

# PHYSICS & SOCIETY

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

## EDITOR'S COMMENTS

With this issue of *Physics & Society*, we begin a series of papers, all with the title “What are nuclear weapons for?” The series is meant to stimulate thought about nuclear weapons policy, about national and international security, and how the enormous changes since the end of the Cold War might, or might not, suggest the need for significant changes in nuclear weapons policy.

The authors all are, or have been, very senior level participants in issues related to nuclear weapons, such as weapons design and production, international nuclear arms negotiations, or nuclear policy formulation.

I consider it an honor to publish these papers by such distinguished experts, and I thank them for sharing their views with the readers of *Physics & Society*.

—JJM

### IN THIS ISSUE

#### EDITOR'S COMMENTS

#### NEWS OF THE FORUM

- 2 Upcoming Forum Election
- 2 Forum Short Course on Physics of Sustainable Energy
- 2 Deadline Approaching for AIP State Dept. Fellowship

#### ARTICLES

- 3 What Are Nuclear Weapons For? *Michael May*
- 7 What are Nuclear Weapons For?  
*John S. Foster, Jr. & Keith B. Payne*
- 10 Nuclear Fuel Banks: A View From the South  
*Fernando de Souza-Barros*
- 14 The Origins of CAFÉ *Allan R. Hoffman*
- 16 The CAFÉ Formula, *David Hafemeister*
- 19 Sputnik – 50 Years Later *Alan J. Scott*

#### COMMENTARY

- 24 Three Inconvenient Truths, *Robert Ehrlich*

#### REVIEWS

- 26 Out of the Shadows: Contributions of Twentieth-Century Women to Physics, Edited by Nina Byers and Gary Williams, *Reviewed by Marty Epstein*
- 27 God: The Failed Hypothesis—How Science Shows That God Does Not Exist, By Victor J. Stenger, *Reviewed by Lawrence S. Lerner*
- 28 The God Delusion by Richard Dawkins, *Reviewed by Richard Wiener*

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# NEWS OF THE FORUM

## Upcoming Forum Election

The FPS nominating committee is looking for suggestions from the FPS membership for nominees (including self-nominations) for the upcoming vacancies on the FPS Executive Committee, and particularly for the positions as Members-at-Large. The Members-at-Large serve for three years. The election is to be held during November-December of this year for terms starting in early 2008. Please contact Phil Taylor ([taylor@case.edu](mailto:taylor@case.edu)) with your suggestions.

## Forum Short Course on Physics of Sustainable Energy

As members of the American Physical Society's Forum on Physics and Society, we are concerned with the need to produce and use energy more wisely. One contribution we feel we can make is to educate fellow physicists, especially those who teach in our colleges and universities, about the technical details of some of the more promising techniques for efficient and renewable energy.

To that end, we are organizing a short course on the Physics of Sustainable Energy: Using Energy Efficiently and Producing It Renewably. The short course is intended to give physicists in-depth technical background needed to evaluate these issues for teaching and research. We have reserved an auditorium in Evans Hall, UC Berkeley for March 1–2, 2008. The announcement lists program as of September 2007. See [www.aps.org/units/fps/newsletters/2007/october/upload/dh.pdf](http://www.aps.org/units/fps/newsletters/2007/october/upload/dh.pdf).

The year after the 1973–74 oil embargo, the APS leaped into action with a study on enhanced end-use efficiency, realizing that it is easier to save a kilowatt-hour than it is to produce a kilowatt-hour. The results of the APS study appeared in the 1975 AIP Conference Proceedings 25, titled Efficient Use of Energy. It launched the energy-careers of Art Rosenfeld, Rob Socolow, Marc Ross, Dave Claridge and others. The energy programs at Lawrence Berkeley National Laboratory and at Princeton are a direct result of AIP25. The LBNL energy program for buildings and appliances has had far more effect than any action on energy supply. Savings of 75% for refrigerators, 50% for lighting and 50% for buildings can be directly traceable to Building 90 at LBNL.

Twenty years ago, the Forum organized a short course, Energy Sources: Conservation and Renewables, at the former Office of Technology Assessment in Washington, DC. The 700–page proceedings of that short course, AIP135, served as a useful textbook for such professors as Art Rosenfeld, then at the University California at Berkeley. The book also

became a valuable reference in the libraries of many physics departments, where such applied topics are often scarce.

The US continues to import oil from the unstable Middle-East. The European Union calls for a 50% reduction in carbon by 2050 and California with 20% by 2020. How will this be done? The short course will be held in Evans Hall (room 10) at UC Berkeley. It is intended to give physicists in–depth technical background needed to evaluate these issues for teaching and research. Don't procrastinate, space is limited, send in your registration without delay!

*David Hafemeister, Physics Department,  
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## Deadline Approaching for AIP State Dept. Fellowship

This is a reminder to members of all AIP Member Societies: Application materials for the 2008-2009 AIP State Department Science Fellowship are due by NOVEMBER 1, 2007. For scientists interested in the nexus between foreign policy and science, there is still time to apply to this program. For this year, AIP has implemented a new paperless application process. Please visit our Fellowships web site at <http://www.aip.org/gov/fellowships/> to apply.

As an AIP State Department Fellow, you will experience a unique year in Washington, making a personal contribution to U.S. foreign policy while learning how the policy-making process operates. The AIP State Department Science Fellowship places one or more qualified scientists in the State Department for a 12-month term to apply their knowledge and analytical skills to S&T issues that are international in scope. An annual contribution to the AIP Fellowship is provided by the American Astronomical Society.

AIP is currently seeking applicants for the 2008-2009 State Department Science Fellowship. The term will start in the fall of 2008. Qualified scientists at any stage of their career are encouraged to apply. Information on applying is provided below. Interested readers can also see our web site <http://www.aip.org/gov/fellowships/> and click on "AIP State Department Fellowship" for more information on the program.

## TO APPLY FOR THE 2007-2008 AIP STATE DEPARTMENT FELLOWSHIP:

Applicants must be U.S. citizens, have a PhD in physics or a closely related field, be members of one or more of AIP's ten Member Societies, and be eligible to receive an appropriate security clearance prior to starting the Fellowship. (The PhD

requirement may be waived for outstanding applicants with equivalent research experience.) Once selected, the Fellow will work with the State Department to arrange an assignment.

You must visit our Fellowships web site <http://www.aip.org/gov/fellowships/> to apply. Applicants will be asked to fill out a form on the web site, providing contact and qualification information. They will also receive instructions on submission by email of the following materials:

1. LETTER OF INTENT, limited to two pages, and providing information on your reason for applying, scientific and professional background, foreign policy interest or experience, and attributes that would make you effective in this Fellowship.

2. RESUME, limited to two pages, with one additional page for a list of key publications.

3. THREE LETTERS OF RECOMMENDATION: Applicants should arrange for three recommendation letters to be submitted directly by your references. The letters should be from those having direct knowledge of your character, professional competence, and attributes or experience that enhance your suitability for this position.

The APPLICATION DEADLINE is NOVEMBER 1, 2007 for the 2008-9 Fellowship term.

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## ARTICLES

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### What Are Nuclear Weapons For?

*Michael May*

From the very beginning of the nuclear era, concerned people from all walks of life have debated what should be done about weapons so destructive that a single one had wiped out the heart of a city and killed over a hundred thousand people. Should they be banned, and, if so, how could that be done in a world where deadly threats to states still existed and where the knowledge needed would inevitably (and did in fact) become ever more widespread? If not banned, could they be considered as just another, if more destructive, tool of war, to be used as military need dictated? Or did they fit a special category, that of making the prospect of war so frightening as to deter war itself if there was a possibility of their involvement? If this last notion corresponded to reality – a doubtful notion since, fifty years earlier, the machine gun had been thought to be so destructive as to make war obsolete, only to be subsequently used in the two most destructive wars in history –, who should be entrusted with those weapons? More realistically, since there was and is no supranational authority, who would in fact come to have them?

Governments seem to have settled in the main on the third of those early ideas, that of nuclear weapons serving as deterrents. The other two ideas have not gone away, however. Given that governments do not always show rationality, that they often do not know what to be rational about, and that they

seldom show much concern for the human race as a whole, the case for nuclear disarmament has remained strong. At the other end of the spectrum, using nuclear weapons to win wars has also retained its adherents. And the question of who should retain these dangerous deterrents, while answered in principle by the 1970 Nuclear Non-Proliferation Treaty (NPT), has not received universal support, as witness the four nuclear-armed states outside the treaty. Nowhere do these questions come into sharper focus than in attempting to cast light on the current question of what should the future U.S. nuclear weapons stockpile look like.

Stockpile issues are the topic of this essay. Stockpile issues however cannot be discussed without considering what the nuclear weapons are to be used for. The U.S. needs one stockpile if nuclear weapons return to the forefront of military doctrine, for instance if lower yield weapons are to be used tactically to destroy underground installations, and another if they are to be kept in reserve indefinitely to deter the use of nuclear weapons by other states. It needs one stockpile if the U.S. plans to keep nuclear weapons into the next century and another if it plans to lead an international movement toward nuclear disarmament on an aggressive time scale, as several prominent former officials propose. These and similar questions have to be resolved whatever the current weapons

programs may be, but the current Robust Replacement Warhead (RRW) program poses them with particular sharpness.

Thus, what yields shall the replacement warheads have? The same as the warheads they replace or some other yields? What configuration requirements shall they meet? The requirements imposed by the current bombs and missiles, or requirements imposed by some not yet designed earth penetrating or other new missile suited to new missions? Yield, robustness, and dimensions are among the defining parameters for a weapon design, and weapon designers cannot proceed without either getting answers to such questions from the relevant authorities or guessing at what those answers will be.

So far, designers are investigating safer, more robust alternatives to existing warheads for Cold War missions.<sup>1</sup> There is only limited interest in nuclear weapons programs in the government at present. What Washington seems to require of the programs is to keep the U.S. stockpile in operating condition and safe, and otherwise just keep going along at moderate levels of expenditures without creating adverse publicity. It may be that this will continue and the RRW program will simply replace existing warheads. But this prospect is at odds with the thrust of, not only the 2002 U.S. nuclear posture and subsequent national strategy documents, but also with the thrust of the postures of four of the five nuclear weapons states. These four have stated that their nuclear weapons are not only for ultimate deterrence, but also to deter or punish any state assisting WMD terrorism.<sup>2</sup> Cold War stockpiles are not well designed for the latter goal. One way or the other, whether now or later, by default or by design, these choices will be made.

What are these choices and what are their consequences? The most fundamental choice is whether the U.S. will commit itself to 1) using nuclear weapons only as ultimate deterrent against aggression that might destroy or severely damage the country or its allies and move steadily meanwhile to arms reductions and other cooperative arms control measures; or 2) whether, as the 2002 U.S. nuclear posture and the new nuclear postures of several other nuclear-armed countries imply, nuclear weapons will be used not only to deter but actively to prevent nuclear proliferation, chemical or biological attacks, and state support of WMD terrorism. Deterring and actively preventing terrorist use of WMD and nuclear proliferation are important goals. Nuclear deterrence and the potential use of nuclear weapons to destroy underground or otherwise protected facilities could assist in reaching those goals. At the same time, minimizing the incentives for any state to acquire or use nuclear weapons is also an important as well as a complementary goal. While the main incentives to acquire nuclear weapons stem from a state's evaluation of its security needs, its domestic politics and its history, the

policies of the U.S. and other nuclear-armed states also figure in the acquisition decisions. For any given state, these two classes of incentives may be in conflict.

If the nuclear-armed states – by and large powerful countries with effective conventional militaries and relatively well-protected by size and alliances – consider nuclear weapons as valuable tools of policy and warfare, security establishments in the many countries that are more vulnerable than they are will consider nuclear weapons more seriously. Nuclear weapons have large political and economic costs, but they are credible deterrents, which can destroy the bases for power projection as well as deny an otherwise superior aggressor the benefits of victory. Indications from the most powerful states, those that set the standards for military excellence, that they themselves need nuclear weapons for their security powerfully reinforces the argument for acquisition that stem from a state's assessment of its security and from its politics.

To the contrary, if the nuclear-armed states move away from nuclear weapons, by reducing their numbers and salience, and especially if they find credible ways to support the security of non-nuclear states, as NATO did for instance, the arguments for acquisition are weakened. The success of the NPT among the majority of nuclear-capable but non-nuclear weapon states for the past thirty years attests to the importance of credible security arrangements that guarantee, as well as possible, the security of peaceful states that abide by the NPT.

Actual first use of a nuclear weapon by any country would have an even more pronounced effect on incentives to proliferation. First use of a nuclear weapon by anyone would have both direct effects, which would depend on location and circumstances, and indirect effects. The latter cannot be fully assessed ahead of time but they include the cost of giving the world a demonstration of the effectiveness of nuclear weapons as well as the cost of abandoning the sixty-year old taboo against use of those weapons. The last time the weapons were used, in 1945, nuclear weapons hastened the end of the war, helping to save many casualties and ending the war on more advantageous circumstances for the United States, by limiting Soviet advances, and for Japan, by sparing it the split occupation that Germany endured. But most important, despite some very close calls, those two uses did not lead to further use.

We cannot count on this today. The world today is vastly different from the world of 1945: it is more familiar with the needed technologies, it is wealthier, and with wealth comes greater availability of materials and facilities.

And it is different politically. No longer do two colossi, located far away from each other, stride the political world.

The West may be dominant economically and in some measures of military power, but neither the West nor any other major power can determine whether states in the rest of the world will go nuclear nor whether nuclear capable states will go to war with each other. The world today is more similar to the usual historical situation than the post-World War II world was: a number of states in disparate situations, many of which have reason to be insecure, many of which can acquire the latest weapons. No one can predict the consequences of using nuclear weapons in such a world, but first use today seems unlikely to be a last use, especially if that first use turns out to be militarily effective.

The above argues that the continued reliance of major powers on nuclear weapons and the expansion of nuclear missions can influence other states toward acquiring these weapons. Proliferation heightens the danger of both nuclear war and nuclear terrorism: more governments with conflicting interests will have the weapons and more nuclear weapon materials and essential components will be available in different places and under different security. First use would have unpredictable consequences, including an increased likelihood of further use. The right stockpile, in this view, would therefore be a stockpile that contributes minimally to proliferation, a decreasing stockpile, kept in the background of policy, and not a stockpile aimed at greater utility in a variety of circumstances.

