

# PHYSICS & SOCIETY

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

## EDITOR'S COMMENTS

In the July 2004 issue of this newsletter, we published an article, "Purex and Pyro are not the same," by William H. Hannum, Gerald E. Marsh, and George S. Stanford, concerning reprocessing methods for nuclear waste materials and their relationships to energy production and to vulnerability to terrorism. In this issue, we provide a response by Richard Garwin to that article. We also requested, received, and herewith publish, a response by Hannum, *et al*, to Garwin's response, as well as Garwin's response to the latter. In other words, we present you here with a full-fledged

written conversation, in a point/counter-point format, on some important issues surrounding electricity generation from nuclear fission. One of us (JJM) wishes to express many thanks to Drs. Hannum, Garwin, Marsh, and Stanford for making this conversation possible. In addition, we present a contribution on the same topic by Robert Albrecht and David Bodansky in their article "Oil, CO<sub>2</sub>, and the Potential of Nuclear Energy." With these papers, P&S is very pleased to present its readers with a veritable feast on a subject that looms large as crude oil prices hover around

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

**Co-Editors:** Al Saperstein, Physics Dept., Wayne State University, Detroit, MI 48202, [ams@physics.wayne.edu](mailto:ams@physics.wayne.edu); Jeff Marque, Senior Staff Physicist at Beckman Coulter Corporation, 1050 Page Mill Rd., MSY-14, Palo Alto, CA 94304, [jjmarque@gte.net](mailto:jjmarque@gte.net).  
**Reviews Editor:** Art Hobson, [ahobson@comp.uark.edu](mailto:ahobson@comp.uark.edu). **Electronic Media Editor:** Andrew Post-Zwicker, [azwicker@pppl.gov](mailto:azwicker@pppl.gov). **Layout at APS:** Amera Jones, [jones@aps.org](mailto:jones@aps.org). **Web Manager for APS:** Joanne Fincham, [fincham@aps.org](mailto:fincham@aps.org). ***Physics and Society* and be found on the Web at <http://www.aps.org/units/fps>.**

\$50/barrel and as reports from Asia continue to emphasize the growing appetite for petroleum there.

As a continuation of our multi-issue series of articles concerning the dangers of nuclear weapons after the Cold War (the idea for which series was hatched by Wolfgang Panofsky in May 2003 during a conversation with JJM), we are very fortunate to have an article by Dr. Lynn Eden, of Stanford University's Center for International Security and Cooperation (CISAC), on the subject of mass fires following nuclear detonations in a wartime environment. In this editor's opinion, one of the most salient pieces of informa-

tion in Dr. Eden's paper is that mass fire, and not blast, is expected to contribute to the great majority of destruction and killing from nuclear detonations in urban and sub-urban areas. Dr. Eden's article is based on her book, published this year by Cornell University Press, entitled Whole World on Fire: Organizations, Knowledge, & Nuclear Weapons Devastation. Recall that the worldwide debate on "nuclear winter" during the 1980's was based on simulations of the consequences of fire, not blast or nuclear radiation.

We thank our editorial staff for news on the Forum and the book reviews.

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## ELECTION RESULTS

Marc Sher, Forum Elections Coordinator

The election results are now in. The winners are:

**Chair-Elect:** Caroline Herzenberg

**Vice-Chair:** George Lewis

**Executive Committee:** Mark Goodman, Sherrie Preische

There were 640 votes submitted (only somewhat more than 10% of our membership!). Somewhat surprisingly, there were a larger than usual number of people who voted twice---once after the first announcement and once two months later after the second announcement. There were 65 such duplications. It turns

out that 50 of these had some differences, and so (in accordance with agreed-on procedures) the first was counted. I did check to see how things would have changed if the second had been counted, and it would have resulted in a net shift of three votes (less than the expected root-N), and wouldn't have changed the outcome. I will try to see if someone can rewrite the script to check voter names to send a warning if they have already voted, so that this issue will not be relevant in the future.

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## FORUM AFFAIRS

Session on "Einstein and Social Responsibility"

*APS March Meeting in Los Angeles*

FPS is sponsoring an invited paper session dealing with Einstein's efforts on behalf of social causes. The session will be held Thursday, March 24 at 11:15 am, in the Los Angeles Convention Center. The four speakers will address the wide scope of his social concerns, as one can learn from the titles and abstracts below.

1. **Ze'ev Rosenkranz of Caltech's Einstein Papers Project will speak about "The Genius as National Icon: Albert Einstein's involvement with the Zionist movement."**

This talk includes discussion of Einstein's induction into the Zionist movement; the interaction between his emerging fame and his involvement with the Zionist movement; his views on major

Zionist issues and on Zionism's role within the German-Jewish community, his intensive involvement in planning for and establishing the Hebrew University of Jerusalem, his positions in the discussions and controversies regarding the University's character and development; and his main actions on behalf of Zionism (such as trips to the U.S. and Palestine).

**2. Virginia Holmes of Caltech's Einstein Papers Project has titled her talk "Was Einstein Really a Pacifist? Einstein's Independent, Forward-Thinking, Flexible, and Self-Defined Pacifism."**

Skeptics sometimes question whether Einstein was really a pacifist. These critics cite Einstein's dramatic contributions to physics, which made nuclear weapons possible, and his 1939 letter to President Franklin D. Roosevelt, which urged the U.S. development of such weapons, as examples of at least an inconsistent stance on pacifism. Holmes plans to show, however, that Einstein's pacifism began early in his life; it was a deep-seated and repeated-expressed conviction; and it was an independent pacifism that flowed from his own responses to events around him and contained some original and impressively forward-thinking elements. Moreover, Einstein defined pacifism in his own terms, not according to the standards of others. This self-defined pacifism included the flexibility to designate the Nazis as a special case that had to be opposed through the use of military violence. Holmes will trace specific actions Einstein took in opposition to war, such as the pacifist "Appeal to the Europeans" put out by Einstein and a handful of intellectuals in response to the militarist "Manifesto to the Civilized World" signed by 93 German intellectuals. Throughout the Weimar period of 1918 to 1933, Einstein continued to take public and private stances as a pacifist. As did many pacifists, Einstein also linked his advocacy for peace with a concern for social justice, which included opposition to antisemitism and advocacy for Zionism. In the U.S., where Einstein lived from 1933 on, in the first ten years after World War II, and also in the last decade of his life, Einstein inspired American pacifists with his strong stances against war and nuclear weapons.

**3. Fred Jerome, author of The Einstein Files: J. Edgar Hoover's Secret War Against the World's Most Famous Scientist will report on "Einstein on Race and Racism."**

More than one hundred biographies and monographs of Einstein have been published, yet not one mentions the name Paul Robeson, let alone Einstein's friendship with him, or the name W.

E. B. Du Bois, let alone Einstein's support for him. Nor is there any discussion of the many Civil Rights campaigns Einstein actively supported. Finally – or firstly – nowhere in the ocean of Einsteinia – anthologies, biographies, articles, calendars, posters, tee-shirts will one find even an islet of information about Einstein's visits and ties to the people in Princeton's African American community.

One explanation for this historical amnesia is that Einstein's biographers and others who shape public memories felt that some of his "controversial" friends, like Robeson, and activities, like co-chairing the American Crusade to End Lynching, might somehow tarnish Einstein as an American icon. That icon, sanctified by Time magazine when it dubbed Einstein "person of the century," is a myth, albeit a marvelous myth. In fact, as myths go, Einstein's is hard to beat: The world's most brilliant scientist is also a kindly, lovably bumbling, grandfather figure: Professor Genius combined with Dr. Feelgood! Opinion-molders may have concluded that such an appealing icon would help the public feel better about science or about America. Politics, after all, is ugly, making teeth grind and fists clench, so why splash politics over Einstein's icon?

Yet it is not so much the motive for the omission, but the consequence that should concern us: Americans and the millions of Einstein fans around this increasingly tribalized world are left unaware that he was an outspoken, passionate, committed anti-racist.

If racism in America depends for its survival in large part on the smothering of anti-racist voices, especially when those voices come from popular and widely respected individuals -- like Albert Einstein -- then this presentation aspires to play a small role in a grand un-smothering.

**4. Patricia Rife, author of Lise Meitner and the Dawn of the Nuclear Age, will discuss "Einstein, Ethics and the Atomic Bomb."**

Her talk will discuss the letter to President Roosevelt that Einstein signed in 1939, warning the U.S. government about the danger that Nazi Germany might gain control of uranium in the Belgian-controlled Congo in order to develop atomic weapons. In 1945, he became a member of the Princeton-based "Emergency Committee for Atomic Scientists." Rife will describe Einstein's philosophic and ethical convictions about peace and his public stance against war (1914-1950). The talk will be illustrated by rare Einstein slides.

## MARCH 2005 MEETING, INVITED PAPER SESSION

[Editor's note: The following titles, authors, and abstracts concern invited papers for a session at the March 2005 APS meeting. The session number is as yet unknown, but the date and time of the session are tentatively scheduled for Tuesday at 8 a.m. JJM]

**THE PHYSICS COMMUNITY'S DEFENSE OF HUMAN RIGHTS**

Presiding: Myriam Sarachik, City University of New York

**1. Nicholson Medal Talk—Physicists and Human Rights: Reflections on the Past and the Present.**

JOEL L. LEBOWITZ, *Departments of Mathematics and Physics, Rutgers University*

The great success of science in promoting the wealth and military power of nations has fueled its growth from a hobby of few to a profession of many. By the early decades of the twentieth

century these included, particularly in Germany, a good number of Jews. Thus, the official persecution of Jews there, following the coming to power of Hitler in 1933, directly affected many scientists, including some, like Einstein, who were world famous. I will discuss some of the actions--and inactions--of physicists in response to this and to later events directly involving the human and professional rights of colleagues. These include the McCarthy period in the United States, and the refusenik/dissident period, symbolized by Andrei Sakharov, in the Soviet Union. I will also discuss the question of what, if any, are the special social responsibilities of scientists today.

## **2. Einstein, social responsibility of physicists, and human rights in China.**

LI-ZHI FANG, Physics Department, *University of Arizona, Tucson*

Since Einstein first visited Shanghai on 1922, he was deeply and constantly concerned about the cases of injustice, suppression, and human rights abuses in China. The strong sense of social responsibility shown by Einstein is an illustrious role model for Chinese intellectuals, especially physicists, who advocate the universal principle of human rights. I will briefly review this history. I will also briefly report what has been done and is being done by Chinese physicists during the long and difficult journey toward democracy and human rights in China.

## **3. Physicists For Human Rights in the Former Soviet Union.**

YURI CHERNYAK, *Massachusetts Institute of Technology*

In his 1940 paper 'Freedom and Science', Albert Einstein emphasized that "intellectual independence is a primary necessity for the scientific inquirer" and that "political liberty is also extraordinarily important for his work". Raised in the tradition of intellectual independence and dedicated to the scientific truth, physicists were among the first to stand up for freedom in the USSR. It is no coincidence that the founders of the first independent Human Rights Committee (1970) were physicists: Andrei Sakharov, Valery Chalidze and Andrei Tverdokhlebov. In 1973 a physicist, Alexander Voronel, founded a Moscow Sunday (refusenik) Seminar – the first openly independent scientific body in the history of the USSR. In 1976 physicists Andrei Sakharov, Yuri Orlov and the mathematician Natan Sharansky were the leading force in founding the famous Moscow Helsinki Human Rights Watch group. This talk briefly describes the special position of physicists (often viewed as Einstein's colleagues) in Soviet society, as well as their unique role in the struggle for human rights. It describes in some detail the Moscow Sunday Seminar, and extensions thereof such as International Conferences, the Computer School and the Computer Database of Refuseniks. The Soviet government considered such truly independent organizations as a challenge to Soviet authority and tried to destroy them. The Seminar's success and its very existence owe much to the support of Western scientific organizations, who persuaded their members to attend the Seminar and visit scientist-refuseniks. The human rights struggle led by physicists contributed substantially to the demise of the Soviet system.

## **4. Human Rights in Iran after the 1978 Islamic Revolution.**

HADI HADIZADEH YAZDI, *Department of Physics and Astronomy, Ohio University*

Iranians have been fighting for their rights since early 1900. The history of this struggle will be reviewed with emphasis on what might be termed the modern era, which began with the return of Ayatollah Khomeini to Iran in February 1979. A brief summary of the modern Iranian Constitution also will be presented. Although Iranians had been promised a democracy within the framework of Islam, in reality Ayatollah Khomeini instituted a theocratic regime dominated by himself as "Supreme Leader" with almost unlimited powers. Surprisingly, these powers actually were expanded after Khomeini's death. For years now, many Iranian intellectuals, as well as a good portion of the nation, religious or not, have been challenging the absolute powers of the Supreme Leader through legal means, with sometimes tragic consequences to individuals. Friction between the so called "reformists" and the "fundamentalists" is on the rise, with no end in sight. International support shown by some nongovernmental organizations such as APS, and human rights institutions such as Amnesty International, have had substantial roles in easing these frictions. Frictions stemming from conflict between the "elected" and "non-elected" bodies in the political system will be discussed. The roles of political activists, reformists, and the so-called "religious nationalists" – and the consequences that they are facing – will also be discussed.

