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PHYSICS & SOCIETY

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Editor's Comments

In this issue of Physics and Society we begin by highlighting the major activities of the Forum. The Joseph A. Burton Forum Award is given yearly to recognize outstanding contributions to the public understanding or resolution of issues involving the interface of physics and society. The Leo Szilard Lectureship Award 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. Please join me in congratulating the 2014 recipient of the Burton award, Michael M. May of Stanford University and the co-recipients of the Szilard award, M.V. Ramana of Princeton University and Ramamurti Rajaraman of Jawaharlal Nehru University.

Also, congratulations go to our newest FPS Fellows, Jan E. Beyea from Consulting in Public Interest and Charles D. Ferguson II from the Federation of American Scientists. You will find citations for both awards and our Fellows in the "News of the Forum" section of the newsletter.

The 2014 March meeting in Denver has several Forum-sponsored sessions including talks on secrecy and science, public access to satellite data, and physics and the economy. At the April meeting in Savannah, FPS has sessions on future transportation, energy efficiency, innovation, popularizing physics, and the life of Leo Szilard. Details on all of these sessions, including dates and times, session speakers, and titles of the talks can be found later in this issue.

Finally, as I've written in a previous issue, we have started to focus on using social media platforms as a tool to get the Newsletter into the hands of those that are interested in our activities but not yet a member of the Forum. Matthew Parsons, our social media coordinator, has his first status update on his recent initiatives in this regard.

As I sit down to write this message, Congress had just passed the omnibus spending bill for the 2014 fiscal year. Our first article, by Richard Wiener, is timely in that it reminds us that it is not simply the amount of federal funding appropriated, but what type of research is funded. He asks whether we are still willing to fund proposals that may be groundbreaking, but do not necessarily have a definite probability of success.

In our second article, Jerry Marsh responds to an essay in the December 2013 issue of *Physics Today* on the relevance of the B-61 bomb, by explaining the physics behind an earth-penetrating warhead. Then, Al Cavallo updates for us his recent article from the *Bulletin of Atomic Scientists* on the role of OPEC in setting oil prices and the impact on carbon emissions. Finally, we have book reviews on the Manhattan Project by my predecessor Cameron Reed and Al Gore's latest book.

We are always looking for interesting topics and authors willing to write about the latest advances at the intersection of physics and society. Please contact me with your ideas and consider submitting an article for publication in a future edition of the newsletter.

Andrew Zwicker
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FORUM NEWS

Update from Social Media Coordinator

I am excited to be working with the Forum as the Electronic Media Editor in response to Dr. Zwicker's request for a volunteer in the July 2013 edition of this publication. It just so happened that I was taking serious consideration to ways that I could get involved with outreach through the APS at that time, so I jumped at the open invitation. As a third year undergraduate physics student, I'm enthralled to have the opportunity to play a part in physics outreach through an organization such as the FPS and to learn more about significant issues where physics and society are intertwined. While I plan to spend my research career continuing to develop the scientific basis for fusion as a commercial energy source, I strongly believe that every scientist has a part to play in public outreach. The Forum is the perfect venue for me to take on such a role and further develop my interest in societal issues such as science education and developing methods of sustainable energy.

Identifying ways to spread our news outside of the FPS through social media has led me to establishing partnerships with the APS Forum on Graduate Student Affairs and the Society of Physics Students National Organization. The link between social media and student audiences is a natural place to start, and as a student myself I'm excited to see these collaborations forming. In addition to spreading our announcements through the publications of these groups and sites such as Twitter and Facebook, we will also be looking to open discussions through more formal mediums such as LinkedIn. If anyone has suggestions for additional ways that we can extend our audience through a social media presence, I would be happy to hear them!

Matthew Parsons (msp73@drexel.edu)

2013 Fellows

Jan E. Beyea

Consulting in Public Interest

For more than three decades of public service through research, analysis, and presentations on issues of major societal concern, including environmental degradation, nuclear reactor safety, energy efficiency, and energy use.

Charles D. Ferguson II

Federation of American Scientists

For applying technical knowledge to public policy on nuclear issues, including nuclear energy, nonproliferation, nuclear and radiological terrorism, and nuclear safety and security; and for communicating that knowledge to society.

Forum on Physics & Society Awards

JOSEPH A. BURTON FORUM AWARD

To recognize outstanding contributions to the public understanding or resolution of issues involving the interface of physics and society.

Michael M. May

Stanford University

"For his significant and sustained contributions to technical and policy issues pertaining to nuclear weapons, nuclear terrorism, energy and environmental impact; for mentoring generations of students and colleagues on these issues; and for efforts to increase public understanding and awareness on these issues."

LEO SZILARD LECTURESHIP AWARD

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 lecture format is intended to increase the visibility of those who have promoted the use of physics for the benefit of society.

M.V. Ramana

Princeton University

"For outstanding contributions to promote global security issues, through critical analyses of nuclear weapons and nuclear energy programs in India and associated risks in the subcontinent, and efforts to promote peace and nuclear security in South Asia through extensive engagements and writings."

Ramamurti Rajaraman

Jawaharlal Nehru University

"For outstanding contributions to promote global security issues, through critical analyses of nuclear weapons and nuclear energy programs in India and associated risks in the subcontinent, and efforts to promote peace and nuclear security in South Asia through extensive engagements and writings."

March APS meeting, Denver, CO, March 3-7

Monday March 3, 2014, 14:30

SECRECY AND SCIENCE

Classified research and development has grown significantly in the last decade. What are the implications of increased secrecy for science? Does it affect scientists' morale? Can outcomes be assessed objectively? Does it impact U.S. S&T prominence?

