VOLUME 8, NUMBER 1 NOVEMBER 1999
Science for Democratic Action
AN IEER PUBLICATION

Wind Versus Plutonium: A Comparison

BY ARJUN MAKHIJANI
Based on the 1999 IEER Report by Marc Fioravanti, *Wind Power Versus Plutonium*[1]

In theory, wind or plutonium could provide a long-term energy source for humanity. Plutonium has evident proliferation and environmental liabilities, which have been documented in many IEER publications.[2] Long-term economics therefore would seem to be the only factor favoring plutonium. In order to examine this factor in detail, IEER prepared a study comparing plutonium and wind as energy sources, which included a case study on Japan. We chose Japan because it has a relatively low potential for land-based wind energy and a high-population density. If we leave aside the question of consequences of accidents, the land requirements of wind energy are considerably larger than for a plutonium economy. Hence, if the economic comparison turned out favorably for wind, the conclusion could be generalized to many other countries and areas relatively easily.

IEER used offshore wind power technology in its comparisons because placing turbines offshore addresses many of the environmental issues that have been raised with wind power. Specifically, this option can be used in countries and areas with severe land constraints, such as Japan. Offshore wind power plants have been successfully operated in Denmark, Germany, and Sweden, starting in 1991.

Over the past half a century, huge amounts of resources have been spent worldwide in developing plutonium as an energy source while the efforts to develop wind power have been far more meager. Tens of billions of dollars have been spent on breeder reactors alone. These reactors convert non-fissile uranium-238, which is relatively plentiful in nature but not a useful reactor fuel, to fissile plutonium-239, at a rate that yields a net increase supply of fissile material due to reactor operation. Additional tens of billions of dollars have been spent on reprocessing, a technology used to separate and recover plutonium from irradiated reactor fuel. Yet, plutonium is nowhere near commercialization. Even Electricité de France, the world's largest user of plutonium (MOX) fuel, and British Nuclear Fuels Limited, the British reprocessing company, attribute a zero value to their plutonium stocks.

There is no commercially viable plutonium breeder reactor program in any

SEE **WIND VERSUS PLUTONIUM** PAGE 7
ENDNOTES, PAGE 9

VESTAS WIND SYSTEMS

Wind turbine at Tunø Knob, the second offshore windfarm built in Denmark. Tunø Knob, commissioned in 1995, was built in a former naval shooting range. (Greenpeace International)

EDITORIAL

End Plutonium Fuel Programs

BY ARJUN MAKHIJANI[1]

For over half a century, the nuclear establishment has promised the world energy from plutonium. It was to be plentiful in supply, lasting into the indefinite future and, in the 1950s, even "too cheap to meter." After tens of billions of dollars in research and development expenditures and little to show for it, programs for the use of plutonium must be viewed as failures.

Plutonium is now widely recognized as an uneconomic fuel. It is not competitive with uranium and is highly unlikely to be in the foreseeable future. The key plutonium fuel technology, the breeder reactor, converts uranium-238, which is not a nuclear reactor fuel, into plutonium-239, which is. However, breeder reactors have a dismal record, especially given the amounts of resources that have been poured into them. Of the 2,600 megawatts of breeder reactor capacity in the mid-1990s, almost half was in a single reactor in France,

SEE **END PLUTONIUM FUEL PROGRAMS** ON PAGE 2
ENDNOTES, PAGE 9

INSIDE

END PLUTONIUM FUEL PROGRAMS

FROM PAGE 1

Superphénix, which has since been shut (see main article on wind power on page 1).

Moreover, the process used to separate plutonium from irradiated reactor fuel, called reprocessing, is in many ways the dirtiest part of the nuclear fuel cycle. It has been responsible for extensive pollution of the seas, rivers, and soil. It has resulted in highly radioactive liquid waste, which must be stored in tanks. Among the problems posed by these tanks is the risk of catastrophic explosions, such as that which occurred in a military high-level waste tank in the Soviet Union in 1957. A complete electrical power failure at the French reprocessing plant at La Hague in April 1980 could have resulted in a similar disaster but fortunately did not because a spare generator was found offsite.

The recent accident at the Tokaimura plant, in the processing of medium-enriched uranium fuel for Japan's experimental breeder reactor, provides another illustration, if one were needed, of the immaturity of the program, despite decades of effort. Japan's regulatory system was not up to the task of ensuring that there were appropriate radiation measuring devices, evacuation plans, or worker training. It is clearly unprepared for the added burden of ensuring the safety of commercial reactors fueled with plutonium in mixed with uranium-238. (Fresh fuel containing uranium-235 and uranium-238 is currently used). A severe accident in such a reactor would imperil not only local people with fallout, but much of East Asia as well.

The use of plutonium fuel also puts weapons-usable plutonium into circulation in the commercial economy which increases proliferation dangers. Currently, there are vast quantities of plutonium stored at many sites. For instance, thirty metric tons of separated commercial plutonium sit unused in about 12,000 steel bins at the Mayak complex in Russia, raising fears that some of it might wind up in a black market. The plutonium from just two of those bins is enough to make a nuclear bomb. Now, with the Russian economy in severe distress, terrorism having reached the heart of Moscow, it is time to rapidly put plutonium into non-weapons usable forms (see *Energy and Security* No. 3 and *SDA* vol. 5 no. 4), and move on to a safer energy future.

While the nuclear establishment has been powerful enough to secure continued funding for plutonium as an energy source in several countries, despite its dismal past and prospects, the key for alternative energy sources lies in their economics. Our study on wind power shows that improvements in technology have made wind energy more economical than plutonium already, with every prospect that the relative economic advantage of wind power will continue to grow in the coming years.

Other energy technologies, notably the rapid development of fuel cells both as stationary electricity sources and for vehicles, have improved the outlook that the world can achieve economic and environmental goals simultaneously, if both goals are vigorously and sensibly pursued. Wind power and fuel cells are two of the key technologies. When they are put into the context of existing high-efficiency technologies such as cogeneration of electricity and heat or combined cycle natural gas fired power plants (see *SDA*, vol. 6 number 3, March 1998), or hybrid gasoline-electric cars (see box on page 14), it can be shown that it is possible to meet a reasonable

SEE **END PLUTONIUM FUEL PROGRAMS** ON PAGE 9
ENDNOTES, PAGE 9

Science for Democratic Action

Science for Democratic Action is published four times a year by the Institute for Energy and Environmental Research:

6935 Laurel Avenue, Suite 204
Takoma Park, MD 20912, USA
Phone: (301) 270-5500
FAX: (301) 270-3029
E-mail: ieer@ieer.org
Web address: www.ieer.org

The Institute for Energy and Environmental Research (IEER) provides the public and policy-makers with thoughtful, clear, and sound scientific and technical studies on a wide range of issues. IEER's aim is to bring scientific excellence to public policy issues to promote the democratization of science and a healthier environment.

Thank You to Our Supporters

We gratefully acknowledge our funders whose generous support has made possible our project to provide technical assistance to grassroots groups working on nuclear weapons-related issues, and our global outreach project.

W. Alton Jones Foundation • John D. and Catherine T. MacArthur Foundation • Public Welfare Foundation • C.S. Fund • Rockefeller Financial Services • John Merck Fund • Ploughshares Fund • Unitarian Universalist Veatch Program at Shelter Rock • Town Creek Foundation • Beldon II Fund • Turner Foundation • CarEth Foundation • Janelia Foundation • Stewart R. Mott Charitable Trust

Thanks also to the *SDA* readers who have become donors to IEER. Your support is deeply appreciated.

Credits for This Issue

Production: Cutting Edge Graphics

Science for Democratic Action **is free to all readers.**

Editor: Lisa Ledwidge

This letter, signed by 75 groups and individuals in 17 countries worldwide, was delivered to the National Academy of Sciences' Committee on the Biological Effects of Ionizing Radiation (BEIR VII) at its September 3, 1999 meeting in Washington, D.C. That meeting marked the beginning of a three-year project undertaken by the BEIR VII Committee to re-assess the human health risks of exposure to low-levels of ionizing radiation. The Committee's work, sponsored by the US Department of Energy, US Environmental Protection Agency, and US Nuclear Regulatory Commission, is likely to influence radiation protection standards worldwide.

***The letter remains open for signature.** It will be delivered again, with additional signatures, to the BEIR VII Committee at their next meeting, scheduled tentatively for mid-December 1999. **To sign on, contact IEER** by email or fax (ieer@ieer.org or 301-270-3029) with your name, organization (indicate if for identification purposes only), city, and state.*

ieer

INSTITUTE FOR ENERGY AND
ENVIRONMENTAL RESEARCH

September 3, 1999

Richard R. Monson M.D., Chair
c/o Rick Jostes, Staff Officer
Committee on the Health Risks from Exposure
to Low Levels of Ionizing Radiation (BEIR VII)
National Academy of Sciences
2101 Constitution Avenue, NW
Washington, D.C. 20418

Dear Dr. Monson,

We are writing in connection with your committee's work on assessing the effects of low-level radiation in the form of the Biological Effects of Ionizing Radiation (BEIR) VII review.

We are pleased that the BEIR VII Committee has set out to "consider a large amount of published data … concerning the risks to humans of exposure to low levels of ionizing radiation" (BEIR VII Project Scope). We expect that, as part of this work, the Committee will examine conflicting evidence and interpretations in the process of identifying biological effects and risk factors. We look forward to following closely the Committee's deliberations throughout this important process and to participating in them.

The work of past BEIR Committees has been influential in setting the tone and terms of the scientific debate on the issue and in the radiation standard-setting process. Therefore, we believe it is crucial that the full range of information and issues regarding the health effects of ionizing radiation be considered. The BEIR V report considered only risks of cancer, some aspects of genetic damage (though it did not estimate risks of "diseases of complex genetic origin, which are thought to comprise the largest category of genetically-related diseases," p. 4) and mental retardation arising from in-utero exposure.