## **5. The American Physical Society's Involvement in the Defense of Human Rights.**

EDWARD GERJUOY, *Department of Physics and Astronomy, University of Pittsburgh*

This session has been organized to remedy the possibility that many APS members do not fully appreciate how important and praiseworthy a role scientists in general, and physicists in particular, have played in the defense of human rights worldwide. The preceding talks in this session have described the efforts, often at great personal risk, of physicists and other scientists residing in a few selected oppressive states (namely China, the former Soviet Union, and Iran), to defend their and their fellow citizens' human rights. The preceding talks also have made reference to the frequently crucial support these embattled foreign scientists have received from scientists in the United States; the ready availability of such support is another important aspect of the scientific community's dedication to human rights. In this talk I shall concentrate on the support activities of this sort undertaken by the U.S. physics community through the APS via the APS Committee on the International Freedom of Scientists (CIFS), of which activities the U.S. physics community can be justly proud. More specifically, I will review the history of CIFS since its formation, including details of its more noteworthy efforts on behalf of human rights. I also will very briefly summarize the important human rights efforts undertaken, independently of the APS, by several other organizations of American scientists (e.g., the Committee of Concerned Scientists (CCS) and the American Association for the Advancement of Science (AAAS).

## Report on POPA Activities

At its meeting on October 23, the APS Panel on Public Affairs approved a discussion paper prepared by its members on one issue—the proposed Moon-Mars program—and initiated studies on two additional topics—science advice to Congress and the link between nuclear power and nuclear proliferation.

### Moon-Mars mission

The APS issued the Moon-Mars report along with a press release on November 22. (Both the press release and the report are on the POPA website, [http://www.aps.org/public\\_affairs/index.cfm](http://www.aps.org/public_affairs/index.cfm).) The report addresses a proposal by President Bush on January 14, 2004, for a return of humans to the Moon by 2020, followed by human exploration of Mars and other destinations. The executive summary of the APS report asserts that “Very important science opportunities could be lost or delayed seriously as a consequence of shifting NASA priorities toward Moon-Mars. The scientific planning process based on National Academy consensus studies implemented by NASA roadmaps has led to many of NASA’s greatest scientific—and popular—successes. We urge the Federal Government to base priorities for NASA missions on the National Academy recommendations.”

The report also states that “extraordinary scientific and technological difficulties confront President’s Bush’s vision for a Moon-Mars initiative. The budget for the proposed program remains very imprecise and is expected to grow substantially. The constraints that inevitably will be imposed on other federal scientific programs are already evident, especially within NASA. Before the United States commits to President Bush’s proposal, an external review of the plans should be carried out by the National Academy of Sciences.”

The budget passed by Congress in November included a 5% increase in NASA’s budget. Sean O’Keefe, the NASA administrator, called the budget victory “as strong an endorsement as anyone could have hoped” for the national space policy outlined by the president in January.

### Other initiatives

Ever since the demise of the Congressional Office of Technology Assessment, there have been concerns about the adequacy and quality of science advice given to Congress. Two Congressmen have recently drafted separate bills creating some form of technology assessment capability, but the bills have not met with much success. At its October meeting, POPA created a subcommittee to (1) assess the methods Congress has for obtaining scientific advice; (2) identify any gaps in those methods and (3) identify ways to fill any gaps. The subcommittee will report back to Congress at the January meeting.

On another front, there has been growing concern that the development and expansion of nuclear power is a significant proliferation threat. Congressional staffers have asked the APS for some guidance on this issue. As a result, POPA created a subcommittee to (1) frame the issue of proliferation resistance and fuel cycles; (2) identify general approaches for reducing proliferation risks; and (3) recommend technology pathways that can be applied to reduce proliferation risks at present, in the near term and in the long term. This subcommittee will also report in January.

Barbara Goss Levi  
FPS representative to POPA

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## ARTICLES

### Underestimating the Consequences of Use of Nuclear Weapons: Condemned to Repeat the Past’s Errors?

Lynn Eden

This article draws on Lynn Eden, *Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation* (Ithaca, NY: Cornell University Press, 2004)

Seriously studied for almost sixty years, nothing would seem better understood than the effects and terrible consequences of the use of nuclear weapons.<sup>1</sup> Yet, surprisingly, for decades, one far-reaching effect—the mass fire damage caused by “firestorms”—was neither examined in depth nor widely understood. This matters because, for modern nuclear weapons, under almost all conditions and for many targets of interest, the range of devastation from mass fire substantially exceeds that of damage from blast. Once mass fire began to be studied analytically and through reanalysis of empirical experience, the quite well-developed findings were not widely accepted. There may be somewhat greater acceptance now, but, when it comes to nuclear operations, understanding by physicists is not enough. Knowledge has to be incorporated into organizational procedures, specifically, the algorithms used in strategic nuclear war planning.

There is currently a low level of effort to develop a methodology to predict collateral fire damage, but as of mid-October, 2004, fire damage prediction is still not incorporated into the U.S. strategic nuclear war plan—that is, as a mechanism of destruction for deliberately targeted forces and installations. There is no program underway to do so.<sup>2</sup>

Underestimating the damage caused by nuclear weapons is an important part of the historical explanation for the inflated force requirements—“overkill”—that led the United States and Soviet Union to build nuclear arsenals in the tens of thousands of warheads. But underestimating damage matters importantly now as well. To paraphrase George Santayana, those who do not understand the past may well be condemned to repeat its errors.

Particularly salient today are regional conflicts in which a decision or threat to use nuclear weapons would in all likelihood be based on a severe underestimate of the damage that could result. Indeed, in the South Asian crisis of May 2002, the United States

specifically sought to warn the leaders of India and Pakistan of the consequences of a nuclear exchange. However, a U.S. defense intelligence assessment prepared for that purpose was based on blast effects alone. The study estimated that twelve million people would be killed, *but it did not include deaths from mass fire*.<sup>3</sup> If it had, the estimate would undoubtedly have been much higher.

Beyond the very important possibility of underestimating damage and death from nuclear weapons in the event of use, there are similar kinds of phenomena in which important aspects of the physical world are not well understood or, if understood, are not incorporated into political decisions and organizational procedures. Such phenomena are more common than might at first be thought.

In what follows, I first explain what I mean by mass fire. I then make some bald assertions, much more fully argued and documented in *Whole World on Fire*, about the predictability and range of mass fire. I very briefly summarize why predictions of mass fire damage were not developed for many years. I also briefly summarize how a small team, led by physicist Harold Brode at Pacific Sierra- Research, developed a methodology to predict nuclear fire damage. I explain what happened to that work. And I close by drawing out some implications for other areas of policy.

Mass fire is roughly synonymous with the more common term “firestorm”—though physicists tend to prefer the former term. A nuclear mass fire can occur in an area containing a fuel load typical of a city or suburb. A nuclear detonation would first cause myriad simultaneous ignitions over this large area. These fires would begin to coalesce and to heat an enormous volume of air that would rise. Like a gigantic bonfire, this rising hot air would cause cooler air near the surface to be sucked in from the periphery. This air would move at hurricane force toward the center, become superheated, and rise—causing additional hurricane winds to rush in from the periphery and further intensifying the mass fire. No one within the area would survive.<sup>4</sup>

Such mass fires are fundamentally different from the famous fires that destroyed London, Chicago, and San Francisco, the vast forest fires of the late nineteenth century that swept the Great Lakes states, and the Cerro Grande fire that nearly destroyed Los Alamos National Laboratory in 1999. These were not mass fires, simultaneously set over vast areas, but large propagating “line fires.” Such line fires are highly destructive, but do not occur in the same time frame, nor with the scale and intensity, of a mass fire. The mass fire set at Hiroshima by a 15 kiloton atomic bomb, for example, completely burned out an area of 4.4 square miles within hours, not days.<sup>5</sup>

Some have argued that although nuclear mass fires could be highly destructive, they would be subject to weather and other conditions, and therefore cannot be reliably predicted. It has also been argued that the probability and range of such fires is not as predictable as damage from nuclear blast. Finally, it has been argued that for the specific targets of interest to war planners, the range of fire damage is not greater than the range of blast damage. However, the work of Harold Brode and his collaborators, as well as that of MIT professor Theodore Postol, establishes that mass fire creates its own environment, and therefore is highly predictable. (Think of a piece of the sun being brought to earth.) Mass fire and extensive fire damage would occur in almost every circumstance in which nuclear weapons were detonated in a suburban or urban

area. The circumstances in which mass fire damage would not occur—for example, during torrential rainstorms—are rare, and their probabilities are calculable in advance. Although weather can affect the range at which fires will occur, this variation can be reasonably well predicted. Nuclear fire damage is, in fact, as accurately predictable as blast damage: The uncertainties in the range at which mass fire would cause damage are no greater than the uncertainties associated with blast.<sup>6</sup> Finally, many targets of interest to war planners, such as military, command, industrial, and political targets, are co-located in urban or suburban areas, and for nuclear weapons of approximately 100 kilotons or more, the range of severe damage from fire is likely to be significantly greater than the range of severe damage from blast. Under most circumstances, damage from mass fire would extend two to five times farther than blast damage.<sup>7</sup>

Why were predictions of fire damage not developed for many years? The answer goes back to before World War II. Fundamentally, organizations can only solve the problems they set out to solve. Those involved in air target intelligence focused on being able to destroy specific installations with high-explosive blast weapons. Despite excursions into incendiary operations in World War II, the emphasis remained on precision targeting with high-explosive bombs. The emphasis on blast damage can vividly be seen in the end-of-the-war U.S. Strategic Bombing Survey. According to a careful reading by Harold Brode, the multi-volume reports on Hiroshima and Nagasaki concentrated on structural damage due to blast. “[F]ire, although fully reported, was viewed as interfering with their objective of identifying and quantifying blast damage.”<sup>8</sup>

Despite the inevitable area damage caused by nuclear weapons, the emphasis on precision targeting and blast damage carried over after the war into the early development of blast damage prediction in what became known as the VNTK system—the main tool for predicting damage, that is, blast damage from nuclear weapons for use in U.S. strategic nuclear targeting. There was no comparable development of fire damage prediction for many years following. Further, those involved in developing blast damage prediction—including such outstanding civil engineers as Nathan Newmark, a University of Illinois professor—were not intellectually equipped to predict fire damage. The whole process became self-reinforcing: what could be predicted seemed to those involved as inherently more predictable; what could not be predicted seemed inherently unpredictable.

This is not to say that some physicists were unaware of nuclear fire damage. Indeed, President Eisenhower’s science adviser, George Kistiakowsky, wrote that because U.S. nuclear war planners “used blast effect as the only criterion of damage and neglected thermal radiation [and the] fires which will be caused by it... the question may be raised as to whether [it results] in overkill and will create unjustified additional ‘force requirements.’”<sup>9</sup> Nonetheless, this insight was not used within the government to build expertise and develop knowledge about nuclear fire damage.

Beginning in the late 1970s, the Federal Emergency Management Agency (FEMA) and then the Defense Nuclear Agency (DNA), began to fund exploratory work for a small team led by Harold Brode at Pacific-Sierra Research to develop a methodology to predict fire damage for use in strategic nuclear targeting. Why did

the government decide to fund this work—at Brode’s initiative? In fact, it was not unusual for DNA to fund exploratory work. The question might better be asked as to why Brode did not choose to work on the problem earlier. In any case, the interest generated by the “nuclear winter” controversy beginning in late 1983 resulted in further funding for Brode’s efforts—since where there’s smoke, there’s fire. By the early 1990s, Brode and his colleagues had teamed up with DNA, and also the Defense Intelligence Agency (DIA) and nuclear war planners from the Joint Strategic Target Planning Staff (JSTPS) to predict combined fire and blast damage to 50 and then 300 example targets. By the end of this process, they had demonstrated a method not only for predicting fire damage, but for incorporating those predictions into the government’s VNTK system for predicting blast damage. Indeed, in early 1991, the government came close to incorporating fire damage predictions into nuclear war planning. However, the post-Cold War environment and an ultimate inability to persuade high-level military officers of necessity and feasibility led to the shelving of the project by year’s end.<sup>10</sup> Although interest in predicting fire damage was revived in the mid-1990s, work is no longer being done to develop a combined method to predict fire and blast damage for use in strategic nuclear war planning—although some interest continues in predicting collateral fire damage.<sup>11</sup>

It is consequential that U.S. nuclear war planning does not take full account of the physical devastation that would occur were nuclear weapons to be used. Yet the implications of *Whole World on Fire* are broader than this. Like the VNTK system based only on blast damage, the representation of the physical world in documents, routines, and technologies may be inaccurate or incomplete. Many examples abound, from the construction of the *Titanic* (shipbuilders did not understand just how brittle was the steel plate used), to the failed design of the Tacoma Narrows bridge, to the lack of anticipation that a jet aircraft flying into the World Trade Center could also ignite fire from the thousands of gallons of jet fuel released into the building. Such situations probably cannot be altogether avoided, but the immediate correction of serious design errors in the Citicorp Center in New York and the John Hancock Tower in Boston (both built in the 1970s), points to the general solution: democratic accountability and open professional oversight.

