achieve gender equity as the letters in the December 2006 issue purporting to claim otherwise.

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Nuclear power challenges and alternatives

In the 1980s Long Island politicians closed and dismantled a brand new nuclear power plant at Shoreham. The reasons given were that with conservation the region didn't need a new power plant, and if the avoidance of a nuclear accident saved even one human life, closing down the plant was worth the cost. However, since then the Long Island Power Authority has built several new fossil-fuel power plants on Long Island and is now considering building one in Yaphank. Most people don't realize that burning a ton of fossil fuel puts more than a ton of toxic waste into the air: nitrogen oxides, hydrocarbons, ozone, acid rain, smog, and carbon dioxide, which is a greenhouse gas. The Environmental Protection Agency says that the toxic waste from fossil fuels kills tens of thousands of people in the US each year.

In the January 2007 issue of PHYSICS TODAY (page 13), Walter Scheider writes, "When all costs are accounted, nuclear energy is not cost-competitive with fossil energy." But fossil fuel is not the answer for the future. In that same issue (page 14), Alan Robock writes, "The most important reason why nuclear power is a bad idea is that it results in nuclear weapons proliferation." The latest nation to test nuclear weapons was North Korea. The next one may be Iran. Does anyone think they got their weapons from US power plants?

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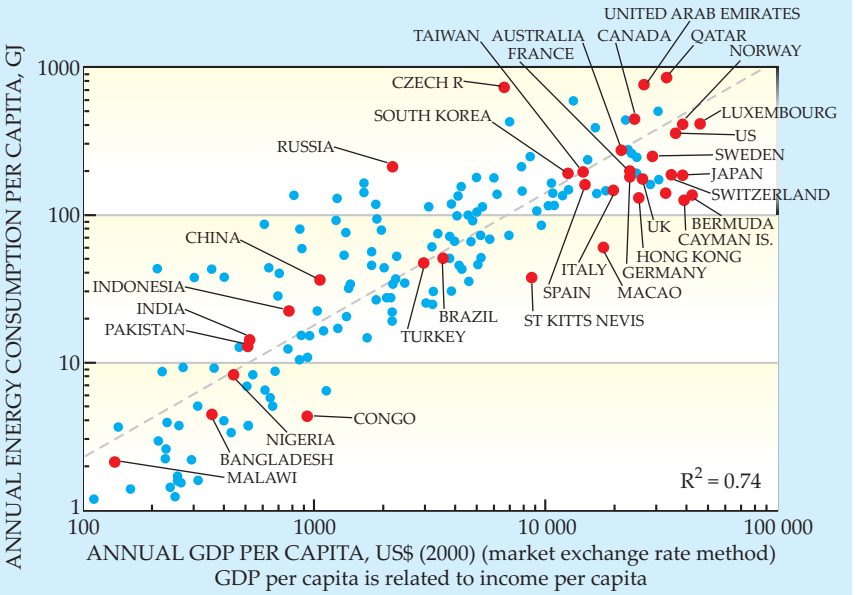
Walter Scheider and Alan Robock both write that they oppose nuclear power, largely because of safety and proliferation considerations. It would be wonderful if there were a vast, risk-free, universally agreed-on power source, but that is not the case. Yet the world needs energy. Consider the figure, compiled by mechanical engineer H. Douglas Lightfoot from information available from the US Energy Information Administration. It plots per capita energy consumption versus per capita gross domestic product. The correlation is nearly absolute; there are no points in the upper-left and lower-right corners.



Source: Energy Information Administration, *International Energy Annual 2003*, Washington, DC (8 July 2005).

Countries shown near the top of the chart have generally well-educated populations that live relatively comfortable, longer lives; people in the countries near the bottom have much less education, shorter life spans, and few comforts. Civilization can largely be defined in terms of per capita energy use. The goal of world development must be to improve the conditions of countries low on the list; this must happen if the 21st-century world is to find a measure of peace. Even if the United States were to cut its energy use in half and the rest of the world were brought up to that level, it would mean a tremendous increase in energy use.

Scheider and Robock reject nuclear power, but the alternatives are little better. Oil and natural gas will only provide energy for the planet for 20 or 30 years. Coal supplies are adequate for a long time, and China and India are rapidly developing that resource. However, coal is a heavy contributor to global warming. Wind and solar power depend on climate conditions and daylight. And biofuels require a great amount of acreage because of the extremely low efficiency of photosynthesis. By any reasonable measure, nuclear power must be an important part of the mix.

Even nuclear fuel is in very short supply—shorter than coal—for a once-through fuel cycle. Breeding nuclear fuel must play an important role in the mid to late 21st-century world. As a fusion scientist, I have advocated using fusion neutrons to breed nuclear fuel as well.[1] But if we find no new energy sources by midcentury, not only will we be unable to improve the lot of countries low on the chart, the countries now high up will begin to slide back down. Energy depletion, not nuclear power, is the real threat to civilization.