George Dyson, Secrecy versus Openness: Historical Perspectives
David Relman, The Growing Tension between Openness and Risk in the Life Sciences
Paul McEuen, Intellectual Property and Corporate Research: Threats to Scientific Openness
Bruce Held, Espionage and Science

Tuesday March 4, 2014, 08:00

KEYHOLE TO THE WORLD: PUBLIC ACCESS TO SATELLITE DATA FOR ENVIRONMENTAL, SECURITY, AND SOCIAL ENDS

Accessibility of satellite data today enables scientists and other analysts to do previously unimaginable work on environmental, security, and social problems. What is done today, what are the gaps, and what might be possible in the near future?
Jeff Dozier, 40 years of Landsat images: What we learned about science and politics
John Amos, Tentative: Tracking Oil spills, Detective Gas leaks, and Monitoring Coal waste using Satellite Imagery
Ted Scambos, Mapping Earth's Last Frontiers Step by Step: meter-scale images and Earth's Poles
Others TBA

Thursday March 6, 2014, 08:00

IMPACTS OF PHYSICS RESEARCH ON THE ECONOMY

What is the importance of physics research to economic activity and how might increasing or decreasing investments in physics affect the economy? We will hear from some experts and leaders.
Eric Isaacs, Physics for Knowledge and Economic Growth
Thomas Baer, Lasers and their Economic Impact in the United States
Venkat Selvamanickam, Applications of Superconductivity and Impact on U.S. Economy
Others TBA

April APS meeting, Savannah, GA, April 5-8

Saturday April 5, 2014, 10:45

HYPERLOOP AND OTHER TRANSPORTATION IDEAS

Cosponsored with GERA

This session looks ahead to revolutionary ideas for transportation.
Rhett Allain, Hyperloop Homework as an Inspirational Assignment
Stephan Granade, Hyperloops, Nuclear Spacecraft, and the New York City Subway
Aatish Bhatia, Can we build a more efficient airplane?

Saturday April 5, 2014, 15:30

EXTREME ENERGY EFFICIENCY

Cosponsored with GERA

Science and technology achievements and goals for energy efficiency beyond what are thought of as the usual bounds.
Karina Garbesi, Driving Extreme Efficiency to Market
Robert van Buskirk, Understanding the "Moore's Law" of Clean Technology Innovation, and Planning for the Extreme Energy Efficiency of the Future
Tina Kaarsberg, Extreme Energy Efficiency: In the city, in the country, and beyond

Sunday April 6, 2014, 10:45

JOSEPH A. BURTON FORUM AWARD AND LEO SZILARD LECTURESHIP AWARD

The Burton Award is for contributions to public understanding of issues of physics and society. The Szilard Award is for the use of physics for the benefit of society in such areas as the environment, arms control, and science policy.
Michael May
R. Rajaraman
M.V. Ramana

Monday April 7, 2014, 10:45

THE MANY WORLDS OF LEO SZILARD

Organized by FHP with FPS as cosponsor

Some background about this ingenious man and his insights, with personal recollections and comparisons.
William Lanouette, The Many Worlds of Leo Szilard
Richard Garwin, Leo Szilard In Physics And Information
Matthew Meselson, Leo Szilard: Biologist and Peace-Maker

Monday April 7, 2014, 15:30

PHYSICS AND INNOVATION

Inventors and innovators talk about the connection of physics to innovation.
Eric Fossum, Hasan Padamsee, and one more TBA

Tuesday April 8, 2014, 13:30

POPULARIZING PHYSICS

Speakers who are engaged in popularizing physics will share insights from their activities.
David Lindley, Explaining today's physics through history and biography
Diandra Leslie-Pelecky, Multimedia Communication of Physics
Mats Selen, Why Everyone Loves Science

ARTICLES

A Lesson about Taking Chances

Richard Wiener

As Washington remains divided and highly partisan, it is clear we are in an era of little or no increase in federal support for fundamental research in the sciences. According to Michael Lucibella, writing in the November 2013 issue of APS News, "Federal spending on science has been nearly flat since 2010 as a percent of total discretionary spending and down in actual adjusted dollars." In this climate, an obvious concern is that federal agencies will become even more conservative and solely commit limited resources to research likely to be successful even if resulting advances are only incremental.

As a Program Director for Research Corporation, a private foundation which supports fundamental research in the physical sciences, I struggle with the issue of how much risk my foundation should take. Everyone wants to support great science; no one wants to waste precious dollars. However, sometimes it is the willingness of funders to take a chance on truly risky projects that allows researchers to make the biggest breakthroughs. To remind myself of the importance of risk, I find it instructive to consider examples in which a funder didn't play it safe and the resulting payoff was huge.

Here's a case in point from the files of Research Corporation: the discovery that the expansion of the Universe is accelerating.

Back in 1980, Richard Muller, a physicist at the University of California, Berkeley, submitted a proposal for high-risk research to the National Science Foundation.

Ahead of the curve Muller recognized the potential for astronomical sky surveys using a CCD, at the time only recently developed for digital imaging, when operated with a small computer. Muller believed the CCD-computer combination would enable the automated search and discovery of supernovas in the early stages of their violent expansions.

When the NSF declined funding, Muller turned to Research Corporation. Muller wrote, "We propose an automated survey of several thousand galaxies every night, making full use of recent advances in automatic imaging techniques and small computers … A careful study of the supernova light curve and spectrum could allow the supernovas to be used as a "standard candle" for the measurement of Hubble's Law and estimation of the average mass density of the Universe (i.e., to answer the question of whether the Universe is finite or infinite)."

Research Corporation's records show the decision makers recognized how important, though risky, this project was. A review panelist wrote:

> Grant. 1) Science is extremely important. 2) R.A. Muller is a prize-winning physicist – he's a good experimentalist who gets things done. 3) The fact that even he has to come to us for funds shows again that the system is totally closed to new departures. 4) Muller's previous ventures (observing 30K radiation from NASA airplanes and optical feedback control) show the same originality … He will vault over corpses …

And the program officer's comment was prescient:

> This is one of the more exciting proposals to come along in quite awhile. If Muller can pull this off, the ramifications could be enormous.

Research Corporation funded the project and Muller's vision proved farsighted indeed; but it took several years to develop the technology to automatically locate supernovas. By that point Muller had founded the Supernova Cosmology Project (SCP) based at Lawrence Berkeley National Laboratory. Carl Pennypacker and Saul Perlmutter were key researchers participating in the project.

