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Editor's Comments

In addition to two feature articles and two book reviews, this edition of P&S contains summaries of papers given at Forum-sponsored sessions during the APS March and April meetings held in Dallas and Anaheim, respectively. The breadth of the issues discussed in these invited talks and contributed papers is an impressive indicator of the vigorous activity of the Forum, and I encourage all members to have a look at them and to reflect on how you might become involved with Forum activities and contribute to *P&S*.

Our two feature articles for this edition concern issues very much in the science-and-society sphere. Perhaps no scientific issue will have as great an impact on society over the coming decades as energy supply. But many chemical elements crucial to energy-related technologies are in short supply or can be subject to disruptions in supply. The issue of such "Energy Critical Elements" was the subject of a recent study carried out by a joint committee of the APS and the Materials Research Society, and the results of the study are summarized in an article by its four main authors, Robert Jaffe, Jonathan Price, Murray Hitzman, and Francis Slakey. Our second feature article, by Szilard Award winner John Ahearne, describes the role of honesty, integrity, and perseverance in science; this article is based on remarks made by Dr. Ahearne at the award presentation in Anaheim. Our book reviews dealing with preparing for climate change and the physics of the Manhattan Project. Full disclosure: I am the author of the Manhattan Project book. However, I had nothing to do with the selection of the book for review or of the reviewer; these matters were handled by our very capable reviews editor, Art Hobson.

—Cameron Reed

FORUM NEWS

FPS-Hosted Sessions at the APS March Meeting

Philip Taylor and Brian Schwartz

The annual March meeting of the APS was held at the Dallas Convention Center from March 21-25, 2011. FPS hosted or co-hosted sessions on Robotics; Science, Art and Culture; and K-12 Outreach and Engagement. The following paragraphs briefly summarize the papers presented. The complete scientific program of the meeting can be found at http://meetings.aps.org/Meeting/MAR11/Content/2061. Summaries of all sessions were not available at press time.

Session P8: *The Physics, Technology, and Future of Robotics.* This session was co-sponsored with the Forum on Industrial and Applied Physics and was organized by Brian Schwartz and chaired by Philip Taylor. The session comprised four talks, each of which presented a slightly different view of the progress that physicists have helped make in robotics in the past few years. The first speaker was Randy Dumse, who was a physics student at the University of Northern Iowa and a naval officer before forming his own electronics component company in the 1980s. In a talk entitled "Where's the Physics in Robotics?" he described a problem he solved for the movie industry, which needed a method of automating the way a camera operator pans and zooms a movie camera. It was necessary to have a movable boom sturdy enough to support an elevated camera operator so that the right camera angles and distances could be achieved. With Randy's device it was possible to use a much cheaper and more agile boom that carried only the camera, while a computer automatically pointed and focused to get the desired artistic effect.

The next talk was by Paul Bouchier, a firmware architect and president of the Dallas Personal Robotics Group. His talk, "Recent Advances in Robotics and Career Opportunities for Physicists", described some of the most significant advances in robotic systems over the last year in the areas of autonomous and partly autonomous robots. Robots have been thought of as "dumber than a dog", in that they don't defend themselves, but this may be changing. Within the United States, most of the advances made outside academia are in support of national defense. We saw some amazing movies of tiny insect-like helicopters flying at great speed and with alarming precision through tiny windows. Within academia there is now a movement towards open-source robotics programs, which should do for robotics what Linux did for computing.

The third talk was "Physics and Robotic Sensing -- the good, the bad, and approaches to making it work", given by Brian Huff from the University of Texas at Arlington. He started by telling us how some of the technological advances that have benefited consumer electronics have direct application to robotics. These have resulted in a dramatic reduction in size, cost, and weight of computing systems, while simultaneously doubling computational speed every eighteen months. The same manufacturing advancements that have enabled this rapid increase in computational power are now being leveraged to produce small, powerful and cost-effective sensing technologies applicable for use in mobile robotics applications. The inertial sensors that trigger air bags to inflate in cars, for example, can provide cheap components for robotic navigation. However, despite the increase in computing and sensing resources available to today's robotic systems developers, there are sensing problems typically found in unstructured environments that continue to frustrate the widespread use of robotics and unmanned systems. As we switch from the blind one-armed robot on the production line to autonomous vehicles or automated health-maintenance devices, the need for more intelligent, inexpensive, and robust sensors grows. A particular example where this need is felt is in the effort to build expendable robots capable of clearing minefields.

Finally, Steve Rainwater of the Network Cybernetics Corporation described "Robot Competitions Around the World", of which there are now more than 1,000 every year. Some of these robots are lawnmowers, vacuum cleaners and sailboats, while some operate in the air or underwater. The goal is to make them able to assist or to compete with humans. Examples include the robotic bartender who dispenses cocktails and conversation, or the human exoskeleton that can be donned to win weightlifting competitions. Steve concluded the session with some more amazing movies showing how much progress has been made in developing robotic rats that can run through a maze at staggering speeds. The computational speed is so fast that in order to maximize the acceleration around corners it was necessary to increase the friction of the robot's wheels with the ground. This was achieved by installing under the belly of the robotic rat a vacuum pump that sucked it to the floor of the maze, and enabled accelerations much greater then that due to gravity!

Session H8: *Science, Art, and Culture.* This session was chaired by Brian Schwartz of the Graduate Center of the City University of New York and featured four talks. A review of parts of the session appeared in the Dallas Observer Blog, http://blogs.dallasobserver.com/cityofate/2011/03/physicists_probe_science_behin.php. The first speaker was David Hanson of Hanson Robotics (david@hansonrobotics.com), who spoke on "Robotics in the World of Entertainment." Hanson is a builder of robots that simulate human beings. He displayed a robotic head and upper-body based on his favorite science fiction author, Philip K. Dick, who wrote the novel on which the movie Blade Runner was based and wherein humans and robots are indistinguishable. Hanson also described a flexible material which he patented and named Frubber. The robot's face is made of Frubber, and 28 tiny motors are programmed to enable the face develop very realistic expressions. Further information can be found at http://hansonrobotics.wordpress.com/ and http://www.pbs.org/wgbh/nova/tech/social-robots.html.

The second speaker in this session was Stephen Wharton, who is an engineer and director of new technology for the Tulsa-based company Winnercomm (see stephen.wharton@skycam.tv). Wharton spoke on "XPower plus the Physics of Rodeo." Winnercomm provides technology for better visualization of sports programming for ESPN and other network sporting events. Wharton described a puck-sized sensing device he developed which can be put on the rear of a bucking bull and which measures the g-forces that a rider will experience. He showed that the data can be used to quantify the degree of difficulty of riding the bull and can be used in the scoring of bulls and bull riders. For more information, see http://www.cablecam.com/AboutUs.aspx?id=94 and http://www.usatoday.com/tech/news/techinnovations/2006-09-05-rodeo-tech_x.htm.

The third talk was titled "Singing Tesla Coils", and was presented by Joe DiPrima. DiPrima plays in the band ArcAttack that constructs Tesla coils that become part of the band's sound. Two custom engineered Tesla coils throw out electrical arcs up to twelve feet long with buzz-like sounds reminiscent of the early days of synthesizers. ArcAttack's six member band plays rhythmic instrumental melodies while a robotic drum set accompanies them. During the show, the band MC walks through the sparks of the Tesla coils wearing a thin-layer Faraday suit. For more information see http://www.arcattack.com and http://gizmodo.com/5367329/arcattack-lightning+proof-musicians-share-their-tesla-coil-secrets.

The last speaker in this session was Davey Griffen of Texas A & M University, who spoke on "The Science of Barbecue (Texas Style)." Griffin is associate professor in the Department of Animal Science at Texas A & M who is a meat specialist and teaches a course on The Art and Science of Barbeque. Davey described the different cuts of beef and why slow cooking in a moist environment helps tenderize and break up the collagen, which holds the protein muscle fibers together, by liquefying it into soft gelatin. Davey also joked that slow cooking gives the diner more time to drink beer. Davey also suggested a number of first-rate barbeque restaurants in the Dallas area. For more information see http://animalscience.tamu.edu/facultystaff/faculty/griffin.htm and http://www.nbbqa.org/_pdf/BBQ101_2009_Downloadable.pdf

These contributions have not been peer-refereed. They represent solely the view(s) of the author(s) and not necessarily the view of APS.