Reference

1. M. Hoffert et al., *Science* **298**, 981 (2002); W. Manheimer, *J. Fusion Energy* **25**, 121 (2006).

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The comment by Walter Scheider that Three Mile Island "remains an icon of a profit-driven industry cutting corners" echoes one by Anatoly Alexandrov, president of the Soviet Academy of Sciences and a strong supporter of the "RBMK" reactor, a particular type built only in Russia and used in the Chernobyl nuclear power plant. Alexandrov said that "such an accident [as TMI] can only happen in America where they put profits ahead of safety." Lecturing in Dubna, Moscow, and Gatchina just after TMI, I told listeners that if they believed Alexandrov, they were condemned to have a serious accident in the country within a decade. Alas, I was right. The centrally planned economy of the Soviet Union did far worse in ensuring safety than the US, and the Chernobyl accident occurred.

The profit motive, if suitably guided by good analysis tools, can enhance safety. Fortunately, we now have "risk-informed regulation."

Much of the improvement in safety since TMI has been profit driven. It was the industry that set up the Institute of Nuclear Power Operations and the

World Association of Nuclear Operators. Those organizations set safety targets and guidelines and put pressure on members to follow them. Analysis by the Nuclear Regulatory Commission and university groups strongly suggests that if the safety targets and procedures, guided by a rigorous analysis, are met, the reactor will be safer. Other than closing it, the safest way to operate a power plant is to have it running smoothly and continuously. That is also the most profitable, so the requirements of safety and profitability tend to coincide; the analysis spotlights those areas where they do not. Industry efforts have increased plant availability from 60% in the 1970s to 92% today.

The cost of nuclear power to the consumer depends very much on public acceptance, and it is the antinuclear movement that has set up the expensive, often unscientific roadblocks to that acceptance. There are signs that improved plant performance in the past 20 years has increased public acceptance and therefore profitability.[1] However, few utility company presidents would order a new nuclear power plant today without some assurance that past roadblocks will not be reinstituted.

Although disposal of the waste from nuclear fission is a problem, it is a much smaller one than the disposal of carbon dioxide from burning coal. That waste can produce the climate change that is Alan Robock's professional concern. But his stated opinion that "the waste disposal problem is not solvable in the near future" can only apply to the political problem rather than to the scientific one. Independent committees agree that a technical solution is possible. Political maneuvers in late 2005 delayed or prevented the temporary storage of nuclear waste on the Goshute Indian Reservation in Utah. It is but one example of the political impasses that delay the storage of nuclear waste material. The funding cut in December 2006 for the US Department of Energy's presentation of the case for the Yucca Mountain nuclear waste repository is another.

Scheider and the authors of the references he quoted incorrectly blame the power company for the confusion at TMI. However, neither the Associated Press nor any major newspaper accurately quoted the press releases from the Nuclear Regulatory Commission. From noon on the day of the accident, I was involved in explaining events to the public, and I could say with assurance that the expressed fears were vastly overstated. I recommended that the press quote NRC press releases verbatim and then comment as they wished, but that recommendation was ignored.

A study by the European Commission (http://externe.jrc.es/index.html) states unequivocally that if coal plants were forced to pay their full external costs, they would not be built. But Scheider is right in one important respect. The lay public is not stupid, and the details of nuclear power can be explained to them. For such an explanation I recommend David Bodansky's excellent book.[2]

References

1. R. Wilson, *Int. J. Global Energy Issues* (in press).
2. D. Bodansky, *Nuclear Energy: Principles, Practices, and Prospects*, 2nd ed., Springer, New York (2004).

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I find it surprising that anyone should be considering building new nuclear power plants in the US when a simple, mature technology is available that can deliver huge amounts of clean energy without any of the headaches of nuclear power. That technology is concentrating solar power (CSP), which uses mirrors to concentrate sunlight and create heat. The heat is then used to

raise steam and drive turbines and generators, just like a conventional power station. Solar heat can be stored in melted salt or other substances so that electricity generation can continue through the night or on cloudy days. This technology has been generating electricity successfully in California since 1985, and it currently provides electricity for 100 000 homes. Plants are being planned or built in many parts of the world.

The CSP technology works best in hot deserts. But with transmission losses at only about 3% per 1000 km, transmitting solar electricity throughout the US is entirely feasible and economical with the use of highly efficient, high-voltage direct-current (HVDC) transmission lines.

Waste heat from electricity generation in a CSP plant can be used to desalinate seawater—a useful endeavor in arid regions.

The report *Trans-Mediterranean Interconnection for Concentrating Solar Power*, commissioned by the German government (available at http://www.trec-uk.org.uk/reports.htm), predicts that CSP plants in North Africa and the Middle East will become one of the cheapest sources of electricity for Europe, including the cost of transmission. A large-scale HVDC transmission grid has also been proposed by the wind energy company Airtricity to optimize the use of wind power throughout Europe.