"In the early days, people thought measuring expansion with supernovas would be too hard," reflected Perlmutter, as quoted by Paul Pruess, writing on the Lawrence Berkeley National Laboratory website. However, Pruess adds,

> The SCP went on to show that distant supernovas, short-lived and unpredictable as they are, can nevertheless be collected "on demand," allowing observers to schedule telescope time in advance and accumulate enough data to make confident estimates of expansion.
>
> "In retrospect it seems obvious, but we realized that the whole process could be systematized [Muller's fundamental high-risk idea]," Perlmutter explains. "By searching the same group of galaxies three weeks apart, we could find supernova candidates that had appeared in the meantime. We could guarantee four to eight supernovas each time, and all of them would be on the way up, growing brighter instead of already fading."[1]

Eventually the SCP discovered the remarkable fact that the expansion of the universe, first announced by Édouard Lemaître in 1927, was actually accelerating. Perlmutter shared the 2011 Nobel Prize in Physics with Brian Schmidt and Adam Riess for providing evidence for that acceleration. By then cosmologist Michael Turner had coined the term "dark energy" as he and others struggled to explain the cause of cosmic acceleration.

Muller, although no longer searching for supernovas, continues to produce groundbreaking research and important new ideas, as evidenced by his leadership of the Berkeley Earth project, which produced an exhaustive analysis of historical global temperature change that shows a strong correlation with atmospheric carbon dioxide levels.

As Carl Pennypacker told me recently:

> The fact that the Research Corporation was willing to take a chance on young investigators on potentially paradigm-shifting research was unique then, and is still largely unique and rare in modern science funding. As federal funds continue their relentless and steady decline, there is a tendency in many science communities to create experiments that are very safe and risk-averse and are designed by committee. Such safe experiments are important and needed, but they often cannot help develop the big breakthroughs we made.

[1] *http://newscenter.lbl.gov/feature-stories/2009/10/27/evolving-dark-energy/*

Richard Wiener is a Program Director at the Research Corporation for Science Advancement and a member of the Editorial Board of Physics and Society.

A Nuclear Bomb Worth More than its Weight in Gold

Gerald E. Marsh

Introduction

In the December 2013 issue of Physics Today David Kramer tells us—in an article titled A nuclear bomb worth more than its weight in gold?—that "some critics of the B-61 life extension program question whether the program is necessary." And, "Representative John Garamendi (D-CA) questioned why the B-83, a newer bomb that officials acknowledge won't need a life extension for at least 10 years, shouldn't replace the B-61". Strangely enough the article omits the principal reason why the administration may think the B-61 is worth more than its weight in gold.

The B-61 Mod 11, as stated by Kramer and others, can be configured to have various yields ranging from under 10 kilotons (kt) to 360 kt. But what is far more important is that the B61 is a gravity bomb, meaning that it is a weapon intended to be dropped from aircraft, and is consequently designed to withstand significant g-forces. It can therefore, if given a proper nose cone, be deployed as a nuclear earth-penetrating warhead (EPW). While the B-83 is also a gravity bomb—and has been put forth for a nuclear earth-penetrating role—it has a maximum yield far greater than is ever likely to be necessary and is larger and far heavier than the B-61, which would restrict deployment options.

Before discussing the technical issues surrounding earth-penetrating nuclear weapons, a little relevant history may be helpful. During the latter part of the last century, there were deeply buried targets that could only be attacked with surface bursts using high yield bombs like the B53, which remained in service until the mid-1990s. It has a yield of ~9 megatons and is heavy and large enough that B52 bombers could only carry a limited number on a given mission. These missions were such that there was a good possibility that the planes would be unable to return. A strategic EPW delivered by either submarine launch ballistic missles (SLBMs) or intercontinental ballistic missiles (ICBMs) was a very attractive alternative.

In the late 1980s there was an Earth Penetrating Warhead Requirements Study[1] for which I served as technical director. At the conclusion of the study, it fell to me to give the final briefing to the Hard Target Kill Steering Group chaired by the then director of the Offensive and Space Systems section of the Office of the Director of Defense Research and Engineering (DDR&E) of the Under Secretary of Defense.

The briefing was devastating to what was supposed to become a multi-billion dollar program. This is the only major, high-visibility program I know of that, after having reached Phase II (Feasibility), was redirected to Phase I (Concept Definition). Hundreds of people scattered across the defense establishment had been involved. The program died shortly after my study report was distributed. How and why this happened is a rather interesting story.

During the course of the study I found that the intelligence was severely skewed; the simplified methodology that the community was working with to model the propagation of shock waves through the earth was flawed—and had no experimental basis or theoretical justification; that the method of calculating the coupling of energy from a nuclear burst to the earth as a function of height of burst was incorrect; that existing weapons were capable of destroying a very large fraction of the target base when realistic numbers were used for depth, hardness, and coupling; and that even if a new weapon was needed, relatively simple and cost effective modifications to an existing weapon would suffice. This was after both Livermore and Los Alamos had designed, developed, and tested large yield weapons, far larger than it turned out was necessary.

At the time, the development and testing of nuclear weapons was normally done after a military requirement had been established in Phase III (Engineering Development) not Phase I. This fact turned out to be a crucial driver. At a 1987 meeting at the Defense Nuclear Agency, a high level member of the Office of the Secretary of Defense told me that he was aware of the fuzzy nature of the intelligence data, and that whether or not the requirement is clear, Phase II of the program must be initiated to justify the money spent by the DOE laboratories. Others also informed me that the Air Staff did not see a clear EPW requirement either, but nonetheless would support a Phase II because SAC (Strategic Air Command, which no longer exists) wanted it. At that same period of time, however, a letter from the Office of the Secretary of Defense specified the need for survivability and excluded solo-based weapons.

The B-61 Mod11 is very much a part of this history because using it as an earth-penetrating weapon deployed on cruise missiles was known then as "the interim solution", an option to be avoided if the strategic EPW program was to move forward. In the end, this option became the only solution needed to fulfill national guidance.[2]

Since the time covered by this précis of late 20th century nuclear EPW history, the world has dramatically changed. Nonetheless, I suspect the administration would still like to retain a nuclear earth-penetrating capability, though its usefulness could well be questioned. An understanding of the technical issues surrounding these types of weapons may be of use to the physics community who are very likely to play a part in the debate over such weapons.