Total nuclear disarmament is another question, however. The world political situation described argues that the consequences of abandoning nuclear deterrence entirely are also unpredictable and could also be dangerous. The current unsettled and more broadly nuclear-capable world argues against bringing back nuclear weapons to the forefront of military doctrine but it also argues against precipitate nuclear disarmament – unless of course it can be done verifiably, universally and, most important, irreversibly. All three of those conditions are difficult to meet but the last is the most difficult. So long as war is possible, a war to the finish between two disarmed but nuclear capable adversaries could easily lead to an exceedingly dangerous race to rearm. The distinctive feature of nuclear weapons that makes them much more difficult to ban than chemical and biological weapons is that chemical and biological weapons are terror weapons, effective against civilians and unprepared military but not against a prepared modern military. On the contrary nuclear weapons are effective military weapons: with a few missions and relatively little expense, they can defeat even large scale conventional attacks, especially those attacks that require force projection at a distance and therefore air bases, ports of debarkation, logistical centers, and other vulnerable and costly targets. They are in fact partial equalizers against the

might of the United States especially, given the long-term U.S. priority on force projection.

The most important argument against complete nuclear disarmament is that powerful states have historically initiated the most devastating wars. For at least two centuries before the advent of nuclear weapons, those wars spread devastation while doing little but adjust boundaries in minor ways. Since the advent of nuclear weapons, the world's most powerful states have avoided full-scale war with each other. No one can demonstrate that the advent of nuclear weapons ended (at least so far) war among the most powerful states, but no other political mechanism has changed – not the way political leaders come to and hold power, not the limited rationality in the world's capitals especially as regards to hostile countries, not the security dilemma generally – while the fear of nuclear devastation has been a major consideration in instilling realism and caution in disputes. That fear has not been salient since the end of the Cold War and it is tempting to think that relations among those states have changed in some other fundamental way, perhaps owing to economic interdependence. What those other ways are however does not readily come to mind. In particular, most of the same states were economically interdependent in 1913.

So a world without nuclear weapons is a distant prospect, as distant perhaps as a United Nations or other accepted authority that could and would guarantee all states against wars to the finish. More likely is a world where nuclear weapons are a background and diminishing presence, where nuclear-armed states do more to move toward fulfillment of their disarmament obligations under the NPT, and where meaningful security assurances are extended, as it becomes possible, to states that may otherwise seek nuclear weapons for security. Evaluating how much more likely presents a mixed picture.

On the one hand, there are cooperative international efforts to bring about nuclear disarmament in North Korea and to prevent Iran from acquiring facilities that could be used to make highly enriched uranium. It is noteworthy however that both are countries with which the U.S. has long had hostile relations and of which it requires little else than non-proliferation and an end to support of terrorism. In the cases of countries that were either allied with the U.S. or needed by the U.S. for some strategic purpose, such as Israel and Pakistan, on the other hand, U.S. efforts to prevent nuclear proliferation or to roll it back have either been absent or have taken a relatively low priority. The record therefore is mixed, although the U.S. historically initiated most nuclear non-proliferation initiatives.

Beyond these immediate problems, the nuclear-armed states put essentially zero political muscle behind nuclear disarmament and little toward reducing the number and salience

of nuclear weapons. Numbers are being reduced, if slowly, but systems are being modernized in most nuclear-armed countries. France, Russia and the United Kingdom as well as the U.S., have explicitly broadened their nuclear deterrent targets to include states that assist WMD terrorists, along with abandoning their very limited commitments to no-first-use of nuclear weapons. India has no doctrine of no-first-use and has given no assurance that it will not use nuclear weapons against non-nuclear states (so-called negative security assurances). Pakistan's doctrine is not so clear but is likely to be patterned on India's. Only China has remained with its initial policy of no-first-use and no use against non-nuclear states. On the whole, there is little sign of a concerted approach to dealing with the nuclear danger.

There are steps that the nuclear-armed states can take that would help rebuild the NPT consensus despite the asymmetric nature of the treaty. Such steps include different nuclear postures that take better account of the need to cooperate with other states; agreement of the nuclear-armed powers to the International Court of Justice ruling that the use or threat of use of nuclear weapons would violate international law; more clearly defined negative security assurances, conditional only on adherence to the UN Charter and not on good relations with any major power; actual Entry Into Force of the Comprehensive Test Ban Treaty, a formal step that makes the treaty binding on all signatory parties and which is conditional on the United States and China, among others, ratifying the treaty; more great power support for Nuclear Free Zones. These all would help, in some cases significantly. But they do not go to the demand for nuclear weapons based on local insecurities.

Must then further and more significant steps to allay the nuclear danger wait upon the difficult and probably distant resolution of conflicts in insecure regions of the world such as the Middle East and South Asia? The major powers come together to an extent on resolving the Palestine problem and the Iran problem. They may yet come together to resolve the Iraq problem. But resolving today's problem will not be good enough if new problems arise tomorrow, as they surely will. Some general agreement on the conditions for international

support, for getting the benefits of civilian nuclear technologies, for dealing with WMD terrorism such as exist in principle now must get the kind of believable great power support that Cold War alliances used to get. Cold War alliances, for all their defects, especially on the Soviet side, did manage to keep most of the then-nuclear capable countries from going nuclear. Security arrangements are not enough but they are necessary if more meaningful steps toward nuclear disarmament are to be taken.

What steps to take where, how to take the first steps, how to get a durable consensus among the P-5 (which have a special obligation) to begin with and among the other nuclear-armed states subsequently, those questions define a long-term agenda for diplomacy backed by meaningful inducements and example. This paper cannot pretend to begin to flush out the details of that agenda. But if the U.S. is to go in that direction, the goal of its stockpile should be limited to maintaining last-ditch deterrence, principally against the use of nuclear weapons by others against U.S. allies and indeed, if the UN Charter principles are to be implemented, against any state.

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#### Footnotes

<sup>1</sup> Deputy Secretary of Energy Clay Sell, remarks to the Carnegie International Nonproliferation Conference June 26, 2007 "While the RRW will not represent a new role for nuclear weapons, and will have no new or different military capabilities, the RRW will have more robust performance margins that will increase reliability and enable us to significantly reduce the size of the overall stockpile."

<sup>2</sup> Russia: Sokov, Nikolai. "The Russian Ministry of Defense's White Paper: The Nuclear Angle." Nuclear Threat Initiative. October 2003 <http://www.nti.org/db/nisprofs/russia/weapons/whitepap.htm> France: Chirac, Jacques. Address on France's Strategic Forces. Landivisiau, France. January 19, 2006. United Kingdom: Department of Defense, "The Future of the United Kingdom's Strategic Deterrent." Government of the United Kingdom. London. December 2006. China: Office of State Control, "China's National Defense in 2002." Government of the People's Republic of China. December 9, 2002.

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## What are Nuclear Weapons For?

*John S. Foster, Jr. and Keith B. Payne*

Recently there has been a round of initiatives advocating the long-term elimination of nuclear weapons and/or their near-term reduction to small numbers.<sup>1</sup> With the end of the Cold War, many thoughtful people understandably ask why the United States should continue to maintain nuclear weapons. What role do they serve? Couldn't we defeat most plausible adversaries with our conventional forces alone?

A problem with these recent initiatives is that they tend to emphasize the risks of maintaining U.S. nuclear capabilities, while generally ignoring or dismissing superficially the risks of giving up those capabilities. The postulated benefit from giving up U.S. nuclear capabilities typically is presented in terms of the contribution such a move supposedly would make to global nuclear non-proliferation. When the continuing possible need and requirements for deterrence are broached, it typically is to assert that most or all deterrence needs can be satisfied by U.S. non-nuclear forces. For example, "...the United States, now the world's unchallenged conventional military power, can address almost all its military objective by non-nuclear means. The only valid residual mission of U.S. nuclear weapons today is thus to deter others from using nuclear weapons."<sup>2</sup> This now common assertion is a logical non-sequitur: whether or not U.S. conventional weapons can satisfy most U.S. military objectives tells us precious little about what may be necessary to satisfy U.S. deterrence objectives.

As a matter of fact, the on-going development and deployment of new nuclear weapons in Russia and China and the spread of mass destruction weapons to rogue states make effective deterrence as important now as it was during the Cold War, and nuclear weapons are likely to continue to be critical to effective deterrence. And, while superficially counterintuitive, the net effect of U.S. nuclear capabilities almost certainly is a positive and essential contribution to nuclear non-proliferation. The following provides a brief elaboration of four reasons why nuclear weapons remain critical to U.S. and allied security.

To address the question "What are nuclear weapons for?" requires that we examine the multiple roles served by nuclear weapons. We need to look beyond the military characteristics of U.S. nuclear weapons and address the broader spectrum of national defense goals that they serve. These goals - deterrence, assurance, and dissuasion - reflect our long-standing core objectives of protecting the United States and allies, working to limit the proliferation of nuclear weapons and other weapons of mass destruction, and steering potential

adversaries away from military challenges and competition.

There should be no desire to rely on nuclear weapons *per se*; precision conventional weapons and defensive capabilities may rightly assume a relatively greater role, as was emphasized in the 2001 Nuclear Posture Review. There is, however, a continuing need for nuclear weapons to support these overarching U.S. defense goals of deterrence, assurance, and dissuasion. None of these roles for nuclear weapons follows from a "war-fighting" policy orientation, or presumes the actual military employment of nuclear weapons, or entails a requirement to do so. The value of nuclear weapons for these traditional core goals of deterrence, assurance and dissuasion resides in their continued role as a withheld threat. Identifying these roles for nuclear weapons in the new strategic environment was a focus of the 2001 Nuclear Posture Review (NPR).

**Deterrence:** The value of effective deterrence did not end with the Cold War; it remains essential to national security, and nuclear weapons remain essential to effective deterrence. By helping to prevent war and the need to use force, nuclear deterrence does not represent a disdainful "trap" as some commentators have claimed. Nuclear weapons are an enormously valuable tool of deterrence in the contemporary strategic context and should be given up only after long and careful consideration. As Winston Churchill observed, "Be careful above all things not to let go of the atomic weapon until you are sure and more than sure that other means of preserving peace are in your hands!"<sup>3</sup>

Strategic nuclear weapons that can threaten an adversary's valued targets from afar are, and are likely to remain, essential for holding particularly well-protected targets at risk for deterrence purposes. These targets are, for all practical purposes, invulnerable to non-nuclear threats and are likely to remain so for the foreseeable future. For example, during the 1991 Gulf War many hardened Iraqi facilities were destroyed but some bunkers were, "virtually invulnerable to conventional weapons."<sup>4</sup> Similarly, according to statements by Clinton Administration senior officials in 1996, the Libyan chemical weapons plant located inside a mountain near Tarhunah could be threatened with destruction only by nuclear weapons.<sup>5</sup>

The potential importance to effective deterrence of the U.S. capability to hold these types of targets at risk from afar is suggested by the attention and resources some adversaries devote to protecting and shielding them. Adversaries unsurprisingly seek to protect what they value. And, as Dr. Harold

Brown, Secretary of Defense during the Carter Administration, emphasized when in office, U.S. deterrence threats should be capable of holding at risk those assets particularly valued by the adversary. In some important cases U.S. non-nuclear threats cannot do so and can promise little deterrent effect.

In addition, there is no doubt that some opponents who were *not* deterrable via U.S. non-nuclear threats were in fact deterred by what they interpreted to be nuclear threats. This deterrent effect is a matter of adversary perceptions, not our preferences: Whatever we believe about the lethality of U.S. non-nuclear weapons and what should be their deterrent effect, and whatever our hopes might be about how adversaries should think and behave, the actual behavior of past adversaries, including Khrushchev, Mao, and Saddam Hussein, has shown beyond doubt that there can be a profound difference between the deterring effects of nuclear and non-nuclear weapons. In some cases, given the adversary's views and the context, only nuclear deterrence works. To assert that nuclear weapons now are unimportant is to suggest either that deterrence is no longer important, or that the future will be much more benign than the past, and that we will not again confront such opponents armed with dangerous weapons. There is every reason to reject both propositions. U.S. policy with regard to nuclear weapons should not be based on optimistic hopes that so contrast with the actual past behavior of foes. Given past experience, the burden of proof is on those who now contend that nuclear deterrence no longer is necessary to preserve the peace.

The question is not whether we "want" to rely on nuclear weapons for deterrence. It is whether we are willing to accept the risk of deterrence failure that would be introduced by our inability to threaten some adversaries' highly-valued targets that may be essentially impervious to non-nuclear weapons and/or our inability to threaten nuclear escalation in response to a severe provocation. The risk of deterrence failure flowing from such incapacities can not be calculated with precision. Because multiple contemporary opponents possess nuclear and/or biological weapons, the consequences of deterrence failure could be measured in thousands to millions of U.S. and/or allied casualties. The risk of deterrence failure following from U.S. abandonment of nuclear capabilities may be low or high depending on the opponent and context. But even low-probability events deserve serious consideration if they have potentially severe consequences. The move to reliance on non-nuclear weapons to hold enemy targets at risk would carry the increased risk of deterrence failure, and the probability may not be low.

**Assurance:** Nuclear weapons are essential to the U.S. extended deterrent. This "nuclear umbrella" is central to the basic

U.S. defense goal of assurance. This is not a trivial goal. The assurance provided to allies by U.S. security commitments, particularly including the U.S. nuclear umbrella, is key to the maintenance of U.S. alliance structures globally. It is part of the basic security considerations of countries such as Japan, South Korea and Turkey. The continuing role of U.S. nuclear weapons for this purpose may not be the preference of those in the United States who would prefer that the U.S. umbrella be non-nuclear. But what does or does not assure allies is not decided by U.S. commentators or U.S. political preferences, but by the allies themselves. The United States can decide if the assurance of allies is a worthy continuing goal, but only our allies can decide whether they are sufficiently assured. In this regard, available evidence points strongly to the fact that *nuclear* weapons remain critical to the assurance of key allies. For example, the recent responses by Japan and South Korea to the North Korean nuclear test of October 9, 2006 demonstrated explicitly that U.S. *nuclear* weapons are viewed by allies as critical to their confidence in the U.S. extended deterrent. The discomfort felt by allies and friends in the Middle East given the prospect of Iranian nuclear weapons points in the same direction.