*Lynn Eden, Ph.D., is associate director for research and senior research scholar at the Center for International Security and Cooperation, Stanford Institute for International Studies, Stanford University. Eden has written on U.S. foreign and military policy, arms control, and Cold War history. She was an editor of The Oxford Companion to American Military History (Oxford University Press, 2000). Whole World on Fire received the Robert*

*K. Merton award for best book in science, knowledge, and technology from the American Sociological Association, 2004. Eden can be reached at [lynneden@stanford.edu](mailto:lynneden@stanford.edu), (650)-725-5369. See also [www.wholeworldonfire.com](http://www.wholeworldonfire.com)*

#### Endnotes

1. See for example Samuel Glasstone and Philip J. Dolan, eds., *The Effects of Nuclear Weapons*, 3rd edition (Washington, DC: USGPO, 1977) and earlier editions dating from 1950.
2. Personal communication with author, October 19-20, 2004.
3. Thom Shanker, “12 Million Could Die at Once in an India-Pakistan Nuclear War,” *New York Times*, May 27, 2002; Elisabeth Bumiller and Thom Shanker, “Bush Presses Pakistan on Kashmir and Orders Rumsfeld to Region,” *New York Times*, May 31, 2002; Todd S. Purdum with Seth Mydans, “U.S. Envoys Ready to Press Two Foes in Kashmir Crisis,” *New York Times*, June 3, 2002.
4. An extended discussion of mass fire can be found in Lynn Eden, *Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation* (Ithaca: Cornell University Press, 2004), chap. 1.
5. Eden, *Whole World on Fire*, p. 20.
6. See Eden, *Whole World on Fire*, chap. 1. Also, Gilbert Binniger, Roger Craver, and Suzanne Wright, *Staff Officers’ Guide for Targeting Uncertainties*, DNA-TR-89-115, prepared for Director, Defense Nuclear Agency, Washington, DC (n.p., January 1990), p. 47, argues that range predictions for airblast under free-field conditions “can be in error by as much as  $\pm 30\%$ .”
7. Ashton B. Carter, “Assessing Command System Vulnerability,” in Carter, John D. Steinbruner, and Charles A. Zraket, eds., *Managing Nuclear Operations* (Washington, DC: Brookings Institution, 1987), pp. 561-563, 571-572. The specific targets of interest may be different today, but similar targets are to be found in urban and suburban areas. Regarding range of damage, see Binniger, Craver, and Wright, *Staff Officers’ Guide*, p. ix, discussed in Eden, *Whole World on Fire*, p. 246.
8. Comments by H.L. Brode on the United States Strategic Bombing Survey (1947), September 2004, enclosed in Harold Brode letter to author, 30 September 2004.
9. Kistiakowsky quoted in Eden, *Whole World on Fire*, p. 1.
10. See the detailed narrative in Eden, *Whole World on Fire*, chaps. 9-10.
11. Eden, *Whole World on Fire*, chap. 10; personal communication, October 19-20, 2004.

## Another View of the Role of Nuclear Power

*Richard L. Garwin*

I begin with a comment on a recent paper in P&S.<sup>1</sup> In their paper, the authors argue that U.S. energy problems would be largely solved by the deployment of “proliferation-resistant fast reactors”. In support of this argument, they make a number of serious errors in their discussion of the utility of reactor-grade plutonium (R-G Pu) in the fabrication of nuclear explosives:

“... weapons made from R-G Pu have a yield that is highly unpredictable-- they would be very likely to ‘fizzle,’ producing no mushroom cloud at all.” (p. 10.2.8)

“... even as a terrorist weapon that will definitely fizzle ...” (p. 10.2.8)

It is not true that a terrorist weapon will “definitely fizzle” nor that a “fizzle” will produce no mushroom cloud at all. In a report of which both Michael M. May and I were coauthors<sup>2</sup> (see pp. 33-34), the Committee on International Security and Arms Control notes,

“While this yield is referred to as the ‘fizzle yield,’ a 1-kiloton bomb would still have a radius of destruction roughly one-third that of the Hiroshima weapon, making it a potentially fearsome explosive. Regardless of how high the concentration of troublesome isotopes is, the yield would not be less. With a more sophisticated design, weapons could be built with R-G Pu that would be assured of having higher yields.”

The report refers to a classified study of 1994 done for the Committee by LLNL<sup>3</sup> What a 1-kt weapon would do if detonated in Manhattan is detailed in a recent paper.<sup>4</sup> In sum, hundreds of thousands of people would die within minutes of the 1-kt explosion—the minimum “fizzle” yields that could occur either with weapon grade Pu or R-G Pu. It would be a nuclear explosion with all its characteristics—blast, fire, radiation, and severe fallout.

Surely the authors of (1) do not wish us to explain precisely how to make an even more effective weapon with R-G Pu.

My correction of these overstatements has more to do with the urgency of enhancing protection of separated R-G Pu (of which tens of tons—enough to make thousands of nuclear weapons—now exist in the UK, France, and Japan), than with the normal in-process characteristics of the pyro-processed material that is the subject of the Forum article.

There, though, the question is not what would be normal operation, but whether the line, in general, could be configured to separate purer Pu, thus reducing the challenge to building a nuclear weapon from the Pu in process or in storage. A 1-GWe reactor fissions about a ton of Pu (or U-235) per year, and so any prudent cycle would have a ton or more of Pu in readiness for fueling—enough for 100 nuclear weapons.

Here, too, the authors overreach, quoting an emphatic judgment, “... that the transuranic impurities render the material far too hot (thermally and radioactively), and far too many spontaneous neutrons, to make it at all feasible.” (p. 11.1.6)

Despite the fact that this material has almost 1000 times the spontaneous neutron emission rate as R-G Pu ( $2 \times 10^5$  compared with 200 neutrons/sec/gram) the fizzle yield in an implosion device would not be reduced below that obtained with R-G PU— that is, in Mark’s illustration, 1-2 kilotons.

The thermal power is a greater problem. An R-G Pu implosion weapon core would give off less heat than a 100-W light bulb, whereas the pyro-processed core would deliver on the order of seven times that. This would make it unsuitable for the usual approach to construction, but, unfortunately, would by no means make it impossible to construct.

The Integral Fast Reactor (IFR) Pu ingot (as configured to feed a light water reactor (LWR) fuel-fabrication line) would provide some 50 R/hr at 0.5 m distance, in comparison with 100 times less radiation flux at that distance from R-G Pu. This would certainly add difficulties in the fabrication, and would make the core more readily detectable in case of attempted clandestine delivery.

I agree that it is “very much easier to make a bomb with highly enriched uranium than with R-G Pu [or, I add, with weapon-grade Pu] But “That route would surely be taken by any organization that did not have access to weapons-grade plutonium.” would be true only if they did have access to HEU and not to R-G Pu.

The authors note that pyro processing in the form of electrochemical methods has had considerable development and demonstration and poses less proliferation hazard than does aqueous reprocessing. Still, with the electrochemical system they wrote that “... this threat, however remote, is justification for rigid safeguards on electrochemical separation facilities.” (p. 10.2.4) Indeed, the chosen proliferation path in recent years appears to be the acquisition of “peaceful” nuclear technologies in the guise of a nuclear power system, and the covert or explicit denunciation of the International Atomic Energy Agency (IAEA) nonproliferation regime, converting those materials and facilities for enrichment or reprocessing to the production of weapons. This is the route followed by North Korea, and apparently begun by Iran.

Other statements in the article are also misleading, as:

“The most credible nuclear terrorist threat, a dirty bomb, requires only access to spent nuclear fuel, and the controls on this material in various parts of the world are minimal.” (p. 9.1.8)

Nuclear fuel is unlikely to be involved in a dirty bomb, because there are more conveniently available intense radioactive sources of Co-60 or Cs-137 used in industrial radiography devices or systems for sterilization of food.

A widely available and authoritative report on reprocessing technologies is available on the web.<sup>5</sup> The STATS report (pp. 440-441) addresses Argonne National Laboratories (ANL) estimates of cost for pyro processing of LWR spent fuel, with a target of \$350/kg HM (per kilogram of heavy metal contained in the spent fuel). Although such a number would require that pyro processing be six times cheaper than large-scale aqueous reprocessing, STATS quotes an estimate that “unit reprocessing cost for an investor-owned plant for pyrochemical processing of LWR spent fuel would be, instead, 57% greater than that for an aqueous reprocessing facility of the same throughput.” Furthermore, the electrochemical pyro processing system has a great deal of flexibility so that it could very probably be operated to produce quite pure Pu, with little of the contaminating transuranics—hence the need for “rigid safeguards.”

Moving beyond nonproliferation, what is the cost of the advanced fast-reactors that would be required not only to produce electricity at acceptable cost, but also do this with the added burden of burning LWR spent fuel? Let me point the reader to two books that discuss these matters broadly.<sup>6,7</sup>

My own judgment is that fast reactors have a great deal to offer in the long-term future. But we will get there only with rigor in the development and evaluation of the reactor technology, cost, and safety—and only if nonproliferation requirements are part of the design for any future reactor.

A great friend of nuclear power, Edward Teller, wrote,

“For the fast breeder to work in its steady-state breeding condition you probably need something like half a ton of plutonium. In order that it should work economically in a sufficiently big power-



producing unit, it probably needs quite a bit more than one ton of plutonium. I do not like the hazard involved. I suggested that nuclear reactors are a blessing because they are clean. They are clean as long as they function as planned, but if they malfunction in a massive manner, which can happen in principle, they can release enough fission products to kill a tremendous number of people. ...But, if you put together two tons of plutonium in a breeder, one tenth of one percent of this material could become critical. I have listened to hundreds of analyses of what course a nuclear accident can take. Although I believe it is possible to analyze the immediate consequences of an accident, I do not believe it is possible to analyze and foresee the secondary consequences. In an accident involving a plutonium reactor, a couple of tons of plutonium can melt. I don't think anybody can foresee where one or two or five percent of this plutonium will find itself and how it will get mixed with some other material. A small fraction of the original charge can become a great hazard."<sup>8</sup>

All these questions must be faced honestly and resolved collectively to the satisfaction of all technically capable, open-minded participants. They are not now being so addressed.

I agree that aqueous reprocessing has no place in the current commercial nuclear power industry. It is uneconomical compared with the once-through cycle and adds to the proliferation hazard. But if it were commercially viable, even with the increased costs that would be associated with effective nonproliferation measures, and if it were accompanied by political commitments on the part of those who have developed commercial nuclear power in conjunction with the IAEA, to return those facilities to their suppliers in case of denunciation of the IAEA, I would support even aqueous reprocessing for an economy that would ultimately involve both once-through reactors and breeders.

COMMENTS ON THE CURRENT SCENE.<sup>9</sup> Nuclear power is in the news in the United States these days primarily because of controversy about shipment of spent fuel, storage of spent fuel in pools at the reactor, and dry-cask storage.

I have studied these questions not only for my book, but also for the National Research Council in conjunction with a book on terrorism,<sup>10</sup> and I believe that there is no significant hazard for transport of spent fuel in approved U.S. dry casks. Experiments done by Sandia National Laboratories show that even with large shaped-charge explosive systems, it is difficult to volatilize and disseminate any significant amount of radioactivity. Dry casks are durable against being struck by an aircraft and, to my mind, are a far safer form of storage than are spent-fuel pools.

I believe that some independent analyses<sup>11</sup> of possible vulnerability of spent-fuel pools to terrorist attacks are quite reasonable, and that neither the industry nor the NRC has provided anything better. As a result, I have long advocated taking this threat seriously and not only protecting pools against attack, but also maintaining on site and at centralized locations expedient repair kits and equipment that could stanch leaks of coolant and provide substantial coolant inflow in order to maintain the shielding and cooling of the spent fuel in case of explosive attack.

In "Making the Nation Safer," the National Research Council Committee writes, "... emergency cooling of the fuel in case of attack could probably be accomplished using 'low tech' measures

that could be implemented without significant exposure of workers to radiation." The Nuclear Regulatory Commission states that it "agrees with this statement," and notes that its February 25, 2002 Order directed licensees to develop guidance and strategies to maintain or restore spent fuel cooling capabilities using existing or available resources." But unless the Commission and the industry acknowledge the vulnerability and its nature, it will be a very long time before effective post-attack spent-fuel cooling will be implemented.

As for attack on reactors by large aircraft or by light aircraft carrying explosives, I have published my judgment that explosives carried by light aircraft can be a considerable threat and should be taken seriously, with largely passive close-in protection against this specific threat.<sup>12</sup>

I have visited reprocessing plants in France and in the UK, and find them more serious potential sources of dispersed radioactivity than is an individual reactor. Then, too, there is opportunity for insider terrorist attack as well, a threat that need to be addressed with imagination.

As for the Yucca Mountain repository for commercial spent fuel, I believe that the decision procedure has proceeded at a glacial pace, and that engineering design of the emplacement lags far behind what is possible. At this late date, it is still not clear as to whether there will be backfill around the containers, or whether there will be "drip caps", or, if drip caps, whether they would be made of titanium alloy or (as I advocate) the equivalent of a tile roof, with overlapping, small, durable rock plates supported by coarse gravel. The benefit of tile over a fabricated drip cap is that it is redundant, and that water coming in is reliably shunted out, without vulnerability to single-point failure.

In sum, Yucca Mountain should be completed and storage begun, with provision for surveillance of the integrity of the entombed waste and replacement if necessary.

Successful civil nuclear electricity requires acceptable levels of cost, accident risk, proliferation hazard, and vulnerability to terrorism. "Cost" includes that of raw uranium, enrichment services, fabrication, waste disposal, and decommissioning. A useful current study on nuclear power, its technology, impact, and economics has recently been published by MIT.<sup>13</sup> A 1-GWe plant (a million kW) operating at 90% capacity factor produces some 7.9TWh of electrical energy per year, that it can sell at about \$0.06/kWh--a gross income of \$470 M. It pays a fee of 1 mill/kWh for a decommissioning sinking fund, and another 1 mill/kWh for the U.S. government to accept and dispose of the spent fuel-- \$8 M/yr for each charge.