It is important that the BEIR VII process address the full range of risks that have not been conclusively evaluated so far. This should include risks that have come to light since the BEIR V report (such as the combined effects of radiation and hormonally-active agents, also called endocrine disrupters) as well as issues that could have been addressed in BEIR V, but were not. We have compiled a list of some of the most crucial issues that we believe you should address. These issues are as follows:

- **Effects of radionuclides that cross the placenta:** This should include consideration of the effects on the developing fetus itself (e.g. miscarriages, malformations, and developmental effects other than mental retardation) and the effects on relevant organs at critical periods of

SEE **BEIR LETTER** ON PAGE 4

BEIR LETTER

FROM PAGE 3

fetal development. This study of health effects on the developing fetus should specifically include effects on development of specific organs, and the indirect effects of harm to organs such as the thyroid. We are especially concerned about radionuclides such as iodine-131, carbon-14, and tritium that could become part of the fetus in ways that could profoundly affect its well being. For instance, tritium, being a form of hydrogen, combines with oxygen to form water. Tritiated water behaves chemically like ordinary water. If ingested, a fraction of it becomes incorporated into the cells of the body, including genetic material. Such radioactive water also crosses the placenta. The potential for the resultant in-utero exposure to cause miscarriages, birth defects, and other health problems needs to be examined. The BEIR VII committee's evaluation of the risks of low-level radiation should include all such radionuclides and effects. If there are gaps in present knowledge, these should be identified clearly and their implications should be spelled out.

- **Effects of radiation on female fetuses:** Considering that ova are formed once per lifetime during females' fetal development, the Committee should evaluate the effects of radiation on the reproductive system of female fetuses and the possible effect of such radiation on the children of females irradiated in this way.
- **Effects of organically-bound radionuclides:** Radionuclides such as tritium or carbon-14 can become part of the DNA. Upon radioactive decay, they transmute into other elements. (Tritium becomes helium-3 and carbon-14 becomes nitrogen-14.) Such transmutation events could adversely affect the DNA. The potential health effects of such transmutations need to be evaluated.
- **Synergistic effects:** Exposure to radiation is sometimes coupled with exposure to other hazardous substances. The Committee should consider health effects caused by combined exposure to radioactive and non-radioactive substances. Special attention should be given to substances such as hormonally active agents that affect the hormonal system and the possibility that such disruption might increase the risk of cancer and other diseases arising from radiation exposure. Conversely, radiation exposure might damage the endocrine system, thereby increasing vulnerability to other disease-producing agents in the environment. The possibility of variability of such risks depending on age of exposure (and whether exposure takes place in-utero) should also be considered.
- **Data integrity and quality:** Worker dose records of the Department of Energy and its predecessor agencies in the United States, the Atomic Energy Commission, are deeply flawed. The environmental contamination records are similarly deeply flawed. We know these things about the United States because much of the raw data record has become public through lawsuits, Freedom of Information Act requests, etc. Use of studies that accept official US worker or offsite dose estimates without evaluation of the raw data is highly questionable to say the least. Since the raw data in other countries are still largely secret, there is even less reason to accept them at face value. For instance, there is evidence that the health data in the former Soviet Union are questionable. The Committee should review these and related fundamental questions of data integrity and address whether any of this record is suitable at all for assessing the risks of low-level radiation, and if so how it should be used. The Committee should also address what criteria of data quality it will apply to the information contained in the studies it reviews. In this context, we do not believe that it will be enough to simply accept peer-reviewed studies as correct if they have not evaluated the soundness of the underlying official dose and health data. Finally the impact of misclassification of radiation exposures and health outcomes and health-related selection factors, should be considered in interpreting all epidemiological studies, including studies of A-bomb survivors.
- **Effects on various populations:** The concept of "standard man" or "average" is often used to set radiation protection standards. Given the potential large variability of actual health

SEE **BEIR LETTER** ON PAGE 5

BEIR LETTER

FROM PAGE 4

effects of radiation in various populations, the Committee should assess the errors in risk estimates produced by the use of this concept. For instance, the age-dependence of the dose response relationship for various health effects should be explicitly spelled out, not only for children, but also for older age groups. Another example is the potential variation in sensitivity to low-level radiation among individuals who are otherwise of similar demographic make-up.

In many of these areas, it may be that there is simply not enough knowledge to come to reliable scientific conclusions. In such cases, the Committee should clearly and frankly say so and recommend a research agenda. If possible, this should be accompanied by qualitative discussions of the mechanisms of potential health effects. It is of crucial importance to us that all areas where risk cannot be reliably calculated are clearly identified. If the types of risk can be qualitatively ascertained, the risks should be spelled out. If even the qualitative risks cannot be assessed, that conclusion would also be very material.

We have not discussed cancer-related issues above because we are presuming that the Committee will address the full range of relevant literature in regard to carcinogenic effects. It would be helpful if the committee published and updated frequently a list of the publications that it is reviewing, so that we may be able to follow the review and add to that list, should we feel that to be necessary or desirable.

We look forward to providing scientific input throughout the BEIR VII process and expect that the Committee will fully address the issues we have raised as seriously as it might were those same issues raised by a member of the Committee.

We appreciate the opportunity for public comment and ask that it be expanded as needed to fully accommodate the issues and evidence that we want to put forth. We look forward to your response. Do let us know if you have any questions or need more information. Please address your questions or responses to Lisa Ledwidge or Arjun Makhijani. Thank you very much.

Sincerely,

Lisa Ledwidge, Outreach Coordinator, ieer@ieer.org
Arjun Makhijani, Ph.D., President, arjun@ieer.org

OTHER SIGNATORIES:

David E. Adelman, Natural Resources Defense Council, Washington, D.C., USA
Glenn Alcalay, Co-chair, National Committee for Radiation Victims, New York, New York, USA
Jennifer Aldrich, Executive Director, Physicians for Social Responsibility/ Oregon, Portland, Oregon, USA
Dave Andrews, Vice Chair, Campaign for Nuclear Disarmament, Wales, UK
Didier Anger, le CRILAN, France
Paulette Anger, le CRILAN, France
Caron Balkany, Concerned Citizens for Nuclear Safety*, Santa Fe, New Mexico, USA
Dan Becker, Director, Global Warming and Energy Programs, Sierra Club, Washington, D.C., USA
Rosalie Bertell, Ph.D., GNSH, President, International Institute of Concern for Public Health, Toronto, Ontario, Canada
Patricia T. Birnie, Chair, GE Stockholders' Alliance, and Chair, Environment Committee, Women's International League for Peace and Freedom, Tucson, Arizona, USA
Philippe Brousse, Secrétariat du Réseau "Sortir du nucléaire," Lyon, France
Elizabeth Brown, East Bay Peace Action, Albany, California, USA
Kateri Caron, Spokane, Washington, USA
Vina Colley, Portsmouth/Piketon Residents for Environmental Safety and Security, McDermott, Ohio, USA
Professor David Close, Department of Physics, East Tennessee State University, USA
Mary Byrd Davis, Uranium Enrichment Project of Earth Island Institute, Georgetown, Kentucky, USA
Cyndy deBruler Executive Director, Columbia River United, Hood River, Oregon, USA
Greg deBruler, White Salmon, Washington, USA
Anushka Drescher, Ph.D., Berkeley, California, USA
Gordon Edwards, Ph.D., President, Canadian Coalition for Nuclear Responsibility, Montreal, Quebec, Canada
Nader Entessar, Professor of Political Science & International Studies, Spring Hill College*, Mobile, Alabama, USA
Cathey E. Falvo, M.D., M.P.H., Program Director, International & Public Health Graduate School of Health Sciences, New York Medical College*, Valhalla, New York, New York, USA

