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EDITOR'S COMMENTS

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Erratum

We wish to report an error in our January 2006 issue. In Akio Minato's article "4S (Super Safe, Small and Simple LMR)", the last sentence of the section Cost and Economy should read, "The cost study of 4S with 50MWe…shows the busbar cost is around 4 cents/kWh…." The figure of 40 cents/kWh is in error.

In This Issue

Our readers will note two more articles on aspects of nuclear power, both of which can be construed as pro the expansion of civilian nuclear power. We view the Forum, and this, its quarterly journal, as a forum for physicists - encouraging the open reasoned discussion of issues important to physicists and the general society in which they are imbedded. Such discussion requires the presentation of all scientifically valid sides to each issue. (We don't attempt to present the flat earth "alternative" to present "theories" of our Solar System.) It is clear that many people, including many physicists, are skeptical – even hostile – to the growth of nuclear power. They should be attempting to counter the pro-nuclear power materials published in this journal. It has been difficult to obtain such publishable "counter" material. Hence, this is an open invitation for submission of scientifically well-grounded articles, commentaries, or letters on all sides of the nuclear power issue – as well as other public policy issues which have a major physics component.

IN THIS ISSUE

ARTICLES

Advanced Nuclear Reactors — Their Use in Future Energy Supply

John F. Ahearne[1]

Introduction

The term "advanced reactor" is understood to mean reactor design beyond what is now deployed:

> "Advanced designs consist of evolutionary designs and designs requiring substantial development efforts. The latter can range from moderate modifications of existing designs to entirely new design concepts. They differ from evolutionary designs in that a prototype or a demonstration plant is required, or that not sufficient work has been done to establish whether such a plant is required."[2]

Terminology that has become in wide international use is that of generations:

> Generation I reactors were the first to be developed and many were small. Perhaps the only Generation I reactors still in operation are six small (under 250 Mwe) gas cooled plants in the UK. All others have been shut down.

Generation II reactors are what constitute most reactors operating today.

Generation III reactors are what have been built in the last few years in France and Japan. Some are called Generation III+, such as the ABWR in Japan, the new Korean PWR, the AP-1000, the EPR, and the ESBWR.

Generation IV reactors are usually referred to as advanced reactors. None have been built and none are close to being under construction.

As of 31 December 2004, there were 440 nuclear plants in operation with a net rating of 365,759 Mwe. The three countries with the largest number of reactors in operation were the United States (104), France (59), and Japan (53). There were 26 reactors under construction at the end of 2004 with the leading countries being India (9), Russia (4), and Japan (3). These numbers indicate the shift of nuclear growth to Asia and away from the US and Western Europe. Accelerating this shift has been the Swedish decision to close down the 12 Swedish nuclear plants (two have now been shutdown) and the German government's decision to phase out nuclear power in that country.

Two issues whose concern is not uniform across the globe have stimulated the resurgence of interest in nuclear power:

1. global warming and
2. the rising cost of natural gas.

The Asian growth is driven by need for electricity. US interest is due primarily to the rising price of natural gas assisted by a positive attitude by the federal government.[3]

New designs, i.e. "advanced reactors."

Reactors with the term "advanced" are and have been built. All these are classed as GEN III+. They include the ABWR (advanced boiling water reactor) built in Japan and the Korean APR-1400, modeled after the CE System 80+. The latest with a commitment to be built is the French EPR selected to be built as the fifth reactor in Finland and announced by France to be built in Brittany. Japan also is building two large (1540 Mwe) advanced pressurized water reactors (APWR) of Japanese design. The Korean reactor exemplifies a clear trend in Asia, where countries are designing and building their own reactors. This is seen in Japan, South Korea, China, and India. For example, in June of 2005, the 540 Mwe PHWR Tarapur-4, a reactor designed and built by the Nuclear Power Corporation of India, was connected to the grid.

Using a term of the 1990's, these are evolutionary reactors, improved (often significantly) modifications of existing reactors. The gas-cooled pebble bed modular reactor (PBMR) also is related to previous reactors but with operational experience limited to one German research reactor and a small pebble bed reactor in operation in China, the 10 MWe HTR-10. China has announced plans to build a 160 Mwe commercial demonstration pebble bed reactor. The early proponent of commercialization has been Eskom, the large South African utility. In South Africa licensing progress has been halted on an EIS objection but the program seems likely to build a 165 Mwe demonstration reactor to be operating within the next ten years. The PBMR offers small size, gas cycle efficiency, and accident-resistant fuel.

Characteristics of newer reactors

Design	Supplier	Features
ABWR	GE	1350 Mwe BWR operating in Japan; being built in Taiwan.
SWR 1000	Framatome	1013 Mwe BWR. Under development.
ESBWR	GE	1380 Mwe passive safety features BWR. Submitted to the US Nuclear Regulatory Commission for design certification.
AP1000	Westinghouse	1090 Mwe passive safety features PWR. Not yet ordered but some US utilities have indicated preference for this reactor.
EPR	Framatome	1545–1750 Mwe PWR. Ordered by Finland and France.
IRIS[4]	Westinghouse	100 – 300 Mwe PWR. Under development.
PBMR	Eskom	165 Mwe modular reactor. Under development.
ACR-700	AECL	700 Mwe CANDU heavy water reactor. No sales yet.
GT-MHR	General Atomics	288 Mwe modular gas-cooled reactor for Russia.
HTR-PM	Chinergy	160 Mwe steam cycle pebble bed. Ordered.
4S	CRIEPI /Toshiba	10-50 Mwe Na cooled fast reactor;30 year core; 10 Mwe proposed for a remote village in Alaska.

Each of these reactors was designed to be simpler, safer, and have lower cost than currently operating reactors. The passive safety feature reactors rely on gravity, natural circulation, and compressed air to provide cooling of both the core and the containment in the case of a severe accident. This permits a reduction in systems that were designed to force coolant into the system. For example, compared with a typical similar size reactor, passive safety systems in the AP1000 led to 50 % fewer valves, 35 % fewer pumps, 80 % less pipe, 48 % less seismic building volume, and 70 % less cable. Similar passive emergency cooling features are provided in the ESBWR design.

GEN IV

In 2002, the US led the formation of a 10 nation (plus the European Union) organization, the Generation IV International Forum (GIF), to lay out a path for development of the next generation of nuclear plants. GEN IV plants are aimed for deployment before 2030. Six types were selected for further examination by participating countries:

VHTR: the Very High Temperature Reactor, selected by the US. This is planned to use helium cooling, a Brayton cycle for power conversion, and either a prismatic graphite core or a pebble bed core with ceramic and graphite coated fuel particles. The DOE reference design is for a plant of 400-600 Mw of thermal power, passive safety features, and with core outlet temperature approaching 1000 oC, with a design goal of producing hydrogen as well as electricity.

SCWR: the SuperCritical Water-cooled Reactor. By using very high pressure, similar to that in widely-used fossil-fired boilers, water remains a single phase fluid, improving reactor thermal efficiency (about 45 % compared with typical LWRs having 33 %). The reference design is 1700 Mwe with a core outlet temperature of 550 oC. Selected by Canada.

LFR: the Lead-cooled Fast Reactor. Selected by the US but of lower priority than the VHTR.

SFR: the Sodium-cooled Fast Reactor. Japan is taking the lead on the SFR, which also is planned to use a closed fuel cycle.

GFR: the Gas-cooled Fast Reactor would use helium or CO2 as the working fluid.. France is taking the lead on the GFR.

MSR: the molten salt reactor, where the fuel is in the circulating molten salt mixture of fluorides of sodium, zirconium, and uranium. France is leading a GIF steering committee with the US and the European Community and limited programs are underway in France and the European Community to evaluate this concept.

Other reactors

Many other reactors are being studied or developed. These include the following, which do not include all that have been announced or described in the literature.

- The Indian ATBR (A Thorium Breeder Reactor) designed to run on thorium and produce 600 Mwe.
- The SSTAR (small, sealed, transportable, autonomous reactor), a lead-cooled fast reactor for 10 to 100 Mwe and contained completely in a sealed container with fuel to last 30 years.

- Westinghouse BWR 90+, a 1500 Mwe design to meet European Utility Requirements.
- The Russian Gidopress 1000 Mwe V-392, an improved version of the VVER-1000, is being built in India and China.
- In July 2005 Russia announced plans to build reactors on boats to supply hard-to-reach locations in the remote northern coast. The reactor probably will be the KLT-40, used in icebreakers, that can provide 30-35 Mwe and up to 20 Mw in heat.
- The Argentinean CAREM (advanced small nuclear power plant) is an integrated modular 100 Mwt/27 Mwe PWR.
- The South Korean SMART (System-integrated Modular Advanced Reactor) is a 330 Mwe PWR.
- The French NP-300 is based on a submarine PWR and can be used for electricity generation (100-300 Mw) or desalination.

The main role of nuclear plants is to generate electricity, usually as a base load generator. However, plants also are used to provide heat (e,g., the four Bilibino 11 Mwe plants in Chukotka, Russia), to power both naval vessels and icebreakers, and for water desalination. A new interest is in using nuclear power to generate hydrogen. This is seen in the US NGNP (Next Generation Nuclear Plant) program which is planned for hydrogen production.

