs got sidetracked as Teller over-reached for credit as part of his lobbying to create a second weapons' lab at Livermore. Ford concludes (pg. 23): "As to Teller, I have to conclude that, despite his later testimony about his thinking in December and January, his ideas about radiation implosion and the equilibrium Super had not gelled prior to his February meeting with Ulam." Teller avoided mentioning the Ulam connection in his book "The Legacy of Hiroshima." Ford knew both Ulam and Teller well as he calculated yields for the various designs. Ford followed these events as a participant and as a thorough student of historical documents. Bethe has also written on these events,[3] stating the following: "In January 1951, Teller obviously did not know how to save the thermonuclear program" (p. 14).

Ford discusses the divisive history of the H–bomb project. On 30 October 1949, the General Advisory Committee of the Atomic Energy Commission advised to proceed with building high–yield boosted uranium weapon and to cease building H–bombs. The GAC decision was based on moral grounds and because there was no clear path to the H–bomb at that time. Once it became clear that H–bombs could be built, moral dissuasion disappeared. Teller was greatly disturbed by the GAC decision, which contributed to his over-reach to exclude credit from Stan Ulam.

Over the years it has been my pleasure to deal with Ken Ford when he was chair of the Forum on Physics and Society in 1981 and during 1987–93 when he directed the American Institute of Physics. I did not know of Ford's 1950's involvement with the H-bomb until I read his book. The Epilogue of his book spells out his personal response to weapons' work over the decades. He knew that the factor of 1000 increase in yield was going to be a major problem for our planet, and concluded that he would no longer participate in these matters. In 1968, at a public meeting in Cloudcroft, New Mexico, Ford stated in a calm way that he would no longer work on nuclear weapons. The public statement was given, not to gather press attention, but to preclude a future change of his mind. I am glad that Ken Ford wrote *Building the H Bomb*, to tell us

1 *Richard Rhodes,* Dark Sun: The Making of the Hydrogen Bomb, *Simon and Schuster, 1995.*

2 *K. Ford, "Building the H–Bomb: The Big Idea,"* APS News, *pg. 8, June 2015*

3 *Hans Bethe, "Memorandum on the History of the Thermonuclear Program," LANL, May 28, 1952 (declassified), and "Comments on the History of the H-Bomb,"* Los Alamos Science, *pg. 43–53, Fall 1982.*

some of the history and physics of H-bomb weapons, to tell us revealing stories of himself and other participants, and to tell us of his moving personal journey along this difficult path.

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