SEE **BEIR LETTER** ON PAGE 6

BEIR LETTER

FROM PAGE 5

Ansar Fayyazuddin, Assistant Professor of Physics, Stockholm University, Stockholm, Sweden
Martin Forwood and Janine Allis-Smith, CORE (Cumbrians Opposed to a Radioactive Environment), Barrow-in-Furness, Cumbria, UK
Michel Fremont, le CRILAN, France
Surendra Gadekar, ANUMUKTI, Vedchhi, India
Sanghamitra Gadekar, ANUMUKTI, Vedchhi, India
Ann Harris, Director, We The People, Inc., of Tennessee, and Executive Director, Alliance for Public Health & Safety, Ten Mile, Tennessee, USA
Ruth M. Heifetz, M.D., M.P.H., Senior Lecturer, Department of Family and Preventive Medicine, School of Medicine, University of California-San Diego*, San Diego, California, USA
Ira Helfand, M.D., Co-Founder and Past President, Physicians for Social Responsibility, USA
Felicity Hill, Director, U.N. Office for Women's International League for Peace and Freedom, New York, USA
Laura Hunter, Environmental Health Coalition, San Diego, California, USA
Joe Jaffe, retired physicist, San Diego, California, USA
Carol Jahnkow, Executive Director, Peace Resource Center of San Diego, San Diego, California, USA
Chuck Johnson, Director, Center for Energy Research, Salem, Oregon, USA
Judith Johnsrud, Director, Environmental Coalition on Nuclear Power, State College, Pennsylvania, USA
Deb Katz, Citizens Awareness Network, Shelbourne Falls, Massachusetts, USA
Robin Klein, President, Hanford Action of Oregon, Portland, Oregon, USA
Prof. Dr. Wolfgang Koehnlein, President, German Society for Radiation Protection, and Institut fuer Strahlenbiologie, Westfaelische Wilhelms-Universitaet, Muenster, Germany
Cathy Lemar, Military Toxics Project, Lewiston, Maine, USA
Bernard Lindberg, Chairperson, Mankato Area Environmentalists, Mankato, Minnesota, USA
John Loretz, Executive Editor, Medicine and Global Survival*, Cambridge, Massachusetts, USA
Michael J. Manetas, Department of Environmental Resources Engineering, Humboldt State University, Arcata, California, USA
Robert A. McFarlane, M.D., Clinical Professor Emeritus of Surgery, Oregon Health Sciences University, Portland, Oregon, USA
Janot Mendler, Director for Operations, GEF/UNDP International Waters:LEARN*, Boston, Massachusetts, USA
Robin Mills, Director, Maryland Safe Energy Coalition, Baltimore, Maryland, USA
Giorgio Nebbia, Professor Emeritus, Faculty of Economics, University of Bari*, Italy
Dale D. Nesbitt, Staff scientist, Lawrence Berkeley National Lab, Retired, California, USA
Andi Nidecker, Associate Professor, University of Basel, and Executive Council, Swiss Chapter of Physicians for Social Responsibility and International Physicians for the Prevention of Nuclear War, Switzerland
Baku Nishio and Hideyuki Ban, Co-directors, Citizens' Nuclear Information Center, Tokyo, Japan
Rudi H. Nussbaum, Ph.D., Professor Emeritus, Portland State University, for Northwest Radiation Health Alliance, Portland, Oregon, USA
Sonya Ostrom, Metro New York Peace Action Council, Brooklyn Heights Peace Action, Eastside Peace Action, Flatbush Peace Action, Greenwich Village Coalition for Peaceful Priorities, NOBSAC (North Bronx Social Action Committee), Shorefront Peace Committee, SNAP (Stop Nuclear Arms Proliferation), and Westside Peace Action, New York, New York, USA
David Ozonoff, M.D., M.P.H., Professor and Chair, Department of Environmental Health, Boston University School of Public Health, Boston, Massachusetts, USA
Perline, Ph.D., engineer and physicist, Paris, France
Carolyn Raffensperger, Science and Environmental Health Network, Windsor, North Dakota, USA
Bruce Reznik, Executive Director, San Diego BayKeeper, San Diego, California, USA
Norman Rubin, Director of Nuclear Research and Senior Policy Analyst, Energy Probe, Toronto, Ontario, Canada
Gladys Schmitz, Vice-chairperson, Mankato Area Environmentalists, Mankato, Minnesota, USA
Betty Schroeder, Co-Chair, Arizona Safe Energy Coalition, Tucson, Arizona, USA
Monique Sené, GSIEN, Orsay, France
Victor W. Sidel, M.D., Professor of Social Medicine, Albert Einstein College of Medicine, Bronx, New York, USA
Pamela Sihvola, Co-chair, Committee to Minimize Toxic Waste, California, USA
Norma Sullivan, retired college English professor, San Diego, California, USA
Dr. Jinzaburo Takagi, Citizens' Nuclear Information Center, Tokyo, Japan
Tim Takaro, M.D., Chair, Hanford Task Force, Washington Physicians for Social Responsibility, Seattle, Washington, USA
Alyn Ware, Consultant at Large, Lawyers' Committee on Nuclear Policy, New York, New York, USA
Harvey Wasserman, Citizens Protecting Ohio, Bexley, Ohio, USA
Carroll Webber, Ph.D., Greenville, North Carolina, USA
David Crockett Williams, Coordinator, Global Peace Walk Project, and Initiator, Global Emergency Alert Response, Tehachapi, California, USA
Steve Wing, Department of Epidemiology, School of Public Health, University of North Carolina*, Chapel Hill, USA
Alexei Yablokov, Center for Russian Environmental Policy and Program for Radioactive and Nuclear Safety by International Socio-Ecological Union, Moscow, Russia
Alla Yaroshinskaya, Yaroshinskaya Ecological Charity Fund, Moscow, Russia

*Affiliation provided for identification purposes only

WIND VERSUS PLUTONIUM

FROM PAGE 1

country. The two largest operating breeder reactors in the world are in the former Soviet Union and they use uranium, not plutonium as a fuel. Breeder reactor programs have been stopped in many countries, including the United States, due to technical problems, cost, and proliferation concerns.

One dramatic example of the failure of breeder reactor was the December 1995 accident at the Monju breeder reactor in Japan, which was shut down due to a large liquid sodium leak and fire. The reactor first achieved criticality in April 1994. Another major example relates to the Superphénix, once the world's largest fast breeder reactor. On June 19, 1997, the operator of Superphénix announced that the facility, located in France, would be permanently shut down. Superphénix operated only 278 days of full-power equivalent between 1986 and 1997. Total costs of the Superphénix project were estimated at 60 billion francs (1994 francs), or about $9.1 billion, by 1996 (before the shutdown was announced).[3] The decommissioning and post-operation costs of Superphénix alone, estimated at 9.5 billion francs (about $1.4 billion), would be enough to pay the capital costs for about 825 megawatts (MW) of offshore wind power capacity. Further, given the history of the two energy sources, if the money devoted to Superphénix had been devoted to wind, the total generation of electricity would have exceeded that reactor's output by a factor of ten or more by this time.

Development of offshore wind energy resources offers the prospect of avoiding the most severe impact of land-based wind power: the use of large stretches of land for placement of wind turbines. Although offshore construction involves additional costs, these are at least partly offset by more constant winds and higher wind speeds, as well as elimination of land acquisition costs. Less turbulent winds result in less turbine wear and therefore longer turbine life. Visual impacts can be reduced or eliminated by offshore wind turbine siting. However, offshore wind turbine siting is not free of possible adverse impacts. These include potential impacts on shipping lanes and on marine ecosystems. Assessment of such impacts needs to be made an integral part of demonstration projects.

The cost of electricity from offshore wind farms has decreased over time, from about 8.8¢ to 9.9¢ per kilowatt-hour (kWh) for the first projects, to about 5.5¢ per kWh for the 1997 Bockstigen project in Sweden. The offshore wind turbines have performed well and their costs have declined substantially during the 1990s. They have also proved reliable.

By comparison, the costs of breeder reactors have not declined with time or experience, even though the very first electricity ever to be generated from a nuclear reactor was from a breeder reactor (the Experimental Breeder Reactor I at the Idaho National Engineering Laboratory in 1951). The table on this page shows a comparison of wind electricity costs with plutonium fuel use in light water reactors and in breeder reactors. The detailed assumptions underlying these calculations can be found in IEER's report at http://www.ieer.org/reports/wind/index.html.

One disadvantage of wind energy is that it is intermittent. While lower capacity utilization – that is, a smaller number of hours of operation at full power equivalent – is factored into the costs calculated above, wind energy cannot be used as the only or main source of energy without storage devices or a complementary supply from other sources (such as solar energy and biomass fuels). Further, wind energy cannot be used in road transportation

SEE **WIND VERSUS PLUTONIUM** ON PAGE 8
ENDNOTES ON PAGE 9

MEASURING ENERGY

WATT – A metric unit used to measure the rate of energy generation or consumption. One horsepower is equal to 746 watts.

MEGAWATT (MW) – A common measure of generating capacity for large power plants. Equal to one million watts.

JOULE – A metric unit of energy, equal to one watt of power operating for one second.

KILOWATT-HOUR (kWh) – A unit of energy equal to 3.6 million joules. It is the amount of energy generated by a one-kilowatt source operating for one hour.

WIND VERSUS PLUTONIUM: ELECTRICITY COSTS

Cost Component	Offshore Wind	Mixed-oxide (MOX) fuel – light water reactors	Breeder reactors
Capital cost	4.2 ¢ / kWh	3.8 ¢ / kWh	7.6 ¢ / kWh
Fuel cost (exclusive of reprocessing)	Not applicable	0.9 ¢ / kWh	0.9 ¢ / kWh
Reprocessing cost	Not applicable	0.7 ¢ / kWh	1.0 ¢ / kWh
Operating and maintenance costs	1.2 ¢ / kWh	1.5 ¢ / kWh	1.5 ¢ / kWh
Nuclear waste disposal costs for MOX spent fuel	Not applicable	0.2 ¢ / kWh	0.2 ¢ / kWh
Decommissioning costs	0.14 ¢ / kWh	0.1 ¢ / kWh	0.1 ¢ / kWh
Total	**5.54 ¢ / kWh**	**7.2 ¢ / kWh**	**11.3 ¢ / kWh**

WIND VERSUS PLUTONIUM

FROM PAGE 7

without additional investment, but same is true of plutonium.

Assuming for the sake of argument that self-sufficiency in energy is a sound goal for a country's energy policy, the most crucial aspect of the goal is having enough fuel for transportation. This is because oil is the most vulnerable to price fluctuations and supply instability, while at the same time being very difficult to replace in the short and medium term. However, replacing oil with either wind or plutonium requires major changes in the transportation system so that neither energy source holds an *a priori* advantage with respect to the goal of automotive sector energy self-sufficiency.

There are two ways to use electricity — whether from wind, plutonium or any other energy source — in automotive transportation. It must either be used to power electric vehicles or converted to hydrogen for use in vehicles powered by fuel cells (see page 10).

As a result, the use of either plutonium or wind energy in vehicular transportation would also require massive changes either by conversion to electric cars or by the use of fuel cells. Such changes are likely to be desirable in any case for reasons of efficiency, reduction of urban air pollution, and/or reduction of greenhouse gas emissions. Currently, it appears that fuel cells, which use hydrogen as a fuel, would likely be the most efficient and least polluting way to achieve the transformation of automotive transportation (see table on page 12). Hence, we compared the cost of using wind with that of using plutonium as the energy source for a fuel cell based road transport sector.

The cost of wind-derived hydrogen, based on 5¢ per kWh electricity, would be about $33 per gigajoule (GJ) for a fuel cell powered vehicle, equivalent to $1.66 per gallon for a gasoline-powered vehicle. The comparable cost of hydrogen from breeder reactors would be almost twice that ($60 per GJ), possibly more.

Our evaluation of the long-term issues associated with both wind energy and breeder reactor technology indicates that, even considering additional costs for energy storage to compensate for the intermittent nature of the wind, wind energy is more attractive than breeder reactors.