In addition to some of the GEN IV reactors listed above, a design that resulted from earlier work in the GEN IV program is the Advanced High Temperature Reactor (AHTR) which combines the coated-particle graphite-matrix fuel that has high safety value and low-pressure molten salt coolant. The outlet temperature can be 1000o C for use in production of hydrogen. The growing interest in hydrogen is as an energy-carrier to replace oil-based transportation fuels. In addition to production challenges, storage and transportation obstacles remain to be overcome. Industrial heat processes, e.g., metallurgical processing are another application for high temperature reactors.

Until the recent possibility of the use of nuclear power to produce hydrogen, the three factors leading to renewed interest have been population growth (particularly in China and India), continued rise in the price of natural gas (the US), and climate change. Several recent studies have concluded that nuclear power could be one of the options to address the climate change problem.

Challenges

It appears that nuclear power will continue to grow, the larger numbers driven by increases in per capita use of electricity. The largest forecast growth is in China. Nuclear capacity is forecast to grow to 40 Gwe by 2020 and possibly to 300 Gwe by 2040. In India, the current 2.7 Gwe capacity is planned to grow to 20 Gwe by 2020. Much of this growth will use existing designs. If the insatiable demand for electricity continues as the large populations in the developing countries are to improve their living standards, and if nuclear power remains one of the means of supplying that electricity, the new, advanced designs should be available and will offer advantages over those already built. However, getting to the point where some of the most advanced designs will have been tested in a demonstration or prototype system will take time and money.

There are two principal fuel cycles, once-through and closed. In the once-through fuel cycle, spent fuel is removed from the reactor and stored for later permanent disposal. In the closed fuel cycle, the spent fuel is processed to remove fission products and the uranium and plutonium separated for re-use. The requirements for the once-through fuel cycle are for fuel that can withstand much higher burnup than fuel now in use. Currently a “high burn up fuel” will be used for up to 60 Mwd/MTHM (Megawatt days per metric ton of heavy metal). A goal is to reach 100, which would prolong each operating cycle and reduce the total amount of spent fuel that must be stored or disposed of. Developing new fuel recycling processes and bringing them to the point they can be funded and licensed will take at least 10-20 years.

Other research needs relate to materials issues as much higher operating temperatures are planned along with use of coolants not well studied. The reactor design concepts that have not been built will face engineering issues once a prototype operates. Issues will arise for all the novel designs in the GEN IV list and for many of the other new concepts. For example, use of a direct helium cycle (Brayton) will be both a technical and a licensing challenge. Many R&D issues must be successfully addressed before these GEN IV advanced reactors can be expected to make significant contributions to meeting energy needs.

Although not apparently a major factor affecting plans for nuclear power in most areas of the world, in the US, which has the largest nuclear program and the electricity growth demand to support substantial growth in nuclear power, the cost of electricity has been the dominant factor in what type of generation gets built. Whereas two other countries with large nuclear power programs, France and Japan, have extremely limited domestic sources of energy, the US is one of the world's leaders in coal reserves. As the US has moved to reduce the economic regulation of generation, cost has become a competitive key and "[c]apital cost is the single most important factor determining the economic competitiveness of nuclear energy."[5]

Most new reactor concepts are described as having construction costs much below those of currently operating reactors. Outside of the US, newer reactors have had construction costs that appear to be around $2000 (US)/kWe. The goal of new designs is to have overnight costs[6] be no more than $1000 (US)/kWe. One approach to achieving substantial cost reduction is the elimination of active safety systems. Another is to reduce the size of the structure, to reduce the total concrete and rebar, which can be a significant cost saving.

"There is a concern, particularly in the United States, that the further expansion of nuclear power will increase significantly the risk of proliferation of nuclear weapons."[7] With the exception of India and apparently North Korea, nuclear power programs have not been used to develop nuclear weapons. However, the knowledge gained by working in nuclear power programs, such as handling the radioactive material and access to sensitive technologies (A. Khan[8]) can assist in developing nuclear weapons. Nevertheless, the main difficulty in building a nuclear weapon is to obtain the HEU or plutonium needed to make a nuclear weapon. A recent review by the US American Physical Society[9] concluded:

"Nuclear reactors themselves are not the primary proliferation risk; the principal concern is that countries with the intent to proliferate can covertly use the associated enrichment or reprocessing plants to produce the essential material for a nuclear explosive."

The report recommended improving international collaboration on non-proliferation and make proliferation resistance a higher priority in the design of nuclear energy systems such as reprocessing facilities

Fuel extracted from a reactor after use, spent fuel, is highly radioactive as well as hot. How to use the uranium and plutonium in that fuel or how to safely dispose of that fuel has been a controversy for decades. For once-through fuel cycles, the generally accepted technical solution has been to dispose of the spent fuel in a geological repository. However, after decades of that being the desired approach, no country has managed to construct a repository. The main obstacle has been public opposition to locating such a facility. Finland is currently the country most likely to first build a geological repository for spent fuel. The United States has been working on developing a repository in Yucca Mountain, Nevada for nearly 20 years. Although substantial tunneling and construction have been done, continued opposition by the State of Nevada has slowed progress substantially, as have problems with the Department of Energy's program. A license application has not been submitted to the Nuclear Regulatory Commission and, even if all objections were resolved in favor of the site, the repository could not open until well past 2010.

Some countries reprocess the fuel to extract and reuse the uranium and plutonium. This substantially reduces the waste mass (most of that in the spent fuel is uranium) and can separate out the short-lived isotopes that are the primary heat source. France and England operate reprocessing facilities to handle their own fuel and that from other countries. Japan is about to open a reprocessing facility and Russia has operated a facility.

Even after reprocessing, high activity long-lived waste must be stored. If not reprocessed, the problem is larger. The GEN IV systems are planned to be associated with reprocessing (or, in the new euphemism, reuse).

The challenges for expansion of nuclear power differ by country. In Sweden and Germany, well run nuclear power plants are being shut down because of the policy of the elected governments. In Russia, an ambitious plan for nuclear power expansion is held back because of lack of funds. Prime Minister Blair recently said that the new energy plan being developed for the UK will consider new nuclear plants. In the US, the obstacles have been cost and public opinion. The recent Energy Bill in the US offers loan guarantees and production tax credits for new nuclear power plants and may encourage new construction. Expansion in these countries would not have the impact on energy supply as will the large expansion occurring in India and China.

Controversies

In addition to the cost and proliferation, the main controversies regarding nuclear power are whether the publics will accept new nuclear plants, whether sites can be found where the public will accept a geological repository, and whether future development should be based on the once-through or the closed fuel cycle. The first two are public attitude issues, the last is a technical and proliferation policy issue. Regarding public attitudes, bringing the public into decision processes early, although at least in the US the laws require the federal agencies to make the final decisions, will substantially improve the climate for nuclear power to go forward. This has been seen in repository siting in Finland and Sweden.

The issue of sustainability of nuclear power concerns the question as to the adequacy of long-term uranium supply. The amount of uranium available has been argued about for decades. Supporters of moving to breeder reactors (which transform the more prevalent isotope of uranium, U238, which will not fission and therefore cannot be used as a reactor fuel, into plutonium for use as fuel) have claimed the world will run out of uranium to fuel the reactors. It should be noted that the nuclear fuel makes up a very small part of nuclear power operating costs, usually only about one-tenth, and that the price of the uranium is only about one-third of that tenth, with most of the cost being in actually making the fuel from the uranium.

An MIT study examined a growth scenario of going from less than 400,000 Mwe today, worldwide, to at least 1,000,000 Mwe by 2050. The authors wrote (emphasis in original): "*We believe that the world-wide supply of uranium ore is sufficient to fuel the deployment of 1000 reactors over the next half century* and to maintain this level of deployment over a 40 year lifetime of this fleet."[10] This study provided a detailed analysis to support this position.

There is enough uranium.

Conclusions

Regarding the main challenges for expansion of nuclear power, safety has been greatly improved, there is increasing effort to address non-proliferation concerns, but little progress has been made in developing a permanent solution to the problem of nuclear waste and resolving public attitude issues. There are a plethora of new designs, promising improved safety and lower cost. These promises must be shown to be met by actual construction and operation. However, GEN III+ plants are being constructed and will be the units on which expansion will be based in the next decade.

As for use in future energy supply, the main role of nuclear power currently is to supply electricity. Since the past decade has demonstrated the linkage between electricity use and GDP, across all economies, the real growth in nuclear power will be in countries that are growing in per capita use of electricity. These are in the developing world of Asia, not in the developed world of the West. Asia is buying and building, Europe is dormant, and the US may restart. In the US there are an increasing number of press releases, but no orders. Vendors and utilities may be waiting to see how new government money will be administered.

If uranium is plentiful, the argument for the closed cycle that it is needed to prevent running out of fuel is not persuasive. The remaining issue is whether the closed cycle is necessary to resolve the inability to site a repository.

Finally, in all new initiatives, the concerned publics should be involved early, not after a decision has been reached. Not doing so is the fundamental reason for Nevada's vehement opposition to Yucca Mountain.