The fuel-cycle cost, including supply and disposal is typically 6 mill/kWh. But most of the cost of nuclear electricity is capital cost. Quite the opposite is true for natural gas, widely used in the United States for "peaking power," because the capital component of cost is small compared with the cost of fuel.

If instead of the current \$30/kg for uranium in the form of "yellow cake," the cost rose to \$130/kg, this would add about \$1000 to the cost of a kilogram of reactor fuel. Since the yield of electrical energy is about 20 megawatt days per kg, the cost of the fuel would rise by about 2 mill/kWh, by any account affordable, even if not

competitive, at some sites, with electricity from coal without a substantial carbon tax.

Since the “reserve” of terrestrial uranium is about 3 million tons at current prices (and 20-200 million tons at prices up to about \$200/kg), and since each GWe reactor consumes about 200 tons of raw uranium per year (or 12,000 tons over its 60-year life), those interested in expanding nuclear energy ought to urge governments to support R&D into acquiring uranium from seawater, where there is a total of about 4 billion tons. Japan has a small program on seawater uranium, with costs projected somewhere between \$100 and \$1000/kg. It is clearly in the public interest to have a better understanding of the future supply.

In the meantime, with 300 1-GWe reactor equivalents operating in the world, the cost and supply of uranium is no problem.

As for “normal accidents,” it is my judgment that any of the well-designed and widely deployed reactor systems operating in the world is adequately safe, when properly operated. The major assumption of proper operation is often not warranted, as is evident from the discovery in February 2002 that the Davis-Besse reactor (near Toledo, Ohio) had over the years developed a large hole penetrating substantially through the forged steel pressure vessel head, to the thin stainless-steel liner.

Terrorism is, unfortunately, a fact of modern life with the purpose of, and the potential for, targeting entire societies. It is no longer acceptable for the NRC to disclaim a responsibility in this area, with the statement, “the possibility of a terrorist attack ... is speculative and simply too far removed from the natural or expected consequences of agency action [ellipsis in original].”

Terrorism must be taken seriously not only for the civil nuclear establishment but also for various other elements of civil infrastructure. But that would take me too far afield in this article. We can talk about the future of nuclear power on the assumption that the NRC and other regulatory bodies worldwide take seriously the terrorist threat and implement adequate measures to prevent and respond to it (including capability for near instantaneous central response).

As indicated, there is no shortage of uranium at affordable prices, and therefore reprocessing of any type has no role in commercial light-water reactor systems. Nor does reprocessing substantially reduce the amount of heat in the spent fuel nor the cost of disposal. Yucca Mountain is designed to hold only 76,000 tons of spent fuel, which would accommodate only the output of existing reactors. Evidently a substantial expansion of world reactor capacity would require much more in the way of mined geologic repository capacity, which is needed in any case for the disposition of the vitrified fission product waste from reprocessing as practiced in France. Such repositories are planned there, as well.

The near-term solution is to remove the restrictions on transfer, between nations, of properly conditioned spent fuel, either from the once-through cycle or the vitrified fission product waste, so that one can enter an era of competitive, commercial, mined geologic repositories. The repository and the spent fuel forms would be approved by the IAEA, and backup to security would need to be provided by a consortium of nations under the authority of the United Nations.

Future reactors should be deployed underground to provide greater protection against terrorist attack. Robust types with enhanced protection against release of radioactive materials in case of accident or terrorist attack include the helium-cooled graphite reactors such as the high-temperature gas-turbine reactor (HTGR) and the pebble-bed reactor.

I am entirely open-minded about breeder reactors, or near-breeders coupled with accelerators, or (for the near-term) near-breeders whose neutron economy is enriched by feeding excess plutonium removed from nuclear weapons. Any breeders must be designed with a compatible fuel reprocessing and fabrication system, in which non-proliferation and robustness against accident and terrorism are important components.

In agreement with the authors of (1), I recognize that reprocessing is essential for such reactors, and I add that it offers, in principle, the possibility of lower costs than that for reprocessing of LWR fuel. This is because about 5 kg of spent LWR fuel must be reprocessed to substitute for 1 kg of fresh LWR fuel, whereas for a breeder, the ratio is much closer to 1:1. And the separation of fission products need not be the factor 107 achieved by the PUREX process, but a mere 100:1.

In conclusion, I judge that nuclear power has much to offer for the U.S. energy future, but industry and government the world over have much to do to protect reactors and other facilities against accident and terrorist attack, and to provide enhanced barriers so that nuclear power does not contribute to proliferation of nuclear weapons.

1. “Purex and Pyro are Not the Same,” by Hannum, W.H. Marsh, G.E., Stanford, G.S. Physics & Society, July 2004, pp. 8-11.

2. “Management and Disposition of Excess Weapons Plutonium,” Report of the National Academy of Sciences, Committee on International Security and Arms Control, W.K.H. Panofsky, Chair, National Academy Press, Washington, DC, January 1994.

3. The footnote on p. 33 of (2) reads: “See W.G. Sutcliffe and T.J. Trapp, eds., ‘Extraction and Utility of Reactor-Grade Plutonium for Weapons,’ Lawrence Livermore National Laboratory, UCRL-LR-115542, 1994 (S/RD). For unclassified discussions, see J. Carson Mark, ‘Explosive Properties of Reactor-Grade Plutonium,’ Science and Global Security, 4:11-128, 2003.” The footnote continues: “The Pu-240 content even in weapons-grade plutonium is sufficiently large that very rapid assembly is necessary to prevent preinitiation. Hence the simplest type of nuclear explosive, a ‘gun type,’ in which the optimum critical configuration is assembled more slowly than in an ‘implosion type’ device, cannot be made with plutonium, but only with highly enriched uranium, in which spontaneous fission is rare. (This) makes HEU an even more attractive material than plutonium for potential proliferators with limited access to sophisticated technology. Either material can be used in an implosion device.”

4. “Nuclear and Biological Megaterrorism,” by R.L. Garwin, presented at 27th Session of the International Seminars on Planetary Emergencies, Erice, Sicily, August 19-24, 2002, see [www.fas.org/RLG](http://www.fas.org/RLG) (A shorter version was published in MIT’s Sept. 2002 Technology Review, titled “The Technology of Megaterror” at <http://www.technologyreview.com/articles/garwin0902.asp>)

5. "Nuclear Wastes: Technologies for Separations and Transmutation," Committee on Separations Technology and Transmutation Systems (STATS), N.C. Rasmussen, Chair, National Academy Press, Washington, DC, 1996. (<http://books.nap.edu/catalog/4912.html>)
6. "Megawatts and Megatons: The Future of Nuclear Power and Nuclear Weapons," by R.L. Garwin and G. Charpak, The University of Chicago Press, January 2003. (Note errata at [www.fas.org/RLG](http://www.fas.org/RLG))
7. "Nuclear Energy: Principles, Practices, and Prospects," Second Edition, by David Bodansky (Springer-Verlag; November 30, 2004).
8. Edward Teller, "Fast Reactors: Maybe." *Nuclear News* (August 21, 1967).
9. "Science, Technology, Fission, and the Future," by R.L. Garwin, Keynote Speech presented at the American Nuclear Society Banquet, November 19, 2002.
10. "Making the Nation Safer: The Role of Science and Technology in Countering Terrorism," by L.M. Branscomb (Co-chair) and R.D. Klausner (Co-chair), et al, National Research Council of the National Academies, National Academies Press, Washington, DC, 2002.
11. "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States," by R. Alvarez, et al, April 21, 2003 (Published in *Science and Global Security*, 11:1-51,2003. See also NRC response in *ibid*, 11:203-211, 2003, and reply by R. Alvarez, et al, in *ibid*, 11:213-223,2003.
12. "Science, Technology, Fission, and the Future," by R.L. Garwin, Keynote Speech presented at the American Nuclear Society Banquet, November 19, 2002.
13. "The Future of Nuclear Power," J. Deutch and E.J. Moniz, Co-chairs, Massachusetts Institute of Technology, 2003. <http://web.mit.edu/nuclearpower/>

*Richard L. Garwin is IBM Fellow Emeritus at the IBM Thomas J. Watson Research Center, Yorktown Heights, NY. He is a physicist, member of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine. Since 1950 he has consulted with the Los Alamos National Laboratory on nuclear weapons technology and testing. He contributed to the early thermo-nuclear weapon design and has received from the US Government the Enrico Fermi Award, the National Medal of Science, and the R.V. Jones Foreign Intelligence Award. His biography and many papers are at [www.fas.org/RLG](http://www.fas.org/RLG).*

## Response to Garwin's Paper

In his paper *Another View of the Role of Nuclear Power*, Dr. Garwin comments on the potential use of reactor-grade plutonium (R-G Pu) for nuclear explosives. We agree, of course, that one should keep in mind potential misuse of materials associated with nuclear power as well as with nuclear weapons. His remarks underscore the thrust of our previous paper, *PUREX and PYRO Are Not the Same*: if a technology can reduce the threat of nuclear terrorism or improve our energy posture or environment without increasing the threat of nuclear terrorism or nuclear- weapons proliferation, it should be pursued as a matter of urgent priority. Pyrometallurgical recycling can reduce the threat of nuclear terrorism, improve our energy posture, and address constructively the issue of nuclear waste.

"My own judgment," Dr. Garwin states, "is that fast reactors have a great deal to offer in the long-term future. But we will get there only with rigor in the development and evaluation of reactor technology, cost, and safety—and only if nonproliferation requirements are part of the design for any future reactor." We concur. Dr. Garwin recognizes that the material from pyro recycle is a far greater challenge to a would-be bomb maker than what we now think of as R-G Pu, and that is important. Only very innovative people with extensive weapons-design experience would have a chance of effectively using this highly complex material.

And we fully agree that international safeguards of nuclear operations are essential, to prevent the "[conversion of] those materials and facilities for enrichment or reprocessing to the production of weapons." The fast-reactor fuel cycle, however, requires neither enrichment nor pure plutonium—so development of either process would be *ipso facto* evidence of intention to proliferate.

In discussing the relative economics of the pyro cycle, Dr. Garwin quotes the "authoritative" STATS report—whose pessimistic economic projections are based on obsolete data (see the detailed

critique by Boardman et al<sup>1</sup>). We also note that Garwin's discussion of the cost of nuclear power barely acknowledges the "externalities" associated with other forms of energy—hidden subsidies like the health effects of burning coal, or the impact on home heating costs when natural gas is used to produce electricity. Inclusion of those costs would make nuclear power look very good indeed.

Dr. Garwin notes that spent fuel is not likely to be the material of choice for a dirty bomb. This may or may not be the case, but he later expresses concern over the possible vulnerability of spent-fuel pools. Some would consider an attack on a spent-fuel pool as a form of a "dirty bomb."

Missing from his comments is a sense of urgency. The nation needs to deal more effectively with the surfeit of weapons-usable materials and the accumulating spent fuel, while using nuclear power to help meet growing world-wide energy demands. An aggressive program to complete the demonstration of pyrometallurgical recycle technologies, including safeguards, offers the potential to move forward on all these issues. Doing nothing is not acceptable.

*William H. Hannum has been a senior official with the Department of Energy; Gerald E. Marsh, retired from Argonne National Laboratory, is a physicist who served with the U.S. START delegation and was a consultant to the Office of the Chief of Naval Operations on strategic nuclear policy and technology for many years; George S. Stanford is a nuclear reactor physicist, now retired from Argonne National Laboratory after a career of experimental work pertaining to power-reactor safety.*

1. Boardman, C. E., C. E. Walter, M.L. Thompson, and C. S. Ehrman, "The Separations Technology and Transmutation Systems (STATS) Report: Implications for Nuclear Power Growth and Energy Sufficiency." On the Internet at <http://www.nationalcenter.org/NPA396.html>.

## Richard Garwin again:

I noted that the authors erred in their statements that weapons made from reactor-grade Pu (or, for that matter, from pyro-processed Pu) would have yields that were highly unpredictable and that a fizzle would produce “no mushroom cloud at all.” In contrast, if such a weapon were detonated, it would produce a yield of at least one kiloton and in an urban environment immediately kill no fewer than 100,000 people. I judge that the authors now agree, since they took no issue with this point.

Similarly, I judge that the authors now apparently understand and agree that the highly enhanced neutron emission from normal pyro-processed Pu would not further reduce the yield of an implosion weapon below that from R-G Pu. It is false comfort to assume that weapon-design experience is helpful in this regard.

The authors have not replied to my question as to what it would take to reconfigure the pyroprocess line “to separate purer Pu, thus reducing the (heat)challenge to building a nuclear weapon from the Pu in process or in storage.” Why not?

To classify an attack on a spent-fuel pool or nuclear reactor “as a form of a dirty bomb,” confuses the situation and diverts attention from something that sorely needs to be addressed-- the reduction of hazard from (portable) radiological dispersal devices that might be explosive in nature but that might equally well simply be nebulizers or other means of dispersing radioactive materials.

I am not negative on the cost of pyro processing in the fuel cycle of a fast reactor itself that can itself be shown to be both safe and economical. I do believe that reprocessing of the spent fuel that already exists from lightwater reactors would add significantly to the cost of disposal. The authors counter with an approving reference to a February 2002 paper by C.E. Boardman, *et al*, which criticizes the STATS report estimate of reprocessing cost; Boardman, *et al*, argue that the lessons learned from development of three plants (the Japanese plant at Rokkasho-Mura being the latest) “would result in significantly lower unit reprocessing costs.” But STATS in 1996 assumed for Rokkasho a range from \$5.2 to \$6.2 billion, and the 2004 official Japanese estimate is now 2.2 trillion yen or \$20.5 billion. It is difficult to project a cost lower than the estimate based on \$6 billion capital cost if the plant will now cost more than \$20 billion for the same throughput.