FPS-Hosted Sessions at the APS April Meeting

Cameron Reed and Pierce Corden

The annual April meeting of the APS was held at the Hyatt Regency Hotel in Orange County/Anaheim, CA, April 30-May 2, 2011. FPS hosted sessions on electromagnetic pulses, nuclear weapons at age 65, Forum Award recipients, deepwater drilling, the status of arms control, and science diplomacy. The following paragraphs summarize the papers presented. The complete scientific program of the meeting can be found at http://meetings.aps.org/Meeting/APR11/Content/2070. Transcripts and slides from many of the talks given at the meeting can be found at http://www.physics.wisc.edu/apsapril2011.

Session B5: *Electromagnetic Pulse Phenomena.* This session was organized by Benn Tannenbaum, chaired by Valerie Thomas, and featured three talks. The first was given by Peter Huessy of the National Defense University Foundation, who spoke on "EMP Threats to US National Security: Congressional Responses." Huessy opened his talk by stating that protection from EMPs is a matter of common national defense, and reviewed the work of the 2001 congressional Commission to Assess the Threat to the United States from Electromagnetic Pulse Attack. As a result of the commission's 2004 report, congress passed legislation to protect the electrical grid of the U.S. from such attacks; the work of the commission now continues as a congressional caucus. Among other developments, the Federal Energy Regulatory Commission has ruled that utilities can add cost of protection to their rate structures;

the cost of this is estimated to be some $200-300 million for the entire power grid. Huessy argued that such developments are an excellent example of cooperation between government, congress, the private sector and non-governmental organizations. Huessy closed by summarizing many ongoing threats in this area, such as solar storms and indications that the Iranians have tested a missile that can be used in an EMP mode.

The second speaker was Yousaf Butt of Harvard University, whose talk was titled "Nuclear EMP and Geomagnetic Threats in Context." Butt first reviewed the nature of nuclear-event electromagnetic pulses. These consist of three sub-pulses, which are termed E1, E2, and E3 pulses. E1 pulses are created by prompt gamma-rays which generate electrons by Compton scattering in the atmosphere within about a microsecond of bomb detonation. E2 pulses arise from scattered gamma-rays and persist to about 0.01 seconds after detonation; these are similar to lightning storms, and electronic devices can be protected in the same way as from such storms. E3 pulses are magnetohydrodynamic disturbances which can induce low-frequency currents in transformers over about 100 seconds. Solar Coronal Mass Ejections impacting the Earth's magnetic field can induce electric fields similar to E3 pulses; such an event took down the power gird in Quebec in 1989. Butt stated that a significant issue is that there are some 2500 large transformers in the United States, but these are typically not stockpiled and may require a year to replace. Mitigative actions could include better space weather prediction which would allow utilities to preemptively shut down transmission facilities, stockpiling of critical components, establishing backup communication links, and education of grid operators. It was Butt's opinion that the likelihood of geomagnetic storms exceeds that of nuclear EMP strikes.

In a more technical paper, third speaker Michael Dinallo of Sandia National Laboratory addressed the audience on "Nuclear Electromagnetic Pulse Review." With considerable analysis of the corresponding fundamental boundary-value electromagnetic theory, Dinallo reviewed the physics of EM pulses, covering such considerations as atmospheric conductivity, current induction in devices and above-ground wires, and coupling into outlets within buildings. He then described the results of experimental simulations on electronic devices. Detrimental effects include thermalization, metalization, breakdowns, and localized melting. Research is ongoing in areas such as civilian response (alternate communication channels), in-field shielding, materials properties, and laboratory characterization of component responses to pulses.

Session E5: *Nuclear Weapons at 65.* This session was chaired by Patricia M. Lewis and featured two talks. The first was given by Rebecca Johnson, Executive Director of the Acronym Institute for Disarmament Diplomacy in London. Johnson addressed the audience by Skype with accompanying slides; her talk was titled "Nuclear Weapons at 65: Time to Retire?" She opened by reminding listeners that the effects of nuclear weapons have spatial and temporal coverage - from prompt effects to long-term radiation exposure - more extensive than any other type of weapon. In view of this, she feels that the status quo is not realistic, and that since such weapons cannot be used to deter terrorism they should be considered criminal by being subject to humanitarian law, that they should be outlawed and abolished, and that their use should considered a war crime. She argued that it would be easier to verify a total prohibition on such weapons than a partial ban.

The second speaker was Jay Davis, Founding Director of the Defense Threat Reduction Agency and currently President of the Hertz Foundation, who spoke on "Issues for Future Nuclear Arms Control." He described how as the number of nuclear weapons in the world decreases, each successive treaty will involve more participants. Trust will have to be built among the participants, and the cost and intrusiveness of inspection regimes will necessarily increase. Eventually, states such as Israel, Iran and North Korea will have to be a part of the process. Davis suggested a number of sequential steps to bring the numbers of weapons down. First, to get to about 1,000 weapons for both the United States and Russia, declarations of reserve weapons, "tail-counting" technologies, and protocols for verification procedures would have to be developed. China, the United Kingdom, and France will likely need to be involved at this step, which Davis estimated will probably require a decade. To get down to 500 weapons, a strategy for modifying the current United States "nuclear umbrella" strategy will need to be developed; one possibility might be to count weapons according as groups of allies. At this step, which Davis estimated may take yet another decade, Israel, India, and Pakistan may have to be brought in as observers. He remarked that 500 weapons may be an appropriate point for a "long pause", as at this level nuclear weapons are still coupled to conventional weapons. At lower numbers, anti-ballistic missile systems become more credible and can upset deterrence theories. Issues at the level of 500 weapons will also involve replacement and maintenance of infrastructure, design labs, and the issue of military career motivation. To get down to 200 weapons per state, Israel, India, and Pakistan will have to be involved, and the issue of a fissile materials cutoff treaty, the nuclear fuel cycle, and dealing with rogue states will have to be addressed. An important political question for the United States will be: With whom are we willing to accept parity? At the level of 50-100 weapons, Iran and North Korea become part of the equation, and the issue of detecting small numbers of clandestine weapons will be important. Davis closed by remarking that, beyond this, it is difficult to have a clear vision: a "hard minimum" may be reached at a level of about 25 weapons per state.

Session J5: ***Forum on Physics and Society Awards Session.*** This session was chaired by outgoing Forum chair Charles Ferguson. M. Granger Morgan of Carnegie-Mellon University, the Joseph A. Burton Forum Award recipient, spoke on "How a Physics Education has Influenced Practice and Graduate Education in Technically-Focused Quantitative Policy Analysis." Morgan related how he came to appreciate in the early 1980's that virtually no risk and policy analyses made any attempt to characterize uncertainty. With a group of colleagues, he solicited input from atmospheric science experts on estimates of uncertainties associated with the health effects of sulfur pollution from coal-fired power plants. This work evolved, with the help of many students and colleagues, into developing sophisticated computer models which utilize probability-density analyses to study various policy issues. In the early 1990s, Morgan moved into the area of climate change analysis; this part of his talk was illustrated with examples of probability-distribution analyses of equilibrium changes in global average temperature offered by 16 climate experts. The results showed that different sets of plausible assumptions can give dramatically different results. In many cases, Morgan argued, the best that we can hope to do may be to describe a broad range of possible futures; substantial uncertainty within the climate-analysis community is often not reflected in reviews. In the last part of his talk he described a unique program in Engineering and Public Policy that he has developed at Carnegie-Mellon University.