Acknowledgements

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Footnotes

1 *Sigma Xi, The Scientific Research Society, ahearne@sigmaxi.org*

2 *"Terms for describing new, advanced nuclear power plants", IAEA-TECDOC-936, IAEA, 1997, p.9.*

3 *"The NEPD [National Energy Policy Development] Group recommends that the President support the expansion of nuclear energy in the United States as a major component of our national energy policy", National Energy Policy, Vice-President Dick Cheney, May 2001, P. 5-17.*

4 *International Reactor Innovative and Secure*

5 *"The Economic Future of Nuclear Power: Study Conducted at the University of Chicago", done for the Nuclear Energy office of DOE, August 2004.*

6 *The cost if the plant could be built with no inflation cost and no interest cost for borrowed money.*

7 *Federal Energy Research and Development for the Challenges of the Twenty-First Century, Report of the Energy Research and Development Panel of the President's Committee of Advisors on Science and Technology, November 1997, P. 5-11.*

8 *Khan used centrifuge designs he acquired while working in a European enrichment facility to build centrifuges to produce the highly enriched uranium used in Pakistan's nuclear weapons. He then apparently allowed to be sold or sold his centrifuges to several other countries, probably including North Korea, Libya, and Iran.*

9 *"Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk," A report by the Nuclear Energy Study Group of the American Physical Society Panel on Public Affairs, May 2005.*

10 *The Future of Nuclear Power: An Interdisciplinary MIT Study, 2003, p.4; http://web.mit.edu/nuclearpower*

Bombs, Reprocessing, and Reactor Grade Plutonium

Gerald E. Marsh and George S. Stanford

A recent, ill-conceived call to action from the Union of Concerned Scientists says this:

"In his State of the Union address, President Bush called for investment in 'clean, safe nuclear energy.' This seemingly harmless phrase, however, does not describe the controversial new program currently under consideration by the administration and some members of Congress. Under this new plan, the U.S. would 'reprocess,' or separate, weapons-usable plutonium from the spent nuclear fuel generated by U.S. power reactors.

"This proposal would make it easier for terrorists to acquire the material for making a nuclear bomb. It would require the construction and operation of an array of nuclear facilities that would handle enough plutonium annually to make thousands of nuclear weapons. It would also make disposing of nuclear waste more difficult, encourage other countries to reprocess, and cost a tremendous amount of money. Help us make this program politically 'radioactive:' please tell your representative and senators to keep nuclear material out of the hands of terrorists by rejecting all efforts to fund this dangerous plutonium reprocessing program."

The fundamental problem with that position is failure to accept the fact that reactor fuel is going to be recycled, whether we like it or not. Nuclear power is expanding rapidly world-wide. Its growth will be exponential for some time, and long-continued use of a fuel cycle that uses less than a hundredth of the energy in the mined uranium is out of the question. China, India, Japan, South Korea, and Russia are already among the nations that see the coming need to multiply their energy resources with fast-reactor technology and recycling. The development will be managed well, or it will be managed badly.

Our views [1,2,3] on nuclear power and reprocessing are well known to readers of Physics and Society and will not be rehashed here. Our thesis this time is that the growth of nuclear power can—and must—be managed well.

The outlook is not nearly as bleak as it seems to the UCS. The root of their concern, apparently, is the oft-quoted mantra, "all plutonium is weapons usable," an assertion that we will examine. We will also look at the claim that reprocessing "would . . . make disposing of nuclear waste more difficult, encourage other countries to reprocess, and cost a tremendous amount of money."

For starters, the UCS claim that "Under this new plan, the U.S. would 'reprocess,' or separate, weapons-usable plutonium from the spent nuclear fuel" is just plain wrong. The Global Nuclear Energy Partnership (GNEP) announced by the Administration in February of 2006 [4], specifically does not do that—the plutonium is always mixed with other elements that render it useless for weapons without further processing.

More generally, however, the widespread apprehension about the weapons potential of pure reactor-grade plutonium is overblown. That worry has three sources: an article by J. Carson Mark, with an appendix by Frank von Hippel and Edwin Lyman, on the probability of different yields [5]; the 1962 test of a nuclear device using reactor-grade plutonium, which successfully produced a nuclear yield; and the claim that weapons of modern design could use reactor-grade plutonium with no degradation in yield. We will consider each of these in turn.

Let's be clear that we do agree that reactor-grade plutonium needs to be safeguarded. We also agree that acquisition of reprocessing facilities gives a nation the potential to subvert them, in conjunction with specially operated reactors, to produce weapons-grade plutonium. That reality is why reactors need to be safeguarded, and, as we point out in Ref. 3, reprocessing should be done under the aegis of an international organization such as the International Atomic Energy Agency or the International Energy Agency. The GNEP is a step in the right direction, and we fully support it.

Carson Mark's Article

Carson Mark calculated the range of fizzle yields to be expected from a Trinity-style device made with reactor–grade material ("Trinity" was the first test of an implosion-driven plutonium warhead, at Alamagordo, New Mexico, in 1945). Figure 1 is reproduced from the appendix by von Hippel and Lyman.

For the reactor-grade plutonium curve, setting the spontaneous neutron emission rate at 20×10^5 per second is equivalent to choosing the mass as 10 kg, since the spontaneous emission rate of reactor-grade plutonium is ~200 n/s/g. According to the curve, there will always be a yield ratio of at least 2.7%, and the probability of degradation to a yield ratio less than 0.1 is about 83%. This is why it is often said that likely fizzle yields range from 100 tons to a kiloton or so, for a Trinity type of device. This is also why reactor-grade plutonium must be safeguarded—it's possible get an explosion with the stuff.

Fortunately, the technical hurdles are daunting.

Subnational Groups

The possibility of getting a yield does not mean a terrorist group could readily do so—they would have great difficulty even with weapons-grade plutonium. They would face two major hurdles: the heat generated by the material, and the difficulty of fabricating the high-explosive assembly.

As Mark noted in his article, heat is generated in the assumed type of device at a rate of about 100 watts—versus 8 watts in a modern fission weapon. This corresponds, he estimated, to an equilibrium temperature of 190oC, well above what the high explosive can withstand. He then did some hand-waving, using the high thermal conductivity of aluminum, to argue that a "thermal bridge with a total cross-section at the surface of the core of only about one cm2 could halve the temperature increase induced by reactor grade plutonium." Since high-explosive breakdown, as he notes, becomes significant beginning at 100 oC, more than one cm2 would obviously be needed.

We intentionally use the term "hand-waving" because incorporating aluminum fins in the high explosive without interfering with the implosion process is non-trivial—well beyond the capabilities of a terrorist group. Even making an implosive assembly with no thermal intrusions is no simple task. After all, a significant part of the Manhattan Project was devoted to designing and fabricating the high-explosive lens assembly. Terrorist "explosive experts" can use semtex and other explosives to make bombs, but that does not mean they would have anywhere near the expertise to duplicate the Manhattan Project's result in their proverbial basement, let alone incorporate non-perturbing thermal bridges.

Melting reactor-grade plutonium to make cores, casting the high explosive in the required shape, and dealing with the heat generated in an assembled explosive device—all are simply beyond any reasonable estimate of what a terrorist group could do.

Gun-Type Devices and Reactor-Grade Plutonium

It has been suggested that terrorists might use reactor-grade plutonium in a gun-type device, since they would not care if the yield is degraded by pre-initiation, provided they could get even a few tons of TNT equivalent.

In the Manhattan Project, the original plan for plutonium was to use a gun-driven assembly. That effort, code named "Thin Man," was under Robert Oppenheimer's direct supervision. Work on it continued until Emilio Segre's experiments on the spontaneous fissioning of plutonium proved that it could not be used to bring together reliably even high-quality plutonium. Oppenheimer then decided to abandon Thin Man. Work on the gun continued, however, focused on uranium, with the code name changed to "Little Boy." Little Boy was developed with few major complications. It used a special gun that could withstand high breech pressures. The bomb weighed some 9000 pounds. We suggest that the scenario where terrorists would even attempt to build a Little Boy type of device lacks credibility.

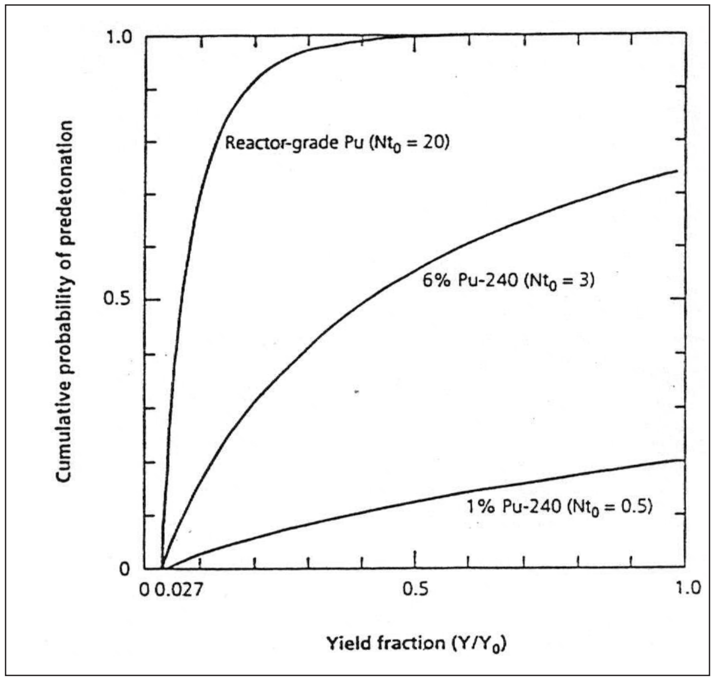

Fig. 1. Y is the yield as reduced by predetonation, Y0 is the design yield, N is the number of spontaneous neutrons per second (here specified to be 0.5, 3, and 20x105), and t0 is the time interval during which the imploding assembly is supercritical (here about 10-5 sec). (From Ref. 5.)