I urge the reader to read the STATS report on the web (and to search it with the search engine provided there by the National Academies Press) and to access also the February 2002 Boardman reference. The urgency is to get the facts straight and to do the analyses that can be done with existing data, and then to do the needed experimental work on pyroprocessing and reactor design (not construction) until we find an approach that can lead to competitive energy supply, with consistent attention to all required costs and benefits.

## Oil, CO<sub>2</sub>, and the Potential of Nuclear Energy

*Robert W. Albrecht and David Bodansky*

### 1. The relevance of nuclear power

Hannan, Marsh, and Stanford (HMS) argued in the July 2004 issue of this newsletter for using nuclear energy in a fuel cycle based upon fast reactors and pyroprocessing.<sup>1</sup> We elaborate here on the potential of nuclear energy to address our key energy problems in a sustainable fashion.<sup>2</sup>

The first of these problems is dependence on oil. Despite talk of conservation and “energy independence,” U.S. oil consumption has risen from 17.3 mbd (millions of barrels per day) in 1973 to 20.0 mbd for 2003 and net petroleum imports rose from 35% of consumption to 56%, for a cost in 2003 of \$122 billion.<sup>3</sup> Without dramatic change, the situation will continue to worsen. World dependence on oil from limited areas—primarily the Persian Gulf region—is particularly dangerous because it spawns conflict and transfers wealth to politically problematic oil producers.

A major challenge is to develop alternatives to oil, which is uniquely easy to store, transport and use in transportation. A second major challenge is to restrain emissions into the atmosphere of CO<sub>2</sub> and pollutants. Here, the easiest target is coal-fired electricity generation, which is the source of about one-third of U.S. CO<sub>2</sub> emissions. A harder target is oil in transportation—the source of another third of CO<sub>2</sub> emissions. While many other approaches can and undoubtedly will contribute to addressing these global challenges, the focus of this article is on the contribution that nuclear fission power could make in the United States.<sup>4</sup>

The most straightforward contribution is in electricity generation. Nuclear power, with 104 reactors and a capacity of 99 gigawatts-electric (GWe), now provides about 20% of U.S. electricity. Coal-fired generation provides about 50%. It could be replaced by the addition of 250 GWe of nuclear capacity.

Replacing oil addresses both the oil consumption and CO<sub>2</sub> problems. The share of petroleum used in the various sectors in 2003 was: electricity—3%, residential & commercial—6%, industrial—25%, and transportation—66%. By ill chance, the replacement difficulty rises as the sector share rises.<sup>5</sup> Possible ways for nuclear power to substitute for oil in transportation include: powering electrified mass transit, freeing natural gas for use in vehicles, powering electric or hybrid vehicles, and providing energy to produce hydrogen or hydrocarbons (e.g., methanol) for use as a vehicular fuel.

None of these possibilities is likely to make an immediate major contribution, and most require significant modifications to vehicles and their supporting infrastructure. For the next decade or two the most effective approach to reducing oil consumption is to switch to fuel-efficient “conventional” vehicles including hybrid vehicles. Over longer times, the cumulative impact of the above-cited substitutions could be great. Consider the eventual replacement of 10 mbd of oil. This might be accomplished with an additional generation capacity in the neighborhood of 230 GWe.

Together, coal and oil replacements yield a ballpark figure of 500 GWe for the scale of a major “meaningful” expansion of U.S. non-fossil-fuel generating capacity (ignoring the growth in electricity demand that is likely to occur aside from these initiatives). The practicality of nuclear power providing the major share of such an expansion, over perhaps 50 years, will be considered in Section 4.

## 2. Weapons proliferation and terrorism

Arguments against nuclear power have traditionally emphasized four issues: safety, waste disposal, economics, and weapons proliferation. A quarter century of accident free operation of nuclear plants outside the USSR has mitigated safety concerns, and “precursor” analyses of reactor operations have confirmed dramatic safety improvements. Technically sound solutions exist for the disposal of today’s wastes, and planned sustainable fuel cycles could hold down future waste volumes. The economics of nuclear power are improving, given projected reactor construction economies, increasing oil and natural gas costs, and a growing awareness of the external costs of fossil fuel use. These three issues are no longer Achilles’ heels. We concentrate here on the most serious of the concerns: proliferation, including terrorism.

Historically, civilian nuclear power has played almost no role in the development of nuclear weapons. Nonetheless, it can contribute to a weapons program by creating a cadre with relevant training and providing a cover for obtaining equipment, including uranium enrichment or fuel reprocessing facilities. The most sensitive material for weapons proliferation is highly enriched uranium (HEU). Civilian nuclear power plants do not use HEU, but HEU might be obtained by proliferators from cascades of centrifuges or by diversion from stockpiles in weapon states. Especially with the threat of bomb development by terrorists or sub-national groups, safeguarding HEU is the highest priority anti-proliferation task (other than the protection of bombs from nuclear stockpiles).

A great deal of attention has been given to the possibility that plutonium from civilian reactors might be stolen or diverted for bomb production. In the U.S. once-through fuel cycle, the intense radioactivity of the fission products in the spent fuel and the containment of the fuel pellets in discrete fuel rods make diversion and subsequent plutonium extraction impossible without elaborate equipment beyond the plausible range of a terrorist group. With reprocessing, the separated plutonium loses this protection. However, this “reactor grade” plutonium contains significant quantities of  $^{240}\text{Pu}$  and  $^{242}\text{Pu}$  and, as discussed in HSM, is a very difficult material to use for bomb manufacture with any reprocessing method. With pyroprocessing, bomb manufacture is even more difficult. Further, in the fuel cycle contemplated for use with the fast reactors discussed below, the pyroprocessing plants and the reactors are parts of integrated facilities, or nuclear parks, with reactors and fuel processing co-located. With little or no material crossing the boundaries, nuclear parks greatly reduce accessibility to sensitive material. Nonetheless, a diversion might be accomplished by a rogue element in the nuclear establishment or by a government that suddenly decides to obtain weapons. Such possibilities, and the fear that we would be setting a bad example, contributed to the abandonment of the U.S. reprocessing and breeder reactor programs.

With or without reprocessing, HEU remains the dominant proliferation route. It is likely to be easier to obtain uranium and enrichment equipment than to obtain useful plutonium. Further, a uranium bomb is by far the easier to build. Thus, uranium is most likely the material of choice for a nuclear terrorist and it is becoming a favored choice in the national programs of “aspiring” countries. For terrorist groups, the greatest danger is that they will obtain a finished bomb by theft in a country with poor security or by gift (or purchase) from a terror-friendly country. Next best for them would be to obtain HEU and use it to construct a weapon. More difficult would be to use enrichment equipment to produce their own HEU.

With many paths to nuclear proliferation, no restraints on nuclear power in “peaceful” countries can prevent weapons development elsewhere. A more promising approach, admittedly with no assurance of success, is a rigorous international framework of material controls and inspections, presumably spearheaded by an invigorated IAEA. Substantial nuclear power programs of their own might better enable the “peaceful” countries to assist the IAEA in establishing strong and comprehensive anti-proliferation programs as well as give them greater ability to supplement the IAEA’s efforts with their own economic carrots and sticks.

## 3. Future reactors

Today’s 104 U.S. light water reactors (LWRs) were all ordered by 1973. Reactor performance has improved dramatically in recent years, with the average capacity factor increasing from 62% in 1989 to 88% in 2003. The NRC has approved 20-year license extensions (from 40 years to 60 years) for 26 units and many more extensions are expected. The reactors all use a once-through fuel cycle, where spent fuel is not reprocessed and the “waste” consists of intact fuel assemblies.

The U.S. DOE undertook new nuclear initiatives in the late 1990s with two main components: (a) a near-term program with the goal of deploying a new reactor by 2010, and (b) a longer term program, the Generation IV (GEN-IV) program for nuclear units that were originally targeted to come on-line in about 2025.

The ABWR (advanced boiling water reactor) is the only advanced reactor now on the U.S. market that has received a standard design certification from the U.S. Nuclear Regulatory Commission. Several are operating in Japan and others are being built in Japan and Taiwan. It is an example of an “evolutionary” BWR. An evolutionary PWR has been ordered by Finland. These reactors are similar in concept to existing LWRs. They are large, about 1300-MWe to 1600-MWe, benefiting from economies of scale.

Another option is offered by so-called “innovative” reactors, which depart from the evolutionary reactors by incorporating greater design changes and more explicit reliance on passive features to provide for safety against reactor accidents. Often, but not always, they are smaller. Altogether, in addition to the ABWR, the NRC is considering seven power plant designs that have been proposed by manufacturers in this country and abroad.

In the GEN-IV plan, the main thrust for the decade 2004-2013 is the Next Generation Nuclear Plant (NGNP), presently planned to be the Very High Temperature Reactor (VHTR), with a target deployment date of 2016. This is a small gas-cooled reactor proto-

type designed to reach the high temperatures required for efficient hydrogen production. It operates with a once-through fuel cycle and thus does not itself meet the sustainability goals of the GEN-IV program. The GEN-IV plan includes two other thermal spectrum reactors and three fast-spectrum reactors.

Each of the three fast-reactor systems is capable, in principle, of meeting the sustainability and anti-proliferation goals that are key stated features of the GEN-IV program. Sustainability looks to the very long-term and requires effective utilization of fissile fuel resources and the reduction of “the long-term stewardship burden” of nuclear waste handling. The anti-proliferation goal seeks to make the nuclear materials used or produced in nuclear power operations “unattractive” and inaccessible for use in weapons.

The fast reactor systems are defined by their primary coolants: helium in the gas-cooled fast reactor (GFR), sodium in the sodium-cooled fast reactor (SFR), and lead or lead bismuth eutectic in the lead-cooled fast reactor (LFR). The projected sizes range from 10 MWe to 1700 MWe. For example, the LFR, in factory-made units for small markets, may generate as little as 10 MWe although a full sized plant with an output greater than 1000 MWe is feasible. The SFR may generate as much as 1700 MWe. The GFR and the LFR have the capability of reaching maximum coolant temperatures of 800 to 850°C and could be used for thermochemical hydrogen production. One of the major development challenges is to design and test fuel that is tailored to each reactor type, especially as the fast neutron energy spectra are different in the different reactors.

All three reactor types are breeder designs. This means that after a few fueling generations the only new fuel introduced to the system is depleted or natural uranium.

#### 4. Achievability and sustainability

There is no clear indication that a new U.S. nuclear power plant will be ordered in the near future, and the DOE’s near-term deployment target of 2010 almost surely will be missed. One possible incentive for a utility order would be the extension to nuclear energy of the 1.8 cents/kWh production tax credit that is now given to forms of renewable energy.

For a sustainable long-term program an eventual switch to GEN-IV fast reactors will be needed. The FY04 budget for the GEN-IV program was only \$27.7 million. The lion’s share was for the NGNP (i.e., the VHTR), with only \$1.4 million for the three fast reactors together. Even assuming contributions from other countries, this is an astonishingly trivial effort to devote toward research whose purpose is to address critical national needs. (It is less than the annual gross revenue intake of a single well-performing McDonald’s franchise.) Given a more substantial budget the DOE schedule can be accelerated. If it is not, then there will be no substantial contribution from fast reactors before mid-century (considering the time delay between prototype completion and large-scale construction). An accelerated development schedule would help to reduce waste problems, conserve uranium, and increase our flexibility to make corrections as the need is seen.

We already hypothesized a 500-GWe target for additional U.S. generating capacity. If a nuclear expansion of this magnitude proceeded from 2015 to 2055, on average the equivalent of about

15 1000 MWe reactors would have to be added annually (allowing 100 GWe for replacement of existing reactors). The history of U.S. reactor orders in the 1966-1974 period---in the heyday of nuclear optimism---and even more the example of the buildup in France, suggests that this rate is achievable.

There are probably at least 20 million tonnes of uranium available at a cost of under \$260 per kg of uranium. This would be adequate for about 100,000 GWyr of reactor operation at present rates of uranium utilization. Worldwide, this would suffice for 60 years of operation of 1700 1000-MWe reactors at present rates, and close to 3000 reactors with reprocessing of spent fuel. The supply of fissile material could be augmented by going to more expensive terrestrial ores, by using thorium in a 232Th-233U fuel cycle, and perhaps by drawing upon the 4 billion tonnes of uranium in the oceans. Thus, there is no immediate resource problem. For the further future, the fissile resources would become quasi-infinite in a breeder reactor fuel cycle, because one then obtains about 100 times the energy per tonne of uranium and more dilute and much more plentiful ores become affordable.

The Yucca Mountain repository is designed to receive 63,000 tonnes of commercial spent fuel, equivalent to the output from 2100 GWyr of operation. For a U.S. total of 600 reactors, a new “Yucca Mountain” could be needed every four years. This is extremely unlikely to happen. Alternatives, such as deep borehole disposal could help substantially, but, as stressed by HSM, a fast reactor fuel cycle with pyroprocessing provides a more fundamental long-term solution. In pyroprocessing, the spent fuel is reduced to a melt and an electrochemical separation is made between the fission products and the heavy metals. Fission products are waste, but their mass is small. The heavy metals, which contain most of the long-lived activities, are returned to a fast reactor, to be consumed in fission.