As discussed above, EPWs were developed to attack deeply buried targets by using the shock wave resulting from the explosion to crush them. In the meantime, there has been much discussion of the possibility of developing low-yield EPWs to penetrate into the earth to one hundred feet or more to incinerate buried stocks of chemical or biological materials. The purpose of the low nuclear yield would be to minimize or eliminate radioactive fallout while achieving high enough temperatures to guarantee complete incineration.

For example, the July 2001 joint DOD and DOE report to Congress on the defeat of hard and deeply buried targets stated that: "Nuclear Weapons have a unique ability to destroy both agent containers and CBW agents. Lethality is optimized if the fireball is proximate to the target. This requires high accuracy; for buried targets, it also may require a penetrating weapon system." The 4 July 2003 issue of Science was quoted as saying, with regard to mini-nucs and EPWs, "If we were able to do this research . . . we would be able to knock out chemical [and] biological threats . . . and not cause any collateral damage."

In addition to an introduction to some of the physics involved with EPW effectiveness, I show below that these claims are without merit.

The technical portion of this article is organized as follows. We begin with a short discussion of the phenomenology of underground nuclear bursts. This is followed by what might be termed a mini-analysis for low-yield EPWs. It begins with a determination of how far into the earth an EPW must go to optimally couple energy to the ground. Next, given the geology at the impact area of the target, one can determine how deep an EPW is capable of penetrating. For EPWs to be effective against a given target, one must determine what parameters characterize the target, the geology within which it is located, and from this information what yield would be required to destroy the target. And finally, but not least, one needs to know where the underground target is located.

Phenomenology of underground nuclear explosions

The phenomenology associated with a shallow underground nuclear burst of a fairly large yield (335 kt) is shown in Fig. 1. The figure shows the configuration at some 200

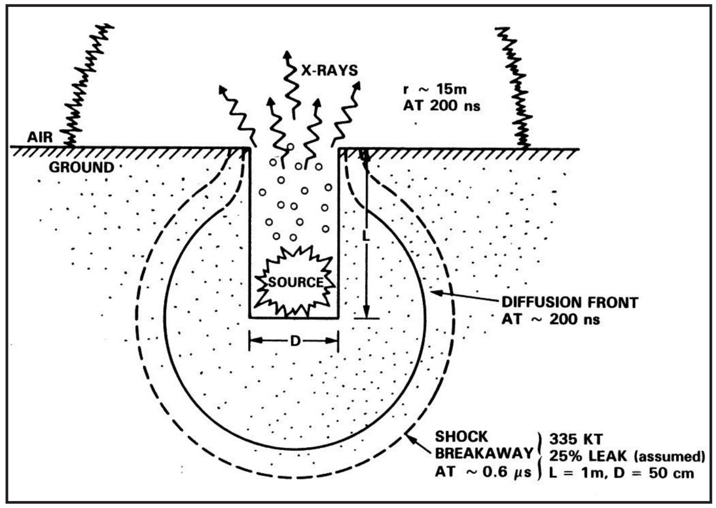

Figure 1. Coupling of the output from a 335 kt nuclear explosion at a shallow Depth of Burst (DOB).

ns after the weapon has detonated. At that time the energy partition of the "source" is approximately 80% X-rays with a black body spectrum corresponding to ~1-3 keV; 17% debris kinetic energy with a characteristic velocity ~3000 km/sec; and some 2% neutrons having energies of 2 and 14 MeV. The

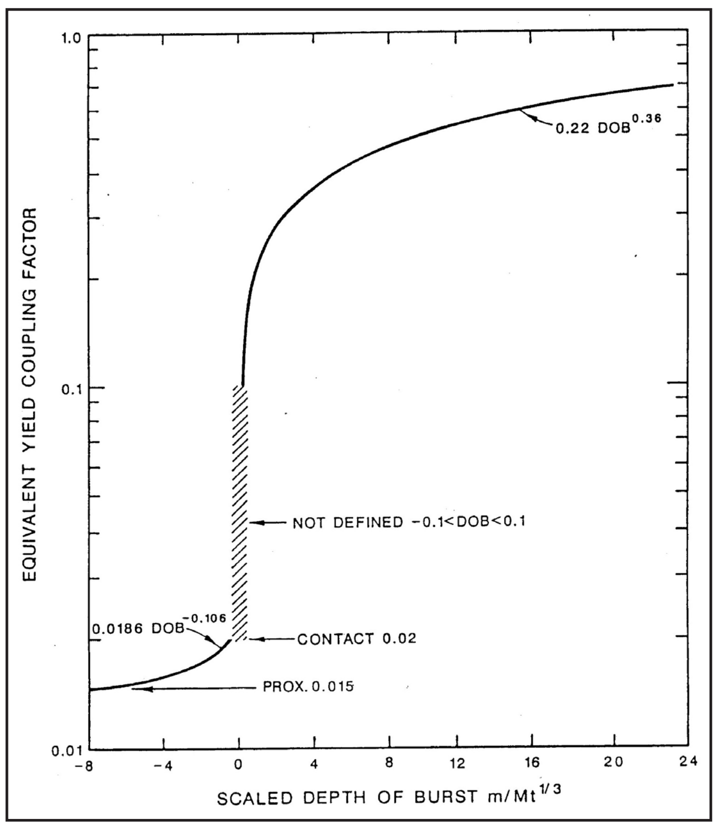

Figure 2. Equivalent Yield-Coupling Factor as a function of Scaled Depth of Burst. A negative scaled depth of burst corresponds to an above ground burst. The equations for the two parts of the curve are given in the figure.

soft X-rays are dominant and are absorbed in a thin layer of earth surrounding the burst thus raising its temperature to an enormously high value. The various forms of energy absorbed produce a very strong shock wave, which subsequently propagates into the ground and also upward where it throws debris into the atmosphere.

Penetration depth needed to optimally couple a low-yield nuclear EPW

Figure 2 gives the equivalent yield-coupling factor (what fraction of energy released by a nuclear weapon is coupled to the ground to produce a shock wave) as a function of scaled depth of burst (DOB). If we ask that the weapon have an equivalent yield coupling factor of ~0.6, the scaled DOB would be around 15 m/Mt$^{1/3}$.