The 1962 Test

The Department of Energy has released the following information about the 1962 test:

- "A successful test was conducted in 1962, which used reactor-grade plutonium in the nuclear explosive in place of weapon-grade plutonium."
- "The yield was less than 20 kilotons."

There are very good reasons why the details of the test have not been made public. It was not a simple test, and the details of the design rightly remain classified. The test did give a single data point for the reduction in yield due to pre-initiation—undoubtedly it was consistent with the curves given above—but it finessed the heat-generation problem.

Thus, while the 1962 test arguably confirmed what was already known—that a yield can be obtained—it cannot be used as evidence that reactor-grade plutonium is an acceptable material for building nuclear weapons, nor can one conclude from it that terrorists could successfully detonate even a crude device based on that material.

Designs using Reactor-Grade Plutonium with No Yield Reduction

Probably all sides of this debate will agree that only a modern design could even conceptually use reactor grade plutonium without a severe degradation in yield. "Conceptually," because such a scheme has never been tested in the United States—nor elsewhere, to our knowledge.

While modern designs may deal with the problem of pre-initiation, the heat problem is not totally eliminated and would still be of concern. The development of modern, efficient fission weapons required an extensive testing program, and any nation making such an effort will not waste its time and money on reactor-grade plutonium. It is far simpler to produce weapons-grade plutonium, as other nations, such as India, have done.

The discussion above is restricted to the problems of pre-initiation and heat generation. There are other problems with bomb design and construction that are outside the scope of this article.

Reprocessing

Reactors based on a thermal neutron spectrum (virtually all of today's power reactors) cannot extract even one percent of the energy in the original ore. The increasing rate at which new reactors are being planned and built around the world will sooner or later put a strain on the supply of low-cost uranium. But efficient recycling with fast-spectrum reactors can get essentially all the energy from the mined uranium, rendering the cost of uranium ore irrelevant to the cost of power. Already at least six countries are planning to implement such a technology (China, India, France, Japan, Russia, and South Korea).

Nuclear fuel is going to be recycled more and more, and it behooves us to accept the inevitable and strive to ensure that it is done in the best way possible. Fortunately, the UCS is simply wrong in claiming that reprocessing would "make disposing of nuclear waste more difficult, encourage other countries to reprocess, and cost a tremendous amount of money."

Rather, waste management is made very much easier. The decree that Yucca Mountain must isolate the waste for more than 10,000 years is due primarily to the presence of long-lived transuranic elements. Appropriate reprocessing will allow those troublemakers to be consumed in fast reactors, leaving only the real waste—the fission products—to be disposed of, and their radioactive toxicity fall below that of the original uranium ore after less than 500 years. Effective waste management becomes a slam dunk.

Encourage other countries? The lesson of the last thirty years is that what the United States does with its spent fuel is irrelevant to other countries' decisions to reprocess. If the United States does not recycle its used fuel, the unabated buildup of plutonium and waste will strangle nuclear power in this country, while the rest of the world forges ahead without U.S. input regarding either technology or policy.

Costs are addressed in reference 1. In a nutshell, while the technology has yet to be demonstrated on a production scale, there are no evident show-stoppers—there is no reason to suspect that the resulting power will not be competitive, even before factoring in the cost saving from avoiding the construction of more repositories like the one in Yucca Mountain.

Conclusions

Let's keep in mind that our best protection against international nuclear conflict lies in reducing the level of international tension, and that energy-related conflicts are a major cause of such tension. Only nuclear power has the potential to ensure that the nations of the world have sufficient indigenous energy without intolerable environmental consequences.

The terrorist threat from reactor-grade plutonium has been greatly exaggerated by the argument that what is theoretically possible to do can be done by subnational groups.

The notion that the potential for proliferation will increase if spent fuel is reprocessed to close the fuel cycle and allow a rational waste disposal policy is simply incorrect.

The points we want to make are two: First, while it is not utterly impossible for terrorists to make a nuclear explosion, appropriate safeguards, combined with major technical problems and other, easier ways for terrorists to do damage, can make the probability low. Second, since recycling is not going to go away, the choice is simple: manage it poorly, or manage it carefully and safely.

Wishing it away is not an option. The Union of Concerned Scientist's call to action is ill-founded, and could harm the chances for this country to formulate a coherent and realistic energy policy. If the UCS were to use its influence to promote a safe and realistic international control of the nuclear fuel cycle, it would be part of the solution instead of part of the problem.

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[4] http://energy.gov/news/3161.htm

[5.] J. Carson Mark, "Explosive Properties of Reactor-Grade Plutonium," Science & Global Security 4, 111 (1993).

Gerald E. Marsh is a physicist, retired from Argonne National Laboratory, who has worked and published widely in the areas of science, nuclear power, and foreign affairs. He was a consultant to the Department of Defense on strategic nuclear technology and policy in the Reagan, Bush, and Clinton administrations, and served with the U.S. START delegation in Geneva. He is a Fellow of the American Physical Society. His most recent book is: "The Phantom Defense: America's Pursuit of the Star Wars Illusion" (Praeger Press).

George S. Stanford is a physicist, retired from Argonne National Laboratory. B.Sc. with Honours, Acadia University; M.A.,Wesleyan University; Ph.D. in experimental nuclear physics, Yale University. He is a member, American Nuclear Society, and a past member of the American Physical Society. He has served on the National Council of the Federation of American Scientists. Co-author: Born Secret: The H-Bomb, the Progressive Case, and National Security (Pergamon, 1981), and Nuclear Shadowboxing: Contemporary Threats from Cold-War Weaponry (Fidlar Doubleday, 2004). His technical publications have pertained mainly to experiments in nuclear physics, reactor physics, and fast-reactor safety.

Some Religious Implication of Modern Cosmology

Priscilla Laws

We're in Wonderland:

Alice laughed. "There's no use trying," she said: "one can't believe impossible things."

I dare say you haven't had much practice," said the Queen. "When I was your age, I always did it for half-an-hour a day. Why, sometimes I've believed as many as six impossible things before breakfast."[1]

Tales filled with seemingly impossible ideas about of the creation, evolution and ultimate fate of our Universe have been told and re-told for centuries. How can scientists reconcile the mythos, religion and faith that are so vital to our humanity with the awesome power of our human capacity for logic, reason and science.

The key to our ability to study the evolution of the Universe is the fact that we are able to look back in time. Light moves at a finite speed. Thus we see our Sun as it was 8 minutes ago, the next nearest star as it was 4 years ago, and so on.

In addition, knowledge is greatly enhanced by data sent to us from space by new instruments such as the Hubble Deep Space Telescope and the WMAP Probe that is mapping the intensity of 13.3 billion year old electromagnetic energy. Scientists also use particle accelerators here on Earth to learn about the interactions of high-energy fundamental particles.

The latest story of our origin and ultimate fate, known as the standard big bang model[2], is based on new data and theories that are not yet in popular books on Cosmology.

How Did We Arrive at the Present?

At the dawn of time, 13.7 billion years ago, our Universe was unbelievably small and hot. The Big Bang started with a quantum era that lasted only one 10 million billion billion billion billionths of a second (or 10^{-43rd} seconds). This ridiculously short era cannot be investigated or explained by science. This is because our tiny expanding ball was less than 10^{-35} meters in diameter — below the limit of knowability set by quantum theory. So, like the Earth in the Genesis story, the very early Universe is without form. Would Alice or the Queen call this an impossible idea?

The next 13.7 billion years of evolution involved continuous expansion and cooling. As particles in the Universe cooled, on average, they moved more slowly. As the Universe expanded, its density decreased and particles encountered each other less often. Even if particles attract each other they cannot stick together if they are moving too fast or if they are too far apart. The rate at which various types of new particles evolve depends on the average temperature and density of the universe. We can demonstrate the reason for this dependence by observing whether or not particles that are magnetically attracted to each other can stick together when they are moving rapidly.

The first known era of cosmic evolution starts when a soup of quarks, gluons, electrons and other fundamental particles began interacting. This set off a continuous sequence of processes that led to the formation of nuclei and electrons, then atoms, then clouds of atoms, then stars and galaxies and then combinations of atoms into both simple and complex molecules, and finally living organisms.

During the 1st second most of the quarks cooled enough so that gluon forces caused them to form into nearly indestructible electrons, protons and neutrons—the stuff eventually needed to form the atoms that we're made of.

After about 3 minutes strong nuclear forces caused neutrons and protons to combine and become atomic nuclei.

Then 380 thousand years later electrons and the nuclei combine to form atoms.

In the next 13.3 billion years gravitational forces between electrically neutral atoms caused them to form clouds of matter. These clouds eventually condensed into stars, galaxies and solar systems. When large stars, called supernovas, accreted too much matter, they exploded and dispersed heavy elements throughout the Universe. Supernova fragments gave birth to new stars and solar systems containing the heavy atomic elements needed to produce complex molecules.

About 5 billion years ago our solar system began forming into a spiraling system containing debris from earlier supernova explosions. Atoms combined into increasingly complex molecules both on Earth and on comets and asteroids that bombarded the Earth.

Early forms of life date back 4 billion years with the creation of self-replicating molecules which started the process of biological evolution. Modern homo sapiens emerged in Africa about 100 thousand years ago-- an intelligent, self-aware species capable of pondering who they are and how they came to be. Another impossible idea for Alice?