The large-scale utilization of nuclear fission power (or “clean” alternatives) could help achieve important goals, including the reduction of oil imports, the conservation of oil and natural gas for “higher” applications, the reduction of emissions of CO<sub>2</sub> and other pollutants, the production of hydrogen, and the desalination of ocean water. It would probably take in the neighborhood of 50 years to develop the new electrical generating capacity and to implement the needed changes in the transportation systems and building characteristics. However, acceptance of gradual progress fits in with the building of near-term reactors now, while laying the foundation for building Generation IV reactors later as they are developed and qualified for commercial deployment.

The long-term potential of electrification should not blind us to the more immediate potential of less ambitious approaches, such as the improvement of the efficiency of gasoline-powered cars. Further, other energy sources, including solar, wind, “clean” coal, and fusion power might in principle provide the electricity. However, there is little present danger that these other options will be forgotten. The greater danger is that the opportunities offered by nuclear energy will be inadequately exploited.

*Robert W. Albrecht  
Department of Electrical Engineering  
bob@ee.washington.edu*

Robert W. Albrecht is Professor Emeritus of both Electrical Engineering and Nuclear Engineering at the University of Washington. He has been at the University of Washington since 1961. He is a fellow of the American Nuclear Society. He has published many papers on nuclear reactor dynamics and served as a consultant to laboratories in the US, Germany, France, Brazil, and Japan.

David Bodansky is Professor Emeritus of Physics at the University of Washington. He has been with the Physics Department since 1954, serving as Chairman from 1976 to 1984. He was a member of the APS Panel on Public Affairs during 1985-87 and 1992-96, and was POPA Chair in 1995. He is the author of *Nuclear Energy: Principles, Practices, and Prospects* (2nd edition: Springer-Verlag/AIP Press, 2004).

#### Endnotes:

<sup>1</sup> William H. Hannum, Gerald E. Marsh, George S. Stanford, "PUREX and PYRO Are Not The Same,"

Physics and Society, 32, no. 3, July 2004: 8-11.

<sup>2</sup> In our discussion here we focus on the U.S. situation. Of course, the problems are global but the problems and approaches discussed here are applicable, at least in part, to many other countries---especially the OECD countries.

<sup>3</sup> U.S. Department of Energy, Annual Energy Review 2003, Energy Information Administration Report

DOE/EIA-0384(2003), September 2004. [AER03]

<sup>4</sup> Coal-fired electricity generation in 2003 was 224 gigawatt-years (GWyr). At a 90% capacity factor this electrical output could be provided with a capacity of 249 GWe. [AER03, op. cit., Table 8.2a.] We here ignore the increased electricity use with time, although we recognize that the effects of economic and population growth and technological changes are likely to outstrip the reductions achieved from higher efficiency.

<sup>5</sup> In some cases, the replacement of oil could be facilitated by a switch in which nuclear power replaces some of the natural gas used in electricity generation, and the freed natural gas substitutes for oil in other sectors.

<sup>6</sup> The natural gas could be used directly as compressed natural gas (or liquefied natural gas) or it could be used to produce methanol which can substitute for gasoline.

<sup>7</sup> Hydrogen, now used extensively in the chemical industry, is most economically produced by the steam reforming of natural gas, resulting in both natural gas consumption and CO<sub>2</sub> production. It can also be produced by electrolysis of water, using nuclear power or any other electricity source. A more efficient production approach with nuclear energy is to use a thermochemical cycle at very high temperatures (above 800 °C). A study prepared for the Panel on Public Affairs of the American Physical Society suggested that a hydrogen fuel cell automobile could have an energy efficiency equivalent to a gasoline mileage of 82 mpg, compared to an average of 22 mpg in conventional automobiles [Craig Davis, Bill Edelstein, Bill Evenson, Aviva Brecher, and Dan Cox, "Hydrogen Fuel Cell Vehicles" (June 2003); at [http://www.aps.org/public\\_affairs/popa/reports/fuelcell.pdf](http://www.aps.org/public_affairs/popa/reports/fuelcell.pdf)]. At the gasoline heat content of 5.21 million BTU (5.50 x 10<sup>9</sup> J) per barrel [AER03, op. cit., Table A3], 1 mbd corresponds to an annual energy of 2.0 EJ, and motor gasoline consumption at the 2003 rate of 8.9 mbd therefore corresponds to an annual energy of about 18 EJ. Hydrogen, in the above model,

would be used at an energy rate that is only about 27% (i.e. 22/82) as great. If the hydrogen is produced by electrolysis with a 75% efficiency for conversion from electrical energy, the total electrical energy requirement would be about 18 x 0.27 \* 1.33 = 6.5 EJ, or slightly over 200 GWyr. (For electricity generated with a 33% thermal efficiency, the primary energy input is about 19.5 EJ---quite close to the 18 EJ of gasoline that is being replaced.)

<sup>8</sup> In an intriguing if still highly speculative scheme, methanol (CH<sub>3</sub>OH) would be produced using CO<sub>2</sub> extracted from the air as the carbon feedstock. Thus, there would be no net CO<sub>2</sub> production and the only important inputs and outputs would be uranium and methanol. The latter is an attractive automotive fuel, unlike hydrogen.

<sup>9</sup> This is a somewhat arbitrary target, lying between the 2003 rate for consumption of motor gasoline (8.8 mbd) and the 2003 net petroleum imports (i.e., petroleum products and crude oil) (11.2 mbd).

<sup>10</sup> As in Note 7, 1 mbd of motor gasoline corresponds to an annual energy of 2.0 EJ. Without knowing the specific "substitution" method, one cannot calculate the electrical energy required. As a rough guide, we assume that the primary energy required for electricity generation is about the same as the energy of the oil replaced---in this case 20 EJ for 10 mbd. (It was seen in Note 2 that this energy equivalence holds reasonably well for hydrogen production by electrolysis, with the hydrogen used in energy-efficient cars.) At a 33% thermal efficiency, 20 EJ of primary energy corresponds to an annual generation of about 210 GWyr and to an additional nuclear capacity of roughly 230 GWe at a 90% capacity factor.

<sup>11</sup> A "precursor" in this usage is a reactor mishap which, if followed by other possible mishaps, could lead to reactor core damage. Nuclear Regulatory Commission analyses find that the average value of the calculated annual "accident sequence precursor" index has improved (was reduced) by more than a factor of 100 since the Three Mile Island accident in 1979, as seen by comparing averages for the pre-TMI (1969-1978) and post-TMI periods (1993-2000).

<sup>12</sup> The original weapons states (China, France, the USSR, the United Kingdom, and the United States) all had nuclear weapons before they had civilian nuclear power. For the countries that developed weapons more recently, India may have drawn to some extent on civilian power facilities, Israel has no nuclear power, and Pakistan relied on uranium enrichment in facilities that had nothing to do with the civilian program. Among weapons aspirants, Iraq and Libya have had no civilian power and North Korea obtained its plutonium from special purpose "research" reactors. Iran may prove to be an exception by coordinating a civilian power program with possible weapons aspirations.

<sup>13</sup> The importance of terrorist dangers from uranium is reflected in a paper put out under the auspices of the Weapons of Mass Destruction Commission, an international commission initiated by the Swedish Government and chaired by Hans Blix [Charles D. Ferguson and William C. Potter, *Improvised Nuclear Devices and Nuclear Terrorism*; at <http://www.wmdcommission.org>].

<sup>14</sup> The difficulty with reactor grade plutonium arises from the spontaneous neutrons emitted from <sup>240</sup>Pu and other

Pu isotopes. It is generally accepted that a highly expert group could make a bomb with reactor-grade plutonium, albeit one that "fizzles". The rationale for this conclusion is discussed at length by Carson Mark [Science and Global Security, vol. 4, no. 1 (1993): 111-124]. The reactor-grade plutonium is assumed to have 1.3 % <sup>238</sup>Pu, 24% <sup>240</sup>Pu, and 5% <sup>242</sup>Pu, along with 60% <sup>239</sup>Pu and 9% <sup>241</sup>Pu. In a companion paper, Frank von Hippel and Edwin

Lyman estimate the probable yield from such a bomb to be of the order of 1 kiloton [Science and Global Security, vol. 4, no. 1 (1993): 125-12]. The difficulty of building such a bomb and the skill level required appears to be somewhat controversial. Thus, HMS appear to believe that the difficulty is greater than suggested by Mark. In any case, the material from pyroprocessing contains other actinides beside uranium and plutonium (Np, Am, and Cm). If these “minor actinides” are not removed from the plutonium no bomb can be produced. Removing them would add to the difficulties, most likely putting the task still further beyond the capabilities of a terrorist group.

<sup>15</sup>In the earliest days of nuclear power, it was recognized that to use uranium and thorium resources fully it is necessary to breed the fertile material (<sup>238</sup>U and <sup>232</sup>Th) into fissile material (<sup>239</sup>Pu and <sup>233</sup>U). Uranium and thorium were believed to be relatively rare. So, the very first nuclear reactor to generate electricity was a fast experimental breeder reactor (EBR-I), early experiments were conducted using heavy metals for the coolant (mercury), and one of the earliest reactors built by a utility (Fermi reactor built by Detroit Edison) was a fast breeder reactor. The first two naval reactors were the Nautilus (a PWR) and the Seawolf (a sodium-cooled reactor). LWRs became the norm after the Nautilus proved to be superior to the Seawolf. Nuclear optimism unleashed a swarm of explorers who found unexpectedly large deposits of uranium and thorium. Thus, the urgency to breed was tempered. The U.S. nevertheless went ahead with EBR-II. The commercialization of the breeder reactor was slated to begin with the Clinch River Breeder Reactor (CRBR). To support CRBR development, the Fast Flux Test Facility was constructed and operated. All of these breeder reactors were sodium cooled. A fuel blockage accident in the Fermi reactor dampened enthusiasm for fast breeder reactors. Then, the fear of proliferation together with an apparent abundance of uranium caused the US to adopt the once-through fuel cycle in the 1970s, and the once-through fuel cycle became the favored approach of many energy policy makers. Although U.S. officials hoped that other countries would follow its lead, this has not occurred. The commitment to the once-through fuel cycle and the abandonment of breeding and reprocessing eventually caused the cancellation of the CRBR and, later, the termination of the Integrated Fast Reactor and Fast Flux Test Facility development programs. However, the once-through fuel cycle uses uranium resources inefficiently and creates a need for large waste repositories like Yucca Mountain, limiting our ability to sustain a large long-term nuclear program.

<sup>16</sup>Of the eight countries known to have nuclear weapons, Pakistan used only uranium, China started with uranium, and the United States used uranium and plutonium almost simultaneously. The remaining countries (France, the UK, the USSR, India and Israel) all used plutonium initially. The three countries that abandoned their weapon programs, before or after building bombs (South Africa, Argentina, and Brazil), all depended on uranium as did the fledgling Libyan program. North Korea started its proliferation efforts with plutonium but may be attempting to enrich uranium. Iran is suspected of following both routes. Iraq appeared to have a plutonium program initially, but this was terminated by an Israeli bombing raid in 1981 and a subsequent uranium program was terminated in 1991 in the aftermath of the Gulf War.

<sup>17</sup> Between 1953 and 1978, US utilities ordered 259 nuclear power reactors. Between 1972 and 1995, 127 orders were cancelled or construction was halted. Between 1964 and 1998, 28 reactors were shut down. No new orders have been placed in the US since

1978, and the orders placed in the 1974-1978 period have all been cancelled.

<sup>18</sup>The GEN-IV program has since been broadened into the Generation IV International Forum to include R&D contributions from many other countries. It focuses on six reactor types, including three fast reactors. For descriptions of this program see: A Technology Roadmap for Generation IV Nuclear Energy Systems, Report GIF-002-00 (December 2002) [at <http://gif.inel.gov/roadmap>] and Generation IV Nuclear Energy Systems, Ten Year Program Plan, Fiscal Year 2004 (DOE, February 27, 2004) [at [http://neri.inel.gov/program\\_plans/pdfs/gen\\_iv\\_program\\_plan.pdf](http://neri.inel.gov/program_plans/pdfs/gen_iv_program_plan.pdf)].

<sup>19</sup>The NRC has also certified the System 80+ and AP600 reactors, but the System 80+ is no longer being marketed in the United States and the AP600 is being supplanted by the AP1000 in the marketing by its manufacturer, Westinghouse.

<sup>20</sup>Finland has ordered a 1600-MWe version of the European Pressurized Water Reactor (EPR). The EPR has been developed in a long-standing French-German collaboration. More recently, the French utility, Electricité de France has announced plans to order an EPR that is to be built at Flaminville (Normandy) at the location of existing nuclear plants.

<sup>21</sup>The candidates for near-term deployment in the United States include:

1. The ABWR, as discussed in text.
2. The Westinghouse “advanced passive” AP1000. It is the design successor to the AP600 which received NRC standard design certification in 1999 but is being supplanted in Westinghouse’s marketing efforts because economies of size make the AP1000 (about 1000 MWe) a more economical reactor than the AP600 (about 600 MWe). These reactors are PWRs that rely heavily on passive safety features—especially for emergency cooling in case of an accident—and are built with far fewer requirements for materials (pumps, valves, piping, electrical cabling) than previous PWRs. The AP1000’s application for design certification is now progressing through the NRC review process.
3. Six reactors that are now involved in “pre-application” discussions with the NRC, prior to formal application for design certification. These are the so-called ESBWR, ACR-700, GT-MHR, SWR 1000, IRIS, and PBMR.
4. The EPR developed in Europe. Although it is not now under NRC review and it may be difficult at the moment to get U.S. acceptance of a French-German design, it may soon have the advantage of having been built and demonstrated in Finland and probably in France.