For this coupling factor, a 10 kt burst (10kt = 0.01 Mt) needs to be detonated at a DOB of

$$\text{DOB} = 15\left(\text{m/Mt}^{1/3}\right)\left(0.01\right)^{1/3}\left(\text{Mt}^{1/3}\right) = 15\left(0.216\right)\text{m} = 3.23\text{m}.$$

What this shows is that very good coupling of energy from a nuclear burst can be achieved by detonating the bomb at a relatively shallow depth.

If one is to use an EPW with a small yield nuclear warhead to incinerate buried stocks of chemical or biological weapons, one must determine how deep an earth penetrating warhead can penetrate.[1] This is answered by the data in Fig. 3.

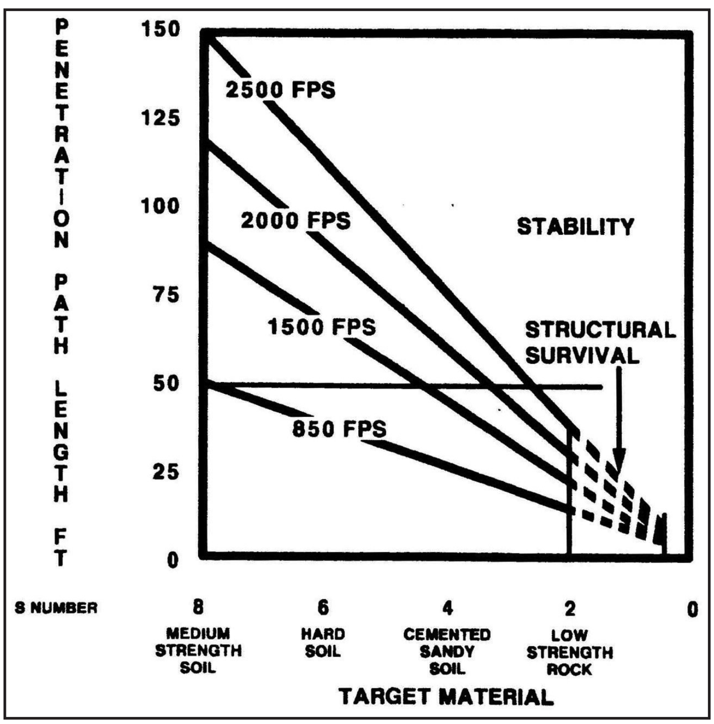

Figure 3. Baseline Strategic EPW Performance. The "Structural Survival" region corresponds to the failure of the EPW. "S" numbers characterize the type of geology.

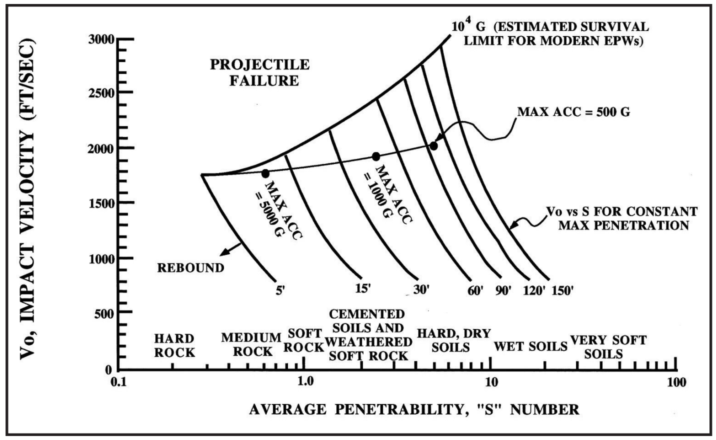

Figure 4. The figure shows the operational limits of current EPW designs imposed by penetrator technology independent of how deployed. This figure does not include limits that may be imposed by other factors such as the nuclear package carried by the EPW.

If we assume that the earth penetrating weapon will be deployed on a cruise missile or is air dropped, the relevant curve in Fig. 3, as will be shown later, is the one for 850 feet per second. There is no possibility of reaching depths of 100 feet in any kind of soil, much less rock where one would expect stores of chemical or biological agents or weapons to be stored.

The general operational limits on EPW designs are an important issue and are better illustrated in Fig. 4.

Required yield

From Fig. 2 one can determine how deep a given yield weapon needs to be buried to achieve a specified coupling of output energy to the ground. How a shock wave resulting from this deposition is propagated through the earth depends strongly on the geology.

Sophisticated modeling is needed to determine peak stress contours as a function of depth and range. Examples of such calculations are shown in Figs. 5(a) and (b). Note that peak stress contours will depend strongly on the type of geology, the air-filled void fraction and the degree of water saturation. Figure 5(b) shows a single 1 kilobar (kb) contour for a 500 kt explosion with a 15 m DOB in a specific geology having a 0.5% air-filled void (AFV) fraction. The attenuation of the shock wave increases with increasing AFV fraction.

On axis peak stress as a function of depth below the burst can also be determined for a given yield and geology. In Fig. 5, this would correspond to a plot of the stress data along the Y-axis (with X = 0) as a function of depth. Curves for different yields can then be found by use of the scaling relationship

1 *ICBM or SLBM deployment of EPWs is not considered here. Such deployments require specially designed maneuverable reentry vehicles and a large-scale development program as was considered in the Earth Penetrating Warhead Requirements Study described in the history given earlier in this article.*