For more information about CSP, see http://www.trec-uk.org.uk.

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Robock replies: I agree with William Morse that fossil fuels produce lots of pollution, particularly CO_2. This is why renewable sources are needed, but nuclear power is not the answer.

The first five nuclear weapons states—the US, the Soviet Union, the UK, France, and China—tried to prevent nuclear proliferation by promoting civilian nuclear power through the nuclear nonproliferation treaty. But the reactors produce plutonium, which can be used to make weapons. Therefore, while telling other countries they could not have nuclear weapons, those five nations gave them the means to do so.[1] Israel developed nuclear weapons with assistance from France. The UK, the US, and Canada helped India build its first reactor. China, the Soviet Union, and European nations aided Pakistan. Pakistan and other countries helped Iran and North Korea.

Richard Wilson is wrong in saying that the nuclear waste disposal problem is just political. Opposition is based on the legitimate concerns of neighbors who do not want the waste nearby without assurance that they will be safe, and the proposed site of Yucca Mountain has geological problems that render it unsafe.[1]

Wallace Manheimer is correct that energy is needed to provide a more comfortable life. But it can come from sources that do not emit greenhouse gases. And through regulation of the industry and a tax on carbon emissions, energy can be used much more efficiently than in the past. Coal with carbon sequestration is part of the solution; an abundant energy source is used but not allowed to produce global warming. Gerry Wolff illustrates an innovative way that solar power can be part of the solution.

We currently use the atmosphere as a sewer without paying the costs. Fossil-fuel and nuclear industries in the US are heavily subsidized by the federal government. Changes in government policy—for example, vehicle mileage standards—and allocation of resources to support efficiency; solar, wind, tidal, and wave power; cellulosic ethanol and biodiesel; and clean coal technology (with carbon sequestration) will allow us to maintain sources of energy for comfortable lives and still limit the environmental damages of global warming. Such developments will also stimulate new businesses and technologies that we can export and will reverse the US's appalling lack of environmental leadership and global concern. That is how a superpower should behave.

Reference

1. H. Caldicott, *Nuclear Power Is Not the Answer*, New Press, New York (2006).

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Scheider replies: William Morse and Wallace Manheimer deal with future energy needs and whether there will really be no better alternative than the nuclear option. While relevant, that is beyond the scope of my original letter, which was about the legacy of the Three Mile Island accident. Scholarly works in 2004 suggest that a better grasp of why people still reflect on TMI some 28 years later might be useful in understanding, for example, Morse's reference to politicians who closed the nuclear power plant at Shoreham. Undoubtedly, their constituents' TMI-induced distrust of the industry's concern for safety outweighed their appreciation of technological fixes implemented since 1979.

Richard Wilson rightly includes the Soviet Union with my observation that the bottom line of nuclear management appears to place greater value on getting it running than on making it safe. At Chernobyl, as at TMI, the frontline crews played roulette, taking risks for the sake of what they took to be their industry superiors' priorities, to make it go and hope for the best. How else can the public interpret the failure to find the cause of a relief valve's first observed failure (at TMI) that resulted in its unrecognized failure again in the moment of crisis? One can hope that the new organizations cited by Wilson and new "safety targets and guidelines" will change the industry's maintenance ethic, but one should not be surprised if the public remains skeptical.

It's a chump's choice between the release of toxic fossil-fuel waste and the risk of a catastrophic nuclear accident. Who will give odds on the risk? The best objective hint is the periodic descent of the nuclear lobby upon Congress every time the Price-Anderson legislation by which your taxes insure the industry against liability exceeding $9 billion comes up for renewal.

I deny Wallace Manheimer's claim that I reject nuclear power. I reject systemic risks of nuclear accidents. I like Carlo Rubbia's simple and nearly foolproof thorium-fueled, proton-beam-primed reactor.[1] Why is the industry proposing, instead, to mix thorium in conventional reactors where it is primed by excess reactivity of uranium or plutonium? Because the money isn't there to develop Rubbia's idea. Nor, equally regrettably, is money flowing to Gerry Wolff's proposal and others like it.

Reference

1. R. L. Garwin, G. Charpak, *Megawatts and Megatons: The Future of Nuclear Power and Nuclear Weapons*, Knopf, New York (2001), p. 153. See also the article from the April/May 1995 issue of the CERN Courier, http://einstein.unh.edu/FWHersman/energy_amplifier.html.

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Unwired energy questions asked, answered

The "Unwired Energy" Update item (PHYSICS TODAY, January 2007, page 26) reports a wireless energy-transmission system working over a few meters, proposed by Marin Soljačić, Aristeidis Karalis, and John Joannopoulos of MIT.

The item concludes with the state-