<sup>22</sup>These are the Supercritical Water-Cooled Reactor (SCWR) and the Molten Salt Reactor.

<sup>23</sup>The stated “primary mission” of the SFR is “the management of high level-wastes, and in particular, management of plutonium and other actinides” [DOE, Feb. 2004, op. cit., p. 43]. The reason for this primary mission is that the SFR will not be able to reach the high coolant temperatures required for thermochemical hydrogen production. It has a fast enough spectrum to be capable of burning actinides, although its spectrum is softer than the spectra of the GFR and LFR and therefore has the least favorable breeding ratio of the trio. Of course, the SFR can generate electricity.

<sup>24</sup>Because fuel properties over long exposures to neutrons change as the fuel burns, it is mandatory that very detailed irradiation studies of fuel elements be carried out before the deployment of any new reactor type that has a neutron energy spectrum that is substantially different from earlier experience. This testing must be



carried out with a neutron flux that has an energy spectrum (after degradation by scattering) characteristic of the reactor type being considered. The spatial profile of the fission rate in the fuel---and, equivalently, the power generation distribution---depends upon the neutron spectrum and the geometry of the core, including the fuel rod diameter. The spectrum is different for different coolants and the associated differences in fuel element design and core geometry. The tests are important to evaluating the ability of the fuel to stand up under high burnup (i.e., high energy output per unit mass) and to evaluating the negative feedbacks that should come into play in case of reactor transients.

<sup>25</sup>See, e.g., McDonald's Franchise Equity Bulletin (November 20, 2003). Typical sales are \$1.6 million per store. (High performers may double this average.)

<sup>26</sup>Nuclear capacity in France increased from 2.9 GWe in 1975 to 55.9 GWe in 1990, corresponding to an average annual capacity increase of 3.5 GWe per year. France in 1973 (before any of the reactors that are still operating had been completed) had a population less than 1/5 of the U.S. population in 2002, a GDP about 1/10 of the 2002 U.S. GDP (in constant dollars), and (as a rough surrogate measure of industrial potential) an electricity output less than 1/20 of the U.S. 2002 output [Energy Balances of OECD Countries, 2001-2002 (OECD, 2004)]. Thus an increase of 15 GWe per year is a comparatively modest goal for the United States, for reactor deployment that does not start until about 2015.

<sup>27</sup>There have been no pressures on uranium supplies to date, and therefore little incentive to develop comprehensive surveys of world uranium resources over the full range of potentially affordable prices. Therefore, any number such as 20,000,000 tonnes is very imprecise and useful only for approximate orientation. A price of \$260 per kg of uranium corresponds to an electricity cost of 0.6 cents/kWh for a standard LWR in a once-through fuel cycle.

<sup>28</sup>An MIT study describes a "balanced" reprocessing (non-breeding) fuel cycle that uses 166,460 tonnes of U per year to support a 1500-GWe fleet operating at a 90% capacity factor. This is equivalent to 10,000,000 tonnes for a 60-year lifetime for these reactors. [The Future of Nuclear Power, An Interdisciplinary MIT Study, John

Deutch and Ernest J. Moniz, co-chairs (MIT, 2003); at: <http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf>]

<sup>29</sup>With breeders, the energy derived per kg of uranium is increased by roughly a factor of 100. In addition, with this efficient use of uranium, both seawater and low-grade terrestrial sources become affordable, making it possible to generate essentially unlimited amounts of electricity for tens of thousands of years. For example, extraction of 10% of the uranium from the oceans would increase the uranium resource by a factor of 20, and the energy resource with breeders by a factor of 2000. At present uranium use rates, this would allow for  $2 \times 10^8$  GWyr, equivalent to an annual output of 10,000 GWyr (30 times the present world rate) for 20,000 years. A still larger increase would be available by going to ores with a lower concentration of uranium. An analysis by Deffeyes and MacGregor concludes that there is "a 300-fold increase in the estimated amount of recoverable uranium for every tenfold decrease in the ore grade" [Kenneth S. Deffeyes and Ian D. MacGregor "World Uranium Resources," *Scientific American* 242, no. 1, January 1980: 66-76.] Thus, with ore that is 10 times as dilute in uranium the energy resource is increased by a factor of 30,000.

<sup>30</sup>Deep borehole disposal is recommended in the MIT study (op. cit.) as providing a quicker and safer solution to waste handling than waste reduction through reprocessing (see pp. 60-61). However, it is not as open-ended in terms of a large long-term nuclear program.

<sup>31</sup>The fission product mass is about 1.1 tonne per GWyr. This is less than 4% of the mass of the spent fuel in present once-through LWR fuel cycles. The activity of the fission products reaches near-negligible levels by 600 years, although some relatively weak emitters remain (e.g., <sup>99</sup>Tc and <sup>131</sup>I).

<sup>32</sup>The desalination of seawater in a reverse osmosis plant costs about \$1 per cubic meter and requires about 6 kWh per cubic meter [Introduction to Nuclear Desalination, A Guidebook (IAEA, 2000)]. Supplying about 10% of current U.S. water by desalination (i.e. 10% of 2000 m<sup>3</sup> per person per year) would require about 40 GWyr of electric power per year. At present, the need for desalination is greater in other countries, where nuclear power may be less affordable or accessible.

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## COMMENTARY

### Two Brains: A Non-Brainer

*by Alvin M. Saperstein*

There has been much popular discussion, in recent years, of a two-brain basis for human intelligence: a left-brain and a right-brain, one responsible for analytical behavior, the other for holistic and language activity. I am in no position to comment on the usefulness or validity of this basis set. But, as a result of many years of teaching physics and astronomy at the introductory college levels, I am convinced of an alternative two-brain basis for student behavior: an "in-school brain," and an "out-of-school life brain," with very little, if any, connection between the two.

The scientific knowledge so expensively obtained and imparted "in-school" apparently plays very little role in the foundations of our individual and social lives. As a result, contemporary private and public policy shows very little evidence of application of the constraints of the thermodynamic laws or of the finiteness of resources and environment... in spite of the fact that, as measured

formally by certificates and degrees, we are the most educated population the world has ever seen.

Too often we physicists teach science as if the two components of this orthogonal basis set did not exist. We teach to one axis and ignore the strong transition to the other, which occurs soon after the student leaves our classrooms. Consequently, our society pays a heavy price: decaying cities; snail's space transportation systems, air, water and land which are challenges to our health rather than supports for our well-being, and increasingly- competition, and even battle, over shrinking resources and space.

As an example, consider a bright young drama student I had in my Introductory Astronomy class last year. Earnest and hard-working, she struggled with the material (especially its minor quantitative aspects) and eked out an A grade. At the end of the semester, after

the final exam, she came up to me, respectfully and seriously, with a question: What was she to do, since her upbringing and personal commitment led her to believe that our world was only 5000 years old, even though I had spent the semester explaining to the class why they should believe our solar system to be a 4-1/2 billion year old unit of a 13 billion year old universe? She was bright enough, serious enough, concerned enough, and trusting enough, to raise the question. What about the students in that class—or in many, many other such classes, who don't have such trust in their teachers or betray any such concern?

Similar, though more concrete, dichotomies in students' minds are well known. The physics pedagogy research group at the University of Washington has amply documented, through post-teaching interviews with students, that they reply to questions about aspects of the physical world with: "How would you like me to answer—as I've been taught, or as I really believe?"

At an earlier stage of our modern scientific world, men of science contemplated the rational cosmos while other men pursued and tortured witches. But these others had not been under the extensive tutelage of the scientist! There is no reason to believe that either of these two groups had other than a unitary brain. Now

we scientists have had ample access to the minds of our people, creating the presently dominant dual mind of the "common man." If there is another frenzy of witch hunting (or its equivalent) we have no one to blame but ourselves.

I have no simple paradigm to address this orthogonal, strongly coupled, two-state basis of our students' minds. I do know that we ignore the large decay rate from the higher (educated) state to the lower state at our peril. I believe that many of us act as if oblivious to the dichotomy or its importance. Certainly, none of my close colleagues has ever raised or discussed this issue with me.

We continue to withdraw tangible and intangible resources from our environment as if they were limitless. We continue to eject pollutants into that environment as if it were infinite. I have no desire to overthrow the young student's faith, but what good is our science education system if we cannot produce a "school brain" that influences life "after school"?

Alvin M. Saperstein  
Dept. of Physics and Astronomy and  
Center for Peace and Conflict Studies  
Wayne State University  
Detroit, MI 48207  
Ams@physics.wayne.edu

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## REVIEWS

### **The Cosmos in the Light of the Cross**

by George Murphy, Trinity Press International, 213 pp., \$45, ISBN 1-56338-407-5.

George L. Murphy is an Episcopal pastor, has a physics PhD, is a Templeton science and religion Fellow, and teaches theology and science at Trinity Lutheran Seminary in Columbus, Ohio. His goal in this book is to contribute to the dialogue between scientists and theologians by answering questions as to whether God is needed in cosmology or in evolution; and by discussing decision-making on ethical questions arising from new technologies. He outlines several approaches to theology. He discusses Barth's emphasis on the single revelation of the crucified Christ; but he favors the "dependent view" that tries to combine revelation as given in the Bible with results from science.

Murphy argues that the "naïve realism" of classical physics is modified by Heisenberg's uncertainty principle. He discusses various attitudes toward God's action in the world. Murphy favors combining the neo-Thomist and a "kenotic" approach. The former sees God as the primary cause, acting through natural law. The kenotic approach sees God as parent, and we people as His children. Just like a parent, God voluntarily limits His control. Also God is vulnerable, as illustrated by Christ's suffering on the cross. The eternal problem of why God allows evil and suffering in the world is (partially) answered by Murphy's belief that God experienced suffering on the cross. Paul (*Phillipians 2:3-5*) stated kenosis in these words: "Do nothing from selfish ambition or conceit, but in humility regard others as better than yourselves. Let each of you look not to your own interests, but to the interests of others. Let the same mind be in you that was in Christ Jesus."

In Chapters 9 and 10 Murphy begins applying the kenotic approach to discussion of many ethical problems arising from new technologies: possible further use of nuclear weapons, disposal of nuclear waste, organ transplants, genetic engineering, therapeutic cloning, abortion and end-of life issues. I found these chapters disappointing. Murphy adds little to what most readers already know on these thorny issues. On nuclear weapons, Murphy quotes Yoder on criteria for a "just war", and the 1983 statement by the Roman Catholic bishops of the U.S. that there can be virtually no morally acceptable use of nuclear weapons. But does the 1983 declaration apply retroactively to the 1945 decision by President Truman? Should use of nuclear weapons be prosecuted as a war crime? Murphy doesn't tell us. How about organ transplants from patients who are "brain dead"? Murphy states (p. 158), "It is possible to use the criterion of brain death and to require consistent application of well-defined clinical tests for it." It's possible, but does Murphy think it's desirable to use this criterion? On abortion he says (p. 154), "That does not mean that opposition to abortion must be absolute...But that is something quite different from making freedom of choice an absolute." Does Murphy support the Supreme Court decision, *Roe vs. Wade*? On end-of-life issues Murphy states (pp. 158-9), "In the present context this suggests that life is not to be terminated or allowed to end simply to end suffering. But maintaining bodily functions by every conceivable means when the possibility of recovery is gone is not an expression of biblical hope."

Murphy chooses a "moderate position" that attempts to bring out the full implications of "chiasmic cosmology," which Murphy defines as "a view of the universe which sees the Creator present first of all as the crucified One. In his penultimate chapter,

Murphy discusses various anthropic principles, and their relation to theology.

Murphy uses a specialized theological terminology: chiasmic, kenotic and soteriological (“related to salvation”), for example. Since physicists also use strange terminology, we shouldn’t complain on this score.

I do disagree with Murphy’s concentration on the cross as the essence of Christianity. He quotes Luther, “the cross alone is our theology” and “He is not righteous who does much, but he who, without work, believes much in Christ.” Murphy states (p.26), “The cross plays an important role in every serious reflection on the Christian faith.” This reviewer is a Quaker; we Quakers pay great attention to Jesus, but rather little to the cross. We disagree with Luther, by favoring works over faith.

We scientists can tell when we are wrong, and be pretty sure when we’re right; but these decisions are difficult in theology. Murphy states (p. 21), “Although Blaise Pascal did not contribute as much to mathematics or physics as Newton, he was a considerably better theologian.” I know how to verify the first part of that sentence; but I am at a loss as to how to verify the second part.

*Joe Levinger  
Rensselaer Polytechnic Institute  
levinj@rpi.edu*

## **Creationism’s Trojan Horse: The Wedge of Intelligent Design**

*by Barbara Forrest & Paul R. Gross, Oxford University Press, 2004, viii + 401 pp., hardcover, \$40, ISBN 0-19-515742-7.*

Creationism evolves. The selection process driving this evolution is a series of court decisions over the years, unmasking ever more sophisticated attempts to disguise a religious doctrine as science so as to gain entrée to public-school science classrooms.