The second speaker in this session was John Ahearne, a former Director of the Nuclear Regulatory Commission and the Forum's Leo Szilard Lectureship Award winner. Ahearne spoke on what he sees as the three overriding characteristics that physicists must practice: honesty, perseverance and objectivity. In the area of honesty, we all depend on the truthfulness of colleagues; without this, there will be serious damage to the progress and public credibility of science. Ahearne pointed out that scientists who are active in public policy will at times come under pressure to change their position, but argued that if you are sure of your position you should not succumb to that pressure. In the area of perseverance, there is no substitute for hard work. But perseverance, while a necessary condition for success, is not a sufficient one: the reward of a research career is through achievement, not effort alone. Ahearne illustrated this point with an example from his own career involving assessment of weaknesses of Warsaw Pact forces; this is described in more detail in his article elsewhere in this newsletter. In addressing objectivity, he reminded the audience that hope alone is not enough: the world does not behave as we wish it did. Finally, drawing from his experience in analyzing the Three Mile Island nuclear accident as Director of the Nuclear Regulatory Commission, Ahearn remarked that he learned that while scientists must scrupulously maintain their objectivity and integrity when dealing with controversial policy issues, we cannot dismiss the concerns and statements of individuals that lack technical backgrounds when dealing with risk communication.

Session Q5: ***Physics and Engineering of Deep Water Drilling.*** This session was chaired by incoming Forum chair Peter Zimmerman, and featured three presentations. The first speaker was Brian Clark, an engineer with Schlumberger, who spoke on "Physics and the Quest for Hydrocarbons." After a brief review of the nature and properties of the rock layers of the sub-sea environment and a brief description of the structure of drill rigs, Clark described the extensive role of physics applications in deepwater drilling, concentrating on heavily-instrumented "drill collars" that are used to acquire data. These devices are up to about 30 feet long and must be robust enough to withstand extreme operating conditions: pressures up to 20,000 psi, temperatures to 300 F, axial loads up to 80,000 pounds, and shocks in excess of 100 g's. A number of sensors are used to characterize the drilling environment. These include electromagnetic transmitting and receiving antenna for characterizing conductive properties of the medium, nuclear sensors for determining the density of the medium via Compton-scattering of gamma rays from a Cesium-137 source, and pulsed deuterium-tritium neutron sources used to determine the relative amounts of oil and gas in the rock strata via a thermal-neutron return signal which is affected by the hydrogen content of the medium. Instruments are powered through the flow of "drill mud" used to carry away cuttings, and data can be transmitted to remote sites for real-time analyses from which steering directions can be fed back to the drill operator.

The second talk in this session was given by Kenneth Gray of the University of Texas, who spoke on "An Introduction to Deepwater Drilling." Gray gave an extensive description of drill rigs and the sub-sea environment in which they operate. Nowadays, vertical wells are quite rare; most are horizontal or "slant" wells that may extend as far as 9 miles laterally from the rig. A single drilling platform may support 8 to 16 separate drill lines, and drills presently operate in water depths of greater than 10,000 feet with borehole depths of over 35,000 feet below the sea floor. The sea beds of the world are now populated with thousands of "completions", operating wells which direct their products to collecting vessels on the ocean surface. Operation of these wells is complicated by the presence of subsurface oceanic loop currents, which can move pipes miles from their original locations. At the depths at which drills now routinely operate, rocks can behave plastically, and engineers need to be cognizant of their material properties. Much current research in this area is being devoted to developing sophisticated numerical models of rock environments which include three-dimensional simulations of stress/strain tensors to model anisotropic and inhomogeneous media.

The last speaker in this session was Jonathan Katz of Washington University, who spoke on "Viscoelastic Muds---Top-Kill in Rapidly Flowing Wells." Following the blow-out of BP's Macondo well in the Gulf of Mexico on April 20, 2010, Katz was appointed to an advisory panel by Secretary of Steven Energy Chu. Katz reviewed the properties of viscoelastic muds, the type of synthetic, oil-based suspensions used in the "Top Kill" procedure that failed to stem the blowout. Katz had predicted from hydrodynamical considerations that turbulent mixing of the dense mud against less dense upflowing oil and gas would lead to entrainment of the mud in the fluid, with the result that it would be spat out of the well; this proved to be exactly what happened in practice. He then described laboratory experiments which have shown that a more effective surrogate mud may be a brine comprised of corn starch and water which will descend as a coherent slug through the oil and gas.

Session R5: *The Status of Arms Control.* This session was chaired by Pierce Corden of the American Association for the Advancement of Science and featured three talks. Slides from the first two talks are available at http://www.physics.wisc.edu/apsapril2011. Sidney Drell of Stanford University led off with a look-ahead to "What Happens to Deterrence as Nuclear Weapons Decrease toward Zero?" He said we need to escape from the policy of mutual assured destruction (MAD), an ineffective policy against suicidal terrorists and rogue entities. The now-number-one nuclear weapons policy priority is countering proliferation and terrorism threats. Drell cited advances in verification embodied in the New START Treaty that recently entered into force, and technical requirements for reducing arsenals to low levels. The latter include verifying warhead and delivery system numbers and nuclear materials quantities, and cooperation and transparency in non-nuclear military issues. Deterring attempts at breakout and instability in a nuclear-weapon free world are key issues. An example of how technologies can assist in this effort is the Open Skies Treaty which, enhanced with modernized sensors, including the ability to sample gaseous and particulate emissions in the atmosphere, could provide highly capable aerial observation of the entire territories of the Treaty's parties.

Marvin Adams of Texas A&M discussed "Confidence in Nuclear Weapons as Numbers Decrease and Time Since Testing Increases." Challenges in the U.S. Stockpile Stewardship Program — designed to maintain confidence in the reliability, security and safety of nuclear weapons in the non-testing environment – arise from changes that occur in weapons over time, and resulting life extension programs. Life extension involves deliberate physical changes to weapons. Stewardship Program challenges include adequacy of surveillance, workforce recruitment and retention, weapons-science work, technical foundations for assessing changes, and production capabilities. The expert judgment of scientists is indispensable. The Program is working today, but issues for the future include attracting outstanding people and maintaining an adequate non-nuclear experimental program. The technical challenges can be met, but require a sustained national commitment.

The third speaker in this session was Edward Levine, Senior Professional Staff Member, U.S. Senate Committee on Foreign Relations, who addressed "Securing Support from a Skeptical Senate for Further Strategic Arms Controls." The Senate has a Constitutional responsibility to approve treaties by a two-thirds vote. This requires bipartisan support, a challenge for arms control even when public support exists. Senators must have convincing national security reasons to agree to ratification. The Executive Branch must therefore have unified support from the military leadership. This was of particular importance for the New START Treaty. Strategic arms treaties also need the support of the directors of the Los Alamos, Livermore, and Sandia nuclear weapon laboratories. Support from the wider community of scientific experts in matters such as nuclear explosion detection, IAEA safeguards on peaceful nuclear power facilities, and nuclear security is also important. This includes groups such as JASON and the Committee on International Science and Arms Control of the National Research Council. The scientific community plays a key role in identifying the technical challenges posed by further steps in nuclear arms reductions and nonproliferation efforts, as well as possible solutions.

Session Y5: *Science Diplomacy.* This session was chaired by Harvey Newman, and featured three talks. The first, by APS President Barry C. Barish, was titled "Science Diplomacy in Large International Collaborations." Barish pointed out that forefront science is being carried out more and more through large-scale international collaborations such as the Auger cosmic-ray experiment, the ALMA array, ITER, the LHC, and the International Linear Collider, and asked what implications this has for United States science policy. He argued that developing and supporting such projects must be an important part of U. S. science policy in order to keep U. S. science at the forefront and consequently that the U. S. must be a part of such projects in order to remain competitive and to have significant societal impact. Since governments are the key decision makers, the scientific community must remain in close contact with them through organizations that provide advice on projects and costs such as the International Committee for Future Accelerators. He closed by drawing attention to some ongoing issues: that the United States must figure out how to most effectively integrate into doing things such as project governance and accountability with other parties, that year-at-a-time budgeting cannot provide the stable funding required for large projects, and that participation in shared governance conflicts with the usual American approach of rigid steps and reviews, which we tend to impose even when we are a minority partner.