We could decide that we would prefer to withdraw the nuclear umbrella and provide non-nuclear extended deterrence. But, with the nuclear proliferation of North Korea and the apparent Iranian aspirations for nuclear weapons, and the rapid growth of China's nuclear arsenal, the response of key allies to the U.S. withdrawal of its nuclear extended deterrent coverage would create new and potentially severe problems, i.e., nuclear proliferation by U.S. friends and allies who would likely feel too vulnerable in the absence of U.S. extended nuclear deterrence. Japanese leaders have been explicit about the extreme security value they attach to the U.S. nuclear umbrella, and they have suggested that Japan would be forced to reconsider its non-nuclear status in the absence of the U.S. extended nuclear deterrent. Thus, ironically, nuclear non-proliferation is tied closely to the U.S. *preservation of its extended nuclear deterrent*. This point is contrary to the typical contention that U.S. movement toward nuclear disarmament promotes nuclear non-proliferation. Precisely the reverse linkage may be more the reality: U.S. movement toward nuclear disarmament will unleash what some have called a "cascade" of nuclear proliferation among those countries which otherwise have felt themselves secure under the U.S. extended nuclear deterrent and therefore have chosen to remain non-nuclear. We should be extremely careful before moving in a direction that carries the risk of unleashing this "cascade," such as deciding that U.S. nuclear weapons are unnecessary for assurance and moving toward a non-nuclear force structure.



**Dissuasion:** The goal of dissuasion involves discouraging opponents and potential opponents from militarily challenging the United States. Dissuasion does *not* involve the use of force, but it does require the force structure and technology base necessary to discourage opponents from anticipating success in competing militarily with the United States. A past example of dissuasion was the Soviet decision to scale back its deployment of ballistic missile defense in the 1960s: The Soviet leadership understood that the U.S. strategic offensive potential could overwhelm Soviet defenses. The maintenance of U.S. nuclear capabilities and a viable nuclear infrastructure may be necessary to discourage some opponents from choosing to engage in a nuclear competition in arms.

For example, the elimination or steep reduction of U.S. ICBMs could lower the bar considerably for an adversary who might, under such circumstances, consider realistic the possibility of achieving a counterforce strike option against the United States. Maintaining a set of diverse nuclear retaliatory capabilities serves to discourage the aspiration for any such option. Consequently, it may be critical for dissuasion purposes to maintain an adequate nuclear force structure, particularly because if the United States were to decide to severely reduce its deployed forces, it would not be able to recover those capabilities easily, inexpensively or quickly. As the Chinese, by their own statements, move toward greater interest in counterforce nuclear options, keeping the bar high for any possible success in that regard may be critical to future stability. Moving to a very small number of U.S. nuclear retaliatory capabilities could encourage the Chinese in the wrong direction.

**Defeat:** This fourth reason for the maintenance of U.S. nuclear capabilities does envision the potential military value of nuclear employment. The NPR referred to this as the goal of “defeat.” Military war planning and targeting are properly the prerogative of U.S. uniformed “war fighters.” For the purposes of this article it is sufficient to point out that military threats may emerge that can only be countered with confidence by nuclear weapons. Nuclear weapons may be the only means available for promptly destroying hard and deeply buried targets, achieving prompt war termination, preventing an adversary from marching on and annihilating civilian centers, or for possibly eliminating nuclear or biological threats arrayed against the United States and allies. Whether such objectives would be worth the political and human costs of employing nuclear weapons would be a calculation to be made by the president and would likely be shaped decisively by the specific context and the opponent’s prior actions. If the opponent had, for example, already employed biological weapons (BW) with horrific effect against U.S. or allied civilians and military forc-

es, would a President consider a nuclear response appropriate, militarily useful, and/or necessary to prevent subsequent BW attacks? The possibility can not be excluded that a president would want to have the option for nuclear employment under such circumstances, and that employment could then be vital to U.S. or allied survival. It takes considerable hubris to claim knowledge that such circumstances assuredly will not arise in the future, and correspondingly that no critical military employment value can be attributed to nuclear weapons.

There are risks associated with retaining and modernizing the U.S. nuclear arsenal; there are also risks in not doing so. Nuclear weapons may be critical for the deterrence of war and the dissuasion of military competition; and, they are critical to the assurance of allies who have indicated that they will consider moving toward their own nuclear capabilities if they conclude that the U.S. extended nuclear deterrent is no longer reliable. Advocates of the elimination of U.S. nuclear weapons tend to presume they know that adversaries will continue to be deterred by U.S. non-nuclear weapons, that allies will continue to be assured by the same, and that the U.S. “good example” of moving away from nuclear weapons would be emulated. Again, the burden of proof is on those who make such claims, particularly when considerable available evidence points to the contrary. Yet, proponents of moving toward nuclear disarmament have not offered any serious *net assessment* of the consequences likely to follow from their recommended course.

Finally, there are conditions that should attend any significant U.S. steps toward nuclear disarmament. The realization of some of those conditions would represent a more dramatic restructuring of international relations than has occurred since the 1648 Peace of Westphalia. This need not preclude our thinking about steps toward nuclear disarmament, but it certainly should make us wary of moving quickly toward the vision.

For example, one of the reasons deterrence is so valuable is that it provides incentives for self-discipline in the behavior of states that otherwise can not be trusted to behave peaceably, i.e., the lack of trust that can be attributed to such states is the reason we need effective deterrence. Yet, movement toward the elimination of U.S. nuclear weapons would at various key points require considerable trust that friends and foes alike were pursuing the same goal honestly and could, at a minimum, be relied on to give up nuclear and biological weapons. The fact, however, is that not all states are trustworthy, and it is those states that often pose security challenges. In the past, untrustworthy states included Nazi Germany; now they include North Korea; in the future there will undoubtedly be comparable candidates. The appropriate lack of trust that these states will behave benignly and honestly is the reason deterrence is important and why formulas for disarmament

remain visions. The same lack of trust inherent in international relations that creates the need prevents visionary solutions. Again, the proponents of nuclear disarmament have not begun to suggest how this sturdy barrier to the realization of their vision and like visions in past centuries could be brought down while maintaining our security and the security of our allies. We all would like to hear and to believe.

Ronald Reagan was a proponent of a non-nuclear vision; he also repeated the motto “trust but verify” and understood that concomitant conditions such as the realization of highly effective active defenses had to precede the vision. If his vision is to be brandished now in his absence, it should be brandished in its entirety.

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#### Footnotes

<sup>1</sup> See for example, George P. Shultz, William J. Perry, Henry A. Kissinger; and Sam Nunn, “A World Free of Nuclear Weapons,” *Wall Street Journal*, January 4, 2007, p. 15; and, Wolfgang Panofsky, “Nuclear Insecurity: Correcting Washington's Dangerous Posture,” *Foreign Affairs* Vol. 86, No. 5 (September/October 2007).

<sup>2</sup> Panofsky, *Ibid.*, p.109-110.

<sup>3</sup> Winston Churchill, quoted in a speech by British Prime Minister Margaret Thatcher to a joint meeting of the U.S. Congress, February 20, 1985, available at, <http://www.margarethatcher.org/speeches/display-document>.

<sup>4</sup> General Account Office, *Operation Desert Storm: Evaluation of the Air Campaign*, GAO/NSIAD-98-134 (Washington D.C.: General Accounting Office, June 1997), p.198.

<sup>5</sup> Harold P. Smith, *Assistant to the Secretary o*

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## Nuclear Fuel Banks: A View From the South

*Fernando de Souza-Barros*

### Summary

Recently, at the World Economic Forum of January 2007 in Davos, Switzerland, the director general of the International Atomic Energy Agency, IAEA, Mohamed ElBaradei, called once again the attention of the international community to the mounting challenges to stopping the proliferation of nuclear weapons and the urgent need for a new and stronger security framework. ElBaradei's proposal of this new framework that could provide nuclear fuel supply worldwide will be briefly described in this note. The key point of the proposal is the multinational control of nuclear fuel production. The long history of proposals of these production centers – here identified as nuclear fuel banks – is not the scope of this note. One of its key aspects is the issue of their centralization versus the Article IV of the Non-Proliferation Treaty granting indigenous nuclear fuel-cycle developments. A gradual regionalization approach that would include these production plants needs be considered since overly centralized production of nuclear fuel would hardly achieve worldwide consensus. This consensus is identified by ElBaradei as a necessary condition for the implementations of a new framework for multinational control of fuel centers. If nuclear-fuel banks could be implemented,

despite their unavoidable perils due to the expected increase of nuclear enrichment of Uranium-235, and of nuclear waste, capital costs of nuclear installations would be more rational, security aspects maximized, and their built-in safeguards against proliferation could overcome the limitations of the current practices. Moreover, as pointed out in the original proposal (ElBaradei, 2003a&b), these multinational nuclear installations would benefit countries with economic and technological limitations, eliminating the major justification to start indigenous nuclear programs and the current incentives for the international black-market of nuclear technology. In this note, however, other pressing world demands requiring equally strong and fully committed international cooperation will also be discussed. Unhappily, the political trends that are likely consolidating in the 21st Century are sending the implementation of these initiatives beyond any credible time horizon.

### Introduction

The North Korean test of a nuclear device and the recent success of the nuclear enrichment program in Iran brought a new impetus to the proposals for new ways to establish effi-

cient worldwide control of nuclear fuel enrichment and spent fuel reprocessing. Overall, these achievements reinforce a new trend in the acquisition and deployment of small but politically relevant nuclear arsenals, namely that they are unrelated to any high-level threshold of technological developments.

The initial discussions of international nuclear fuels centers date back to 1940's with the 1946 Acheson-Lilienthal report (see Scheinman, 2007, for historical details). However, in that same year, a US Atomic Energy Act and the start of the Cold War blocked concrete international initiatives until the 1960's. One should note that the Atoms for Peace policy for international cooperation was proposed by the US in 1954. This policy fostered research centers on nuclear technology in countries of the Western block conditioned on a bilateral agreement basis: the research reactors commissioned in these centers would have their highly enriched U-235 supplied by the US.

The 1968 nuclear non-proliferation treaty, NPT, preserved the Cold War scenario with the official recognition of the nuclear arsenals of five nations, but granting that non-nuclear nations have the right to develop nuclear technologies for peaceful applications (Article IV). Since the advent of the NPT, however, five other nations have developed the complete fuel cycle technology – and now have nuclear arsenals – and about forty other nations can acquire this capability if they wanted to make that political decision.

Currently, two major approaches for the implementation of these nuclear fuel centers are gaining the attention of the international community: the US proposal for a Global Nuclear Energy Partnership (GNEP) and the Multinational Control of Nuclear Facilities – here recognized as ElBaradei's proposal.

GNEP's guidelines are: (i) promoting the international use of nuclear energy with proliferation-resistant recycling of spent fuel and the development of advanced reactors; and (ii) the establishment of a consortium of nuclear facilities capable of delivering cost-effective nuclear fuel and providing assurances of supplies to nations willing to discard indigenous nuclear-fuel production. These proposals were discussed – among several others – in a recent meeting at the IAEA headquarters in Vienna. The proposal of May 2006 made by six nuclear suppliers to establish a mechanism to ensure fuel reserves under the IAEA conforms with the GNEP i.e., eligible countries would renounce fuel-cycle activities (Meier, 2006). However, the reports on these discussions also disclose that various countries, including Argentina, Australia, Brazil, and South Africa, have expressed their intent to have their own nuclear fuel production (Pomper, 2006).

ElBaradei's guidelines shall be described in the next

section. Briefly, the stepwise implementation of multilateral control of nuclear fuel production does not proscribe states from having nuclear capabilities, upholding the Article IV of the NPT (see Schelman, 2007).

#### *The background elements for multilateral nuclear suppliers*

On October 16th, 2003, ElBaradei published an op-ed in *The Economist* entitled "Towards a Safer World" (ElBaradei, 2003a). The candid appraisal of present-day nuclear affairs made by the director general of the IAEA had a great impact. Although stressing the importance for states' adherence to the obligations of the Nuclear Proliferation Treaty, NPT, ElBaradei recognized that only a new legal framework would meet the nuclear treats and realities of the 21st century. This assessment was based on the following considerations: "(a) the present nuclear-arms-control regime is looking battered; (b) any reform of that regime must begin by conceiving a framework of collective security that does not rely on nuclear deterrence; (c) the technical barriers to designing weapons and to mastering the processing steps have eroded with time." It must be acknowledged that at present there are no major impediments to acquiring the basic know-how to process spent nuclear fuel and manufacture crude weapons, the only requirement being that of making it a national priority (Souza-Barros, 2006). The objectives of ElBaradei's guidelines can be summarized as follows (ElBaradei, 2005): (a) to limit the processing of weapon-usable material (separated plutonium and high-enriched uranium) to facilities under multinational control; (b) to insure that nuclear-energy systems that are deployed, by design, avoid the use of materials that may be applied directly to making nuclear weapons; (c) to place spent fuel and radioactive waste under multinational management.

The first institutional assessment of ElBaradei's proposed guidelines took place in February 2004 at the IAEA headquarters. It was an international seminar on "innovative approaches to nuclear non-proliferation and the nuclear fuel cycle" (Rapporteur's Report, 2004). In the open session ElBaradei reaffirmed his view that urgent action and stronger laws are needed to close serious gaps in controls on exports of sensitive nuclear material and equipment. He also emphasized that "it is time to limit the processing of weapon-usable material (separated plutonium and high-enriched uranium) in civilian nuclear programs, as well as the production of new material through reprocessing and enrichment, by agreeing to restrict these operations exclusively to facilities under multinational control".