CONVERSION CHART ENERGY UNITS

IF YOU HAVE	AND YOU WANT	MULTIPLY BY
Btu	joules	1055
joules/second	Watts	1
Watts	Btu/hour	3.413
power	energy	time

WIND ENERGY UPDATE: JAPAN

In February 1999, nearly one month after IEER released its *Wind vs. Plutonium* report, the government of Japan announced the launch of a study of sea-based power generation, including offshore wind power. Japan's Ministry of International Trade and Industry and Transport Ministry are considering developing offshore windmills and other facilities that use both wind and waves to generate energy. The ministries plan to carry out research to find several sites for such sea-based power-generation facilities, and hope to begin construction around 2002. The force of the wind, fishing rights, and changes in scenery are among the criteria to be used in selecting the sites. Japan plans to increase its wind power generation capacity to 300,000 kilowatts in fiscal year 2010, from 14,000 kilowatts in fiscal year 1996.

Source: Jiji Press Ticker Service, February 6, 1999

Recommendations

Plutonium should have been written off as an energy source long ago in favor of renewable sources. The Paley Commission appointed by President Truman concluded that renewables were far more promising than nuclear power in 1952, before the era of commercial nuclear power had even begun. Plutonium fuel and breeder reactors have been the largest aspect of the failure of the nuclear power dream from every point of view. Now that wind energy, and especially offshore wind energy, is economical and available, there is no conceivable argument for continued public investment in plutonium energy technology. It should be stopped forthwith.

For energy technologies that are close to commercialization and are desirable on environmental and/or energy security grounds, public monies should be invested in a manner that encourages both performance and investment of private funds in research and development to lower costs. The installation of substantial amounts of wind power in the short-and medium-term as a way to reduce greenhouse gas emissions and achieve other environmental and non-proliferation goals is highly desirable. The question is how taxpayer and ratepayer resources should be invested so that the cost of achieving these desirable objectives is minimized.

A review of the past record of government policies to encourage wind power indicates that purchase each year by public authorities and/or utilities of pre-specified amounts of capacity by open bid would achieve the desired goals of stimulating a transition to an energy future that is environmentally sound and

SEE **WIND VERSUS PLUTONIUM** ON PAGE 9
ENDNOTES ON PAGE 9

WIND VERSUS PLUTONIUM

FROM PAGE 8

does not pose proliferation risks. The government would specify the areas, including offshore regions, in advance and private parties would bid to supply electricity over a 15 to 20 year period at specified prices. This would encourage private research and development and performance-based competitive bidding that would efficiently use public resources and systematically lower costs.

For the United States, we propose the government purchase 1,000 megawatts per year of wind capacity at least until the year 2010 at which point a major evaluation should be completed. Sites could be selected based on a number of criteria such as nature of the wind resource, regional energy needs, sites with minimal land impacts, and ecosystem impacts. The bids should require guaranteed performance over a specified period of time.

This would be somewhat analogous to the way in which leases for petroleum exploration are put up for bid in the United States, with the difference that in the case of wind the approximate size of the resource is already known. Hence contracts would be for actual delivery of wind-generated electricity (rather than exploration, which is the objective in petroleum leases).

The US Department of Energy has announced a goal of having 10,000 megawatts of wind energy on line in the United States by the year 2010. This would be achieved mainly through tax breaks and a federal program to purchase wind energy sufficient to supply 5 percent of the federal government electricity use by the year 2010. While the goal of large increases in wind capacity by 2010 is sound, the method chosen may not result in as much cost reduction as the one suggested by IEER (see IEER's wind report for a discussion).

1. *Wind Power Versus Plutonium: An Examination of Wind Energy Potential and A Comparison of Offshore Wind Energy to Plutonium Use in Japan* (IEER January, 1999) can be viewed at http://www.ieer.org/ieer/reports/wind/index.html. All references can be found in this report, unless otherwise mentioned.
2. See IEER's web page, http://www.ieer.org for publications related to plutonium.
3. Economic data in other currencies have been converted to US dollars based on purchasing power parity exchange rates.

END PLUTONIUM FUEL PROGRAMS

FROM PAGE 2

level of energy needs, reduce greenhouse gas emissions, reduce urban air pollution, and eliminate further proliferation and other security concerns associated with the present global energy system. A sound energy policy that would help achieve a relatively modest decrease in costs of key technologies is one crucial missing ingredient to enable us to link to that more desirable future.

In 1952, the Paley Commission, appointed by President Truman, judged the promise of renewable energy sources to be greater than that of nuclear power for meeting energy needs and preventing economic dislocations due to disruptions in foreign oil supply. But shortly thereafter, the US government chose to ignore that recommendation in favor of pursuing nuclear power, largely as part of its Cold War propaganda campaign.

It is well past the time when Cold War dreams of plutonium as a "magical" energy source should have been abandoned in favor of renewable energy sources and technologies that will dramatically change the efficiency of energy conversion and use. These technologies should be pursued with the same determination as nuclear energy was in the first decades of the Cold War. This time, it is a race against time. There are many indications, such as the increased frequency of severe climatic events, that the world is not yet on a course to win the battle against global warming.

It is imperative that powerful governments set aside the pork-barrel plutonium projects with which they have so long fed the nuclear establishment. A firm commitment of public resources to purchase wind power, fuel cell powered vehicles and stationary fuel cell sources, solar energy, and cogeneration for public buildings is needed by the countries with large fossil fuel and/or nuclear power programs. The best institutional vehicle for the acquisition of these technologies is for governments to adopt procurement policies that will provide a steady market for them, while encouraging competition that will enable a decrease in costs over time.

The US government needs to take far greater leadership than it has done, because the United States is by far the largest emitter of carbon dioxide, the largest generator of nuclear energy, and the largest diplomatic and financial influence in the world. Yet, so far, the US government has failed to meet its commitments on the reduction of carbon dioxide emissions made at the global environmental summit in 1992 and is not on track to meet its obligations under the Kyoto Protocol (the global treaty to reduce carbon dioxide emissions - see *SDA* vol. 6 no. 3 - which remains to be ratified by the United States Senate). In view of the promise of these technologies and of the need to play catch up as a result of these failures, an investment of five to ten billion dollars a year in renewable energy technologies, including efficient energy conversion using fuel cells, is warranted. Much of this will be returned directly in the form of reduced energy costs.

1 Based partly on Arjun Makhijani's Foreword to IEER's report on wind energy by Marc Fioravanti (see main article, page 1).

Sustainable Technology Profile: Fuel Cells

The US National Aeronautics and Space Administration (NASA) powers spacecraft with them. Computers at the First National Bank of Omaha get energy from them. Some of Chicago's public transit buses use them.

They are fuel cells. Fuel cells are electrochemical devices that produce electrical power without combustion. They generate electricity chemically, much in the manner that batteries do. But the chemicals that fuel cells use are elemental hydrogen and oxygen, and the product of the chemical reaction is water. Inputs such as natural gas can also be used, though, of course, hydrocarbon fuels would generate some level of carbon dioxide emissions.

Because fuel cells can be made highly efficient and clean, they hold great promise as an environmentally sound energy source that could help reduce greenhouse gas emissions and other pollution. The main obstacle to widespread use of fuel cells is their high cost relative to other devices for generating electricity or powering vehicles.

History

The first fuel cell was demonstrated by Sir William Groves in 1839. Groves showed that the process of electrolysis — the splitting of water into hydrogen and oxygen by the addition of an electric current — could be reversed. That is, hydrogen and oxygen could be recombined chemically to produce electricity.

SEE **FUEL CELL** ON PAGE 11

TYPES OF FUEL CELLS

Phosphoric Acid. This is the most commercially developed type of fuel cell. It is being used in such diverse applications as hospitals, nursing homes, hotels, office buildings, schools, utility power plants, and an airport terminal. Phosphoric acid fuel cells generate electricity at more than 40% efficiency — and nearly 85% if steam this fuel cell produces is used for cogeneration — compared to 30% for the most efficient internal combustion engine. Operating temperatures are in the range of 400 degrees F. These fuel cells also can be used in larger vehicles, such as buses and locomotives.

Proton Exchange Membrane. These cells operate at relatively low temperatures (about 200 degrees F), have high power density, can vary their output quickly to meet shifts in power demand, and are suited for applications, — such as in automobiles — where quick startup is required. According to the U.S. Department of Energy, "they are the primary candidates for light-duty vehicles, for buildings, and potentially for much smaller applications such as replacements for rechargeable batteries in video cameras."

Molten Carbonate. Molten carbonate fuel cells promise high fuel-to-electricity efficiencies and the ability to consume coal-based fuels. This cell operates at about 1,200 degrees F.

Solid Oxide. Another highly promising fuel cell, the solid oxide fuel cell could be used in big, high -power applications including industrial and large-scale central electricity generating stations. Some developers also see solid oxide use in motor vehicles. A 100-kilowatt test is being readied in Europe. Two small, 25-kilowatt units are already on line in Japan. A solid oxide system usually uses a hard ceramic material instead of a liquid electrolyte, allowing operating temperatures to reach 1,800 degrees F. Power generating efficiencies could reach 60%. One type of solid oxide fuel cell uses an array of meter-long tubes. Other variations include a compressed disc that resembles the top of a soup can.

Alkaline. Long used by NASA on space missions, these cells can achieve power generating efficiencies of up to 70 percent. They use alkaline potassium hydroxide as the electrolyte. Until recently they were too costly for commercial applications, but several companies are examining ways to reduce costs and improve operating flexibility.