The second talk in this session was by Neal Lane, who served as science advisor to President Bill Clinton. Lane spoke on "A Scientist's Approach to Diplomacy -- First, Listen and Learn." Lane first addressed what he called two angles in science diplomacy: policy for science and science for policy. The former involves aspects such as research funding and international agreements on facilities, while the latter is concerned with applications of science to areas such as security, health, energy, the environment, and transportation. He then described the work of the National Science Foundation (NSF) and the Office of Science and Technology Policy (OSTP). A continuing issue for the NSF is that while it helps to fund investigators' foreign travel and international facilities, to many in Congress such activities seem more like a form of foreign aid. An important part of the President's Science Advisor's responsibilities is to advise the President on international science and technology matters, and Lane used a 1979 U.S.-China Agreement on Cooperation in Science and Technology as an example of what can be achieved along these lines; the agreement has led to a ministerial-level joint commission on S&T that discusses issues such as new technologies, common global problems, and barriers to cooperation such as intellectual property rights. Lane concluded by reminding the audience that scientists have been able to earn the trust of other people and nations even when official diplomats could not.

The final talk in this session was given by Norman P. Neureiter, Senior Advisor to the Center for Science Diplomacy at the AAAS. Neureiter spoke on "Science Diplomacy in Action." He began giving a definition of science diplomacy as the use of scientific cooperation as a means of active engagement with countries where overall relations are strained or non-existent. While the science in such engagements must be of good quality, the underlying motivation is to develop an instrument of constructive foreign policy aimed at mutually beneficial engagement. Historically, this sort of diplomacy has been oriented toward the Soviet Union, Japan, and China, and was often augmented through non-governmental venues such as the Pugwash conferences. Neureiter described the work of the AAAS Center for Science Diplomacy, which has recently engaged with scientists in countries such as Iran, Syria, Cuba, Myanmar, and North Korea.

A specific current case of science diplomacy is President Obama's initiative to reach out to the Muslim world by sending abroad science envoys to discuss opportunities for scientific and technological partnerships. Lessons learned form science diplomacy are that science is an area where communication can be easier and understanding more likely than through traditional diplomatic channels, and that mutually beneficial cooperation can be achieved in non-sensitive areas. Challenges include the perception that such initiatives "help the enemy", ensuring steady funding, and carrying through meaningful follow-on after initial visits.

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

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ARTICLES

Energy Critical Elements

Robert Jaffe, Jonathan Price, Murray Hitzman, and Francis Slakey

[A recent report prepared under the auspices of the APS Panel on Public Affairs and the Materials Research Society examined the roles and availability of various "energy critical elements" (ECS's) – elements that will be crucial in the development and commercialization of new ways of producing, distributing, and conserving energy. This article is based on the report, which can be found in its entirety at the APS website at http://aps.org/policy/reports/popa-reports/loader.cfm?csModule=security/getfile&PageID=236337. See also "The Back Page" of theApril 2011 edition of APS News *– Ed.]*

Introduction

A number of chemical elements that were once laboratory curiosities now figure prominently in new technologies like wind turbines, solar energy collectors, and electric cars. If widely deployed, such inventions have the capacity to transform how we produce, transmit, store, or conserve energy. To meet U.S. energy needs and reduce dependence on fossil fuels, novel energy systems must be scaled from laboratory, to demonstration, to widespread deployment.

Energy-related systems are typically materials-intensive. If new energy-related technologies are to become widely deployed, the elements required by them will be needed in significant quantities. However, many of these elements are not presently mined, refined, or traded in large quantities, and as a result their availability may be constrained by many complex factors. An element may be "energy-critical" for a variety of reasons: It may be intrinsically rare or unevenly distributed in Earth's crust, poorly concentrated by natural processes, currently unavailable in the U.S., found in concentrations that do not allow for economic extraction, or produced in a small number of countries or in locations subject to political instability. A shortage of these energy-critical elements (ECEs) could significantly inhibit the adoption of otherwise transformative energy technologies, which would in turn limit the competitiveness of U.S. industries and the domestic scientific enterprise. Recently there have been several efforts to identify critical minerals that are both essential to our economy and subject to supply restrictions [1,2,3,4].

In response to growing concern to these issues, the Panel on Public Affairs of the APS and the Materials Research Society (MRS) established in late 2009 a committee to examine the situation and make recommendations. The 14 members of this committee, which was co-chaired by Robert Jaffe and Jonathan Price, have expertise in physics, geology, materials science, energy economics, and science policy. In this article, we review current uses and supply issues for a number of ECE's, and summarize the committee's recommendations for a coordinated set of government actions to facilitate smooth and rapid deployment of desirable technologies. It is sobering to realize that The United States relies on imports for more than 90% of its supply of the majority of ECEs identified in the APS/MRS report.

While we do discuss here particular ECEs and their applications, we emphasize that the report focuses on identifying commonalities and addressing potential constraints on ECEs rather than on attempting to construct a definitive list of ECEs, which will doubtless change with time as technologies, supply lines, and risk factors change. Our report did not consider national defense matters, nor did we consider elements like beryllium that are critical for defense but which do not have prominent energy-related applications.

Energy Critical Elements: Uses and Sources

A present-day list of ECEs would begin with the rare-earth elements (REEs). These include lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), ytterbium (Tb), and lutetium (Lu). The closely related elements scandium (Sc) and yttrium (Y) are often included as well. While promethium, holmium, erbium, and thulium are rare-earths, we do not include them in our list as promethium is unstable and the others have no energy-critical uses at present. Although the U.S. led the world in both production and expertise on REEs into the 1990s, over 95% of these important elements are now produced in China, which is rapidly putting the U.S. and other importers at great disadvantage.

To the rare earths we add the platinum group elements (PGEs) ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir), and platinum (Pt). Additional ECE candidates include gallium (Ga), germanium (Ge), selenium (Se), indium (In), and tellurium (Te), all semiconductors with applications in photovoltaics. Finally, cobalt (Co), helium (He), lithium (Li), rhenium (Re) and silver (Ag) round out