Based on the conclusions of the 2004's seminar, the IAEA appointed an expert group to appraise existing proposals (Multilateral Nuclear Approaches, MNAs). The MNA report (IAEA INFCIRC/640) emphasized that the dominant guide-

lines in the conception of multinational fuel banks should be (i) assurance of non-proliferation; and (ii) assurance of supply and services. A time consideration in INFCIRC/640 is the need for “devising effective mechanisms for assurances of supply of material and services, commercially competitive, free of monopolies, of political constraints, and including backup sources of supply”.<sup>1</sup> As discussed below, one way of addressing these supply assurances is to have a network of nuclear-fuel banks.

#### *The current status of multilateral nuclear approaches*

Last September 2006 a special meeting was held in the Vienna Agency to appraise recent alternative approaches for nuclear fuel supply (Pomper, 2006). The present status of ElBaradei’s proposal is such that the discussion on feasible mechanisms for the new framework still awaits the legitimacy that can only be granted by a forum of all nations. The many constraints for multilateral nuclear partnerships that should be focused in this forum are beyond the scope of this note and can be found elsewhere (Buckley, 2006, Braun, 2006; Dhanapala, 2003; Scheinman, 1981). There also exist difficult technical questions that must be faced (Braun, 2006). For instance, the actual diversity of nuclear reactors raises the valid question of what can be regarded as a viable supply of enriched material. It might be concluded that the ultimate viable supply could only be low enriched Uranium (LEU) in either UF<sub>6</sub> or UO<sub>2</sub> forms. What would constitute practical assurances of obtaining this material? Should IAEA manage supply assurance programs? Is there a consensus on the role of the IAEA in these partnerships? Some nations might argue for an exclusive role of IAEA for verifying that plant operations are conducted according to the established new framework. Under the present state of world affairs, it seems that the simplest alternative to assure back-up sources of nuclear supplies is to again emulate the corporate world and consider incentives leading to the formation of a network of nuclear-fuel banks worldwide. Nuclear fuel banks based upon independent nuclear partnerships in different regions of the world would then assure the existence of back-up supplies to nations in regions having political conflicts. Another requirement for a truly international partnership is for states to share technical knowledge. This procedure is relevant to the search of consensual and viable solutions to nuclear issues, in particular the question of nuclear waste for which shared expertise will be badly needed in order to reach verifiable choices of storage locations. If spent fuel reprocessing is a technical requirement for the partnership, the negotiations of the strict regulatory regime should take into account that the installations in the host country shall have international staff and shared management. The limitations of uranium supplies

should also lead to the development of shared utilities using efficient new-technology reactors.

#### *Pressing demands in world affairs*

Although providing adequate energy while limiting the risk of weapons production remains a major concern, there are other pressing world needs. These can only be met by multinational initiatives and commitments comparable to those that are contemplated for ElBaradei’s proposal. The choice of these demands, which have worldwide implications – hunger, climate change and HIV/AIDS pandemic – is to call attention to the fact that their effects upon populations differ enormously. They are far more severe for those living in the underdeveloped world. This asymmetry makes more difficult the engagement of rich nations to fully commit themselves to international cooperation in order to overcome suffering and disaster in the poor nations. The relevant features that characterize these world tragedies are given below (for a review see Swaminathan, 2006).

To face hunger that afflicts nearly one billion people on the planet there are humanitarian initiatives for providing food supplies to mitigate its terrible consequences. This practice is recognized as the only viable initiative to help inhabitants of the remote corners of the planet. What is not well known is the effect of the unregulated trade of food commodities among poor nations. Swaminathan points out that (quoting) “in many poor nations, 50 percent or more of the population depend upon agriculture for their livelihood security.” Thus unregulated trade between rich and predominantly agricultural countries (quoting Swaminathan) “causes serious social consequences for the loss of livelihoods in villages and leads to the unplanned migration to towns and cities resulting in the proliferation of urban slums”.

All countries are affected by climate change, but the poorest countries will suffer most due to their precarious living conditions. The ever increasing greenhouse gas emission into the atmosphere (IPCC, 2007) and the reports of devastation due to big storms on urban areas of countries with precarious infrastructure are daily features in the media. Since 1997, however, there has been a legal instrument setting limits to greenhouse gas emissions - the root cause of these atmospheric disturbances: the Framework Convention on Climate Change, negotiated by over 100 countries. The Kyoto Protocol, in 1992, follows this framework. Unfortunately, the Kyoto Protocol is yet to be implemented in spite of the growing awareness of the danger due to the lack of motivation among the industrialized nations. At the open session of the World Climate Conference held in Nairobi last November 2006, the then United Nations Secretary-General, Kofi Annan, stated “It is increasingly clear that it will cost far less to cut emissions

now than to deal with the consequences later”, and concluding that “Global climate change must take its place alongside those threats — conflict, poverty, the proliferation of deadly weapons — that have traditionally monopolized first-order political attention.”

The figures relating to the HIV/AIDS pandemic also highlight the overwhelming contrast of its effects between rich and poor countries (HIV/AIDS, 2006). Over 11000 new HIV infections occurred each day in 2005. More than 95% are in low and middle income countries. About 1500 HIV infections happen in children under 15 years of age. Again there is not yet an international framework to meet the control requisites for HIV, in particular a political commitment to achieve free supplies of anti-retroviral drugs to the needy. One should note that the need for a multilateral enterprise for global HIV vaccine has been addressed as a proposal in June 2003 (Klausner et al., 2003) and that though on a modest commitments were made towards this goal from governments and foundations.

### Conclusions

It must be acknowledged that at present there are no major efforts for establishing international cooperation that would bridge the widening gap between poor and rich states. The evidence points to the fact that the political will to face pressing world demands is also absent. The focused international cooperation needed to overcome the present state of affairs shall only come with the realization that these goals are real needs for all nations of the world. Among these goals is the El-Baradei’s proposal of a new and stronger security framework for nuclear fuel supply worldwide. The role of nuclear energy in a not too distant future remains an open question. Nuclear energy is already a significant source among industrialized nations. Thus it should not be surprising that countries in the underdeveloped world would also consider the same goal of securing nuclear energy capabilities for future needs. Together with the deterioration of international order, the emergence of new nuclear capabilities in recent years demonstrates the importance of meaningful initiatives that could lead to a new framework for world cooperation.

### Acknowledgments

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### Footnotes

- 1 The nuclear fuel cycle supply system that has been announced at the G8 Summit in Russia, July 2006, is not a nuclear partnership envisaged with the new framework. In this scheme, a host country with an enrichment facility would supply the nuclear fuel to client countries.

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## The Origins of CAFE

Allan R. Hoffman

The Corporate Average Fuel Economy (CAFE) performance standards, enacted into law in 1975 (Title V, Energy Policy Conservation Act), have governed the fuel economy of new passenger automobile fleets in the U.S. for the past 32 years. They were a response to the oil embargo imposed by OPEC in late 1973. Much has been written about the CAFE standards in the intervening years, and they are again in the news as Congress considers increases in the standards in response to higher fuel costs, global climate change, and national security concerns related to oil imports. This article adds to this literature by providing a first-hand account of CAFE's origins.

Two weeks after President Nixon resigned in August 1974, and at a point where the U.S. Congress was beginning to focus on a response to the Arab Oil Embargo that had cut off roughly a third of U.S. oil imports, I arrived in Washington, DC as a Congressional Fellow of the American Physical Society. The impact of the Embargo had been significant, especially on transportation which accounted for two thirds of total U.S. oil consumption. It restricted public access to gasoline, produced higher gasoline prices, and caused fist fights at the pumps.

After orientation to the rules, practices and vagaries of the U.S. Congress provided to new Fellows by the American Association for the Advancement of Science over a period of several weeks, my assignment as Staff Scientist with the Senate Committee on Commerce began on October 1, 1974. At that time there were very few scientists working on the Hill as Congressional staff members. In response, several professional societies had established a Congressional Fellowship Program in 1973 to bring Ph.D. scientists to Washington at their expense for a year to help Congress with its increasingly scientific and technological responsibilities. The initial class in 1973 had seven Fellows — my class had twelve.

The Commerce Committee was chaired by Senator Warren Magnuson, and Mike Pertschuk and Lynn Sutcliffe served as Staff Director and General Counsel. Both were dedicated civil servants and contributed much to my legislative education that Fellowship year. I am also indebted to Mike Brownlee, with whom I shared an office and who provided invaluable guidance to the new kid on the block.

My first assignments from Mike and Lynn were to think about how to reduce oil imports into the United States, and to learn as much as I could about setting up a gasoline rationing system for the U.S. I worked on this latter task by contacting people who had worked on various kinds of rationing during World War II in the Office of Price Administration. It is not widely known, but the Federal Energy Administration (FEA)

even printed rationing coupons for this purpose. Nevertheless, it quickly became clear that rationing was not a politically acceptable solution to our oil consumption problems.

The obvious target for reducing fuel consumption was the passenger automobile fleet, the primary user of petroleum products. Bob Hemphill, a senior FEA official, and two members of his staff worked with me closely in these early days. We quickly honed in on the three factors that determined the total fuel consumption of the fleet - the number of cars on the road, the average vehicle miles traveled (VMT) per car, and the average fuel economy of the fleet:

**Annual Fuel Consumption = (# cars) x (annual miles driven per car) x (gallons of gasoline consumed per mile driven).**

This latter factor is the inverse of what we refer to as fuel economy – i.e., miles per gallon (mpg). If we were to influence total automobile fuel consumption we would have to create changes in one or more of these three factors.

Over the next several weeks it became clear that limiting the number of cars on the road was politically unacceptable (“unAmerican” is the term I’ve used), and that to limit VMTs it would be necessary to raise the price of gasoline. This would have been my choice, incrementally and predictably raising the price over a period of years. The Congress was unwilling to do this, as exemplified by a series of votes in the U.S. House of Representatives in early 1975 on a proposal to raise the federal gasoline tax. The initial proposal was to raise the tax by 3.5 cents, and this was voted down. Subsequent proposals were at 3.0 cents, 2.5 cents, 2.0 cents, 1.5 cents, 1.0 cents, and 0.5 cents, and all were voted down. After observing this from the House Gallery, I walked back to my office in the Senate, realizing that the only factor we might affect with legislation was the fleet average fuel economy. This was the origin of the CAFE legislation that eventually emerged.

Weeks and months were then spent on researching the U.S. automobile fleet (the 1974 fleet average was approximately 14 mpg) and current and emerging automotive technologies. Considerable time was spent talking with experts in government, academia and the automotive industry as well as others knowledgeable of the industry. During this period I began to work closely with Senator Fritz Hollings of South Carolina, a member of the Senate Commerce Committee and an unsung hero of the CAFE story. In Hill staff parlance he was “the horse that carried the water” for moving legislation forward in the Committee and later on the Senate floor. I also began to work more closely with Lynn Sutcliffe, who provided political expertise and guidance throughout the following months.

These efforts led to a proposal to draft legislation that

would double each manufacturer's new fleet average fuel economy to 28 mpg within 10 years. This goal was set as a "stretch but doable" goal for the industry, and recognized that the industry needed time to reach the goal and that the federal government should not be telling the industry how to do so. The proposal was discussed extensively by the members of the Commerce Committee in a closed meeting and eventually accepted by a majority of the Committee. Senator Hollings was the leading advocate for the proposal, which split the two senators from Michigan – Senator Hart supporting the proposal and Senator Griffin opposing it. An initial version of the proposed legislation was then drafted and shared with three staff members who would help move the legislation through the House legislative process - Charlie Curtis and Bob Nordhaus, who worked for Representative John Dingell, Chairman of the House Energy and Commerce Committee, and Shelley Fidler, legislative director for Representative Phil Sharp, a member of the House Committee. They, along with Lynn Sutcliffe and Mike Pertschuk, are some of the finest public servants I have ever worked with, contributed much to my education, and all are still productive members of the Washington policy community.

The next several months were spent in hearings in the House and Senate on the draft legislation, and in revising the legislation based on these hearings and other information that became available. The House version that emerged, while still quite similar to the Senate version, did diverge in some details, including setting the 1985 10-year goal for the new fleet average at 27.5 mpg. This was also a time when the U.S. automobile industry was beginning to lose market share to Japanese car companies.

As expected, the hearings produced a wide range of opinions. The U.S. automobile industry strongly opposed the legislation, arguing that fuel economy could not be increased to the proposed level at the same time that automobile emissions were being regulated by the Clean Air Act. Other witnesses did not agree, and several of those intimately familiar with the industry argued strongly that the industry on its own would never significantly increase their fuel economies because the profit margin on big cars was so much larger than that of smaller, more fuel efficient cars, given the small difference in manufacturing costs between small and large cars. The industry argued that the proposed legislation would restrict the number of cars that would be available to pull recreational vehicles, but calculations quickly revealed that this argument was unsupportable and the issue went away.

Another issue that arose was how to deal with luxury car fleets that were unlikely to meet the standards. Some quick calculations determined that the amount of gasoline at stake was small, and I recommended that we let the luxury car

purchasers pay the civil penalty for non-compliance and leave it at that, recognizing that we couldn't fix all the problems in one bill. Of course, we were subjected to considerable lobbying on all sides of the fuel economy issue, including one day when Lynn and I met with supporters of the legislation in the morning and strong opponents of the legislation in the afternoon. Our end-of-day conclusion was that we must be doing something right.

The House version of the legislation reached the floor in June, while the Senate version was scheduled for debate in July. I sat in the House Gallery the day of the debate, next to a colleague who worked for the National Automobile Dealers' Association. He was someone I had become friendly with during the intervening months. To my great surprise he was rooting for the bill to pass by a 4 to 1 margin. I remember turning to him and saying: "What's wrong with you? You work for the automobile industry and they are strongly opposed to this legislation. Why are you rooting for it to pass?" His answer: "I've told the industry that this bill is going to pass and they don't believe it. They don't think the Congress has the "....." to pass it." Well, he was right and they were wrong — the bill passed by a margin of three and a half to one.

The bill reached the Senate floor about a month later, and I assisted Senator Hollings while he managed the 6-hour floor debate. He had prepared himself well, not only rereading the bill the night before, but also reading the full report accompanying the bill to the floor which he subsequently sent to every automobile dealer in South Carolina. It was also my first time on the Senate floor. The final vote in the Senate that day in favor of the CAFE legislation was 63 to 21.