The latest and slickest species to appear in this process is intelligent design creationism (IDC). IDC was first set forth in modern dress about 1992 by criminal law professor Phillip Johnson and elaborated mainly by a group of a half-dozen or so, some of whom actually have advanced degrees in areas related to evolutionary biology. However, the essential arguments are no different from those published in William Paley’s 1802 book, *Natural Theology* and long since abandoned by the scientific community. IDC has been the subject of detailed and devastating refutations in numerous books and articles. Forrest and Gross do summarize the numerous fallacies, distortions, ploys, and falsehoods published by the ID creationists, but that is not the main thrust of their book. Rather, they do a signal service to the scientific community and the public at large by setting forth in great detail the broader aims and activities of IDC, which Johnson dubbed the “Wedge strategy.” The aim of the Wedge is nothing less than to revolutionize all of the sciences by introducing the supernatural – the directly acting, directly observable hand of God – as a legitimate and frequently encountered component of scientific discovery. But this is not the end of their ambitions; more on that later.

What is the Wedge? Phase I is “Research, Writing, and Publication. ... Without solid scholarship, research and argument, the project would be just another attempt to indoctrinate instead of persuade”

[emphasis added].

Reasonable enough. However, as Forrest and Gross show in exquisite detail, the voluminous output of the ID creationists contains not a single contribution to science. That has not dissuaded them from extensive “attempts to indoctrinate instead of persuade” in Phases II and III:

Phase II: Publicity and opinion-making. ... The primary purpose of Phase II is to prepare the popular reception of our ideas. For this reason we seek to cultivate and convince influential individuals in print and broadcast media, as well as think-tank leaders, scientists and academics, congressional staff, talk show hosts, college and seminary presidents and faculty and potential academic allies. ... We also seek to build up a popular base of support among our natural constituency, namely, Christians. [It is common practice among evangelicals and fundamentalists to use the term Christian in a narrow sense, excluding the broad spectrum of Christians who do not subscribe to their belief system.]

“Phase III: ... We will move toward direct confrontation with the advocates of materialist science through challenge conferences in significant academic settings. We will also pursue possible legal assistance in response to resistance to the integration of design theory into public school science curricula.... With an added emphasis to the social sciences and humanities, we will begin to address the specific social consequences of materialism [i.e., most of the social evils they perceive as besetting the modern world] and the Darwinist theory [ID creationists routinely call modern biology “Darwinism”—as though one were to call modern physics “Newtonism”] that supports it in the sciences.

In 20 years (starting from the mid-1990s) the ID creationists hope to achieve three broad goals: to see intelligent design theory as the dominant perspective in science; to see design theory application in specific fields, including molecular biology, biochemistry, paleontology, physics and cosmology within the natural sciences, and also psychology, ethics, politics, theology and philosophy in the humanities; and to see its influence in the fine arts; and to see design theory permeate our religious, cultural, moral and political life.

To these ends, the IDC movement has set up a cluster of organizations the chief of which is the Seattle-based Discovery Institute, and specifically its subsidiary the Center for the Renewal of Science and Culture (CSRC), now renamed the Center for Science and Culture (CSC). Funding currently totaling between \$1 million and \$2 million a year is provided largely by organizations with strong ties to the Christian Reconstruction movement, whose ultimate purpose is to supplant the U.S. Constitution with the legal code of the Old Testament.

Forrest and Gross recount in great detail, with 65 pages of meticulous endnotes in small print, the strategies and tactics of the movement. ID creationists produce a flood of publications, including books (nearly all published by evangelical religious or politically very conservative presses), articles in conservative political and religious magazines, and web pages.

In equally fine detail, Forrest and Gross describe and document IDC’s well-organized, persistent campaign to insinuate IDC into public-school curricula. Over the past few years, efforts have been

made at the state level in Arizona, Georgia, Kansas, Minnesota, New Mexico, Ohio, Pennsylvania, West Virginia, and probably other states as well. In this effort, the ID creationists have taken the lead from the older and better known young-earth creationists (YECs) typified by the Institute for Creation Research. There are serious differences between these two camps. The YECs are critical that many ID creationists prefer to say as little as possible about the age of the universe. And unlike the up-front YECs, the ID creationists claim a completely non-religious position when addressing secular audiences, arguing that the Intelligent Designer may as well be a space alien as the biblical God – a position they definitely do not take when addressing evangelical groups. Nevertheless, the IDCs and YECs try to present a united front against the common enemy, science as it is actually practiced.

A parallel aim of the IDC movement has been to establish academic credibility, and Forrest and Gross describe how they have pursued a variety of approaches to this end. In perhaps the most dramatic of these, the president of Baylor University was persuaded, in 1999, to set up the inappropriately named Michael Polanyi Center under the directorship of ID champion William Dembski. This “first intelligent design think-tank at a research university” (so called by Dembski, p. 207) elicited the fury of the Baylor faculty, which had not been consulted on an essentially academic matter. The upshot of the furor that followed was the termination of Dembski’s directorship, the removal of the name, and the absorption of the center into the existing Institute for Faith and Learning, where it was subject to faculty supervision. Dembski’s five-year (1999-2004) contract as an associate research professor was honored, but as of May 2004 the Baylor website shows no trace of him or the center.

These and other efforts have met so far with mixed success at best, but Forrest and Gross give good reason for concern that IDC will do much more damage to science and education in the future. They will not (and cannot) make any impact on scientific knowledge or the working scientists who actually contribute to it. But ID creationists have many allies among Americans in general and in the corridors of power and sources of funding in particular. And though the IDC threat is aimed primarily at biology, there is plenty of reason for physicists to worry as well. The IDC condemnation of “materialism” leads to the dead-end solution “that’s how God did it” for problems in physics (and especially in astronomy and cosmology) as much as in biology. As Forrest and Gross conclude:

Our hope is that readers will see that [Phillip] Johnson’s optimistic assessment of the Wedge’s progress ... is justified, albeit not by the scientific, philosophical or legal, or even generally religious, merits of his case. In the story of the Wedge to date [2003], we see a demonstration of the power of public relations to shape public opinion and policy on the largest scale – in ways that have nothing to do with the true state of scientific knowledge. And our final hope is that readers will consider seriously the question of what they ought to be doing about it.

Lawrence S. Lerner  
Professor Emeritus  
College of Natural Sciences & Mathematics  
California State University, Long Beach  
ls\_lerner@csulb.edu

Endnotes

For example: Pennock, Robert T., *Tower of Babel: The Evidence Against the New Creationism*, MIT Press, 1999; Miller, Kenneth, *Finding Darwin’s God: A Scientist’s Search For Common Ground Between God and Evolution*, Cliff Street Books, New York, 1999.

<<http://www.antievolution.org/features/wedge.html>>. The quotations of Phases II and III and the Wedge goals, below, are from the same source.

A significant exception (and to my knowledge the only one) is William Dembski, *The Design Inference: Eliminating Chance Through Small Probabilities*, Cambridge University Press, 1998.

## **Energy at the Crossroads: Global Perspectives and Uncertainties**

by Vaclav Smil, MIT Press, 2003; 427 pages, \$34.95 (hard cover), ISBN: 0-262-19492-9.

In his preface, Vaclav Smil calls this survey “Reflections on a Life of Energy Studies.” Even for those of us who hadn’t come across this expert author before, a quick glance at the Contents reveals a nearly encyclopedic treatise on all questions of human energy usage. This is a book of solid facts, not assumptions and intentions. The vast list of references gives the critical reader opportunity to check the veracity of the numbers and also the context in which they are cited.

So this is a good book. But is it worthwhile reading for a physicist, in particular for one who has dealt with some of these issues before? In answering that, let me be slightly facetious. As their attitude towards environmental and energy issues go, physicists tend to fall into three distinct categories:

First, dedicated scientists such as Archimedes or perhaps Steven Hawking, who are simply awed by the beauty of Nature. In comparison to Her grand design, human issues such as our individual survival seem trivial and boring.

Second, technological optimists such as Edward Teller, aware of and often competent with the most important environmental problems. For them, problems are there to be solved; we have mastered the ones we encountered in the past 5000 years and there is no reason why we shouldn’t be able to master the present and future ones.

Third, political activists such as Amory Lovins, concerned scientists who analyze and boldly extrapolate present trends, and come to a simple conclusion: Unless human beings change their social behavior radically (in some way or another), humanity is inevitably doomed. They are either strongly engaged in activist programs to avoid such disastrous developments, or are at least sympathetic with people who do.

These three groups have little in common except that each group tends to be disdainful of the other two.

With this introduction, I can sum up my review of Smil’s book rather simply: Energy at the Crossroads will annoy every one of those three groups, but be fascinating and enlightening to physicists

(regardless of which of group they belong to) who have the stamina to carefully study these 400 pages. The reason for this seeming paradox is that there is hardly a single argument in this book to which Smil does not immediately give valid counterarguments. Thus, Smil convinces us that any unwavering stand one may take on energy questions is at least foolish, if not outright dangerous.

The subtitle *Global Perspectives and Uncertainties* already gives a hint that this will not be light “bedtime” reading. It is pedantic in stretches, giving meticulous reviews of what can seem to the superficial reader to be irrelevant details, such as the history of mining technology.

The book begins by describing long-term trends in global energy production, conversion, and consumption, starting essentially at the beginning of the 20th century. It describes in great detail the linkage of these variables to other economic and social data such as economy, quality of life, environment and, last but not least, war. In this approach, today’s fundamental problem becomes clear immediately: During the past 100 years we have seen a dramatic dependence on fossil fuels, particularly in the developed countries, but increasingly in the third world as well. Can this go on indefinitely?

In moving from careful analysis of the past to a discussion of possible energy futures, Smil first inserts a sardonic but thought-provoking interlude: a chapter titled “Against Forecasting.” This is arguably the most important part of the book. Smil makes clear that our ability to reliably project, even qualitatively, any aspect of human energy use for even 10 years ahead is, for all practical purposes, nil. As a simple example, the predictions of global total primary energy demand in year 2000 by the participants of the 1983 International Energy Workshop (including such institutions as the International Atomic Energy Agency, the World Bank, and the Oak Ridge Institute for Energy Analysis, along with several well-known academic specialists) differed by a factor of 3, overshooting or undershooting by as much as 60%! This is an unacceptably uncertain basis for serious policy decisions.

In Fig. 3.8, which gives these results, it can be noted that one individual predicted the actual value for 2000 correctly to within 3%: V. Smil. But instead of admiring the competence of the author, read what he himself says about this: Whereas the total number happened to be on the dot, Smil was as off the track as everybody else in the breakdown of this number in types of energy (coal, crude oil, natural gas, etc.). Thus, the correctness of the sum is actually somewhat fortuitous. There are many more such examples of seriously failing forecasts in this chapter, such as the optimism with which physics Nobel laureates such as Glenn Seaborg or Hans Bethe in the 1950s (and even as late as 1977) foresaw a world shaped by ubiquitous and inexpensive nuclear energy. But equally off the mark were many predictions regarding possible reductions in consumption. To this reviewer, who has been involved in some energy forecasting himself, this chapter is, indeed, delightfully entertaining bedside reading!

In the two ensuing chapters, Smil discusses fossil and nonfossil energies at length and in depth. In light of the recent U.S. ballyhoo about a revival of fission energy, fusion energy, and a future hydrogen economy, the sections on these options are, to say the least, sobering.

Having willingly followed Smil up to this point, the reader is, however, bound to have become somewhat impatient: Where is he leading us to? What are his own convictions? Aren’t there necessary choices to be made? The answers to all three questions are in the last chapter on “Possible Futures,” especially its last three sections: “What Really Matters,” “What Does, and Does Not, Help,” and “Realities and a Wish List.” But once again, they are not easily deciphered. However, in contrast to the impression a superficial reader may have gained so far, Smil is far from entertaining an uninvolved, objectively detached stance. In order to enable readers to judge for themselves what Smil’s ‘own convictions’ are, it is worthwhile quoting two passages from the last two sections:

[Through higher efficiencies] the global economy has been able to lower the energy intensity of its output by 0.7%/year during the past 30 years.... Conversely, today’s global mean [annual consumption] of 58 GJ/capita [would have] required about 75 GJ during the early 1970s—and that rate was the French mean of the early 1960s and the Japanese mean of the late 1960s.

And so the answer is obvious: for more than 90% of people that will be alive in today’s low-income countries in the year 2025 it would be an immense improvement to experience the quality of life that was reached in France and Japan during the 1960s....

Lowering the rich world’s mean seems to be an utterly unrealistic proposition. But I will ask any European reader born before 1950 or shortly afterwards, and hence having good recollection of the 1960s, this simple question: What was so unbearable about life in that decade? What is so precious that we have gained through our much increased energy use that we seem to be unwilling even to contemplate a return to those levels of fuel and electricity consumption? How fascinating it would be to collect a truly representative sample of honest answers!

To begin with [the wish list], I would be overjoyed to see the worship of moderate growth coupled with an unwavering commitment to invest in smart, that is appropriately targeted, protection of biospheric goods and services. Two formidable obstacles are in the way: a disproportionate amount of our attention continues to go into increasing the supply rather than moderating the demand, and modern economists, zealous worshippers of growth, have no experience with running a steady-state economy, and an overwhelming majority of them would probably even refuse to think about its possible modalities. Yet there is little doubt that many of these moderating steps can be taken without materially affecting the high quality of life and at a very acceptable cost (or even with profit). I do not think I exaggerate when I see this to be primarily an issue of attitude rather than of a distinct and painful choice.

In summary, I will dare to rephrase Smil’s conclusions more bluntly, in my own words: The future of energy production and consumption in the 21st century is fraught with many, extremely serious hazards, and there are no simple, straightforward solutions to any of these problems. But one conclusion is unavoidable: the only attitude we cannot afford is to neglect the problem.

*Cornelius C. Noack  
Institute of Theoretical Physics  
University of Bremen  
noack@itp.uni-bremen.de*