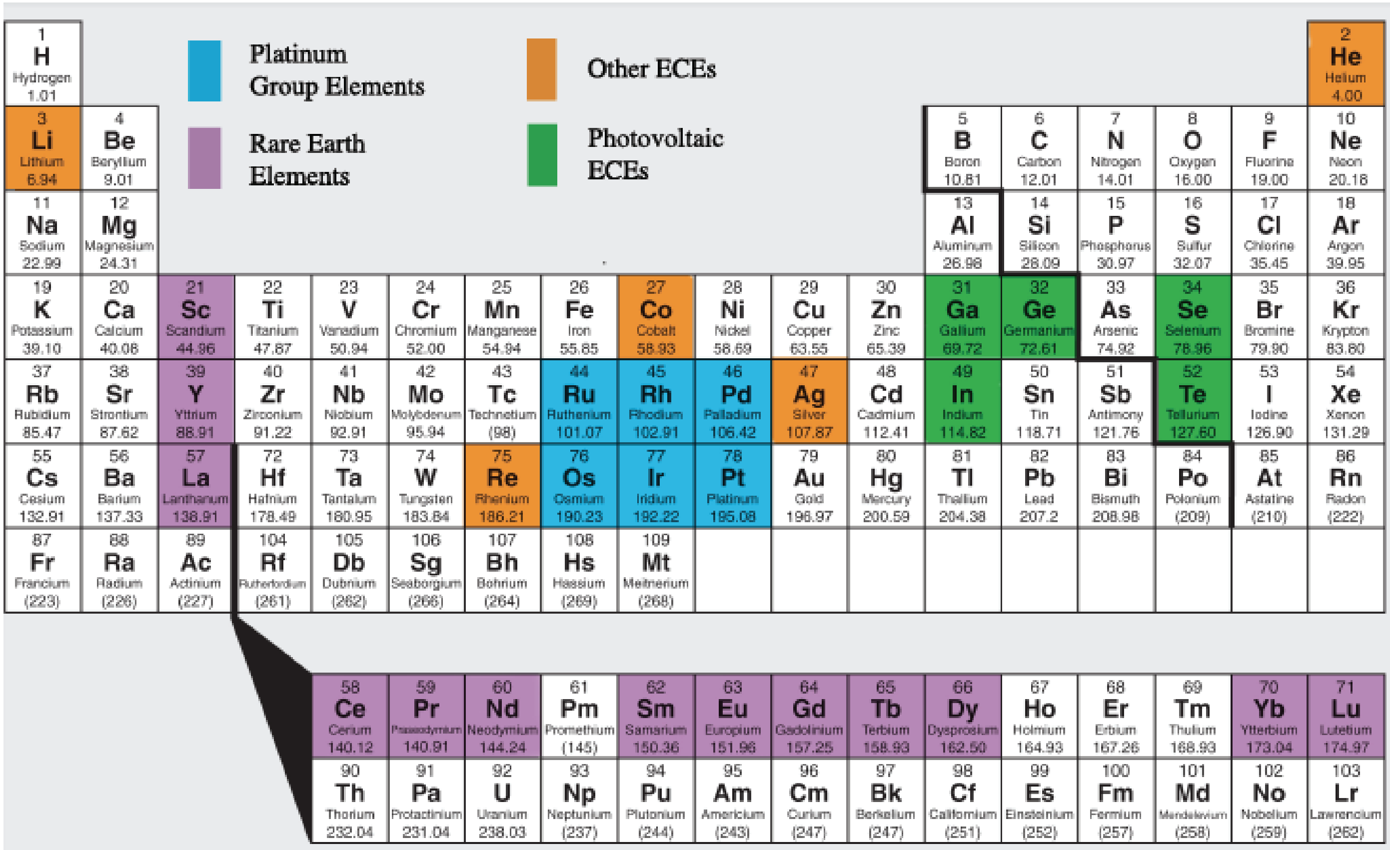

Figure 1. Periodic table highlighting energy-critical elements. The selection of ECEs would have been different in the past and no doubt will be in the future.

the list. Our list of ECEs is highlighted in the periodic table in Figure 1.

These elements are used in a wide variety of technologies. Gallium, germanium, indium, selenium, silver, and tellurium are all employed in advanced photovoltaic solar cells. Dysprosium, neodymium, praseodymium, samarium and cobalt are used in high-strength permanent magnets for energy-related applications such as wind turbines and hybrid automobiles. Lithium and lanthanum are used in high performance batteries. Helium is required in cryogenics, energy research, advanced nuclear reactor designs, and manufacturing in the energy sector. Platinum, palladium, and other platinum-group elements as well as cerium are used as catalysts in fuel cells that may find wide applications in transportation. Rhenium is used in high performance alloys for advanced turbines.

In the following paragraphs we highlight a few particular examples of situations that can affect ECE availability. This is by no means intended to be an exhaustive list.

Germanium is an example of an element that is constrained in its availability because it is not appreciably concentrated by geological processes. While not particularly scarce (it is twenty times more abundant than silver; see Figure 2), it rarely forms minerals in which it is a principal component, and is produced primarily as a by-product of zinc extraction. In 2010, the USGS reported global production of Ge in 2009 from zinc refining to be 140 metric tons (MT), of which 71% came from China. For comparison, 2009 production of Zn was 11,100,000 MT, of which 25% came from China, the world's leading Zn producer.

Among the ECEs, the rare earths, platinum group elements, and lithium are perhaps most vulnerable to geopolitical risks. Platinum production, for example, is concentrated in the hands of a small number of companies in South Africa, which produced 79% of the world's supply in 2009. Also for that year, both South Africa and Russia each produced about 41% of the world's production of palladium (195 MT).

Like germanium, tellurium is an example of an ECE that is now obtained as a by-product of the mining of another element, but the situation for it is exacerbated by lack of information. No ores are mined primarily for their Te; essentially all of it comes from refining of copper. Because Te production is so small (about 200 MT in 2009) compared to that of Cu (15,800,000 MT in 2009), there is little incentive to maximize Te recovery from Cu processing even though

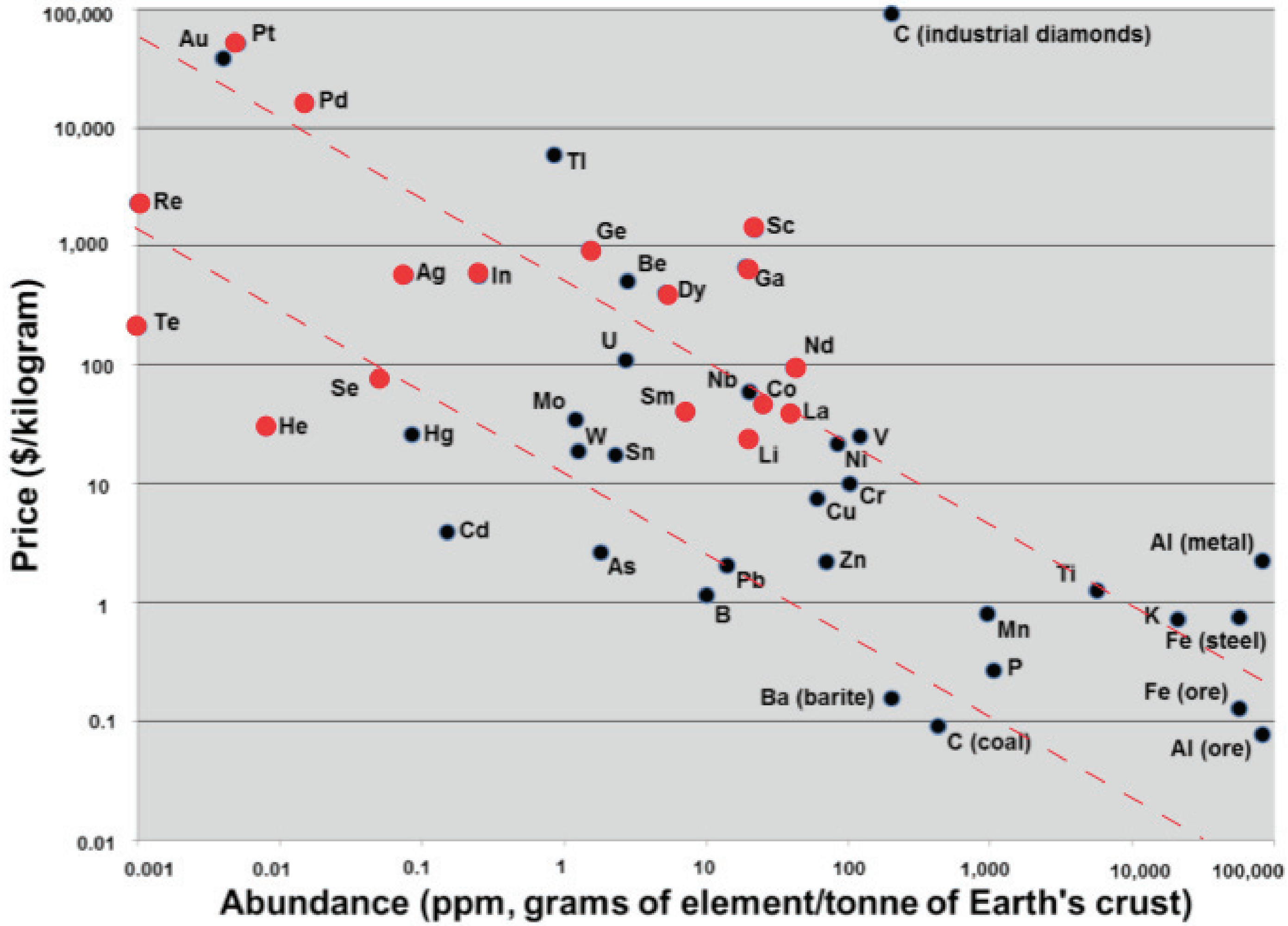

Figure 2. Elemental prices vs. crustal abundance. ECEs are highlighted in red.