The next several months were spent in conference with the House, to resolve the differences between the two versions of the Energy Policy Conservation Act that had emerged from the floor actions. At the staff level this effort on the Senate side was led by Lynn, while Charlie and Bob led the House effort. CAFE was only one of many titles that were proposed as new energy policies for the U.S., and it took until December 1975 to resolve the differences and bring a conference report (the bill agreed to in conference by the House and Senate negotiators) to a vote in both Houses. It was quickly passed just before Christmas and signed into law by President Ford. The signing was followed by a brief celebration at the Hawk and Dove restaurant among House and Senate staff members who had been most involved in the negotiations, accompanied by Representative Dingell who had been a consistent supporter of the legislation. He even offered to pay for the drinks, a kind offer that was appreciated but refused.

There are many enjoyable memories of those days and nights in conference:

- Senator Bumpers' advocacy of legislation that would

cut down on idling time and fuel consumption at street corners. As a result of his successful efforts he became known to the conference staff as “Right-Turn-On-Red Bumpers.”

- working with the talented and fun-loving House legislative drafting staff
- escorting female Senate staff members back through the tunnels between the House and Senate late at night, to make sure they got to their cars safely. This was always interesting, as certain tunnel creatures only came out at night when human activity was minimal.

One final conference anecdote about why the final 1985 standard was set at 27.5 mpg. This number derives from the House version of the legislation, whereas the Senate bill called for 28 mpg.

Midway through the conference deliberations Lynn approached me and asked what our position should be: 28 or 27.5? Doing a few quick calculations revealed that the House method of calculating the average was slightly more stringent than the Senate method, and would lead to slightly greater fuel savings. My advice to Lynn, which he accepted, was to accede to the House position, the House would be pleased that we’d accepted their version of the legislation and gain us some bargaining leverage in other conference negotiations, and the country would benefit from a slightly more stringent standard. Thus, 27.5.

Several months after CAFE became law, an oversight hearing on its implementation was held by Senator Adlai Stevenson, Chairman of the Senate Commerce Committee’s Science Subcommittee. It was a difficult hearing, during which senior representatives of the U.S. automobile industry continued to insist that they couldn’t achieve the mandated 1985 and intermediate standards while reducing exhaust emis-

sions. Having been told by others that the industry would resist strongly in its testimony but not violate a law of the U.S., I quietly passed a note to the Senator asking him to put each of the executives on the record: Will your company meet the standards? They all testified yes.

A final piece of history: about a year after the legislation was signed into law, I ran into the chief lobbyist for one of the automobile companies in the U.S. Capitol. He pulled me aside, told me he would never say this publicly, and expressed his opinion that the legislation had “saved his industry.” That may or may not be true (many in the industry would strongly disagree with his statement), but those of us who worked on CAFE can take pride in helping the country move forward after the oil embargo. The legislation achieved its goal of improving new car fuel efficiency, but, unfortunately, by reducing the cost of driving it stimulated VMT increases which partially offset the possible fuel savings. This is a lesson for the future.

Recently, the New York Times, in an editorial entitled “Crunch Time on Energy” (June 19, 2007), stated that “The most effective energy efficiency policy ever adopted by the federal government is the Corporate Average Fuel Economy requirement of 1975.” More than 30 years have passed since CAFE was enacted, a period during which oil imports and oil prices have increased dramatically, and climate change has been recognized as a serious global challenge. It is clearly time to implement new policies that address these issues and save even more energy in the future.

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## The CAFE Formula

*David Hafemeister*

The Corporate Average Fuel Economy (CAFE) formula mandates that manufacturers comply with a fleet-average fuel economy of 27.5 mpg.<sup>1</sup> Since the gallon parameter is in the denominator, fleet-average fuel economy is not a simple average of individual fuel economies. Consider the average fuel economy of a 20-mpg car and a 10-mpg car. If both cars traveled 20 miles, the total amount of gasoline consumed would be 1 + 2 = 3 gallons, for an average of 40 mi/3 gal, or 13.3 mpg, not (20 + 10)/2 = 15 mpg. Since the guzzler’s mpg

dominates the fleet-average fuel economy, manufacturers are encouraged to improve guzzlers more than already efficient cars. The average fuel economy for our two cars is obtained by averaging the inverse of fuel economy:

$$\langle 1/\text{fuel economy} \rangle = (1/10 + 1/20)(\text{gal/mi})/2 = 0.075 \text{ gal/m}, \quad (1)$$

with an average fuel economy,

$$\langle \text{fuel economy} \rangle = 1/0.075 \text{ gal/mi} = 13.3 \text{ mpg}. \quad (2)$$



The inverse average fuel economy for a fleet of cars is

$$\langle 1/F_{\text{fleet}} \rangle = \sum_i n_i / F_i, \quad (3)$$

where  $n_i$  is the fraction of cars in the  $i$ th subclass with fuel economy  $F_i$ .

A panel of the National Research Council estimated in 2000 that increased fuel economy under CAFE saves the US 2.8 Mbbbl/day.<sup>2</sup> This estimate was not obtained by merely doubling fuel economy, because light trucks and SUVs consume at about 20 mpg, a rate midway between 1973's 13.5 mpg and CAFE's 27.5 mpg. Nonetheless, we ignore the SUV effect to examine a larger point. The first doubling of fuel economy cuts gasoline consumption in half. Unfortunately, a point of diminishing returns undercuts further doublings, but certainly does not negate their worthiness. Assume national gasoline consumption is

$$G = C/F, \quad (4)$$

where  $C$  is a constant and  $F$  is the fleet-average fuel economy. Doubling the fuel economy to CAFE's 28 mpg reduces consumption to  $C/2F$ , saving  $C/2F$ . A second doubling to 56 mpg reduces consumption to  $C/4F$ , saving an additional  $C/4F$ . A third doubling to 112 mpg reduces consumption to  $C/8F$ , saving an additional  $C/8F$ . With each doubling, the effect on fuel economy (for example to 56 mpg) is to make it twice the previous fuel economy (28 mpg), while savings are half as much ( $C/4F$ ) as the previous savings ( $C/2F$ ). If gas consumption  $G = C/F$  is 8 Mbbbl/day with today's fleet, then doubling fuel economy to 56 mpg would save 4 Mbbbl/day. A second doubling to 112 mpg would save an additional 2 Mbbbl/day, and the third doubling to 256 mpg would save an additional 1 Mbbbl/day, a diminished return.

**Technology Change Under CAFE.** Improvements under CAFE came from the following measures:

- mass downsizing of 25%
- electronic engine-controls for more efficient combustion
- 5-speed manual transmissions
- fuel-injection without a carburetor
- 4 valves per cylinder
- front-wheel drive, reducing drive-train losses
- improved aerodynamics, lowering  $C_d$  from 0.4 to 0.3.

Since internal combustion engines can be only marginally improved, there will, at some point, be a departure from complete dependence on IC engines. Such an idea was considered heresy a decade ago. A likely shift is to hybrid cars

that get 50 mpg in cities, followed by the plug-in electric car with lithium-ion batteries, which use gasoline only for trips over about 40 miles. The hydrogen-powered fuel cell car is not likely to be deployed for a several reasons.<sup>3</sup> Other options envisioned are very light cars made with carbon fiber, small diesel engines, compressed natural-gas engines, and ethanol/methanol engines. Super-cars could get 80 mpg with vastly reduced emissions.

**Gas Guzzlers.** We examine the improvement of two cars, one at 10 mpg and the other at 20 mpg. If the 20-mpg car alone is improved to 21 mpg, the fleet average increases by 0.22 mpg to 13.5 mpg. On the other hand, if only the 10-mpg car is improved to 11 mpg, the fleet average increases by 0.86 mpg to 14.2 mpg, four times the improvement of the former case ( $0.86/0.22 = 4$ ). The factor of 4 is obtained by taking the differential of the inverse fuel economy, giving the change in the inverse fuel economy for one type of car proportional to the inverse square of the fuel economy,

$$\Delta(1/F) = -\Delta F/F^2. \quad (5)$$

The ratio of energy savings of  $\Delta F = 1$  mpg for two types of cars (guzzler and saver) is

$$\text{guzzler/saver} = (1/10^2)/(1/20^2) = 4. \quad (6)$$

To discourage purchase of inefficient autos, the 2000 Gas Guzzler Tax triggers a \$1000 guzzler tax on a 22-mpg car (but not on SUVs) and \$7,700 on a 12.5-mpg car.

**Feebates.** An alternative approach to curbing fuel consumption was suggested by Jonathan Koomey and Art Rosenfeld (Lawrence Berkeley National Laboratory), which places penalties on guzzlers and gives rebates for savers. A balance point of 28 mpg was proposed with rebates of \$970 for Ford Escorts (35 mpg) and \$1250 for Honda Civics (37 mpg), and a \$4750 penalty for a Ferrari (15 mpg). On the basis of 1987 sales, \$3.4 billion would be paid in fees and \$1.7 billion would be disbursed as rebates. This scheme was not revenue-neutral (revenues = benefits) to the government, but the structure could be so modified.

To put these rebates and penalties into perspective, we estimate the fuel cost to run a Civic and a Ferrari over a 150,000-mile lifetime:

$$\text{Civic: } (150,000 \text{ mi}/37 \text{ mpg})(\$3/\text{gal}) = \$12,000 \quad (7)$$

$$\text{Ferrari: } (150,000 \text{ mi}/15 \text{ mpg})(\$3/\text{gal}) = \$30,000. \quad (8)$$

Future gasoline payments should be discounted to the present since we can invest money in the present to spend

later. The present net cost energy cost for the Ferrari is sum of the present value of gasoline (about \$20,000) and feebate penalty (\$4850), for a total of about \$25,000 (at the time of purchase). The Civic's net energy cost is much smaller at \$7000 (\$8000 for gasoline)– \$1250 for the feebate). A political difficulty with feebates is that they penalize large US cars and rebate small Japanese cars.

**Electricity vs. Gasoline.** The adoption of electric cars would force a shift in energy units from miles/gallon (or liters/100 km) to kWh/mile. If a car loses 15 kW from aerodynamic and rolling drag at 30 m/sec (68 mph, see PSI text), a trip of 1 km would consume electrical energy at the rate of

$$E_{\text{elec}} = Pt = (15 \text{ kW})(1000 \text{ m})(1 \text{ sec}/30 \text{ m}) = 0.5 \text{ MJ/km} = 0.15 \text{ kWh/km} = 0.22 \text{ kWh/mi} \quad (9)$$

If we consider only the cost of fuel, electricity is considerably cheaper than gasoline. At 10¢/kWh, it costs 2.2¢/mile for electrical energy, while gasoline costs 12¢/mile (25 mpg at \$3/gal). The 200 million US vehicles, each traveling 12,000 mi/yr, require

$$(200 \text{ million})(12,000 \text{ mi/yr})(0.22 \text{ kWh/mi}) = 5.3 \times 10^{11} \text{ kWh/yr.} \quad (10)$$

This amount is increased to allow for energy losses, making total electrical energy needed to  $8 \times 10^{11}$  kWh/yr. Since a 1-GWe plant produces about  $7 \times 10^9$  kWh/yr, it would take 115 1-GWe power plants, or about 20% of the US grid, to sustain an all-electric US vehicle fleet.

A 30-mpg gasoline car consumes energy at a rate

$$E_{\text{distance}} = (130 \text{ MJ/gal})(1 \text{ gal}/30 \text{ mi}) = 4.3 \text{ MJ/mi} = 2.7 \text{ MJ/km.} \quad (11)$$

This gasoline-powered car consumes 5.4 times the energy of the electric car at 0.5 MJ/km. The electric car did better than the gasoline car because electrical motors are 90% efficient as compared to 15% for cars. However, this compares gasoline energy to electrical energy. If the efficiency of a power plant is 33%, the electric car advantage drops from 5.4 to 1.8. If a combined cycle gas makes electricity at 60% efficiency, the electric car's advantage rises upward to 3.2. The favorable efficiency of electric cars would be decisive except for the lifespan and cost of batteries. The ability to generate electricity on board greatly reduces battery requirements, making the hybrid viable. A satisfactory lithium-ion battery for autos is the tipping point for the plug-in electric car.

It is hoped the advent of the lithium-ion battery will broaden the mission of hybrid cars to plug-in electric cars. Demand for electricity in the summer in California peaks at about 50 GW between 2–4 PM and bottoms out at about 26 GW between 2–4 AM. The Electric Power Research Institute

estimated that 13% of the unused power (3.2 GW of the 24 GW reduction) could be used to charge auto batteries, saving 5 million California cars (20 miles/day) from the need for gasoline. This is particularly promising since considerable night-time power is wasted since it comes from base-loaded power plants. The 3.2 GW acting over 6 hours produces

$$(3.2 \times 10^6 \text{ kW})(6 \text{ hr/day}) = 2 \times 10^7 \text{ kWh/day,} \quad (12)$$

which could be consumed by 5 million cars (20 miles/day)

$$2 \times 10^7 \text{ kWh/day}/(20 \text{ miles/day})(1 \text{ kWh}/5 \text{ miles}) = 5 \times 10^6 \text{ cars.} \quad (13)$$

**Cost of Conserved Energy.** Would we be willing to spend \$4000 extra to obtain a 50-mpg hybrid, when compared to a CAFE traditional car that gets 20 mpg in the city? The 20-mpg car that goes 40 miles/day over 250 days travels 10,000 mi/yr and consumes  $10,000/20 = 500$  gal/yr. The 50-mpg car consumes  $10,000/50 = 200$  gal/yr, saving 300 gal/yr. If the extra investment for a Prius is \$4000, the cost of the extra loan and repayment in constant dollars (without inflation) is about \$500/yr for 10 years. This puts the cost of conserved energy for the 50-mpg car at

$$\text{annual cost/annual energy saving} = (\$500/\text{yr})/(300 \text{ gal/yr}) = \$1.67/\text{gal.} \quad (14)$$

Since the 50-mpg car has a CCE 50% of the market price (\$33.50 in 2007), this is a good choice. If the car lasts two decades and is driven more than 10,000 mi/yr, it is a very good purchase. For those living in Europe and Japan, paying \$5 per gallon, the investment is very, very good.