Other Fuel Cells. *Direct methanol fuel cells (DMFC)* are a relatively new member of the fuel cell family. These cells are similar to the PEM cells in that they both use a polymer membrane as the electrolyte. However, in the DMFC, the anode catalyst itself draws the hydrogen from the liquid methanol, eliminating the need for a fuel reformer. Efficiencies of about 40% are expected with this type of fuel cell, which would typically operate at a temperature between 120-190 degrees F. Higher efficiencies are achieved at higher temperatures. *Regenerative fuel cells*, also a very young member of the fuel cell family, would be attractive as a closed-loop form of power generation. Water is separated into hydrogen and oxygen by a solar-powered electrolyser. The hydrogen and oxygen are fed into the fuel cell which generates electricity, heat and water. The water is then recirculated back to the solar-powered electrolyser and the process begins again. These types of fuel cells are currently being researched by NASA and others worldwide.

FUEL CELL

FROM PAGE 10

A few scientists and engineers labored away at the fuel cell after it was first demonstrated, but the invention of the internal combustion engine and the development of oil resource extraction infrastructure in the latter part of the 19th century left fuel cell development far behind. The expense of fuel cells further inhibited development.

Fuel cell development received a boost in the 1950s when NASA turned to fuel cells to fill the need for a compact electricity generator to power space missions. As a result of the investment, the Apollo and Gemini missions were powered by fuel cells, and today, the Space Shuttle is powered by fuel cells.

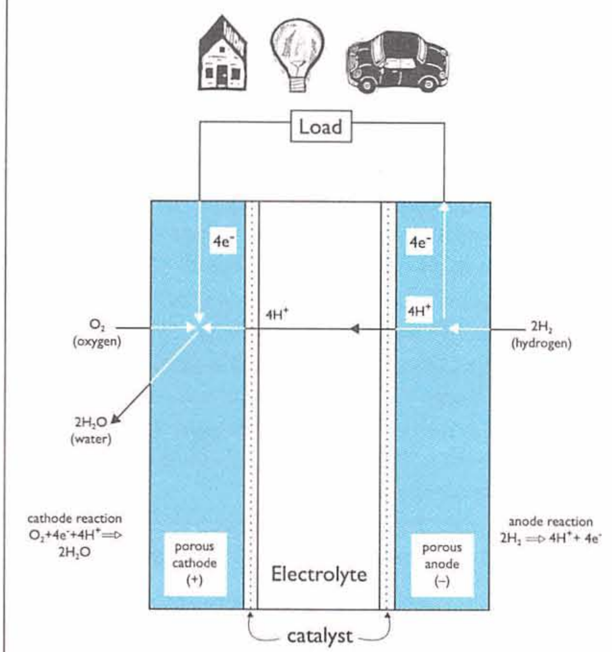
Fuel cells are still mostly experimental, but a few companies sell them commercially.[1] Only in the last decade or so have significant advances been made in commercial fuel cell technology. Some are highlighted on page 15.

How a Fuel Cell Works

Fuel cells are like batteries in that they produce electricity directly as a result of a chemical reaction. By contrast, internal combustion engines burn fuel and hence generate heat, which is then converted to mechanical energy. Unless the heat in the exhaust gases is used in some way (for example, for heating or air conditioning), internal combustion engines are quite inefficient. For instance, the efficiency of fuel cells for use in vehicles, now under development, is expected to be more than double that of current typical gasoline engines in cars.

Although both batteries and fuel cells produce electricity by electrochemical means, they serve two very different functions. A battery is an energy storage device: the electricity that it generates is the result of a chemical reaction of material that is already stored inside. A fuel cell does not store energy, but converts a part of the energy in an externally supplied fuel into electricity. In this respect, the fuel cell is more like a conventional power plant.

There are several different types of fuel cells (see box on page 10). The simplest fuel cell consists of a special membrane, known as an electrolyte. Powdery electrodes are deposited on the two opposite surfaces of the membrane. This arrangement — an electrolyte surrounded by two electrodes — comprises an individual cell. Hydrogen is added to one side (the anode), and oxygen (air) is added to the other (the cathode). At each electrode, different chemical reactions take place (see diagram, on this page).



Overall Reaction
$2H_2 + O_2 \Rightarrow 2H_2O$

At the anode, hydrogen dissociates into a mixture of protons and electrons. In some fuel cells, the electrodes are surrounded by a catalyst, usually made of platinum or some other precious metal, which facilitates this dissociation:

$$2\,H_2 ==> 4\,H^+ + 4\,e^-$$

H_2 = diatomic hydrogen molecule, the form of hydrogen in hydrogen gas
H^+ = ionized hydrogen, i.e., a proton
e^- = an electron

The key to the fuel cell is that the electrolyte allows protons to flow through it (toward the cathode), but not electrons. The electrons flow through an external pathway to the cathode. This movement of electrons constitutes an electric current, which can be used to drive a device external to the fuel cell, such as an electric motor or light bulb. Such a device goes by the generic term "load."

At the cathode side of the fuel cell, the protons (which have traveled through the electrolyte) and electrons (which have traveled through the external load) are "reunited" and react with supplied oxygen, forming water, H_2O:

$$4\,H^+ + 4\,e^- + O_2 ==> 2\,H_2O.$$

SEE **FUEL CELL** ON PAGE 12
ENDNOTES ON PAGE 15

FUEL CELL

FROM PAGE 11

The overall reaction in the fuel cell is:
$2 H_2 + O_2 ==> 2 H_2O$.

Fuel cells operate using hydrogen fuel and oxygen from the air. The hydrogen can be supplied directly or by extracting it from an external supply of fuel like natural gas, gasoline, or methanol. When the source is not hydrogen itself, it needs to be chemically converted in order to extract the hydrogen — a process called "reforming."[2] Hydrogen can also be produced from ammonia, alternative resources such as gas from landfills and wastewater treatment plants, and by water electrolysis, which uses electricity to split hydrogen and oxygen elements.[3] Most vehicle fuel cell technology currently uses methanol.

Various means have been developed to reform fuel into hydrogen for fuel cells. The US Department of Energy developed a fuel processor that works within a vehicle to reform gasoline to provide hydrogen to an on-board fuel cell.[4] A compact fuel reformer, one-tenth the size of current units, was demonstrated by researchers at Pacific Northwest National Laboratory in the US. Northwest Power Systems and Sandia National Laboratory have demonstrated a fuel reformer that converts diesel into hydrogen for fuel cells.[5]

Individual fuel cells generate about 0.7 to 1.0 volts each. To create higher voltages, cells are "stacked," that is, connected in series. To create larger currents, sets of stacked cells are connected in parallel. Combining the fuel cell stacks with a fuel processor, air supply, cooling system, and controls creates a fuel cell engine. The engine can power a vehicle, stationary power plant, or portable power generator.[6] Fuel cell engine sizes vary depending on the application, type of fuel cell, and fuel

SEE **FUEL CELL** ON PAGE 13
ENDNOTES ON PAGE 15

EMISSIONS FROM HYDROGEN FUEL CELL VEHICLES AND BATTERY-POWERED ELECTRIC VEHICLES VERSUS CONVENTIONAL VEHICLES

Estimated percentage change in criteria pollutants and greenhouse gases, relative to baseline, projected for the year 2000[a]

Vehicle	Criteria Pollutants[b]					Greenhouse gases
	Non-methane Organic Gases[c]	Carbon monoxide (CO)	Nitrogen Oxides (NOx)	Sulfur oxides (SOx)	Particulate matter (PM)	
Baseline: Gasoline-powered internal combustion engine (grams per kilometer)	*0.48*	*3.81*	*0.28*	*0.035*	*0.01*	*282.5*
Battery-Powered Electric Vehicle	-95	-99	-56	+321	+153	-37
Fuel Cell Electric Vehicle (compressed hydrogen supplied from natural gas)	-100	-100	-100	-100	-100	-65
Fuel Cell Electric Vehicle (compressed hydrogen supplied from solar power)	-100	-100	-100	-100	-100	-94
Fuel Cell or Battery-Powered Electric Vehicle (hydrogen supplied directly from solar power)	-100	-100	-100	-100	-100	-100

Source: Hydrogen Fuel Cell Vehicles, Briefing Paper, Union of Concerned Scientists, Cambridge, Mass., February 1995.

a. Figures incorporate direct emissions from vehicles plus indirect emissions from production, storage, and distribution of fuels.
b. Criteria pollutants are those regulated by the Clean Air Act: hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matter. The health effects of those pollutants include headaches, physiological stress, and respiratory damage.
c. Includes all hydrocarbons except methane.

Ballard Power Systems has chosen transit buses as the first transportation application for its fuel cell technology. Ballard's and the world's first fuel cell-powered transit bus went on the road in June 1993, a 32-foot transit bus with a 125 horsepower (90 kilowatt) Ballard® fuel cell engine fueled by hydrogen

FUEL CELL

FROM PAGE 12

used. As an example, each of the four individual 200 kilowatt stationary power plants at the bank in Omaha is about the size of a truck trailer.[7]

Applications

Fuel cells can be used to power both stationary and mobile devices. In response to tightening emissions standards in the US, auto manufacturers including DaimlerChrysler, Toyota, Ford, General Motors, Volkswagen, Honda, and Nissan are experimenting with or demonstrating vehicles powered by fuel cells. The first commercially-available fuel cell powered cars are expected to hit the road in 2004 or 2005.[8]

A significant milestone in fuel cell technology was rolled out in June 1993: Ballard Power System's 32-foot demonstration transit bus powered by a 90 kilowatt hydrogen fuel cell engine (see photograph above). Many types and generations of fuel cell passenger vehicles have been developed and operated since then using a variety of fuels. Three hydrogen fuel cell golf carts have been in use in Palm Desert, California, since late-1996. The cities of Chicago, Illinois, Vancouver, British Columbia, and Oslo, Norway are conducting field trials of public transport buses run on fuel cells. Alkaline fuel cell powered taxis are being tested on the streets of London.[9]

Stationary applications of fuel cell technology are being demonstrated but are not widely commercially available. The First National Bank of Omaha in Nebraska uses a fuel cell system to power its computers because the system is more reliable than the Bank's old one of grid-based power backed up by batteries.[10] The world's largest commercial fuel cell system, 1.2 megawatts, will soon be installed in a mail-processing center in Alaska.[11] Laptop computers, a sewage treatment plant, and vending machines powered by fuel cells are also being tested and demonstrated.[12]

Pros and Cons

Fuel cells have several benefits. While current internal combustion engines have an efficiency of only 12%-15%, that of fuel cells is approximately 50%.[13] Fuel cells can also maintain their high efficiencies when run at a fraction of their rated capacity, a significant advantage over gasoline engines.