Te costs considerably more than Cu ($145/kg vs. $5.22/kg in 2009). Tellurium is used in photovoltaic panels, and we estimate that some 400 MT of Te will be required per gigawatt of produced electric power. Predicting the capacity of supply to expand to meet a significantly increased demand for Te is difficult: data on rates of recovery of Te from Cu ores are not available, little is known about the geological and geographic variability of Te in Cu ores or the extent of Te abundance in other sulfide ores, and even less is known about the existence, extent, and reserves of primary Te deposits.

Lithium is an example of an ECE whose future supply in the marketplace is experiencing significant uncertainty associated with delays in production and utilization. As the principal component in one of the most promising forms of high energy-density batteries, many believe Li batteries are the technology of choice for all-electric vehicles. But if electric vehicles are to gain a significant share of the market, Li production must grow. However, there are other materials that could be considered for use in high performance batteries. The choice of which battery technology to develop depends largely on the availability and price of the component materials. Ramping up production of Li from existing mines and developing new ones is not a trivial matter, nor is the design of batteries suitable for all-electric vehicles. Lacking a clear decision on the fundamental battery design, it is not surprising that exploration for and development of new Li supplies remains in limbo.

Rhenium is an example where intrinsic rarity can affect supply: it perhaps the rarest of all naturally occurring, stable chemical elements. In 2006, General Electric (GE) realized that demand for Re, a critical material in its turbine engines, was increasing significantly, with worldwide demand predicted to exceed supply by 2011. GE made a decision to reduce the company's reliance on Re with a strategy that includes both recycling and R&D of substitute materials; this approach enabled them to reduce their use of Re while buying enough time to develop a new alloy that proved to be an adequate substitute [5]. But as many smaller companies cannot afford to engage in this level of recycling and/or substitutional research, a federal role in these areas could be critical to their competitiveness.

Terbium is an example of an element where changed recycling practices could have a dramatic effect on availability. It is used along with europium in color-balanced fluorescent lighting. Although minute quantities are used in each bulb, the world's annual production of Tb is less than 0.5 MT, and it is in chronic undersupply: The price of Tb imported from China was nearly $800/kg in December 2010. When fluorescent lights are recycled, the metal ends are removed and recycled, and the glass is also reused. But the phosphor powder on the inside surface of the glass contains mercury, terbium, and other rare metals. Because mercury is toxic, current practice is to mix the powder into an aggregate compounded with concrete and sequester the concrete from the environment, thereby making the Tb unavailable for recycling.

Lastly, helium possesses a set of unique properties that make it special, even among the ECEs. Because it liquefies at the lowest temperature of all elements and does not solidify, it is indispensable for cryogenic applications. It is also the least chemically active element, cannot be rendered radioactive by exposure to radiation, and has the highest heat capacity of any gaseous element except hydrogen. These excellent thermal, chemical and nuclear properties make it the coolant fluid of choice for advanced nuclear reactor design. With such unique properties, He has already found use in unusual applications, and the breadth of its future utility is impossible to anticipate.

Other factors can complicate the availability of ECEs. Some are toxic, while others are now obtained in ways that produce unacceptable environmental damage. Discovery of new mineral deposits typically takes several years and the time between discovery and start-up of a new mine averages five to ten years [6]. For some elements, large-scale production may require development of new processing technologies, resulting in a time lag between increased demand and the availability of new supplies. Recycling and the existence of secondary markets is quite variable; for example, recycling is highly developed for platinum but is almost non-existent for most other ECEs, and hence significant quantities of ECEs are permanently discarded every year. Sometimes one element can be substituted for another in a technology, but more often than not substitution requires significant redesign, reengineering, and recertification with attendant delays.

A significant positive result of our study, however, is that, with the exception of helium, there does not appear to be any fundamental limit on the availability of any element for energy technologies in the foreseeable future. A practical limit on availability for a particular application will be reached when the material is no longer available at a competitive price, and while it can be anticipated that this will come to pass for some ECEs in the long term, we believe that the problems currently lie in short-term interruptions or constraints on supplies.

Recommendations

To deal with the multifaceted issue of ECE availability, the APS/MRS report makes an number of recommendations for U.S. federal action. The main recommendations are summarized here; full details appear in the report.

(1) Information Collection and Analysis

Collecting and evaluating data required to track the availability and uses of chemical elements is a complex undertaking. While some data are already collected by a number of federal agencies, there is no central entity for tracking minerals and processed materials over their life-cycle. The report recommends that the government should gather, analyze, and disseminate information on ECEs across the life-cycle supply chain, including discovered and potential resources, production, use, trade, disposal, and recycling. The entity undertaking this task should be a "Principal Statistical Agency", a designation that would enable it to require compliance with requests for information. The Report also urges that the federal government regularly survey emerging energy technologies and the supply chain for elements, with the aim of identifying critical applications as well as potential shortfalls.

(2) Research and Development

The report recommends that the federal government establish a research and development effort focused on ECEs and possible substitutes that can enhance vital aspects of the supply chain, including geological deposit modeling, mineral extraction and processing, material characterization and substitution, utilization, manufacturing, recycling, and lifecycle analysis. Such a program would enable the U.S. to expand the availability of and reduce its dependence on ECEs, and could have the added advantage of enhancing the training of undergraduate, graduate, and post-doctoral students in disciplines essential to maintaining U.S. expertise in ECEs. Research on product designs that are more suited to recycling could help ensure that scarce elements are more easily recovered from discarded products, and research in chemical, metallurgical, and environmental science and engineering, and industrial design methods can create high-value reusable ECE materials.

(3) Efficient Use of Materials

The report urges that the federal government establish a consumer-oriented "Critical Materials" designation for

ECE-related products. The certification requirements should include the choice of materials that minimize concerns related to scarcity and toxicity, the ease of disassembly, availability of appropriate recycling technology, and the potential for functional as opposed to non-functional recycling. Further, steps should be taken to improve rates of post-consumer collection of industrial and consumer products containing ECEs. The report also urges greater attention to material efficiency with the aim of producing necessary goods from as little primary material as possible. Beyond recycling, other aspects of efficient material use include improved extraction technology, reduced concentration in applications, replacement in non-critical applications, development of substitutes, and life-style adaptations.

(4) Market Interventions

With the exception of helium, the APS/MSR report does not advocate government interventions in markets beyond those implicit in the other recommendations concerning R&D, information gathering and analysis, and recycling. In particular, the report does not recommend non-defense-related economic stockpiles, as such stockpiles have had unintended disruptive effects on markets [2,7]. Industrial users of ECEs are best able to evaluate the supply risks they face and purchase their own "insurance" against supply disruptions caused by either physical unavailability or price fluctuations.

The single exception to this recommendation concerns helium, which is unique even among ECEs because it is permanently lost to the atmosphere if not captured during natural gas extraction. Helium is critical for current energy R&D and it is anticipated that it will be increasingly in demand in the future for technologies not yet developed. The report recommends that measures should be adopted to conserve and enhance the nation's helium reserves.

(5) Federal Coordination

ECE availability is a complex topic that straddles a number of federal agencies including the Departments of Commerce, Defense, Energy, Homeland Security, Interior, State, and Transportation, the Environmental Protection Agency, the National Science Foundation, and the Office of the U.S. Trade Representative. The capacity to orchestrate a productive collaboration between these agencies and coordinate their efforts with the Office of Management and Budget lies in the Executive Office of the Science and Technology Policy (OSTP). Consequently, the report recommends that OSTP create a subcommittee within the National Science and Technology Council to examine the production and use of ECEs within the U.S. and to coordinate federal actions.

Summary and Conclusions

The importance of a spectrum of elements to both current and future national-scale energy technologies is well-established. Equally clear is that many of these elements are liable to future disruptions in supply due to scarcity, unpredictable geopolitical instabilities, and inefficient utilization. The APS/MRS report gives specific recommendations for governmental actions to address these issues. These recommendations fall within historically accepted roles for government: information gathering, support for research and workforce development, and incentives for select activities.