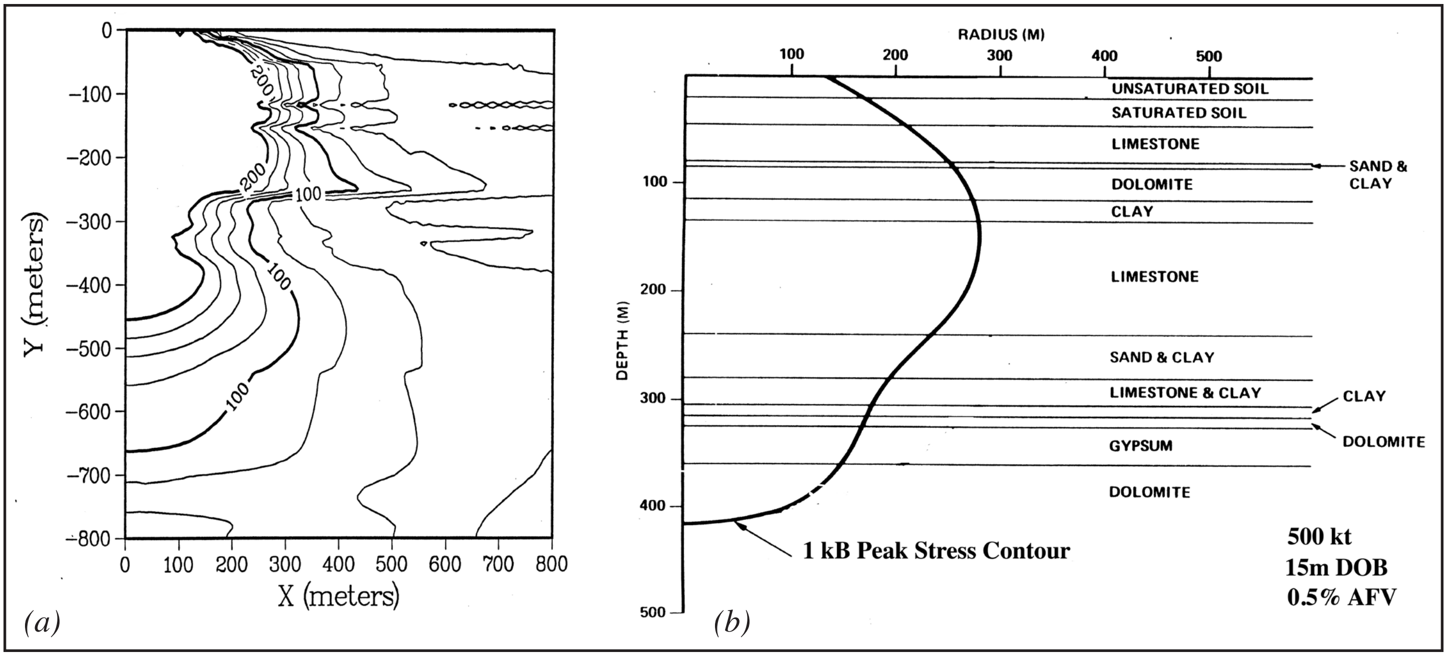

Figure 5. (a) Peak stress contours vs. range for 225 ms after the detonation. Only curves below 1.2 GPa (1 Pa = 10-5 bar) are shown. The contour intervals are 25 MPa. This example is for a DOB of 15 m for a weapon having a yield of several hundred kilotons. (b) A single 1 kb contour for a 500 kt explosion with a 15 m DOB in a specific geology having a ~0.5% air-filled void fraction.

$$\frac{Y_2}{Y_1} = \left(\frac{R_2}{R_1}\right)^3.$$

Here R is the range to effect.

To decide what yield is needed to destroy a given target, one must choose a depth for the buried facility that is to be targeted, its hardness, and the geology within which it is located. The usual choice for analysis purposes is layered limestone and a hardness to crush the facility of 1 kbar. It turns out that in wet tuff, the type of geology assumed here, the depth of the 1 kbar peak overpressure scales roughly as $50\text{m/kt}^{1/3}$ for a DOB = $1.9\ \text{m/kt}^{1/3}$.

This means that if a bunker is at a depth of say 100 m, the yield required for 1 kbar at that depth is given by

$$100\text{ m} = 50\left(\text{m/kt}^{1/3}\right) Y^{1/3}$$

$$Y^{1/3} = \frac{100}{50}\left(\text{kt}^{1/3}\right) = 2\left(\text{kt}^{1/3}\right) \quad \longrightarrow \quad Y = 8\text{ kt}.$$

So 10 kt is in the right ballpark for this type of target. The required DOB would be $1.9\ (\text{m/kt}^{1/3})\bullet(8\text{kt})^{1/3} = 3.8\text{m}$. As we have seen, an EPW in this yield range already exist: Although the 2002 Nuclear Posture Review states that the B61 Mod 11 has only a single yield, there is no obvious reason that this warhead cannot be configured to have various yield options.[3] This is why the B61 is the weapon "worth its weight in gold". And in particular, it is also light enough to be deployed on cruise missiles.

Penetration Depth Needed to Prevent Atmospheric Venting

As mentioned above, there has been some discussion of it being attractive to use low-yield nuclear EPWs to incinerate chemical or biological agents since, it has been claimed, the resulting radioactivity would be contained. The depth of burial used at the Nevada Test Site to prevent venting of radioactive debris from an underground explosion is given approximately by[4]

$$D(\text{m}) \approx 122\left[Y(\text{kt})\right]^{1/3}.$$

For 10 kt, the yield needed to attack the target of the last section, D = 122 (10)1/3 = 263 m. Low yield EPWs will definitely vent since, as was shown above, there is no hope of an EPW being able to penetrate to this depth.

EPW Penetration Depth for the B61 Mod 11

To make use of Figs. 3 or 4, we need an estimate of the EPW impact velocity. Two deployment possibilities come to mind for the B61 Mod 11: cruise missiles and air-dropped from say 10,000 ft.

• Cruise Missile (subsonic) ~500 mph = 733 ft/sec

(Cruise missiles can do a last minute maneuver to increase this impact velocity)

• Air dropped (ignoring air drag):

$$d = \frac{1}{2} a t^2$$

$$v = at$$

$$d = \frac{1}{2} a \left(\frac{v}{a}\right)^2 = \frac{1}{2} \frac{v^2}{a}$$

$$v = (2ad)^{1/2} = \left(2 \times 32 \frac{ft}{sec^2} \times 10^4 \, ft\right)^{1/2} = 800 \text{ ft/sec.}$$

So both cases give about the same velocity of impact and put us on the lowest curve of Fig. 3 as claimed earlier.