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#### Footnotes

1 This paper was adapted from Ch. 15 of *Physics of Societal Issues: Calculations on National Security, Environment and Energy* by D. Hafemeister (Springer, New York, 2007). It was my pleasure to watch Allan Hoffman majestically steer CAFÉ through the Senate and the Senate-House Conference.

2 National Research Council, *Effectiveness and Impact of Corporate Average Fuel Economy Standards*, (National Academy Press, Washington, 2002). Also see, *Automotive Fuel Economy: How Far Should we go?*, (National Academy Press, 1992).

3 G. Crabtree, M. Dresselhaus, and M. Buchanan, *Physics Today* 57, p: 39–44, December 2004. APS Panel on Public Affairs Report, *The Hydrogen Initiative*, [www.aps.org/](http://www.aps.org/)

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## Sputnik – 50 Years Later

*Alan J. Scott*

On October 4, 1957, a basketball-sized object orbited over the United States sending out an ominous radio-signal beeping. The Space Age and Space Race had begun. The satellite was Sputnik – the first artificial satellite to orbit the Earth – and was built by the Soviet Union. This beeping signal, and its socio-political ramifications, dug deep into the American psyche – almost as much as jumbo jets colliding with the World Trade Center.

Back then, the Cold War was in full swing. Fallout shelters were in every community. The Soviets were rapidly building their nuclear arsenal. The Korean War had just ended in a stalemate. The Korean War was a proxy war between communist China (with Soviet Union support) and the West, namely the United States. Fortunately, neither side wanted to directly attack the other for fear of escalation and mutual annihilation. The post WWII euphoria was in full retreat in the United States.

With Sputnik, another front in the Cold War opened up. The Soviets were, or at least appeared to be, superior to the U.S. in technology and science. The “technology gap” caused Congress to pass two initiatives (1) the National Defense Educational Act, and (2) the National Aeronautics and Space Act which created NASA. Both were passed in 1958. One could say, Sputnik, together with the Cold War, spurred a renaissance in U.S. science education and prowess in space. Fifty years after Sputnik, let’s mull over its legacy by examining the state of science education, space exploration, and the militarization of space.

### *Science Education*

The current mantra to support science education is not to close the missile gap but to become more competitive in a world economy. It is to create a workforce for the 21st century; stimulate economic growth while protecting the environment; create citizens knowledgeable about how science and technology interact with society. To create a nation of people informed about energy policy and global climate change. In essence, develop people that can solve problems and make informed, well-thought out decisions in the ballot booth and in the workforce.

Many of these concerns are detailed in a report by the National Academies called *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future* which was published in 2007. The academies are “deeply concerned that the scientific and technological building blocks critical to our economic leadership are eroding

at a time when many other nations are gathering strength.”<sup>1</sup> Science and technology education provides one of the few opportunities to counter the disparity in labor costs that drive jobs overseas.

So how are we doing in science education? It depends on how one measures it. Three common measures include (1) standardized test scores over time and between nations, (2) number of college graduates in science and technology fields, and/or (3) the understanding and interest in science found within the general public.

One thing should be made clear; most experts believe the United States is the foremost world leader in basic research. It also efficiently incorporates research and innovation into strengthening its economic performance.<sup>2</sup>

Now, let’s look at our performance in science education. The United States Department of Education performs a study every four years on the performance of eighth-graders in science called Trends in International Mathematics and Science Study (TIMSS). In 2003, the U.S. outperformed 55% of the 45 participating countries in math and 71% in science. Many Asian countries outperformed the U.S. in both categories.<sup>3</sup> The U.S. conferred 59% of the world’s doctoral degrees in science and engineering in 1957. In 2001, it was down to 41%. About half of all graduate students in the U.S. are international students. Many countries are increasing their incentives to these graduates so that they return upon completing their degrees.<sup>4</sup> The debate on immigration is intertwined with such discussions.

Failure to take challenging math and science courses in high school (and possibly middle school) effectively starts limiting a child’s choices for careers in the sciences. About half of the students entering college interested in completing a science or engineering degree actually do earn one.<sup>5</sup>

The U.S. does spend a large amount of public money on research and development programs primarily through the National Science Foundation (NSF), National Institute of Health (NIH), and the Department of Energy (DOE). Other countries are ramping up their support. As of 2001, only Japan and South Korea spend more money on such programs as a percentage of Gross Domestic Product.<sup>6</sup> This support is endangered with the continued drain on the U.S. budget with military expenditures and entitlements coupled with huge deficits.

A good science education program will be challenging yet interesting. It should generate interest by impressing upon students the importance and relevance science has to

their future. For instance, in my physics class, students will work through an analysis weighing the costs versus benefits of purchasing a swimming pool cover to conserve energy and resources.

Consider the case of Steven Amanti at MIT. His senior thesis was an energy analysis of chemical fume hoods. He found out that if unused fume hoods were closed it would save 17% in energy costs that amounted to \$350,000 per year just at MIT!<sup>7</sup> A good science education will also cause us pause and force us to ask an important question about Al Gore's documentary *An Inconvenient Truth*. Gore does well in conveying the personal lifestyle sacrifices needed to reduce climate change but why didn't he mention that without population control, these sacrifices will soon be negated by modest increases in population and the hitherto consequences?<sup>8</sup>

Student interest is connected to subtle, systemic influences. In U.S. high schools, 60% of students enrolled in physical science classes have teachers who either did not major in the subject being taught or are not certified to teach it.<sup>9</sup> Student dispositions on science are greatly affected by teachers, parents and peers. Just recently, I was talking with some people about the summer solstice. One parent insisted - even after I suggested it was a myth - that on the Spring Equinox eggs have a special property that permit them to be balanced. This notion is simply false - the ability to balance eggs does not depend on which day it is on the calendar!<sup>10</sup> I'm not sure what the kids went away with who were listening to the conversation. Many student peers have a distorted boastfulness in saying they have "never taken" or "never liked" science classes.

The influences that produce student views and interest in science can stretch into elementary classes. The majority of students in my Introduction to Geology class at the University of Wisconsin-Stout are early childhood education majors. I often engage them in a discussion about religion and science after having spent two weeks discussing geologic time - the evolution of life (from fossil records) and the evolution of landforms throughout the earth's history. Many find it terribly uncomfortable and believe that the biblical flood of Noah should be interpreted literally and that people were created suddenly about 10,000 years ago and have not evolved from apes.

Nationally, about 47% of college freshman reject significant tenants of evolution.<sup>11</sup> This position is adhered to by several current Republican presidential candidates for 2008. An ABC poll of a year ago found 61% of Americans thought Genesis is literally true.<sup>12</sup> These future elementary school teachers need to inspire in their students an awe and appetite for knowledge about earth's past undistorted by non-scientific thoughts. I'm not berating religion, per se, but I am being

critical of religious fanaticism. Young earth creationism steps into fanaticism.

The shaping of America's economic and social future is in our hands. And the encouragement of science and technology should be at the forefront. The launch of Sputnik re-oriented our nation's priorities. In this new age, we mustn't become complacent about the current state of science education and constantly strive to improve it. America's future economic strength, good standard of living, and clean environment are at stake.

### *Space Exploration*

The launch of Sputnik in 1957 was a watershed moment for American policy and priorities. News reporters flocked to amateur radio operators who could pick up the radio-signal beeping from Sputnik as it flew over the United States. This was the "beep heard round the world." The launch came about one year after the Soviet Premier Nikita Khrushchev said "We will bury you." (In proper translation it should mean "we will attend your funeral" and not "we will cause your funeral" as conveyed by the media.)<sup>13</sup> President Eisenhower tried to downplay its significance but the concern remained. The Soviets beat the United States into space and were now surmised to have the capability to drop a nuclear bomb on the U.S. from space.<sup>14</sup> The space race had begun. The U.S. created NASA and also tripled the National Science Foundation's budget in one year. Let's first take a glance at the major milestones of space exploration, and then we'll examine the current space program.

One month after Sputnik was launched Sputnik II was launched carrying a heavier payload and a dog named Laika. (Laika was a stray dog from Moscow and given a one-way ticket into space.<sup>15</sup>) In 1958, the U.S. successfully launched Explorer 1 into space. The Soviets launched Luna 1 toward the Moon. (Some say it was intended to impact the Moon.) It measured the Van Allen radiation belts around the earth, flew by the Moon, and was the first satellite to go into orbit around the Sun. The Soviet Luna 2 purposely crashed onto the Moon in 1959.

In the same year, Luna 3 took the first ever photographs of the far side of the Moon. Cosmonaut Yuri Alekseyevich Gagarin was the first person to venture into space in 1961. In 1961, President Kennedy committed the U.S. to landing on the Moon. Cosmonaut Alexei Leonov went on the first tethered space walk in 1965.

At this time, the Soviets were outpacing the U.S. in making significant milestones in space. In 1965, the U.S. Mariner 4 arrived at Mars taking close-up pictures that showed no signs of life. The Soviet Luna 9 was the first to soft-land on

the Moon and take pictures. Thus, the Soviets beat the U.S. to the Moon! Later the same year, the U.S. soft-landed on the Moon with Surveyor 1.

The United States started making its mark in space history with the Apollo missions in the late 1960's. Apollo 8 was the first manned-mission to orbit the Moon and return. Astronaut Neil Armstrong became the first person to set foot on the Moon. The Soviets became the first to soft-land a spacecraft on another planet with Venera 7's landing on Venus in 1970. The Soviet Salyut 1 becomes the first orbiting space station. In 1975, the Soviets and United States linked up in space in the first cooperative mission. The Pioneer and Voyager space probes took the first ever close-up pictures of the Jovian planets.

This takes us into the modern age of robotic missions, space shuttle, International Space Station (ISS), and the Hubble Space Telescope. Things have changed since Sputnik. The Cold War is over. The former Soviet Union has collapsed and Russia is now a partner with the ISS. The European Space Agency (ESA) is active in space exploration and China has even launched people into space.

Robotic probes have landed on Venus, Mars, Titan (a moon of Saturn), and Eros (an asteroid). We have sent probes into Jupiter's atmosphere. Comet material has been gathered and returned to earth in the Stardust mission. The Hubble Space Telescope has peered deep into the cosmos discovering stellar nurseries, remnants of exploded stars, and distant galaxies. It even captured images of a comet colliding with Jupiter and has analyzed the atmospheric composition of an extra-solar planet. The Hubble Space Telescope has been in orbit for 17 years and has taken over 500,000 images which have led to over 7,000 scientific papers published.<sup>16</sup>

The NASA web page <http://www.nasa.gov/missions/current/index.html> indicates about seventy current space missions underway. We have infrared, x-ray, and gamma-ray telescopes in space. The New Horizons is heading for Pluto (our newly designated dwarf planet). Rosetta is heading towards a comet with the intent to land a probe on its surface. Messenger just flew-by Venus and is heading toward Mercury. Venus Express has been in orbit around Venus for one year.

Mars has a fleet of robotic space probes making observations. The two rovers, Spirit and Opportunity, continue driving around Mars and have completed over three years — earth years, that is. The Mars Reconnaissance Orbiter has been transmitting spectacular pictures of the red planet. The Mars Express Orbiter has found enough water ice on Mars that, if liquid, could cover the entire planet 11 meters deep.

This past August 4th, the Phoenix mission was launched sending a lander spacecraft to a polar region on Mars. In late 2009, another — bigger and better — Mars' rover is scheduled

to be launched.

Cassini-Huygen's mission has been at Saturn for about three years. It has found several of Saturn's moons to be geologically active. Titan has rivers and lakes of liquid methane. Enceladus spews material out of ice geysers.

With all this exciting space exploration happening, we should ask what the ISS has accomplished. Well, nothing... nothing of significance. It is a big, space boondoggle built on the promise of developing new medicines, new crystals for industry, and to counter the Russian space station (MIR) which later burned up after re-entering the atmosphere. It lives off public relations, not science.

It has lodged five space tourists which NASA officially classifies as "Spaceflight Participants." It serves as an adventure ride for the wealthy. Several months ago, a cosmonaut aboard the ISS hit a golf ball during a spacewalk. The stunt was paid for by a Canadian golf company and was intended to be used in a commercial.<sup>17</sup>

The ISS is expected to cost taxpayers about \$100 billion by 2010.<sup>18</sup> Robert Park of the American Physical Society states "The only thing the ISS has going for it is micro-gravity, but decades of micro-gravity research on the Shuttle and Mir had no discernable impact on any field of science. Congress may be in a mood to scrap the giant money-shredder; scientists should plead with them to do it." Even the NASA chief administrator, Michael Griffin, has stated "...the space station was not worth the expense, the risk and the difficulty of flying humans to space."<sup>19</sup>

It can be argued that we should abandon the ISS but if human spaceflight is necessary to keep the funding alive for other, more science-related missions, then perhaps killing it would be too rash. It does serve to inspire today's youth to dream and strive for excellence with the hopes of exploring space. But we shouldn't sell it under the false pretenses of advancing science.

On January 14, 2004, President Bush announced<sup>20</sup> a new vision for human spaceflight and directed NASA to start re-directing resources to further this vision. The new vision includes a return to the Moon no later than 2020. Afterwards, human exploration will extend to Mars and perhaps beyond.

Is this vision a good one? In the scheme of things, it doesn't gobble up a large piece of the national budget. NASA currently gets less than 1% of the budget and it is projected to remain less than 1%. (National defense gets 25% and entitlement programs, such as social security and medicare, get about 65% of the budget.)

Will it advance science? Perhaps in small ways with technological spin-offs but we should be leery of this point

being over-sold to the public as with the ISS. The reasons for sending humans instead of robots are dubious. Robots can do everything much more efficiently, cost effectively, and with less risk. Besides, robots don't get entangled in love triangles gone violent (i.e. Lisa Nowak tirade) and sending humans to Mars will subject them to significant radiation exposures.

There are two great 50th anniversary milestones we are commemorating this year in our trek to advance knowledge about space and ourselves. One is Sputnik but the other is knowledge that we are all made of stardust! All the atoms in our bodies, except for hydrogen, were cooked up in ancient stars. This is considered common knowledge today but was first presented in a scientific paper 50 years ago.<sup>21</sup> Space exploration, be it human or robot, opens up our minds to our place in the universe. It generates a great pride in knowing that our civilization can place humans on the Moon and robots onto distant worlds.