Simple calculations show that we have occupied an essentially infinitesimal fraction of a vast Universe for a tiny proportion of the time the Universe has existed.[3]

Some Theological Implications of the Big Bang

A theological question raised by scientists and others who understand the Big Bang model centers around whether on not the model supports the existence of a creator who assembled the matter and energy with an initial set of particles and developed a set of interaction laws to govern its evolution.

One view expressed by British philosopher William Craig is: "Since whatever begins to exist has a cause, there must exist a transcendent cause of the Universe."[4]

A second view is articulated by the well known astronomer, Stephen Hawking, who writes that although there must have been a big bang, at present the quantum limit prevents us from knowing the precise moment when time began. Hawking believes that without this knowledge there is no role for a creator. Nonetheless, Hawking proceeds to conclude his book with the statement:

"…If we do discover a complete theory, it should in time be understandable in broad principle by every one. . .Then we shall all …take part in the discussion of…why it is that we and the Universe exist. .. the answer to that, … would be the ultimate triumph of human reason — for then we would know the mind of God."[5]

But wait, the God that Hawking describes is an impersonal God who has defined the laws of nature. The well-known cosmologist Stephen Weinberg objects to this use of the term God when he says:

"If language is to be of any use to us, we ought to try to preserve the meanings of words. And God historically has not meant the laws of nature, it has meant an interested personality."[6]

At this point in time there is no agreement as to whether the Big Bang Model allows us to prove or disprove the existence of a creator.

What will Happen in the Future?

The poet Robert Frost writes "Some say the world will end in fire, others say in ice." [7] What do scientists think could happen? At 4.6 billion years our Sun is middle aged. In another 5 billion years it will swell, swallow the Earth and die. By then, if we don't annihilate ourselves, we may be able to establish colonies in other solar systems. But what is the long-term future of the Universe?

Ever since its beginning the Universe has been expanding — though not at a constant rate. The first few hundred million years are called the inflationary period because the expansion rate was more rapid than it is now. The present expansion rate is 1 part in 14 billion per year. Predicting the future of the Universe requires us to predict the expansion rate based on our knowledge of the present density of matter in our Universe. Just as some people have strong emotional responses to theories about the evolution of life, people also have emotional responses to theories about cosmic evolution. Here are three of the many scenarios for our future that have been proposed.

The Cyclic Universe: If the density is greater than a critical value, the Universe will continue to expand for another 10 billion years at a diminishing rate until gravitational forces prevail, and then start collapsing under its own weight. After about 25 billion years it once again becomes a tiny hot dense ball. Then it might start another 35 billion year cycle of expansion and contraction.

This scenario should be theologically appealing to those who believe in re-incarnation, a concept with Hindu and Buddhist roots.[8]

A Steady State Universe: If the density of our Universe is below a critical density, the expansion might slow down and possibly stop. So, even though there might be a continuous process of star and solar system deaths and rebirths, the overall structure of the Universe would not change much at first. Eventually a heat death would occur and the Universes evolves toward a constant temperature.

The Steady State Universe is very compatible with Christian notions of eternity.[9]

An Inflationary Universe (a.k.a Endless Expansion): For some reason the rate of expansion and cooling of space accelerates to the point where the speed of expansion exceeds the speed of light. Stars will die and we will lose communication with them and won't even be able to see their cold dark remnants.

This scenario depicts an ultimate death that many people are not comfortable with.

Which model is currently in favor with cosmologists and why? The most recent WMAP cosmic radiation data and supernova explosion data point strongly to a Universe that is currently expanding at an accelerating rate. This doesn't seem to make any sense. In fact is appears to be another one of the Red Queen's impossible ideas. The only plausible explanation offered by scientists is that space is filled with dark energy — an "anti-gravitational" repulsive force, and that as space expands, this repulsive force is becoming stronger and stronger. Although there is other evidence for the existence of dark energy that fills space, for now it is poorly understood.

When Einstein's famous equation, $E = mc^2$, is used to calculate the amount of energy from different sources in the universe, the observational evidence for runaway expansion has led cosmologists to estimate that there is:

5% normal matter: protons, planets, stars, galaxies, etc.

25% dark matter: stars that have collapsed into ultra dense black holes, etc.

70% dark energy: a poorly understood invisible property of space

As always with science, the prediction that we will accelerate into a vacuous oblivion is not certain. Nonetheless, this prediction of ultimate death raises the question, if humanity and our Universe are ultimately going to die, what is the meaning of life? What is the point? Nobel Laureate Stephen Weinberg expresses my answer to these questions beautifully when he says:

"If there's no point in the Universe that we discover by the methods of science, there is a point that we can give the Universe, by the way we live, by loving each other, by discovering things about nature, by creating works of art …"

Priscilla Laws
Dickinson College
lawsp@dickinson.edu

Endnotes

[1] *Lewis Carroll, Alice in Wonderland*

[2] *Big Bang is not an appropriate term for description the expansion of the early Universe. It suggests an explosion with fragments flying apart at high energy. According to cosmologists, there is no explosion. Instead the particles appear to spread out because space itself is expanding.*

[3] *In particular, humans have been on Earth for only a 100 thousanth of the time the Universe has existed. If we compare the diameter of our Earth to the size of the known Universe then the diameter of our Earth is a mere 1 part in 10 billion billion (or 10-19th) of the length of our Universe.*

[4] *William Craig, "The Existence of God and the Beginning of the Universe." Truth: A Journal of Modern Thought 3 (1991), pp. 85-96.*

[5] *Stephen Hawking, The Illustrated A Brief History of Time, Bantam Books (1996), pg. 233*

[6] *Stephen Weinberg, 'Faith and Reason' Transcript published at: http://www.meta-library.net/transcript/margaret-frame.html*

[7] *Robert Frost, "Fire and Ice" (From Harper's Magazine, December 1920.)*

[8] *For example, someone who wrote to the Ask an Astronomer website expressed a preference for the oscillating Universe. He wants to believe in a literal form of reincarnation in which he can be reborn 35 billion years later and live his life again.*

[9] *For example, the Gloria Patri which I heard recited in a Methodist church on New Years Day declares, "Glory be to the father, and to the son and to the holy ghost; As it was in the beginning, is now, and ever shall be, world without end."*

COMMENTARY

Hybrid Fusion

Physics & Society has published numerous articles and letters on energy, including the Jan. 2006 issue which was largely devoted to this subject. In these articles, fusion has rarely been mentioned, and for good reason. The world energy requirements are coming at us rapidly, by mid-century the world will need an additional 10-30 terawatts (TW) of carbon free energy [1]. Another paper [2] shows that the options available to achieve this are few. However because the quest for fusion has proven so difficult, the time horizon for substantial power production by fusion is receding rapidly, almost certainly into the 22nd century.

This author has attempted to examine whether fusion, by embracing the hybrid concept, can play an important role on the mid-century time scale. Let's briefly elaborate on the conventional approach to fusion and the fusion fission hybrid. In the conventional fusion reaction, a deuterium and tritium nucleus combine to form a 3.5 MeV alpha particle and a 14 MeV neutron. It is mostly this neutron kinetic energy which is used, for instance to boil water. In the hybrid, the fusion reactor is clad with fertile material, say 238U or 232Th, and the potential energy of the neutron is then used to breed fission fuel, 239Pu or 233U. Either of these can be used in a conventional fission burner. Since a fission reaction produces about 200MeV, the energy of the fusion reactor is effectively multiplied by about an order of magnitude. Let us see what this means in terms of the economy of a reactor. Imagine that a pure fusion reactor could be built which sold power at 50 cents per kilowatt hour. Clearly no utility would buy it, and none of us could afford it; all of our electric bills would be five to ten times higher than they are now. But now say that this same reactor were used as a hybrid and produced ten times as much energy in the form of nuclear fuel. The fuel cost for the utility would then go down to five cents per kilowatt hour (about the same as gasoline at $1.50 per gallon). Clearly this would be much more viable economically. Thus by using the hybrid, the requirements on the fusion reactor, the most difficult component to develop, are considerably reduced.

The question is whether by exploiting the reduced requirements of the hybrid, fusion can make an impact on mid-century energy requirements. With virtually no support and little interest from either the fission or fusion community, this author has hardly been able to come up with a genuine design. However he has sketched "as more than a dream, but certainly less than a careful plan" what appears to be a promising concept for large scale power production by mid-century or shortly thereafter, the energy park [3]. This is 7 reactors co-located, each producing about 1 GW (3 GW thermal) of electricity or hydrogen, and which treats all of its own wastes. The key to the energy park is a fusion reactor which produces about 1 GW of electric power, but more importantly, breeds nuclear fuel for 5 conventional 1 GW nuclear burner reactors. The fuel produced is 233U which is bred from 232Th. As it is bred, it is immediately mixed with 238U to form a proliferation proof fuel (with roughly 4% enrichment). The waste from these burners goes to a separation plant, where short lived radio nuclides, long lived radio nuclides, and actinides (mostly 239Pu) are separated out. The short lived radio nuclides cool over a period of several hundred years to inert material. The actinides go back to a seventh reactor where they are burned. This would most likely be a fast neutron reactor, but possibly it could be thermal reactor if the fertile material were not 238U, but another material such as 232Th which does not absorb neutrons to build up additional actinides. The long lived radio nuclides (for instance 99Tc, with a 200,000 year life time, and which can be a great threat to a geological repository because many of its compounds are water soluble) go back to the fusion reactor for transmutation. Additional details are given in Ref [3]. Alternately, if anyone is interested and has difficulty getting the reference, I would be glad to send it either electronically or by regular mail.