This tells us that in medium strength soil an EPW with a velocity of impact of 800 ft/sec will penetrate less than 50 ft; in low strength rock, maybe 15 ft. How does this translate into the amount of energy coupled to the earth? The answer comes from Fig. 2. The range of the possible penetration depths of 4.6 m to 15.2 m (15 ft to 50 ft) gives us the following table for both ends of the range:

B61 Mod 11 Yield	SCALED DOB ($m/Mt^{1/3}$) 4.6 m	15.2 m	EQUIVALENT YIELD COUPLING FACTOR 4.6 m	15.2 m
10 kt	21.3	70.4*	0.65	>0.7
360 kt	6.46	21.4	0.4	0.68

** Off scale for Fig. 2. Maximum Scaled DOB on that figure is 24 m/Mt1/3 corresponding to an Equivalent Yield Coupling Factor of 0.7. This means that a 10kt burst at a 15.2m BOB will be almost fully coupled.*

For example, for the 10 kt yield and a detonation at a depth of 4.6 m, the scaled DOB is 4.6(m)/[0.01(Mt)]1/3 = 21.3 (m/Mt1/3); from Fig. 2, the scaled depth of burst of 21.3 (m/Mt1/3) corresponds to an equivalent yield coupling factor of about 0.65.

While the Equivalent Yield Coupling Factor for the B61 Mod 11 set for a yield of 360 kt is only 0.4 when the weapon can only penetrate to 4.6 m into the earth, that is considerably better than the 0.02 for a contact burst (see Figure 2). It is interesting to determine the 1 kb stress for this yield option given the DOB range of 4.6 m to 15.2 m.

The data I have is for a 6 m and 12 m DOB rather than 4.6 m and 15.2 m, but these are close enough to get estimates using the scaling relationship given above. As shown in Fig.6, for a 6 m DOB of a 500kt weapon the 1kb peak stress on axis is at a depth of 465 m. For a 12 m DOB it is 535 m.

Rewriting the scaling relationship given earlier in this article, the radius to effect—in this case the depth to 1 kb peak stress—is:

$$R_1 = \left(\frac{360}{500}\right)^{1\backslash 3} 535 \text{ m} = 480 \text{ m.} \quad (12 \text{ m DOB})$$

$$R_1 = \left(\frac{360}{500}\right)^{1\backslash 3} 465 \text{ m} = 417 \text{ m.} \quad (6 \text{ m DOB}).$$

These depths are more than adequate for most potential targets located in geologies where the EPW can penetrate to the depths used in the example above.

Intelligence, rather than technology, is the key issue

Targeting underground facilities requires not only determining their depth and hardness, and in what geology they are located, but also exactly where they are located. Intelligence is the key issue. Knowledge of surface-feature locations from satellite or other surveillance photography does not necessarily determine the position or configuration of an underground facility. Without such knowledge (and accurate HUMINT is very scarce in the countries of interest) even relatively large-yield nuclear EPWs may not be very effective. Such weapons also cause severe radioactive fallout due to the venting of activated ground material—unlike bursts at an optimal height chosen to maximize blast damage, which should rule out using many of them over a target area to make up for intelligence deficiencies.

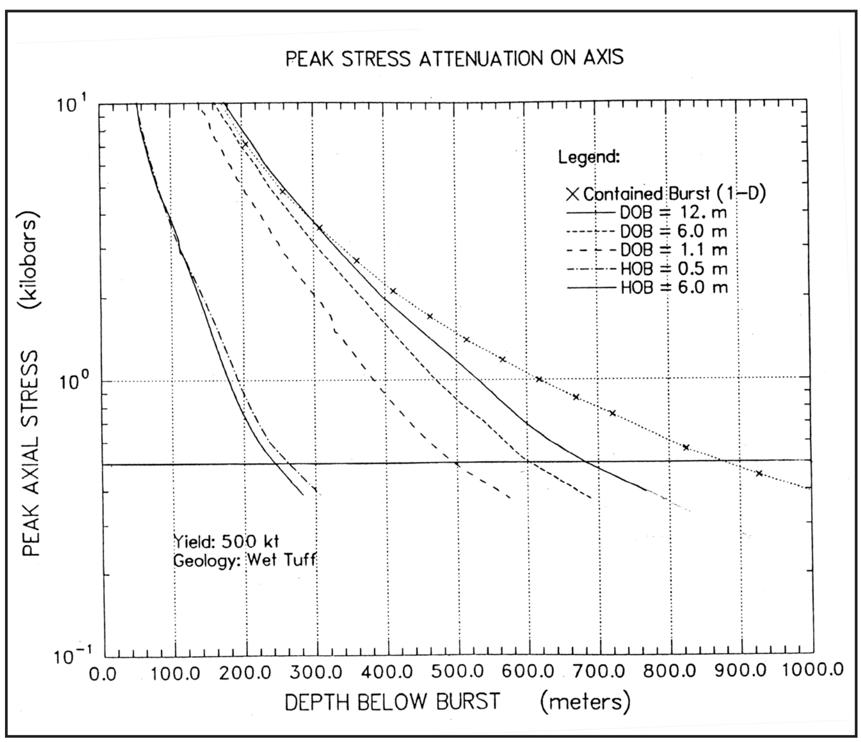

Figure 6. Peal Stress Attenuation on Axis as a function of HOB/DOB.

Conclusions

With regard to small-yield EPWs one may conclude:

• To crush a target having a depth of 100m and a hardness of 1 kbar, a low-yield EPW needs a yield of about 10 kt. For this yield, the required EPW penetration depth is around 4m to obtain good ground coupling.

• It is not possible for an EPW to penetrate deep enough into the ground to prevent the venting of radioactive debris or to incinerate deeply buried chemical or biological agents.

• An air dropped or cruise missile deployed EPW cannot penetrate deeper than about 50 feet or 15.2 m in even medium-strength soil, and much less in harder ground.

• The key issue determining the effectiveness of EPWs is accurate intelligence on the location of buried targets, which is rarely available.