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Honesty, Perseverance, and Objectivity: Lessons from a Life in Public Policy

John F. Ahearne

[John Ahearn is the recipient of the Forum's 2011 Leo Szilard Lectureship Award, which is given to recognize outstanding accomplishments by physicists in promoting the use of physics for the benefit of society in such areas as the environment, arms control, and science policy. The citation for his award reads: "For nearly four decades of selfless dedication to the nation, and for providing a voice of reason in advising on the use of physics for the benefit of society in areas as diverse as nuclear energy, arms control, risk communication, biological safety and ethics in science and engineering." Dr. Ahearne is Executive Director Emeritus and Emeritus Director of the Ethics Program at Sigma Xi; currently, he is Adjunct Professor of Civil and Environmental Engineering at Duke University. He also served as a Commissioner and Chairman of the U.S. Nuclear Regulatory Commission. Dr. Ahearne's award was formally presented at the APS April meeting held in Anaheim, and we are pleased to print an edited version of the remarks he made on that occasion – Ed.]

Thank you very much. Looking at the list of previous awardees, many of whom I know and respect, I feel unworthy to belong on that list. But, fortunately for me, the awards committee thought otherwise. As in a popular song, with a little help from my friends I have received this award.

The award website states that a purpose is "to promote awareness of the application of physics to social problems…." So, then, to what social problems have I applied physics? In this talk I will first describe what I see as fundamental characteristics of a physicist, and then describe how I have attempted to apply these characteristics to various policy issues for over more than a half-century.

Being a physicist is an enjoyable way to live. It provides chances for stimulating involvement with bright people working on projects useful to society. Studying physics develops belief in the value of three relevant characteristics: honesty, perseverance, and objectivity.

Honesty

My mother, a registered nurse, taught me that honesty is always the best way to deal with people and issues [1]. Michael Bishop, a Nobel laureate for Medicine, provided a clear description of the role of honesty in science. In speaking to a group of high school students, Bishop said "Scientists depend upon the truthfulness of their colleagues; each of us builds our discoveries on the work of others; if that work is false, our constructions fall like a house of cards and we must start all over again. The great success of science in our time is based on honesty… . [2] " Certainly, as Bishop noted, we have to rely on the honesty of other scientists in their reporting of results. When cases of dishonesty surface, such as noted in Frances Houle's APS Ethics Task Force report, harm is done to the culture of science, to the public's belief in science, and, of course, to the individuals involved [3].

There are times when being honest can cause friction. The increasingly heated words about global warming demonstrate the intense feelings on all sides of the dispute. I have friends on both sides of the debate and know they are honest in their beliefs. Anyone participating in public policy will at times be under pressure to change a position to accommodate a more senior person. My advice is that, if you are sure of your position, do not cave to that pressure.

Perseverance

Ted Williams, a famous American baseball player, said: "Ballplayers are not born great….and luck isn't a big factor. No one has come up with a substitute for hard work." Similarly, most research does not produce immediate results. My experience is with theory. An idea can provide a beginning path, but to complete the project usually requires months or years of what I could call "enlightened" progress, but what would more accurately be described as dogged perseverance. But perseverance alone is not enough. Physicist Dale Corson, my undergraduate thesis advisor, admonished me when I told him how hard I had worked on my (unsuccessful) project. He said that in the world, rewards come from achievement, not effort. Effectiveness requires both.

One example: When I was an office director in Systems Analysis in the Defense Department, I and my staff examined the possible conflict in Europe between NATO and the Warsaw Pact. It was widely accepted that, in such a case, NATO would be run over by the Soviet might. I had developed a good working relationship with the chief analyst in the CIA's Soviet branch and talked weekly with him. From these conversations, I learned of the many weaknesses in the Soviet forces. These weaknesses became apparent when the Soviet Union collapsed. My staff and I used that information to analyze a potential non-nuclear conflict, and we concluded that NATO would win. I presented this conclusion to the Secretary of Defense. He disagreed - strongly. I then presented it to senior military officers. After review, they agreed. On this, the Secretary accepted the analysis and took it to NATO. When the Soviet Union collapsed, conditions of the Soviet forces and the attitudes in the Warsaw Pact countries showed the correctness of the CIA analysis.

Objectivity

The world often does not behave the way we wish it would. Recall Edward Teller, quoting Niels Bohr: "An expert is one who through personal experience has found out all of the mistakes one can make in a narrow field." Objectivity is what enables one to see beyond wishes and base actions on reality, uncomfortable as that may be. As an example, the recent Fukushima tragedy in Japan wherein a large six-reactor power station has been destroyed challenges the positive descriptions of the Japanese reactor industry and the regulatory body. Objectivity is necessary – hope is not enough.

Over my career, I have been involved with a number of policy issues, including energy studies, nuclear power, nuclear weapons, and health and safety. Many of these involvements have been as a member of or chair of a committee of the National Research Council, the operating arm of the National Academies.

As a developed industrial country, the United States is heavily dependent on the availability of energy supplies. As the consumer of vast amounts of energy, the United States must be concerned about how to maintain the supply and to minimize environmental damage. For decades a controversial part of the energy portfolio has been nuclear power. Until joining the Carter White House, my involvement with nuclear power had been a course taken as an undergraduate engineering student. As the only staff member with a technical background in the group developing the Carter energy plan, I rapidly became immersed in issues relating to the growth of nuclear power (called by Carter in his presidential campaign the option of last resort), the breeder reactor program, reprocessing and non-proliferation. In these discussions the objective, analytic approach of a physicist enabled me to avoid the heat and instead shine some light on the issues. This eventually led me to the Nuclear Regulatory Commission. I became a member a few months before the Three Mile Island accident. Practicing honesty and objectivity were crucial in the years following the accident when meeting with large groups of citizens in the Harrisburg, Pennsylvania area, in talking with press and media reporters, and in Commission meetings. A valuable lesson from such interactions is that communication to be effective must be two-way. Listening is as important as telling. When meeting with those who may not have your technical background, it is a serious failing to dismiss their statements. Their insights may be based on understanding local conditions and values that you may not know or have. Risk communication should not be one-way. Also at times we tend to talk down to the public. One of my students (Lisa Jaworski) commented: "In some sense, scientists have been expecting the public to climb up the ladder of understanding, while refusing to climb down a few rungs."

Recently, as nuclear power has been resuscitated, although is still weak, I have had many opportunities to endorse or criticize positions taken by advocates and opponents. Again, the characteristics of a physicist are important: be honest, be analytical, and be objective. Of course, this approach seldom satisfies either group. When I was on the Commission and applied these characteristics, the president of a nuclear power association labeled me as "wishy-washy" because he never knew in advance what my position would be. I prefer the comment by a senior Commission lawyer as I discussed with him a contentious issue. He expressed that, unlike the other commissioners, I did not start with a predetermined position. With surprise, he said: "You're trying to see what is right!"

Do not succumb to the habit of letting an assistant or a staff member tell you what is important in a document without reading it first. Getting someone else's opinion is valuable, but I found that the best preparation for a meeting was to read the documents that would be discussed. In all my positions, when faced with a complex problem I tried to read all that was available on the issue and then work on the analysis. This is not always the practice in DC, where many problems are immediately decided on desired outcomes or on predetermined policy and like-minded supporters are sought. A good physicist will not follow that path.

In the months before the accident in Japan, many advocates of more nuclear power enthusiastically claimed a renaissance was occurring. European governments were expressing interest in postponing previously planned shutdown of operating reactors. Exaggerated claims were not uncommon, particularly in estimates of the costs of new reactors. There was some opposition but the voices were muted or shouted down. All this changed within days, even hours, of the TEPCO accident. European government leaders scrambled to express positions against nuclear power and opponents surfaced worldwide. Proponents were forced to argue that other operating reactors were safe. But advocacy for new reactors sank. Situations such as these provide the challenges and opportunities for scientists to provide objective analysis.