Several articles in the January 2006 issue, for instance Marsh and Stanford, and Minato have focused on fast neutron reactors. These have the advantage of using all of the uranium, not just the 0.7% which is 235U. Also thorium becomes available as a fertile material. Hence fission breeders have the capability of powering civilization for thousands of years into the future. Also fission breeder technology is much nearer at hand than fusion technology, even if fusion were to embrace the hybrid.

This author certainly has neither the expertise nor experience to do a careful comparison of fission versus fusion breeding. However the fusion breeder could have a number of advantages. Among them: 1) it relies much less on fast neutron fission reactors so the fission technology is more established, simpler, and most likely cheaper; 2) the energy park has virtually no material with proliferation risk anywhere, not in the reactors (except the actinide burner), not in the raw fuel, not in the waste; 3) the fusion based system can treat most of the long lived radio nuclides much more easily than any other system; and 4) the fusion breeder will give the world experience with fusion, which might, over a much longer time, lead to a pure fusion system. Where the number of available technologies for generating the required 10-30 TW of carbon free power by mid-century is so few, this author feels that the fusion based system should receive much more attention than it has.

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Wallace Manheimer
Retired from the Naval Research Laboratory
wallymanheimer@yahoo.com, or wallace.manheimer@nrl.navy.mil
4601 North Park Avenue, #1110
Chevy Chase, MD 20815 USA

Social Responsibility and the Teaching of Quantum Mechanics

Appropriately, both as citizens and scientists, physicists have protested presenting Intelligent Design as a scientific alternative to evolution. Since Intelligent Designers and Creationists at times similarly challenge cosmological evolution, physicists are almost obliged to enter the fray.

There is, however, a social issue closer to the responsibility of physicists, and perhaps even more serious: quantum physics is increasingly and effectively invoked to promote "voodoo sciences" such as ridiculous energy-producing schemes, the justification of homeopathy, "the quantum alternative to growing old," and even contacting ghosts.

Typically such promotions start with correct statements about quantum mechanics, move to legitimate hyperbole, and then go off into complete hype. Take a recent "international hit" movie as our case in point. It's strangely titled: "What tHe #$*! Do wE (k)now!?" (It's sometimes called "What the Bleep?") Time magazine describes it as "an odd hybrid of science documentary and spiritual revelation featuring a Greek chorus of Ph.D.s and mystics talking about quantum physics." Early on, the movie tells of the uncertainty principle and illustrates it with a bouncing basketball being in several places at once. There's nothing wrong with that. Common experience with basketballs allows a layperson to recognize it as pedagogical exaggeration. But the movie gradually blends to quantum "insights" leading a woman to toss away her anti-depressant medication, to the quantum channeling of the 35,000 year-old Atlantis god, Ramtha, and on to even greater nonsense.

A layperson cannot know where the quantum physics ends and the quantum nonsense begins. And many are susceptible to being misguided. According to polls, well over half of Americans (and English) have significant belief in the reality of supernatural phenomena. Robert Park in his book, Voodoo Science: The Road from Foolishness to Fraud, puts the problem well. "Many people…seek a certainty that science cannot offer. For these people the unchanging dictates of ancient religious beliefs, or the absolute assurances of zealots, have a more powerful appeal. Paradoxically, however, their yearning for certainty is often mixed with a respect for science. They long to be told that modern science validates the teachings of some ancient scripture or New Age guru. The purveyors of pseudoscience have been quick to exploit their ambivalence." We should not underestimate how persuasively the imprimatur of physics can be used to buttress mystical notions. We physicists therefore bear a serious responsibility.

When biologists teach evolution, its human implications are right up front, even in introductory courses. A biology student, knowing what the theory says and what it does not say, is able to debate Intelligent Design's challenge to evolution. A physics student is unlikely to be similarly prepared to deal with misrepresentations of quantum physics.

The human implications of quantum mechanics that fuel popular discussion arise in the "measurement problem" and "entanglement." That's at least how we refer to these topics in a physics class, where we rarely go much beyond their mathematical formulation. These same issues are, however, legitimately discussed more broadly in terms of the nature of reality, universal connectedness, and consciousness. But we don't distract physics students with excursions into sensitive issues that extend beyond the boundaries we define for our discipline. Science historian Jed Buchwald notes: "Physicists…have long had a special loathing for admitting questions with the slightest emotional content into their professional work." A result of that attitude is that, unlike the introductory biology student able to defend evolution against Intelligent Design, even an advanced physics student may be unable to convincingly confront ridiculous extrapolations of quantum mechanics.

It's not the student's fault. For the most part, in our teaching of quantum mechanics we tacitly deny the mystery physics has encountered. We hardly mention Bohr's grappling with physics' encounter with consciousness and von Neumann's showing that the encounter is, in principle, inevitable. We ignore Einstein's life-long objection that quantum theory denies the existence of a real world. We hardly discuss the still-unresolved issues raised by Schrödinger, Wigner, Bohm, and Bell, and increasingly discussed today by many others. Not infrequently those discussions extend beyond the purely "physical." Consciousness, for example, comes up explicitly in almost all of today's proliferating interpretations of quantum mechanics. The many worlds interpretation, for example, is also referred to as the "many minds" interpretation, and a major treatment of decoherence concludes that an ultimate understanding would involve a model of consciousness.

Quantum mechanics has provided much to speculate about, and, perhaps stimulated by Bell's theorem, much of that goes well beyond current physics. Bell, for example, says it is likely that the new way of seeing things (yet to be discovered) is likely to "astonish us."

However, the typical presentation in a quantum mechanics class implies that the Copenhagen interpretation has resolved all mysteries. The Copenhagen interpretation is, of course, all we need to describe the world, for all practical purposes. And in a physics class we generally accept that practical purposes are all that need be of concern. But our physics student confronting someone inclined to take the implications of quantum mechanics to unjustified places will find Copenhagen's for-all-practical-purposes treatment an ineffective argument.

Maybe we'd like to present students with a reasonable answer for what's going on in the physical world that goes beyond merely practical purposes. We can't. The best we can do is give an honest answer. Such an honest answer need not take much class time. Even a single lecture or two can be enough to succinctly expose the mystery physics has encountered. It can explore the mystery to show the limits to our understanding and clearly identify as speculation whatever goes beyond those limits. There is little danger in speculation as long as it's understood as speculation.

Such a presentation can be done from an elementary point of view—even in a "physics for poets" class. Just because the contact of physics with such issues can be embarrassing is not a good reason to avoid it. The analogy with sex education comes to mind. We try to present the quantum mystery honestly with an emphasis on what is and what is not speculation in our book, *Quantum Enigma: Physics Encounters Consciousness*, forthcoming this spring from Oxford University Press.

Fred Kuttner and Bruce Rosenblum
Department of Physics
University of California, Santa Cruz
Santa Cruz, CA 95064
phone 831-459-2326 fax 831-459-3043
email brucero@ucsc.edu

LETTERS

Re: The Hydrogen Economy by Jeremy Rifkin Reviewed by John L. Roeder. (P&S, January 2006, pp. 17--18)

The idea of numerous small hydrogen fuel cells powering small electric generators delivering power to the network instead of large power plants feeding a distribution network has the drawback of lowered energy efficiency.

It is well-known that the percentage of energy losses of electrical machinery decrease proportionally with the fourth root of the rated power. For example: a transformer rated at 100 kVA has losses amounting to about 3 percent of the rated power. On the other hand, a transformer rated at 100,000 kVA has losses under one percent of the rated power. One thousand of 100 kVA transformers will thus have losses of 3,000 kVA while a 100,000 kVA transformer would have losses of only 1,000 kVA. This holds quite generally for electric power equipment. Small electric power aggregates are, accordingly, less efficient than the large ones. This is something of which promoters of a distributed power plant seem to be unaware.

Vladislav Bevc
Synergy Research Institute
ako@calalum.org

Education in Evaluating Theory: E.g., Evolution and Gravitation

It is amazing how much trouble one gets into trying to define a simple term like theory, because, although the word is perfectly good for describing gravity, electric fields, or quantum mechanics it seems to turn into a totally different creature when applied toward the life sciences and biology in particular. What is different between Darwin's theory of evolution and Newton's theory of universal gravitation? The answer is simple and may amaze; there are no differences in epistemology between the theory of evolution and the theory of universal gravitation, they are both valid theories supported by the structure of the scientific method.

Richard Feynman may best have put the debate to rest when he, although not talking about the debate between evolution and creationism or intelligent design but rather society in general, stated that "No government has the right to decide on the truth of scientific principles, nor to prescribe in any way the character of the questions investigated... Instead it has a duty to its citizens to maintain the freedom, to let those citizens contribute to the further adventure and the development of the human race."[1] However, it would seem at times that governments are trying to prescribe what is and what is not science; despite what scientists themselves have agreed upon.

Albert Einstein once stated that "A theory is the more impressive the greater the simplicity of its premises is, the more different kinds of things it relates, and the more extended is its area of applicability."[2] It is the sort of critical thinking required to arrive at this scientific point that may get to what is more at the heart of the issue; the ability of people to think critically and abstractly. Thinking critically and defining a term is often normal for those who are currently in universities, and perhaps even more so for those who study the sciences. There is very little ambiguity in the term theory when looked at through the eyes of the scholarly, and there is no reason why that scholarly individual must be the holder of a college or graduate degree. There is no reason to say that the holder of a high school diploma should not be able to make this kind of recognition.