The modular nature of fuel cells means that the capacity of a fuel cell power plant can be increased simply by adding more stacks; this minimizes underutilized capacity, allowing supply to be better matched to demand. Because the efficiency of a set of fuel cells is determined by the performance of the individual cells, small fuel cell power plants are as efficient as large ones. Also, waste heat from stationary fuel cell systems can be used for space and water heating, further increasing efficiency of energy use.

Fuel cells are virtually emissions-free. When fueled by pure hydrogen, heat and pure water vapor are the only by-products. In fact, Space Shuttle astronauts drink the water generated by on-board fuel cells.[14] Other emissions depend on the source of the hydrogen supply. Using methanol results in zero emission of nitrogen oxides and carbon monoxide and very small

SEE **FUEL CELL** ON PAGE 14
ENDNOTES ON PAGE 15

INTERNET RESOURCES ON FUEL CELLS

American Methanol Institute – http://www.methanol.org
Ballard Power Systems – http://www.ballard.com
California Fuel Cell Partnership – http://www.drivingthefuture.org
Distributed Power Coalition of America – http://www.dpc.org/
Energy Efficiency and Renewable Energy Network, US Department of Energy – http://www.eren.doe.gov/RE/hydrogen/
European Fuel Cell Forum – http://www.efcf.com/
Fuel Cells 2000 – http://www.fuelcells.org
Hydrogen & Fuel Cell Letter – http://www.hfcletter.com
ONSI Corporation – http://www.onsicorp.com
US Department of Defense Fuel Cell Demonstration Program – http://www.dodfuelcell.com
US Department of Energy Fuel Cell Program – http://www.ott.doe.gov/oaat/fuelcell.html
World Fuel Cell Council – http://members.aol.com/fuelcells/1.htm

ELECTRIC VEHICLES, HYBRIDS, AND FUEL CELLS

Most **electric vehicles** use a battery-powered electric motor as a power source. The major benefit of battery electric vehicles is zero emissions from the tailpipe. However, they do generate emissions in other ways like at the power plant during recharging and during the production of the batteries, many of which contain toxic materials. The batteries are also heavy, must be replaced every few years, and take hours to charge. The performance of battery electric vehicles has improved, but they're still far from being widely attractive.

A **hybrid electric vehicle** combines two sources of energy, such as a battery-powered electric motor and a conventional internal combustion engine. A computerized system optimizes the mix of power from the conventional engine and the electric motor depending upon driving conditions. Hybrid vehicles are far more efficient than conventional gasoline-powered cars.

Major American auto manufacturers are now developing production-feasible hybrid electric vehicles. Some are collaborating on a prototype car that would use **fuel cells** to produce energy to run the automobile's electric motor.

Sources:
Humboldt State University, Schatz Energy Research Center, http://www.humboldt.edu/~serc/faq.html, viewed October 1, 1999; *Information Please*, at http://www.infoplease.com/ipa/A0004678.html, viewed October 1, 1999; *Frequently Asked Questions (FAQ): Hypercars*, Rocky Mountain Institute, http://www.rmi.org/faq/hyperq.html, viewed October 1, 1999, *Hybrid Car*, Toyota, http://www.toyota.com, viewed October 13, 1999.

FUEL CELL

FROM PAGE 13

hydrocarbon emissions. Emissions increase going from hydrogen to methanol to gasoline, yet very low emissions would still be achieved using gasoline.[15] In any case, displacing today's conventional internal combustion engines for fuel cells would result in a net decrease of CO_2 and nitrogen oxide emissions. (See table on emissions, page 12)

Fuel cells offer added flexibility to energy infrastructures, creating opportunities for distributed generation (multiple decentralized sources of energy, which can reduce transmission losses) and off-grid markets (particularly beneficial for remote or rural areas without access to electricity lines). Fuel cells could allow individual residences or neighborhoods to generate most of their own power, and in the process greatly increase energy efficiency.

Fuel cells offer increased reliability and high-quality power. They are durable, have no movable parts, and generate a steady output of energy.

However, further development is needed on fuel cell technology to improve performance, reduce costs, and thus make fuel cells competitive with other energy technologies. It should be noted that when considering costs of energy technologies, comparisons should be based on all aspects of technology performance, including capital operating costs, emissions of pollutants, power quality, durability, decommissioning, and flexibility.

While hydrogen gas is the best fuel, the infrastructure or vehicle base for this does not yet exist. Existing fossil fuel delivery systems (gas stations, etc.) could be used in the near term to deliver a source of hydrogen in the form of gasoline, methanol, or natural gas. This would eliminate the need for special hydrogen fueling stations, but would require vehicles to have an on-board reformer to convert fossil fuels to hydrogen. The disadvantage of this approach is that it requires the use of fossil fuels and thus results in carbon dioxide emissions. Methanol, currently the leading contender, creates fewer emissions than gasoline but would require bigger on-board tanks since it takes up twice as much room for the same energy content.[17]

Unlike fossil fuel delivery systems, solar and wind electricity systems (which use electricity to create hydrogen and oxygen from water) and direct photo-conversion systems (which use semiconductor materials or enzymes to produce hydrogen) could provide a source of hydrogen without requiring a reforming step, thus without the emissions of methanol or gasoline fuel cells. The hydrogen could be stored and reconverted to electricity in a fuel cell when needed. In the long term, coupling fuel cells with such renewable energy sources is likely to be an effective strategy for providing an efficient, environmentally sound and versatile source of energy.

IEER recommends that local, state, and federal governments devote some of their vehicle procurement budgets to fuel cell powered vehicles and to stationary fuel cell systems to provide electricity and heat to some of their new or existing buildings. This will encourage development of a vital technology and reduce greenhouse gas emissions.

SEE **FUEL CELL** ON PAGE 15
ENDNOTES ON PAGE 15

RECENT ADVANCES IN FUEL CELLS

- Ballard Power Systems of Burnaby, British Columbia, Canada, has developed fuel cell assemblies that generate 25 kilowatts of power (three of these can power a sedan) and run at 85 degrees Celsius. Ballard has investment and research contracts with major automakers totaling more than US$1 billion. Ballard has teamed up with the subsidiary of a New Jersey electric company to commercialize stationary fuel cell cogeneration units.
- The California Fuel Cell Partnership — a collaboration of auto manufacturers, oil companies, a fuel cell company, and the State of California — plans to put 50 fuel cell passenger cars and buses on the road between 2000 and 2003. The Partnership also plans to build two hydrogen fueling stations in California.
- The US government owns and operates 30 fuel cell cogeneration units, the world's largest fleet of fuel cells. Among five cabinet-level departments which invest more than $100 million per year in fuel cell research and demonstration programs, the US Department of Energy spends the most, about $80 million. The governments of Canada, Japan and Germany are promoting fuel cell development with tax credits, low-interest loans and grants.
- DaimlerChrysler (formerly Daimler-Benz) has been road testing a fuel cell vehicle, the NECAR (for New Electric Car), since 1993. Using a variety of fuels, the company has already unveiled four generations of the vehicles, the latest being a hydrogen fuel cell passenger vehicle based on the company's A-class car.
- The cities of Chicago, Vancouver, and Oslo are conducting field trials of transit buses run on fuel cells. Alkaline fuel cell powered taxis are now being tested on the streets of London.
- NASA Space Shuttles use alkaline fuel cells to generate approximately 45 kilowatts of power. These particular cells are very expensive.
- A 10-kilowatt fuel cell powered vending machine was developed by Toshiba. It runs on liquefied petroleum gas.
- Researchers at Northwestern University in Illinois developed an experimental fuel cell that runs directly on natural gas.
- Scientists at Kogakuin University in Tokyo have developed a liquid fuel, reportedly consisting of metals and hydrogen, that can supply hydrogen to fuel cells without the use of a fuel reformer.
- Two companies, FuelCell Energy (formerly Energy Research Corporation) and Bath Iron Works, have partnered to develop a fuel cell power plant for defense marine applications.

Sources: Fuel Cells 2000 website, http://www.fuelcells.org, viewed September 15, 1999; California Fuel Cell Partnership website, http://www.drivingthefuture.org, viewed September 15, 1999; Fuel Cells 2000 press release, March 17, 1999; *Fuels Cell Technology Update*, Fuel Cells 2000, September 1999, http://www.fuelcells.org; Robert F. Service, "Bringing Fuel Cells Down to Earth," *Science*, Vol. 285, No. 5427, July 30, 1999, p. 684.

FUEL CELL

FROM PAGE 14

1 Schatz Energy Research Center website, Humboldt State University, http://www.humboldt.edu/~serc/faq.html, viewed October 1, 1999.

2 An experimental fuel cell that runs directly on natural gas was recently developed by a research team at Northwestern University, near Chicago, Illinois (Source: *Fuels Cell Technology Update*, Fuel Cells 2000, September 1999, http://www.fuelcells.org).

3 Ballard Power Systems website, http://www.ballard.com/faq.asp, viewed September 17, 1999.

4 *Compact Fuel Processors for Automotive Fuel Cells*, U.S. Department of Energy Pacific Northwest National Laboratory, April 1, 1999, http://www.pnl.gov/microcats/fullmenu/compfuelproc.html, viewed October 13, 1999.

5 *Fuels Cell Technology Update*, Fuel Cells 2000, September 1999, http://www.fuelcells.org.