There are vital roles for scientists in public policy, and we must not be reluctant to become involved. Given my early involvement with nuclear weapons at the Air Force Special Weapons Center in Albuquerque, when opportunities came up in DOE, University of California laboratory oversight panels, or the National Academies, I volunteered to work on such issues as the safety of the weapons facilities, the quality of the work at the national laboratories, the credibility of the "bunker-buster" nuclear weapon, and the methodology for examining the health of the nuclear stockpile. I was privileged to become a member of CISAC, the National Academies standing Committee on International Security and Arms Control. This led to discussions in India, China, and Russia and studies jointly with our Russian colleagues on non-proliferation.

To close, I would like to quote Roland Schenkel, the former Director-General of the European Commission Joint Research Center, who last year wrote: "There are policy-makers who bury their heads in the sand when faced with compelling scientific evidence for unpopular policy changes, believing all too easily that science is an a-la-carte menu. … Feeding science advice into policy-making will be challenging. But what is important is that we defend and assert the inherent integrity of science, demonstrate openness, speak in terms the public can understand and show that we take our duty to society seriously. If we strive to achieve this, then evidence-based policy may just win over policy-based evidence."

Physicists must meet that challenge.

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REVIEWS

The Physics of the Manhattan Project

B. Cameron Reed, Second edition (Springer-Verlag, Heidelberg, 2011), 170 pp., hardcover, $69.95, ISBN 978-3-642-14708-1.

This book describes, in complete detail, a course for advanced undergraduate physics majors, on the various physics problems involved in the World War II Manhattan Project that initiated the Nuclear Age. After an introductory chapter on basic nuclear physics and the fission process, some of the principal topics treated are critical mass for a bomb, effects of tamper, bomb efficiency, reactor physics, uranium isotope separation, problems with trace element impurities, and problems with bomb pre-detonation. The author has no access to classified information, and most of the treatments were developed independently by him, using the physics and mathematics appropriate for the targeted students. His treatments involve many calculational simplifications, such as assuming spherical geometry for obviously non-spherical situations (e.g. gun type bombs), but he gives careful consideration to problems from these simplifications, ultimately using information from unclassified literature to evaluate conclusions. He demonstrates extensive familiarity with this unclassified literature, giving abundant references; his collection of these references is a very valuable feature of the book.

The course described includes homework problems, many using Excel spreadsheets available at www.manhattanphysics.com. Some of the results from these spreadsheet calculations are plotted in the book; for example, in the simulation of the Hiroshima bomb based on a 64 kg core of radius 9.35 cm plus a 311 kg tungsten carbide tamper of outer radius 18 cm (these numbers are from unclassified sources), he calculates that nearly all the energy is generated between 0.83 and 0.89 microseconds after initiation, giving a pressure vs time peaking at 50 billion atmospheres, a final core expansion rate of 270 km/sec, and a yield of 11.9 kiloton of TNT, with 1.1% of the U-235 undergoing fission. The U-235 in the core was 3.5 times the critical mass with this tamper. The dependence of yield on tamper is dramatic, increasing by a factor of 8 between 50 kg and 350 kg of tamper mass.

In his treatment of thermal reactors, he calculates the mean free path for scattering in graphite to be 2.6 cm and the number of scatterings required for thermalization to be 50-100; combining these gives a neutron displacement of 19-26 cm which determines the graphite lattice spacing, consistent with the 21 cm lattice spacing in Fermi's original graphite reactor. In other sections he shows that one boron atom impurity per 17,000 carbon atoms in the graphite would cause a serious loss of neutrons, and that the plutonium production is 593 grams/day in a 1000 MW nuclear power reactor and 190 grams/day in the Hanford production reactors, to be compared with the 6200 grams in the core of the Trinity and Nagasaki bombs.

In treating uranium isotope separation by gaseous diffusion, he calculates the number of stages required for 90% enrichment to be 1665. One thousand stages gives only 34% enrichment. In treating the predetonation probability for the Trinity and Nagasaki bombs, he takes the implosion to double the density of the Pu-239 core (including 1.2% Pu-240) in 4.7 microseconds, and derives a non-predetonation probability of about 88%, citing an unclassified source to show that this estimate is realistic. In other separate sections he calculates that the ambient temperature of the Nagasaki and Trinity bombs approached 79 deg-C, and that these explosions viewed from the Moon would have appeared 30 times brighter than Venus.

If one is interested in how such results (and many more like them) were derived by an academic physicist without any information from classified sources, this book would be an enlightening read for anyone with a physics degree or with equivalent knowledge. To go through the mathematical derivations can be time consuming and tedious unless one is driven by intense interest, but it is easy to get the sense of the treatments with a much smaller effort. Although I have taught courses (albeit on a lower level) involving much of the material covered in this book, I learned a great deal from the treatments presented, including many improved physical insights, and lots of quantitative results.

From the teaching viewpoint, if one wants to provide an advanced undergraduate course on applications involving a great deal of interesting physics, this would be an ideal textbook. At first sight, this material might not seem attractive to most students, but for students with an interest in nuclear bombs and nuclear reactors, this course would be not only satisfying but exciting.

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Preparing for Climate Change

Michael D. Mastrandrea and Stephen H. Schneider, A Boston Review Book (MIT Press, Cambridge, MA 2010), 104 pp., hardcover $14.95, ISBN 978-0-262-01488-5.

This slim volume (less than 100 pages of main text) was written by two authors with much knowledge and experience in climate science. Mastrandrea is Deputy Director, Science, at the Intergovernmental Panel on Climate Change (IPCC) Working Group II, and assistant consulting professor at Stanford University. Schneider, who died suddenly in July, 2010, was the Melvin and Joan Lane Professor for Interdisciplinary Environmental Studies in the Department of Biology at Stanford University and a Senior Fellow at the Woods Institute for the Environment. He was also a lead author of the 2007 IPCC Fourth Assessment Report.

As stated in the book's introduction, "Every five to six years, the IPCC publishes its peer-reviewed, world governments-approved Assessment Report, which presents the best approximation of a global consensus on climate-change science." As a result of these reports, the IPCC shared the 2007 Nobel Peace Prize with Al Gore.

This little book's aim is to briefly present some of the main possible deleterious effects of climate change and to suggest what we can do to prevent them and adapt to those we cannot prevent. The book succeeds very well in that task, but does not adequately address the problem of how to get the world to meet the difficult challenge before it is too late. Perhaps that problem is insoluble, as I have not seen a convincing suggestion anywhere.

The book stresses that the course of climate change is uncertain, but that among the possible outcomes are some so dangerous for mankind that we should do our best to reduce the dangers. The best strategy for doing so is a combination of mitigation and adaptation. The authors argue that our efforts at mitigation, which consists in reducing human-caused greenhouse emissions to the atmosphere, will not by itself be sufficient to solve the problem, so that adaptation to the effects of climate change will also be necessary. A third approach to climate change is geoengineering, such as seeding the ocean with iron to promote the growth of carbon-consuming algae, and placing dust in the atmosphere to reflect solar energy. However, the authors caution that geoengineering schemes may have unknown and serious side effects, and therefore they concentrate on mitigation and adaptation.

An important part of the effort to reduce the effects of climate change is assessment of vulnerability of different regions. The authors say that, so far, most efforts have been "top-down," primarily the result of global climate models. They argue that a better way would be to combine top-down approaches with "bottom-up" efforts which emphasize social concerns at the local level.

The book concludes by saying that the present global challenge is to "reduce considerably the rate at which we add to atmospheric greenhouse gas levels." The developed countries should lead the effort both because they have contributed most to the problem and because they have a greater ability to do the job. Also, the developed countries should not neglect the needs of developing countries, both in mitigation and adaptation. The whole world should make a strenuous effort to reduce and to adapt to climate change, as, in my opinion, it may be the most serious long-term problem facing humanity.

In summary, the book provides a short overview of the problem of climate change and what can be done to reduce its severity and lessen its bad effects. For those interested in the subject, it is an excellent place to begin. For those who wish to explore the problem in more detail, references are given.

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