In a recent article written by the Associated Press and published on www.cnn.com, the question of when another Einstein would be born was posed, and a chief point made distinction of the difference in educational training which Einstein received. "One crucial aspect of Einstein's training that is overlooked… is the years of philosophy he read as a teenager — Kant, Schopenhauer and Spinoza, among others. It taught him how to think independently and abstractly…" [3] Sadly the educational system that appears to be in the works in several states, would most certainly stifle any possibility of producing the quality independent and abstract thinkers that we as a country claim to be so essential to our future.

Which begs the question, are those who make the policies of education failing the youths of our nation? The answer unfortunately appears to be a resounding 'yes.' If we would like the citizenry of this nation to be able to look at problems and examine every side of the issue before arriving at a conclusion, we certainly must start teaching our children the basics of philosophy, critical abstract and scientific thought. While it is my personal belief that nothing short of a total overhaul of the education system in this nation featuring a curriculum based on the liberal arts is the best solution that one could arrive at, I am realistic. I understand the long held beliefs and logic behind local control of public education. However, I also think that we as a nation can provide the kind of education that would help shape such ability as illustrated by the liberal arts.

The kind of basic education that all people deserve is not simply a delusion, but is something that as the wealthiest nation in the world we surely must be able to muster. There is no reason why we should not be able to provide our children with the educational background to be able to critically read the works of Popper, Duhem, Hemple, Aristotle, Plato, or Poincaré. After all, does not the study of logic help in the study of mathematics? Does not the ability to describe and quantize what one knows help in the study of science? An education based on asking questions and seeking answers, central ideas to science and philosophy, is possibly the best way to enjoy the ultimate pleasure that lies in finding things out.

Since we as a society claim that we want the populus to be able to think critically, and demand that our children develop these skills early on, we should not allow the arguments of those who have not themselves thought critically to be overshadowing. We say time and time again that we need more art and music in our schools, yet these fall woefully by the wayside. And if we would like children to be able to know and appreciate science, the possibility of gaining that knowledge and appreciation must not be hijacked by those with agendas other than providing education.

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Thomas Hanlon
Sr. Physics Major Ripon College
hanlont@ripon.edu

Should Physicists be Defending Evolution?

In criticism of Ronald Mirman's, "Physicists should be Defending Evolution" (FPS Letter, Jan 2006), I don't think the details of the approach suggested should be adopted.

To get a disbeliever in evolution to believe, one must respect their beliefs: Attributing a "prefrontal cortex" to God, or similar nonsense, would be revealing ones ignorance of religious beliefs and ruining ones credibility.

Also, stop calling it "evolution": The correct theory is "natural selection", or "Darwinian evolution". There are any number of known incorrect theories of "evolution", including of LeClerc, Lamarck, and Lysenko.

To convince someone that evolution by natural selection is the best explanation of living species, one must (a) understand natural selection and (b) be able to present it without precipitating hatred, contempt, or ridicule.

Yes, physicists should be defending evolution by natural selection. But it isn't part of physics. Does Noether's Theorem imply the Hardy-Weinberg Law?

An understanding of evolution isn't necessarily in the skill set of a physicist — any more than good police work is in the skill set of a soldier.

John Michael Williams
Senior Adjunct Faculty
Silicon Valley Technical Institute
john@svtii.com
408-249-5331

The Question of Evolution Versus Religion Should be a Non-issue.

It is abundantly clear that life forms have evolved through the ages. Everyone is aware of the survival advantages of good genes. A religious believer must interpret the bible in a way that is consistent with scientific evidence. To do otherwise is to do a great disservice to religion as it implies that God has designed the world to deceive us.

On the other hand, a scientist who implies that the methodology of science has the potential to answer the ultimate questions of why things are as they are does a great disservice to science. This is contrary to the experience of scientists and contrary to the intuition of the general public paying for our laboratories.

For example, in the last forty years we physicists have taken great pride in "understanding" the weak interactions through the addition of a few brilliant terms to the Lagrangian of the world. Why nature has chosen to implement this particular Lagrangian is ultimately beyond the scope of physics although we can admire its symmetry and relation to other theories.

In the case of evolution, religious believers cannot prove that there are gaps in the theory that will never be closed by future scientific investigation. On the other hand, from a scientific point of view evolution proceeds through mutations which are quantum events. The timing and occurence of individual quantum events have no cause within the physical systems themselves. Even if it could be shown that all mutations leading to the evolution of man were within a few standard deviations of expectation values one can note that the physical laws that predict these expectation values were in place long before life evolved and, if they had been very slightly different, the evolution of life would have been impossible.

The current friction between science and religion could be resolved if all religious believers were willing to incorporate the results of science into their worldview (as most do) and all scientists were frank about the limitations of their methods (as most are).

Louis Clavelli,
Univ of Alabama
lclavell@bama.ua.edu

P&S Editor Has a Closed Mind

Your Ed's comment in Jan. 2006: "Anybody willing to look beyond the point of their nose will recognize that the question of supplying sufficient energy for a growing world, hungry for universal prosperity, without choking that world on the byproducts of the production and use of that energy, is the major problem at the interface between science and society." Such pointy language shows that you are exhausted and your mind is closed on this topic. You go on to mention problems associated with the use of non-greenhouse-gas-producing nuclear energy. Then you state that letters in the issue address the relation between science and religion, but seem unaware of the direct connection between this relation and the US nuclear energy program.

Nowhere in P&S have I seen mention of the fact that the mean atmospheric temperature was higher 6000 years ago than now, then cooled, and has been gradually increasing again during the last three centuries, recovering from the mini ice age of the 15th to 17th centuries. There are many articles and web sites on interglacials, and on the oscillating climate during the last hundred thousand, and hundreds of millions of years. We are now in an interglacial period. The current natural warming might continue for several centuries more. The case for human contribution to the average rate of temperature increase is based on "IT STANDS TO REASON!" arguments (steadily increasing combustion of fossil fuels, which also led Europeans to predict in the 1880s that there would be a "carbon dioxide catastrophe" by 1900), and massaged data. Support of the greenhouse model is amplified by the political availability of research grants to study it. There are two kinds of scientists, those who want to understand and solve a problem, and those who want a research grant to study it.

Reduction of the rate of consumption of petroleum will prolong the availability of petroleum, which is worthwhile, but will have negligible effect on the rate of global warming, according to unmassaged data available so far. Instead of spending billions of dollars on trying to reduce "the manmade greenhouse effect," billions should be spent on figuring out how our institutions (food and water supplies, coastal communities, . .) could adapt to higher mean temperatures and higher sea levels. For two decades I have been proposing this to governments and major industries, but nothing is done so far along these lines.

Your articles on nuclear waste and letters on science and religion are so unbalanced that none mention the fact that

Yucca Mountain is an ancient sacred place that should not be desecrated. There is more than one way of knowing. Religion is a universal characteristic of human societies. Science and spirituality are equally valid areas of enquiry. But effective methods in one of these areas cannot yet contribute to understanding in the other. Biological evolution is simply part of the much larger state of evolution in nature. In both the Big Bang and Steady State Theories of Cosmology the clock is started after Creation. There is not much left of the BBT other than its name. The SST needs more work, including a mechanism for the long-term (greater than quadrillions of years) recycling of mattergy.

P&S is a narrow advocacy publication, rather than a place for discussion toward understanding problems in science and society, and possible contributions from physics toward solutions.

It's time for a change in editorial policy, to display the open mind that characterizes worthwhile scientists.

Gordon Freeman
Tel: 780 492 3468
Chemistry Dept, University of Alberta
Edmonton T6G 2G2
k.np@ualberta.ca

REVIEWS

Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future

National Academy of Sciences, ISBN: 0-309-65463-7, 504 pages, read it at http://www.nap.edu/catalog/11463.html

This NAS committee had 20 members, including the President of my university, Rensselaer Polytechnic Institute. Senator Lamar Alexander asked (p. vii) the NAS to form a committee "to identify urgent challenges and determine specific steps to ensure that the United States maintain its leadership in science and engineering to compete successfully, prosper, and be secure in the 21st century."

Alexander's charge provokes two questions. First, would it be a good thing for the world for the U.S. to maintain its leadership? Second, is there a reasonable chance for the U.S. to maintain its leadership? The committee did not even consider my first question. While I posed it, I will not try to answer it here. The committee implies (but does not specifically state) that the answer to the second question is "yes."

The committee presented (pp. viii and ix) "four recommendations and 20 specific actions to implement them…To emphasize one or neglect another, the members decided, would substantially weaken what should be viewed as a coherent set of high-priority actions to create jobs and enhance the nation's energy supply in an era of globalization. For example, there is little benefit in producing more researchers if there are no funds to support their research." Furthermore (p. 2) "The recommendations focus on actions in K-12 education, research, higher education and economic policy…a total of 20 implementation steps for reaching the goals…."

K-12 actions include recruiting 10,000 science/math teachers each year by awarding 4-year scholarships; strengthening the skills of 250,000 teachers through additional training; and increasing the number of high school students who take AP or International Baccalaureate science and mathematics. These are ambitious goals. I question whether there are enough candidates with good skills and motivation for these programs. Would we be taking too many bright students and young adults away from other fields? And what happens to students who have been recruited if there aren't enough jobs for them? We must include establishment of a "safety net" of scholarships for retraining students for other jobs, if they can't find jobs in the fields for which they have been recruited.