6 Ballard Power Systems website, viewed September 17, 1999.

7 Matthew L. Wald, "Energy to Count On," *New York Times*, August 17, 1999, p. C1, C7.

8 Ballard Power Systems website, viewed September 17, 1999.

9 Fuel Cells 2000 website, http://www.fuelcells.org, viewed September 15, 1999.

10 Wald, 1999.

11 *Fuels Cell Technology Update*, September 1999.

12 Wald, 1999; *Fuels Cell Technology Update*, September 1999.

13 Schatz Energy Research Center website, viewed October 1, 1999.

14 Joe Schwarcz, "Hydrogen, the First Element: What a Blast!," *Washington Post*, September 8, 1999, page H1, H6.

15 California Fuel Cell Partnership website, http://www.drivingthefuture.org, viewed September 15, 1999; Robert F. Service, "Bringing Fuel Cells Down to Earth," *Science*, Vol. 285, No. 5427, 30 July 1999, p. 684.

16 Telephone conversation with Bernadette Geyer of Fuel Cells 2000, October 8, 1999.

17 Service, 1999, p. 684.

Dear Arjun

Dear Arjun,
What is LNTH and will it make me better?
— Baffled in Buffalo

Dear Baffled,

In olden times, LNTH was an acronym for Lavish Neighborhood of Troy in Hellas, which is the Greek word for Greece. The famous Helen of Troy lived there, but she ran off to Paris and Troy has never been the same since.

In the nuclear establishment, LNTH stands for Linear No-Threshold Hypothesis. It is a hypothesis that is used in regulatory practice to assess the cancer risk of low-level radiation. Low-level radiation is defined as a level of radiation dose that does not produce short-term observable effects like skin rash, vomiting, or high white blood cell count. Such observable (or somatic) effects are produced when a substantial radiation dose is delivered in a short time. Most somatic effects occur at doses of 100 rem or more, though white blood cell count changes occur at far lower doses. The same dose delivered over a period of weeks or months would not produce readily observable effects, except at the cellular level. Yet it could increase the risk of diseases (stochastic effects), of which cancer is the most studied.[1]

> The LNT hypothesis... states that a given increment of exposure to radiation, no matter how small, will produce the same increment of cancer risk.

Survivors of the Hiroshima and Nagasaki nuclear bombings have been intensively studied to estimate cancer risk. This has been a huge effort – more than 75,000 people have been studied for over 50 years – which is continuing. The estimates of cancer risk used in regulatory practice are largely based on the study of these survivors. However, since the survivors received rather large doses, and since their radiation dose was received over a very short period, extrapolating the risks to low dose levels delivered over long periods of time has proved controversial and difficult. Moreover, some researchers, notably the British physician, Alice Stewart, and her colleagues, have pointed out that the long-term survivors were probably among the healthier people to start with and this complicates extrapolation of cancer risk to the general population from the survivor group.

There are other sets of exposed populations. First, everyone is exposed to natural background radiation. There are also varying levels of exposure to indoor radon, which depends on house construction and on the region in which homes are located. The difficulty is that everyone is also exposed to many other risk factors, including natural and man-made environmental risks, diet, and heritable factors. Since there is a substantial rate of cancer due to all these other factors, it is very difficult to extricate the risks explicitly attributable to exposure to low-levels of man-made radiation, such as nuclear bomb fallout or radiation exposure in the workplace.

In this discussion we define cancer risk (R) as the expected value of the number of cases of cancer for a given radiation dose (D). Note that the risk of cancer incidence is about 50% greater than the risk of a fatal cancer. The various hypotheses discussed here do not specify a level of risk; they only deal with the *shape* of the curve that describes the risk in relation to dose.[2] (See the equations in the footnote.) There are other factors involved in risk determination including age and sex of the exposed person. Risk also varies by type of cancer. Specifically, risk factors for leukemia are calculated separately from risks of solid tumors, such as lung cancer and breast cancer.

The LNT hypothesis has been the commonly (though not universally) accepted way of extrapolating the risk of exposures at relatively high-levels to that at lower levels. The hypothesis states that a given increment of exposure to radiation, no matter how small, will produce the same increment of cancer risk. So if a person has a certain risk of getting cancer at one rem of exposure, his cancer risk would be doubled for an exposure of two rem, and halved at 0.5 rem. Further, if ten people collectively got one rem, their collective risk would be the same as that of one person being exposed to one rem.

Collective population exposure is expressed as person-rem, which is the sum of all individual exposures in a population. From an estimate of collective dose, one can then apply a constant risk factor to get a statistical estimate of the number of additional cancers that would result from that exposure. In US regulatory practice it is common to assume that the risk of a fatal cancer in a population equals about one excess fatal cancer for every 2,500 person-rem of exposure. Figure 1 shows the LNT hypothesis.

There are other hypotheses about the shape of the dose-response curve. The most common alternative no-

SEE **WHAT IS LNTH?** ON PAGE 17
ENDNOTES ON PAGE 18

DOSE RATE EFFECTIVENESS FACTOR

There is some evidence, mainly from animal experiments, that low radiation doses delivered at low dose rates produce a lower risk than the same dose delivered all at once. This supposed lower effectiveness of low dose rates is express by a factor called the Dose Rate Effectiveness Factor, or DREF. The adjusted risk per unit of dose for low dose rates is obtained by dividing the unadjusted risk by the DREF. It is general regulatory practice to assume that the risk from low dose rates is lower than the unadjusted risk by about a factor of 2. Hence the US Environmental Protection Agency applies a DREF of 2 to the unadjusted BEIR V cancer risk coefficient of 0.08 fatal cancers per person-sievert to get an adjusted risk of 0.04 fatal cancers per person-sievert. The latter figure is the risk factor used in current radiation protection regulation in the United States. (1 sievert = 100 rem)

WHAT IS LNTH?

FROM PAGE 16

threshold hypothesis is the "linear-quadratic" hypothesis. According to this, there is a risk term that is directly proportional to the dose (the linear term) and another proportional to the square of the dose (the quadratic term). Figure 2 illustrates a quadratic dependence of risk on dose (zero linear term).

There are those who believe that there must be a threshold below which there is no increase in cancer risk. They argue that some toxic materials exhibit such thresholds and that radiation has one too. Such thresholds may derive, for instance, from the ability of the body to repair damage caused by lower doses of radiation. Figure 3 shows a threshold hypothesis, with a linear risk response for doses higher than a threshold of T rem. However, it has been pointed out that since human beings are already exposed to natural radiation as well as other natural and artificial exposures that stress the body's repair system, the linear no-threshold hypothesis may, in any case, apply to radiation doses imposed by human activities because they are increments to other exposures. Hence, for the purposes of estimating the risks from human activities, the LNT hypothesis could still be valid and is a sound basis for public health protection.

There is also some evidence from recent experiments that low doses may produce a higher level of risk per unit of dose.[3] This is known as the supra-linear hypothesis, and is shown by Figure 4.

SEE **WHAT IS LNTH?** ON PAGE 18
ENDNOTES ON PAGE 18

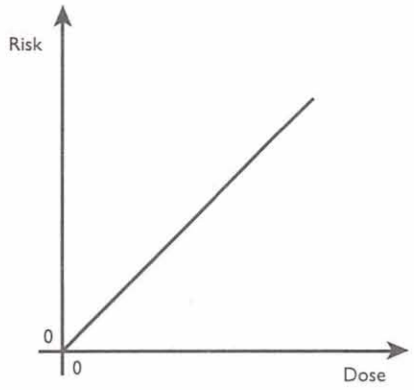


Figure 1: Linear No-Threshold hypothesis

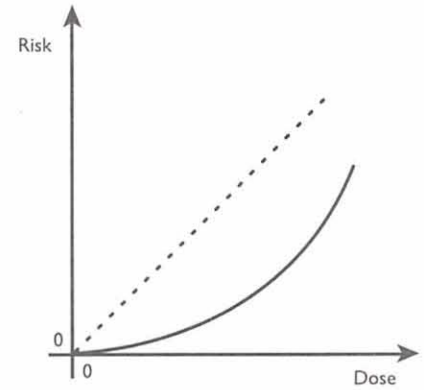


Figure 2: Quadratic Dose response

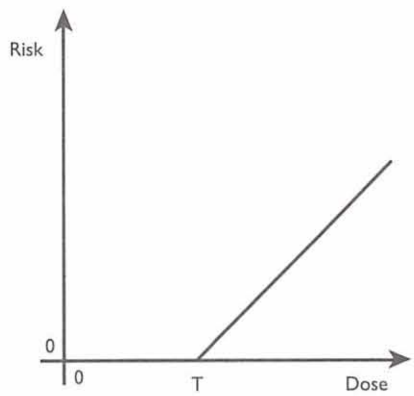


Figure 3: Threshold hypothesis

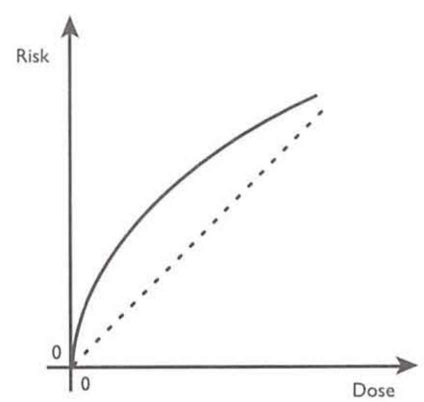


Figure 4: Supralinear hypothesis

WHAT IS LNTH?