The mind upwells with vitality and wonder when scientists announced that an earth-like planet has been identified in orbit around the star Gliese 581 in the constellation Libra.<sup>22</sup> The wildest dreams of our ancestors, only 100 years ago, could not imagine the accomplishments of our modern world and its science. I toast the marvels of MRI imaging, great telescopes, and particle accelerators that re-create conditions in the early universe – millionths of a second after the Big Bang.<sup>23</sup> As Isaac Newton would say, we can see further and deeper than those of previous times because we are standing on the shoulders of giants.

### *The Militarization of Space*

About fifty years ago, Elvis Presley had just made it big, Hollywood filmed the iconic movie *The Day the Earth Stood Still*, and Bill Haley released *Rock Around The Clock*. You can place yourself into the era simply by watching an episode of the old television series *Happy Days*.

But these happy days had a dark side. It was also the age of the disquieting “duck and cover drills” that school children practiced at the first signs of a nuclear weapon detonating nearby. The Cold War and, in particular – Sputnik, spawned new thinking about science education, space exploration, and the militarization of space. Outer space was now part of the world, geo-political military scene. But what the public knows and can debate regarding U.S. military potential and policy can be greatly distorted by secrecy and misinformation. In fact, President Eisenhower was in an awkward situation in balancing the need for secrecy and also dealing with the public aftermath of Sputnik.

He knew more than he could tell. The U.S. had two programs. One was a publicly known satellite program (working

to launch a satellite as part of the International Geophysical Year) and the other was the secret U.S. ballistic missile program. Eisenhower knew that if the two programs were merged, the U.S. could have successfully launched a satellite into space before Sputnik.<sup>24</sup>

This article will discuss the milestones of space weapons and the current world situation of militarizing space. Of course, Sputnik was a strong indication that space can be used for military purposes. First of all, the term space weapons refers to any weapons, in outer space, intended to attack targets in space or on the ground or ground-based weapons intended to attack targets in space.

It is clear that outer space has been militarized for a long time, but probably not weaponized. Satellites are used for military communications, navigation, and surveillance. Space weapons were pursued heavily after Sputnik. The U.S. and Soviets were engaged in a Cold War tit-for-tat in this field.

The easiest and most effective anti-satellite weapon is a nuclear-armed missile launched into space and detonated near a target. The explosion creates shrapnel that can be damaging, but more importantly, it creates an electromagnetic pulse (EMP) which causes the satellite's electronics to malfunction. The U.S. detonated a nuclear weapon in space in 1962 as part of a project called Starfish Prime.<sup>25, 26</sup> The EMP from the explosion caused street lights, televisions, and radios to malfunction over 930 miles away. It also disabled six satellites. (It should be noted that non-nuclear, EMP weapons do exist.) This test, together with many atmospheric tests of nuclear weapons prompted the 1963 Limited Test Ban Treaty which prohibits atmospheric or outer space nuclear explosion tests. The U.S. and Soviets both developed kinetic kill (destruction by collision and not explosion) anti-satellite weapons in the 70's and 80's. Anti-satellite, laser weapons have also been researched by both countries.

Concerns about space weapons began getting addressed in 1967 with the passage of the Outer Space Treaty. This treaty forbids the placing of any weapon of mass destruction into orbit around the earth.

Within the past year, China has entered the fray by successfully testing an anti-satellite weapon. China destroyed an inoperable satellite by using a kinetic kill vehicle. The collision was largely viewed as provocative and irresponsible. It is irresponsible because it created thousands of pieces of space junk, difficult to track, and a hazard to all satellites.<sup>27</sup> An all-out satellite war could render space useless for hundreds of years due to space junk.

China's test pushed the issue of space weapons and national security into the forefront. Victoria Samson, of the Center for Defense Information, recently discussed space

weapons on National Public Radio.<sup>28</sup> She indicated that currently, there are no official space weapons programs. But she did allude to the possibility of secret programs and clearly mentioned programs that have dual-use capabilities. (Dual-use implies a non-weapon program that could have weapon use.) The United States space mission Deep Impact showed that a satellite can be guided to collide with a comet. It is not a far stretch to replace the comet with an enemy satellite and, thus, a space weapon is born.

More exotic space weapons may exist. One such weapon may include robotic, difficult to detect, micro-satellites. Like little robots, they can be deployed to take up a defensive perimeter around a crucial military satellite and perform counter-measures to anti-satellite weapons or be given the command to seek and destroy enemy targets. Such a system is already being deployed by the newest class of nuclear attack submarines such as the USS Virginia. It is equipped to deploy “multiple unmanned, undersea vehicles” (in other words, robots).<sup>29</sup>

So what should the U.S. policy be on space weapons? Space is immensely beneficial for communications, space explorations, and monitoring the earth’s environment. It permits people from anywhere in the world to communicate almost instantly. But its benefits could be endangered without a good policy on space weapons as illustrated by China’s anti-satellite test. The 2008 U.S. budget proposal included \$45 million to research the viability of placing missile interceptors into space and almost \$1 billion in dual-use programs that could involve space weapons.<sup>30,31</sup> In May of 2007, a congressional subcommittee cut some projects involving space weapons but \$9.3 billion remained in the budget for military space programs.<sup>32</sup>

This past year Laura Grego, a staff scientist at the Union of Concerned Scientists, gave congressional testimony arguing that the time is now for pursuing a comprehensive ban on all debris-creating, anti-satellite weapons.<sup>33</sup> It could also be beneficial in the general arms control arena. She stresses that the failure of any “rules of the road” concerning space weapons is detrimental to all nations utilizing space.

The United States government currently opposes any discussions of regulating space weapons. This is unfortunate and Laura Grego laments the situation by stating “...the refusal of the United States to consider space security initiatives in international fora, generate mistrust and strain strategic relationships that are necessary for progress on other crucial issues, such as nonproliferation and terrorism.” The United States needs to move away from its empty philosophy of double standards. On the international stage, we cannot say that “space weapons (or, even, nuclear weapons) are good for

us but not for you.” We need to join the international community in taking steps toward curbing space weapons and nuclear weapons.

If a nation — suppose Saddam Hussein’s Iraq before the Iraq war — possessed satellites that aided their military, could/would/should the U.S. have destroyed them? Answer this question; then, ask yourself if you are comfortable with other nations developing the technology and capabilities to destroy U.S. satellites while being careful not to fall into a double standard. The answer is not merely academic and is fundamentally important in determining the future course of space use.

For a complete and comprehensive analysis of space-based weapons and policy see the Union of Concerned Scientists’ web pages at [http://www.ucsusa.org/global\\_security/space\\_weapons/](http://www.ucsusa.org/global_security/space_weapons/).

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## COMMENTARY

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### Three Inconvenient Truths About Global Warming

Robert Ehrlich

As my friend Art Hobson notes in the July 2007 issue of *Physics & Society*, it is becoming increasingly clear that it is not possible to curb global warming completely. Hobson cites a 2006 study<sup>1</sup> led by former World Bank Chief Economist, Nicholas Stern, which notes that stabilizing atmospheric CO<sub>2</sub> levels at 450 ppm would cost the equivalent of a reduction of world GNP of one percent for many years.

According to Hobson, the Stern study notes that “while if not addressed adequately it will cost 20 percent of world GDP” (now and forever!). As physicists, we are trained to spot numerical comparisons that seem so out of bounds as to be incredible, so I was prompted to look up the Stern study. The report contrasts “no action” to curb global warming (which is clearly not a realistic course of action), with the actions needed to reach the 450 ppm stabilization level. Moreover, the Stern report makes certain economic assumptions, including an extremely low “discount rate”<sup>2</sup> and a severe aversion to income inequalities between nations and between generations that may be justified on ethical grounds, but which depart from

what is assumed in mainstream economic models, and in the real world as well.<sup>2,3</sup>

The more interesting choice, however, is not between no action and a crash program for dealing with global warming, rather; it is between the various strategies for dealing with the problem. These range, for example, from steep carbon taxes that Hobson advocates to taking only those cost-effective actions, such as energy conservation and deploying green energy alternatives as they become cost competitive. An excellent perspective on the relative merits of these strategies can be understood by reading the 2007 report<sup>4</sup> of the IPCC. That report notes it would cost up to \$18 trillion U.S. dollars to eventually stabilize atmospheric CO<sub>2</sub> concentrations at the level of 450 parts per million (ppm), which still would cause a temperature rise by 2100 of around 1.7 degrees Celsius. (Incidentally, \$18 trillion does somehow sound more impressive than one percent of World GNP for 30 years!)

A more gradual approach (which allowed world (not



U.S.!) emissions to increase for another 50 years before reducing them) would lead to an atmospheric stabilization level of 750 ppm. Surprisingly, the temperature rise by 2100 would not be very much higher (around 2.5 degrees Celsius) under this scenario — perhaps surprising in light of the 67% higher CO<sub>2</sub> stabilization level. (Both projected temperature rises have large associated uncertainties.) According to the IPCC report, stabilization at the higher 750 ppm CO<sub>2</sub> level should cost at most 5 percent as much as the 450 ppm level (and possibly as little as zero), because it involves actions that pay for themselves. Thus, in evaluating the tradeoff between these two possibilities, one needs to ask how important is it to pay up to \$200 billion cumulatively to cool the planet by each 0.01 degree reduction from the 2.5 degrees projected under the 750 ppm level?

It could be very detrimental to allow the rise to exceed say 2 degrees, if there really were any evidence this value represented a dangerous threshold or a “tipping point.” But, even if we acknowledge that larger degrees of harm result from higher temperatures, and that tipping points might exist, there is no evidence for 2 degrees Celsius being such a threshold, despite some expressed opinion to the contrary. (Others, including James Lovelock,<sup>5</sup> author of the Gaia Hypothesis, have claimed we are already past the tipping point.) There simply is no evidence for Hobson’s assertion that another 0.75 degree increase “beyond the 1.25 degrees that is already ‘in the pipeline’ because of the delayed effects of the global warming pollutants already in the atmosphere will cause the polar ice cap melting to begin.” Pretending otherwise is not science; it is scare-mongering in pursuit of a political objective.

In fact, from the perspective of those wishing to portray global warming as an urgent problem, a 2 C tipping point is a “Goldilocks” value. If the tipping point was 1.25 C i.e. only 0.75 C less, nothing could be done now to avert disaster — even cutting CO<sub>2</sub> emissions to zero. Were the value only 0.75 C more (2.75 C), global warming becomes a non-urgent matter better solved on a gradual long-term basis. Given the failure of the IPCC to define the “dangerous interference with the climate system” that must be avoided according to the Rio Climate Treaty, could this claimed 2 C tipping point have been simply chosen to convince policymakers and the public of the urgency of the problem? (Aside from the possibility that this value has been chosen by God in order to get humanity to see that it must band together now to save the planet, it seems likely that the choice was made by humans on the basis of politics, rather than science.)

I do nevertheless applaud some of Hobson’s suggestions, including these: increase nuclear power threefold to displace coal; increase wind power 40-fold to displace coal; increase solar power (photovoltaics, solar-thermal electricity genera-

tion) 700-fold to displace coal; increase wind power 80-fold to make hydrogen for zero-emission cars — although I think these should be achieved gradually. But some other suggestions I find unwise. Ethanol, for example, is simply not practical, in terms of the arable land required, the ground level pollutants created, the impossibility of supplying enough ethanol for two billion cars, and the better alternatives available. Likewise, while it is nice to live in an area where one can walk to work, bicycle to work, or live near your work, for the foreseeable future, this does not apply to most Americans, who will probably not welcome the higher gasoline taxes Hobson feels are necessary. Higher gasoline prices might be a good thing, but in all likelihood, rising market prices will do that job all on its own without the necessity of steep carbon taxes. (A modest carbon tax, in contrast, would be far less disruptive to the economy, and could bring about the needed gradual transition to a more energy efficient society.)

Thus, in summary, I believe that we need to face altogether three inconvenient truths about global warming: (a) it is real and could be very serious in the future, (b) curbing it significantly would not be inexpensive and would still lead to a significant temperature rise over the next century, and (c) while the possibility of harm clearly increases along with the magnitude of the temperature increase, we currently have no clear line as to what level is “dangerous,” or what might be the threshold of any alleged “tipping points.”

*Footnotes:*

1. Nicholas Stern, *The Economics of Climate Change: The Stern Review* (Cambridge University Press, Cambridge, UK, 2007).

2. *The discount rate in economic theory refers to the real return on capital. It influences the determination of the optimum balance between emissions reductions today and the benefit of future mitigation of damages. The benefit of future mitigation also in turn depends on the relative importance we attach to the welfare of society today, and that in future generations, including the distant future. It also in turn depends on our assessment of the likelihood that other possible catastrophes such as a nuclear war or a mass epidemic may occur which might lead to severe depopulation that could make global warming a much less urgent problem. It is noteworthy that half of the estimated economic damages due to global warming estimated in the Stern Report methodology occur after the year 2800.*

3. William Nordhaus, “Critical Assumptions in the Stern Review on Climate Change,” *Science*, 317, 2007 201-202.

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## REVIEWS

### **Out of the Shadows: Contributions of Twentieth-Century Women to Physics**

*Edited by Nina Byers and Gary Williams. Cambridge University Press, 2006, 471 pages, ISBN-13 978-0-521-82197-1*

This is an important collection of essays depicting the lives and scientific accomplishments of forty women physicists and astronomers during the 20th century. It provides a comprehensive overview of the role that women have played in physics during the past century while at the same time describing the obstacles that most of them had to overcome solely because of their gender. As might be expected the stories told here cover a diverse range of scientific accomplishments and life histories and as such also provide an interesting overview of twentieth-century history from a scientific and academic perspective.