The committee proposes substantial increases in governmental support for research: more support for early career researchers, and discretionary funding for "high-risk high-payoff research" in the Department of Energy. Certainly the U.S. and the world face a serious crisis in finding affordable energy. Much could be done now to help alleviate the crisis. But in my view the problems stopping action are political and social, and the NAS committee does not address these problems. I agree that further research on energy might also help.

The committee also proposes substantial increases in the number of Americans earning bachelors and higher degrees in science and engineering by granting many undergraduate scholarships and graduate fellowships. They also propose changes in visa regulations and in processing visa applications to attract and keep foreign graduate students and post-docs. My comments are the same as on the K-12 proposals: do we want and need so many more scientists and engineers? I am not competent to comment on the four actions proposed for "Incentives for Innovation."

You can see another summary of the "Gathering Storm" report in Physics Today, December, 2005, pp. 25-26. Also see Shirley Ann Jackson's presidential address to AAAS, in

Science, 310, 1634, 2005. Jackson explores the interaction between science and society, and supports the Vannevar Bush model which leads to the recommendations of “Gathering Storm.” But I believe we must undertake a fundamental reexamination of our economy and technology. Jackson assumes the validity of the Vannevar Bush model for the 21st century--after all, it worked well in the 20th century. I don’t claim to have better answers, but I want to continue asking “are we on the right track?” Of course, Senator Alexander’s charge to the committee answered this affirmatively.

I contrast the NAS report to Jared Diamond’s recent book Collapse: How Societies Choose to Fail or Succeed. Of course Diamond’s book is a better read--the only book-by-committee that I know of that has a good style is the King James Bible. Regarding the relative merits of the NAS report and Collapse, Diamond begins by discussing problems in the Bitterroot Valley in southwest Montana. That society hasn’t collapsed yet, but its problems are severe. Diamond then examines many different societies, some that collapsed, and others which managed to survive. He tries to discern the characteristics that led to collapse on the one hand, or survival (with modifications!) on the other. Diamond makes a good start towards answering my question, “are we on the right track?” The NAS report, unfortunately, doesn’t.

Joe Levinger
Rensselaer Polytechnic Institute
e-mail levinj@rpi.edu

The Republican War on Science

By Chris Mooney, Basic Books, New York, 2005, ix+342 pp., hardcover, $24.95, ISBN 0-465-04675-4

Did you know that:

- The “more than sixty” embryonic stem cell lines whose existence President Bush asserted on August 9, 2001 – or is it twenty-two as later amended – are sufficient raw material for any research, and anyway adult stem cells are just as useful or better for the same research?
- Though it has never met the challenges of a realistic test, the Strategic Defense Initiative system now being deployed will defend us against a swarm of enemy missiles from a major nuclear power – or at least a few missiles from North Korea – or maybe one stray missile launched by a terrorist group?
- Women who have undergone abortions have an increased likelihood of contracting breast cancer and mental illness?
- Condoms are ineffective in protecting against STDs or pregnancy?
- “Morning-after”contraception encourages promiscuity?
- Global warming is not taking place, or if it is, it does not present a serious problem, or if it does, the cause is not anthropogenic?
- Biological evolution is a failed or incomplete theory, and must be replaced or at least supplemented by intelligent-design creationism in K-12 public education?

Every one of these statements, and a lot more like them, is false or is, at the least, contradicted by the overwhelming evidence-based consensus of the community of scientists specializing in the relevant area. And every one of them is the official position of the current Bush administration, or of its allies in Congress, or of a government agency or panel.

Careful selection of facts, sources, or opinions to suit a predetermined policy is common currency in politics, and science has never been immune to this process. The author gives examples from earlier administrations, both Republican and (to a lesser extent) Democratic. But, as the author demonstrates in extenso, misuse of science in the service of politics showed an initial surge during the Reagan administration, and has reached levels previously unimaginable since the 2000 election.

In this much-needed book, Chris Mooney, a gifted and diligent investigative reporter, follows examples of scientific distortion in the name of policy from their origins in interest groups (mainly large corporations and Religious Right organizations) through the Byzantine labyrinths of Washington to establishment as government policy either in law or in administrative practice.

The author begins by defining methods of politically abusing science, which he defines as “any attempt to inappropriately undermine, alter, or otherwise interfere with the scientific process, or scientific conclusions, for political or ideological reasons.” This abuse is manifested in a multitude of ways, which the author distills into eight categories:

- Undermining science itself.
- Suppression or prepublication distortion or truncation.
- Targeting [e.g., pressuring or smearing] individual scientists.
- Rigging the process [e.g., packing scientific panels].
- Errors and misrepresentations.
- Magnifying uncertainty.

- Relying on the fringe.
- Dressing up values in scientific clothing.

In four following chapters, Mooney traces the historical development of political science abuse. He begins with the strong anti-intellectual component of the 1964 Goldwater campaign, and the Republican anger that arose when nearly all prominent scientists who spoke up opposed him on account of his nuclear brinksmanship. Subsequently, backlash to the ban on the use of DDT, the birth of the Environmental Protection Agency, and the cancellation of the SST program led to the founding of the Heritage Foundation and like groups, and to President Nixon's dissolution of the President's Scientific Advisory Committee and abolition of the office of the presidential science advisor.

The antiscience movement grew during the Reagan administration. Stung by the scientific opposition to the highly profitable Star Wars program[1]—and especially by the disastrous and false-data-ridden history of the Teller-inspired X-ray laser–the movement found new allies in the Religious Right, whose incorporation into the GOP coalition was perhaps Reagan's most brilliant achievement. As governor of California, Reagan had nearly succeeded in introducing creationism into the K-12 public school curriculum, and he continued to imply that he supported creationist and other Religious Right measures.

With the coming of the Gingrich Revolution of 1994, science abuse reached new levels. The highly competent, nonpartisan congressional Office of Technology Assessment was abolished in what Mooney calls "a stunning act of self-lobotomy." Subsequently, such scientific information as individual members of Congress could acquire was wont to come from lobbying organizations, and Rep. Rohrabacher of high-tech Orange County went so far as to say that "scientific truth is more likely to be found at the fringes of science than at the center."

Mooney goes on to describe the methods by which corporate and religious interests strive–with considerable success–to discredit scientific consensus that is deleterious to their goals. Those interested in the complexities of Washington political relationships and processes will enjoy threading through many examples. Among these are the battles on the harmfulness of second-hand tobacco smoke, global warming, the toxicity of agricultural pesticides and of mercury in fish, the effects of high-fat diets, the regulation of river flows tapped for irrigation, and on the Religious Right side, intelligent-design creationism, stem-cell research, sex education, and emergency contraception.

Along the way, Mooney draws vivid (though not necessarily flattering) portraits of some key players. Among them are Reagan science advisor George Keyworth, GOP tactician Frank Luntz, Sen. James Inhofe (R-OK), lobbyist Jim Tozzi, creationist Bruce Chapman of the Discovery Institute, and biologist and anti-choice crusader Joel Brind. But perhaps the saddest personal story is that of John Marburger, whose office could perhaps be best described by the title "Not Assistant to the President." A man of unusually strong background both in science and in administration, he has now had to bear publicly aired epithets such as "pathetic" and "prostitute" (voiced by Harvard psychologist Howard Gardner on the Diane Rehm show).

In a brief final chapter, Mooney proposes what might be done about the dismal current situation. Unfortunately, this is the weakest part of a very strong book. Though there are some routine specific suggestions, the author's central point seems to be, "We must also mobilize the natural defenders of Enlightenment values: scientists themselves." But if we must defend the Enlightenment—against what, the Dark Ages? —we are indeed in a pickle.

Lawrence S. Lerner
Professor Emeritus, College of Natural Sciences
California State University, Long Beach
lslerner@csulb.edu

Endnotes

[1] *I have a particularly poignant connection with SDI (Star Wars.) As an advanced graduate student in 1959-60, I participated in a Defense Department Advanced Research Projects Agency (ARPA, later DARPA) program with the acronym GLIPAR (Guide Line Identification Program for Anti-Missile Research). This six-month paper-and-pencil study brought together accomplished scientists and engineers from universities, defense-oriented corporations, and other institutions. The charge was to evaluate the practicality of long-range missile defense through 1985. In the course of the study, we considered or "invented" (on paper) essentially all of the weapons that have since been proposed, including ground-based and space-based particle accelerators, magnetic-field "domes," nuclear-tipped antimissiles, kinetic-energy weapons, nuclear cannons, high-powered optical lasers, and X-ray lasers (impressive, I think, in view of the fact that the first laser was not actually demonstrated until a few months later). The clear conclusion was that such defense would not be practicable and that countermeasures would be cheap and simple. The study cost $6 million. I suspect no one has read it since 1960; though much technology has been developed since 1985, the grounds on which our conclusions were based have not changed much. When one compares the $6 million we spent with what has been spent since then, one is appalled.*

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Forum on Physics and Society
One Physics Ellipse
College Park, Maryland 20740-3844

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Co-Editors: Al Saperstein, Physics Dept., Wayne State University, Detroit, MI 48202, 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. **Reviews Editor:** Art Hobson, ahobson@comp.uark.edu. **Electronic Media Editor:** Andrew Post-Zwicker, azwicker@pppl.gov. **Layout at APS:** Leanne Poteet, poteet@aps.org. **Web Manager for APS:** Sara Conners, conners@aps.org. ***Physics and Society* can be found on the Web at http://www.aps.org/units/fps.**