FROM PAGE 17

Finally, there is the "hormesis" hypothesis, according to which a small amount of radiation could produce some beneficial health effects, by stimulating the immune system for instance. The main evidence put forward for this has been from experiments on mice. According to a summary of the evidence for the hormesis effect, compiled by Charles Waldren, a high dose of radiation produced fewer mutations in some circumstances if preceded by a dose in the 1 to 20 rem range. This supposed protective effect does not appear at lower or higher doses, however, and lasts only for about a day, after which it disappears. Such a hormesis effect, even if it exists in humans, has no public health significance, especially in view of the evidence for other long term risks produced by doses of a few rem.[4]

The vast majority of work on radiation risk has been focused on cancer. There are a number of other potential risks (see letter on page 3). It is possible that non-cancer risks could, at least for some people and in some circumstances, be more severe than cancer risks.

Many of those who have put forth arguments for the threshold and hormesis hypotheses have also been arguing for a relaxation of current radiation protection regulations.[5] This would be highly inappropriate for several reasons. First, there is considerable uncertainty about the health effects of low-level radiation. It is sound public health practice in such circumstances for regulations to err on the side of being more stringent. Second, the risk of radiation has, over the decades, been consistently revised upward. Even though that might not continue indefinitely, it is reason enough not to relax standards or to discard the LNT hypothesis. Third, there is evidence that the response to radiation varies widely among individuals. Standards should be set to protect the more vulnerable populations. Fourth, even if there is a threshold, it is important to remember that regulations are about additions to radiation. The linear no-threshold hypothesis would still be appropriate to assess *excess* cancer risk – that is the risk imposed by *incremental* radiation doses. Fifth, there are many non-cancer effects and synergistic effects that are not yet well researched; some are not yet researched at all. Finally, some of the potentially affected groups are among the most vulnerable to the ill effects of exposure (see letter, page 3). Stringent regulations based on a linear no-threshold hypothesis provide a modicum of protection for non-cancer risks and to vulnerable groups, until such effects can be carefully researched.

There are therefore sound reasons to continue to use the linear no-threshold hypothesis for regulatory purposes. When the questions such as the ones we have raised are answered properly, there will time enough for discussion about revising standards.

1 Low-level radiation arising from alpha particles is called "high-linear-energy transfer radiation" (high LET radiation). Its effects per unit of dose are more severe than for gamma rays and beta radiation (which is "low LET" radiation). Adding up the effects from these two different types of radiation poses a difficult scientific question, which we are not addressing in this brief article.

2 The various hypotheses for cancer risk can be mathematically expressed as follows:

LNTH: $R = k*D$, where R is the cancer risk, k is some proportionality constant, and D is the radiation dose in rem

Linear risk with a threshold dose T: $R= 0$ for $D<T$ and $R = k*(D-T)$ for $D>T$.

Linear quadratic model (no threshold): $R = k_1D + k_2D^2$ where k_1 and k_2 are the linear and quadratic risk coefficients, respectively.

Supra-linear hypothesis (no threshold): $R = k*D^n$, where $0< n < 1$.

The shapes of the curves are determined by these general equations. The values of the risks at various doses depend on the values of the parameters k, T, and n (as applicable). For further details regarding the LNTH and linear quadratic models, see Committee on Biological Effects of Ionizing Radiation, *Health Effects of Exposure to Low-levels of Ionizing Radiation (BEIR V)*, National Research Council, Washington DC, 1990, Chapter 4.

3 Brenner, D., "Did Radiobiology Play a Useful Role in the Recent BEIR VI Report?", Abstract in *Radiation Research*, Vol. 161, January, 1999, pp. 95-96.

4 Waldren, C., "Adaptive Response, Genomic Instability, and Bystander Effects," talk given to the BEIR VII committee meeting at the National Academy of Sciences, Washington, DC, September 3, 1999.

5 Jaworowski, A., "Radiation Risk and Ethics," *Physics Today*, Vol. 52, No. 9, September 1999, pp. 24-29. Jaworowski suggests a 10-fold increase in the allowed radiation dose (from 100 millirem to 1 rem per year) before "radiation-protection authorities would be required to intervene" (p. 29).

ERRATA

In *Wind Power Versus Plutonium: An Examination of Wind Energy Potential and a Comparison of Offshore Wind Energy to Plutonium Use in Japan* (IEER, January 1999), there is an error in table 22 on page 47. The costs for fuel and reprocessing should be, respectively, 0.9 and 1.0 cents per kilowatt-hour. As a result, the estimated cost of electricity from breeder reactors should be 11.3 cents per kilowatt-hour, not 11 cents. Also, the total cost of offshore wind should be 5.54 cents per kilowatt-hour. (This figure is provided to two decimal places because the cost of decommissioning, which it includes, is provided in this way.) The table on page 7 reflects these corrections. (For a list of errata in IEER publications, visit our website at http://www.ieer.org.)

Sharpen your technical skills with Dr. Egghead's
Atomic Puzzler

Gamma Does Dose and Risk

Gamma, Dr. Egghead's dog, has just learned some new equations on calculating cancer risk from exposure to radiation. Because his paws are too big to operate a calculator he needs your help in doing some sample calculations. Gamma has decided to use the linear no-threshold hypothesis in all the calculations.

Population Doses:

Remember that a population dose is the sum of doses received by all the individuals in a population. Population dose is sometimes called "collective" dose and is measured in units of person-rem or person-sievert.

1) People in a large town of 100,000 are exposed to a dose of 1 rem each. What is the population dose?
2) People in a bustling city of 1 million are exposed to a dose of 1 rem each. What is the collective dose?
3) a) The collective dose received by the citizens of a town of 10,000 was 100,000 person-rem. What was the average dose per person?

   b) Is it possible that certain persons in the town would receive more or less than the average dose?

CONVERSIONS

1 rem = 0.01 sieverts (Sv)

person-sievert = (population size) x (dose (Sv) per person)

Risk of cancer from doses:

Remember that a person-sievert is a signal to the reader that more than one person is involved. If 0.05 sievert were delivered to a population of 100, then the population dose would be 5 person-sieverts.

4) BEIR V cites a risk of 0.08 fatal cancers per person-sievert when the dose is delivered at once.
   a) What term is used to describe the number 0.08?
   b) How many sieverts would be needed to produce one fatal cancer in a population?
   c) If the population is 100,000 and the number of fatal cancers due to man-made radiation is estimated to be twenty, what was the average dose per person?
   d) If the population is 100,000 and is exposed to 0.1 Sv per person, what is the estimate of the number of fatal cancers? (The annual dose limit for the general public for non-medical radiation is 0.001 Sv)
5) If the Dose Rate Effectiveness Factor (DREF, see box on page 17) for low dose rates is assumed to be 2, and the unadjusted cancer risk is 0.08 fatal cancers/person-Sv, what is the adjusted risk?

Answers to Atomic Puzzler, *SDA* vol. 7 no. 4, July 1999, "Gamma's Cross-word Puzzle"

ACROSS:

1. bitumen
3. tanks
8. injection
11. granite
12. OSHA
15. VVER
16. plutonium
17. TWA
18. Vienne

DOWN:

2. Italy
4. shale
5. CTBT
6. ANDRA
7. NIOSH
9. NATO
10. vitrification
13. strontium
14. HEU
16. phosgene

Send us your completed atomic puzzler via fax (301-270-3029), e-mail (ieer@ieer.org), or regular mail (IEER 6935 Laurel Ave., Suite 204, Takoma Park, MD 20912 USA), postmarked by December 17, 1999. IEER will award a maximum of 25 prizes of $10 each to people who send in a completed puzzle (by the deadline), right or wrong. There is one $25 prize for a correct entry, to be drawn at random if more than one correct answer is submitted. International readers submitting answers will receive a copy of IEER's 1999 report, *Wind Power Versus Plutonium: An Examination of Wind Energy Potential and a Comparison of Offshore Wind Energy to Plutonium Use in Japan,* in lieu of a cash prize, due to exchange rates.

It pays to increase your jargon power with Dr. Egghead

1. LNTH

a. Acronym for the Lance Throwing contest in the Olympics held by King Arthur.
b. What angry spouses sometimes call each other, short for Low-down No-good Two-timing Horseface.
c. 'Lets No one Turn their Head,' a modern device prescribed by chiropractors to temporarily stabilize the necks of whiplash sufferers.
d. Linear No-Threshold Hypothesis, the generally accepted hypothesis used to explain the relationship between radiation exposure and cancer risk. Says that the effect is proportional to the dose, that a given increment of radiation exposure will produce the same increment of cancer risk at any dose, however large or small.

2. Collective Dose

a. A misspelling of collective doze: a compulsory nap required of pre-school children.
b. A new program in which a given amount of liquor or beer is equally distributed during college fraternity parties in order to reduce excessive drinking by some.
c. A socialist-inspired term in which all doses of medicine are equally distributed.
d. The summation of all doses received by all members of a given population. Often expressed in units of person-sievert or person-rem. Also called population dose.

3. Reforming

a. What the US Congress unanimously supports doing with campaign finance laws.
b. In gourmet restaurants, what is done to discarded or uneaten food before it is re-served.
c. The work done by plastic surgeons.
d. The process by which hydrogen is extracted from a substance, like methanol or gasoline, for use in a fuel cell.

4. Electrolyte

a. A Greek demi-goddess with whom Zeus fell in love.
b. A politician's misspelling of electorate.
c. Title of a song from *Chronic Town*, the musical group R.E.M.'s first album.
d. A key component of a fuel cell which allows protons but not electrons to flow through it.

5. Breeder reactor

a. A reactor in which infertile couples are placed.
b. A modern version of a chicken farm.
c. A holiday spot in Germany.
d. A reactor that is designed to produce more fissile material than it consumes; also sometimes called "fast reactor" since most breeder reactors use fast neutrons for sustaining the nuclear chain reaction.

Answers: 1. d, 2. d, 3. d, 4. d, 5. c (the never-commissioned Kalkar breeder reactor) & d

The Institute for Energy and Environmental Research
6935 Laurel Avenue, Suite 204
Takoma Park, MD 20912

Address correction requested.

NON-PROFIT
US POSTAGE
PAID
MERRIFIELD, VA
PERMIT #1112

Printed on recycled paper.

IEER PRESS