The essays were commissioned to be about 3000 words long, and all but one follow a set format in which a summary of the most important scientific achievements is presented first along with a description of the nature of the work and its place in the general progression of physics and astronomy. The second part of these essays are biographies which always give curriculum vitae type information and in most cases details of the subjects' personal lives. Most were written by scientists who are familiar with the impact that these women had on their fields. The list of authors is quite impressive and includes many very well known physicists and astronomers. Since most of the authors are not experienced biographers the writing style varies, partly as a result of strict adherence to the prescribed format which occasionally leads to repetitive content since in many cases critical biographical details are tightly connected to professional achievements.

The strength of this book is, of course, the compelling nature of the stories themselves. We learn about the critical contributions made by these physicists and astronomers, many of whom are unknown to most of us, told by people who are able to fully appreciate what these women achieved. In addition many of the writers know or knew these women personally, in some cases they are their husbands and/or scientific collaborators, and they write with direct knowledge of the difficult conditions in which many of these women worked. For example Maria Goeppert Mayer, who is a Nobel laureate, did not have a regular paid position from the time she completed her doctoral work in 1930 until 1946 when she started working for Argonne National Laboratory. During the war she worked on the Manhattan project as a group leader but did not have a regular paid position. Agnes Pockels made important

contributions to the early development of surface science. She performed quantitative measurements of the properties of mono-molecular thick surface films while "working alone in her kitchen with an apparatus fashioned out of household items."

In more than a few other cases the women written about here were denied faculty or research laboratory positions because they were married and therefore were supposed to stay at home or because of so-called anti-nepotism rules which were selectively enforced against the female member of a married couple both of whom wanted to work at the same institution. In addition, particularly in the first half of the 20th century, many very well qualified women were denied the higher levels of membership of scientific societies or even official faculty or research positions solely because of their gender. In this regard, Vera Rubin in her essay about the distinguished astronomer Cecilia Payne-Gaposchkin, tells us that Payne-Gaposchkin was never elected to the U.S. National Academy of Sciences and that it was only in the 1970's that the first woman scientist gained membership to this organization.

The book starts with a foreword by Freeman Dyson and an introduction by one of the editors of this book, Nina Byers, both of which give the reader a useful starting point and general perspective. The essays are presented in chronological order starting with Hertha Ayrton (1854-1923) who invented or improved upon several different devices. Her work on stabilizing electric arc lights was of particular importance. The book ends with the experimental high energy particle physicist Sau Lan Wu who received her Ph.D. in physics from Harvard in 1970 and is currently the Enrico Fermi Distinguished Professor of Physics at the University of Wisconsin-Madison. In between we learn of the work of the well known astronomers, astrophysicists and physicists Margaret Burbidge, Vera Rubin, Jocelyn Bell Burnell, Marie Curie, Lise Meitner, Maria Goeppert Mayer, Chien Shiung Wu, Mildred Dresselhaus, Rosalyn Sussman Yalow and others.

But perhaps of most interest are not their stories but those presented of the many other women who made important contributions to their fields but who still remain largely unknown to us, thus giving the erroneous impression to many students that there were, and still are, only a handful of very productive women physicists and astronomers and therefore physics and astronomy are not appropriate fields of study for most women. Some of these scientists are better known than others such as Emmy Noether and Henrietta Swan Leavitt. Emmy Noether who is perhaps best known as a mathematician, also did important work in theoretical physics. She showed us

the connection between symmetries and conservation laws, a result that is given a prominent place in physics textbooks for upper division mechanics but almost always without any indication that this insightful connection was discovered by a woman. In a different area we learn of the experimental work of the astronomer Henrietta Swan Leavitt who provided Hubble and others with a critical tool to measure distances to other galaxies, work that is only now occasionally mentioned in astronomy textbooks. In addition, what we don't read about is the fact that this "brilliant scientist", as she was referred to by Cecilia Payne-Gaposchkin, had little choice as to what she was allowed to work on and that most of her work was officially attributed to Edward C. Pickering the director of the Harvard College Observatory where she worked.

Many of the others written about here are known only to specialists in their own fields and then sometimes only from their publications where their first names, and therefore their gender identity, are usually only given by an uninformative initial. In fact in her introduction Nina Byers states that when this project started as a web site in 1995 she and her colleague Steve Mosszkowski were surprised at the "more than 200 nominations that came in". And she goes on to write "most of the women were unknown to us". Consequently the editors of this book had a difficult job picking which women to include. It should be noted that some of the authors of these essays are themselves outstanding women scientists, many of whom are not included in this book. A more representative list of distinguished female physicists can be found on the web site <http://cwp.library.ucla.edu>.

This is a unique book that, along with the web site mentioned above, begins to inform us about the important role that women have played in physics and astronomy. It is unfortunately still the case that women are woefully under-represented in physics and to a lesser extent in astronomy. This is particularly true in the United States where our upper division and graduate physics classes often have only one or two women at best. Although women wishing to pursue careers in physics now face no official barriers their small numbers often presents a daunting barrier of its own. This book should be a source of encouragement to female students interested in physics and astronomy and it should be on a bookshelf in the office of every physics and astronomy professor or teacher or anyone else who is in a position to give career guidance to young students.

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## God: The Failed Hypothesis—How Science Shows That God Does Not Exist

By Victor J. Stenger, (*Prometheus Books, Amherst, New York 2007*). 294 pp. \$28. ISBN 978-1-59102-481-1 (hardcover).

Over the past few years there has been a spate of publication on the relation between science and religion. Much of the work is by perceptive writers, and many of them are scientists. Over most of the twentieth century scientists, religious or not, felt little need to write on the subject. Perhaps the change is a reaction to the damage done to the body politic by the rise of the religious right. However that may be, dozens of books have received substantial public attention.

These books range over a spectrum that one can roughly characterize as follows, with a parenthetical example for each category:

- 2: The purpose of science is to verify and expand upon the cosmological assertions made in a sacred text. (Members of the Institute For Creation Research, *Radioisotopes and the Age of the Earth*.)
- 1: The disposition of the universe, as elucidated by scientific investigation, points definitively to the existence of a supernatural being, often one already characterized in an existing sacred text. (Frank Tipler, *The Physics of Christianity*).
- 0: Science and religion have little or nothing to do with each other. (Stephen Jay Gould, *Rocks of Ages*).
- 1: The disposition of the universe can be elucidated by purely natural scientific means but inspires awe of a supernatural being who, moreover, is the ultimate source of such important nonscientific domains as morality. (Francis S. Collins, *The Language of God*).
- 2a: The universe can be elucidated in a purely natural way without the need to assume supernatural intervention at any level. Belief in such a supernatural entity, moreover, is a "pernicious delusion." (Richard Dawkins, *The God Delusion*).
- 2b: If a suitably defined supernatural being (God) existed, there would be evidence detectable by scientific means. But in fact, the universe presents evidence precisely to the contrary, firmly establishing that such a God does not exist. (Stenger, the work reviewed here.)

Stenger's expertise as a physicist is clearly evident in this work. He begins by defining the God he is talking about, as distinguished from the unlimited possibilities of all the gods the human mind has cooked up (or might.) Specifically, God is the entity described in the sacred works of Jews, Christians, and Moslems, and expanded upon by various schools of believers. This still leaves plenty of scope, but the definition

does impose limits on the possibilities and thus makes specific discussion possible.

Stenger then sets forth his program:

- Hypothesize a God who plays an important role in the universe.
- Assume that God has specific attributes that should provide objective evidence for his existence.
- Look for such evidence with an open mind.
- If such evidence is found, conclude that God may exist.
- If such objective evidence is not found, conclude beyond a reasonable doubt that a God with these properties does not exist. (p. 43)

In subsequent chapters the author applies this program. First he demolishes the argument from design. He uses examples drawn largely from the recent fuss made by the intelligent-design creationists. These are the people who argue that living things are so complicated they must have been created by an “intelligent designer”—their code word for the evangelical Christian God. Stenger’s description of self-organizing systems is particularly lucid. But he also points out (as others have as well) that the intelligent designer must be far more complex than his creation and thus merely compounds the problem. Next, he shows the inadequacy of a wide variety of claims for the existence of a soul distinct from the brain, of a life force (*élan vital* or *qi*), of material effects produced by prayer, and so forth.

The chapters *Cosmic Evidence* and *The Uncongenial Universe* are the strongest parts of the book. Stenger’s considerable expertise shows in his clear discussion of cosmological issues. He shows that purely naturalistic arguments can be sufficient to account for the origin of matter, “beginnings,” the source of the laws of physics, and the indisputable fact that the universe indeed exists. While no firm or definitive answer yet exists to questions such as “What happened before the Big Bang?” he shows clearly that it is either possible to formulate scientific, naturalistic answers to such questions or to rephrase them so that such answers are possible. He demonstrates, moreover, that no logical benefit arises from hypothesizing divine intervention as a substitute for natural processes. He deftly deconstructs various forms of the anthropic principle and pointedly concludes, “Indeed, the universe looks very much like it was produced with no attention whatsoever paid to humanity.”

In the following three chapters, Stenger turns to familiar arguments of a theological or quasi-theological nature. Few of his arguments are original, though they are well organized. He discounts revelations, prophecies, profound religious experiences, and scriptural dicta arguing that they possess no properties that distinguish them from unfounded imaginings.

He then turns to the familiar assertion that human values and morals require a divine origin. His argument to the contrary is far more convincing than the one Collins makes as the main foundation of his personal religious faith. He shows, moreover, that eschewing divine origins for morality opens an entire field to inquiry.

Stenger then addresses the intractable problem of theodicy: How can evil exist in a world governed by God? (I emphasize again that he is talking about God with a capital G.) It is perhaps unfair “piling on” to attack this problem, considering that hundreds of theologians over many centuries have made no apparent progress, but continue to chew endlessly over the same issues.

Does Stenger achieve his purpose, proving that God does not exist? In one sense, he does. He shows that the natural universe can be understood in increasing depth as scientific knowledge progresses, without recourse to supernatural explanations which, he argues, are really no explanations at all. But all this may be beside the point. For those who wish to believe in God, scientific explanation is after the fact. This is certainly clear for the arguments in the –2 category. But faith is by definition belief in something for which no evidence exists. Such faith poses a dilemma, so far as doing science is concerned. Either the answer to a scientific question is “God did it,” which closes further inquiry, or one ignores God for enough hours of the day to do science.

Whether the reader chooses to apply scientific reasoning to the existence of God or not, *God: The Failed Hypothesis* ought to be stimulating reading.

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## **The God Delusion**

*By Richard Dawkins, Houghton Mifflin Company, New York, 2006, 406 pages, \$27, ISBN 978-0-618-68000-9.*

Richard Dawkins, following in the footsteps of Bertrand Russell’s classic 1927 essay “Why I am not a Christian,” has written a passionate and important polemic against religion and theism. “The God Delusion” is nothing less than a call to arms for scientists to do battle in the current culture war between science and religion, or as Dawkins sees it between reason and dogma.

Dawkins attacks a watered-down version of logical positivism espoused by a variety of scientists and thinkers, which holds that questions of theology are simply outside the realm of science. He specifically challenges Stephen Jay Gould’s notion of “non-overlapping magisteria” which divides science from religion: the former covering the empirical realm and the

latter extending to questions of ultimate meaning and moral value.

Dawkins rightly observes this supposed divide is neither recognized nor respected by theists, who alternately attack science and attempt to use it as justification for dogmatic beliefs. But more fundamentally Dawkins maintains it is plain wrong that science has nothing to say about the hypothesis that God exists. As a matter of completeness, Dawkins rehashes why the various arguments for God's existence are not compelling, although Russell already presents a more concise set of refutations in his famous essay.

The real heart of "The God Delusion" is Dawkins' contention that, as a matter of scientific fact, there almost certainly is no God. Dawkins' "statistical demonstration" of God's likely nonexistence follows from his recasting of the argument from improbability. This is the argument many theists see as an overwhelming reason to believe in God, and also as the basis of the so-called theory of intelligent design. Simply put, the theists' argument is that "...the probability of life originating on Earth is no greater than the chance that a hurricane, sweeping through a scrapyard, would have the luck to assemble a Boeing 747."

Here is where, according to Dawkins, Darwinian natural selection is so revolutionary. Natural selection offers a mechanism that explains what otherwise seems inexplicable: that complexity can occur without design.

Physicists, of course, have already learned this lesson from the study of nonlinear phenomena. But Dawkins' paramount point is that the complexity of the Universe, including life, cannot be explained by design and can be explained by natural selection and other natural mechanisms. "A designer God cannot be used to explain organized complexity because any God capable of designing anything would have to be complex enough to demand the same kind of explanation in his own right."

Fortunately, and this is Darwin's great contribution, design is not the only alternative to chance as an explanation for complexity. Dawkins' contribution is to recognize that fundamentalists are rightfully discomfited by the theory of evolution. The fact that life evolved via naturally selected random mutations destroys the theist argument from improbability and casts a glaring light on how unnecessary, and improbable, God is as an explanation for the complex universe we inhabit.

Dawkins tosses down the gauntlet to scientists and challenges them not to retreat from the fundamentalist onslaught against science. Clearly, most scientists would have no difficulty stating flatly that Greek mythology is completely improbable as an explanation of natural phenomena. Yet many

scientists are loath to challenge the prevailing Judeo-Christian mythologies prevalent in western societies, and instead treat superstitions dating back millennia as deserving of solemn respect.

Scientists are able to recognize the intentional silliness of the mock religion Pastafarianism, which postulates a giant flying spaghetti monster as the creator of the Universe. Scientists know, as well as any empirical statement can be known, that mass murderers aren't rewarded with 72 virgins after they die. Yet how many scientists in Judeo-Christian countries are willing to speak out publicly and flatly state Judeo-Christian creationism is irrational nonsense?

Dawkins advocates strident hostility to religion not only because fundamentalism subverts science and rational discourse, but also because moderate or even liberal religious movements foster fanaticism by treating dogma with respect and thereby undermining reason. Neither does Dawkins shy away from even more controversial reasons for actively opposing religion, arguing that religious upbringing is a form of mental and, far too often, physical child abuse.

"The God Delusion" is targeted primarily to raise the consciousness of agnostics and mildly religious believers—the great middle ground between staunch atheists and fundamentalists. Quite simply, Dawkins hopes to convince liberally minded scientists to actively oppose religion rather than to tolerate it. His plea deserves careful reading and serious consideration.

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