Even for far more deeply buried targets, the B61 Mod 11 with a high yield option can produce a 1 kb stress level at depths in the range of 400-500 m. As Figs. 3 and 4 show, however, current technology does not allow EPWs to penetrate hard rock.

References

1 The data and figures in this article are adapted from the contributions of the many people, organizations, and agencies that participated in this study.

2 The 8 January 2002 Nuclear Posture Review states that: The United States currently has a very limited ground penetration capability with its only earth penetrating nuclear weapon, the B6 Mod 11 gravity bomb. This single-yield, non-precision weapon cannot survive a penetration into many types of terrain in which hardened underground facilities are located" (p. 47). Indeed, penetration of hard rock is a problem; however one wonders how calling this weapon "non-precision" makes sense given the accuracy of cruise missiles. In any case, accuracy is not the principal problem preventing EPWs from being effective.

3 One of the yields given for the B61 in Chuck Hanson's Swords of Armageddon is 10 kt.

4 J.F. Evernden and G.E. Marsh, "Yields of US and Soviet nuclear tests," Physics Today 40, 36 (1987).

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The Elephant in the Room: How OPEC Sets Prices and Limits Carbon Emissions

Alfred Cavallo

Abstract

Despite a North American oil boom, non-OPEC crude oil production is approximately constant because new production roughly balances existing oil field decline. This situation allows OPEC, which has spare production capacity, to control the total global oil supply and therefore oil pricing. OPEC has raised crude oil prices by a factor of about four since 2002, reducing world demand. Thus, world crude oil production has been flat since 2005, and a major source of carbon emissions has been capped. This production plateau has been maintained in spite of significantly increased demand from China, India, and other developing countries. But governments in both developed and developing countries could reduce emissions more efficiently and fairly, and facilitate a much smoother transition to renewable energy technologies, by putting in place, for example, a zero-net-revenue carbon emissions surcharge regime, with all collected funds returned directly to consumers.

It is an ironclad rule for oil companies that petroleum is forever, and while old wells and fields may be exhausted and abandoned, a new giant discovery is always just over the horizon. The one exception to this occurred in 2004, when the Exxon Mobil Corporation with refreshing candor discussed oil quantitatively as a finite, limited resource1. In its report2 "The Outlook for Energy: A 2030 View" it stated that crude oil production outside the Middle East (from non-OPEC producers) would peak by 2010, remain constant for several years and then begin to decline. At the same time it noted that demand for liquid fuels would continue to grow and that it expected OPEC3 (Middle Eastern) producers to increase production as necessary to supply the market. Although unstated, it was evident that from this point on OPEC would fully control incremental supply and that prices could increase quite substantially. This would have profound consequences for the economies of the U.S. and the rest of the industrial world, as well as for those transitioning societies that hoped to follow Western patterns to increase their standard of living. Yet in spite of the alarming implications, the forecast was ignored by almost everyone, including governments, consulting groups and environmental organizations. ExxonMobil, however, based on this forecast decided that it would build no new oil refineries4 since increasing supplies of non-OPEC petroleum would not be available.

While the basis for this projection was never explained, it probably made use of data from the U.S. Geological Survey's (USGS) World Petroleum Assessment 20005, which evaluated world oil resources using the best available science, engaging experts not only in government, but also in intelligence agencies, petroleum companies and petroleum consulting groups. It was by far the most credible study of its kind ever done. In addition, ExxonMobil may have modeled oil production using M. King Hubbert's logistic growth curve-fitting approach (Hubbert, 1956; Cavallo, 2005). This is particularly well suited for a non-OPEC production forecast since for best results a reasonable estimate of total reserves is needed as input; other requirements for the applicability of this econometric model, including affordable prices for consumers and sufficient profits for producers are also met over a long time span. In contrast, most OPEC producers jealously guard information on their oil industries so that OPEC reserve estimates are somewhat uncertain. In summary, all the necessary data and tools needed to make a credible projection of non-OPEC crude oil output were available to Exxon Mobil analysts, as well as to other consulting (Cavallo, 2002) and research groups including those at OPEC6, once the USGS Assessment was released in April 2000.

It is now over seven years since the ExxonMobil projection was made, and well beyond the 2010 non-OPEC peak year given in the report. It is appropriate to ask many questions starting with the obvious one: Was ExxonMobil correct? As is well known, one of the great hazards of making short or long term forecasts, especially about the oil business, is that the future happens in ways that may make fools of the most astute and capable observers, to their enormous embarrassment, due to advancing technology7 or factors trivial or otherwise that were neglected or could not be imagined.

As it developed, ExxonMobil was correct about the peak in non-OPEC crude oil output. Based on data provided by the U.S. Energy Information Administration8, annual average non-OPEC conventional crude oil production increased by 16 percent over ten years, from 36.3 million barrels per day in 1994 to 42.1 million barrels per day in 2004, and then over the past seven years has remained very close to this level. Thus, non-OPEC production has indeed reached a peak/plateau, if somewhat sooner than predicted. Given all the uncertainty involved in making such an estimate, this result should be regarded as a major triumph.

The World Oil Industry: Non-OPEC Producers

To appreciate the profound significance of the non-OPEC crude oil peak, it is necessary to understand, in a general sense, how the world oil industry functions. Crude oil is the backbone of the petroleum industry; other liquids such as ethanol, biodiesel and natural gas liquids (petroleum liquids obtained as a byproduct of natural gas production), included in world oil statistics, have much lower energy content and/or much smaller resource base and will not be able to replace crude oil. Unconventional crude oil, that is oil derived from tar sands, heavy oil deposits or shale oil (produced using the newly developed rock fracturing technology), is much more difficult to extract and also has a small resource base and will only add marginally to world oil output. These other resources will probably prolong the plateau in liquid fuel production, but will not be a replacement for conventional crude oil.

Non-OPEC producers currently supply about 57% of the world crude oil demand. There are several different categories of non-OPEC producers: publicly or privately owned and operated companies (e.g. ExxonMobil, BP, Shell), national oil companies such as Pemex (Mexico's state oil company) or quasi-national companies such as Petrobras (Brazil) or CNOOC (China National Offshore Oil Company). All of these very diverse organizations share the same objective: to find and produce as much oil as possible as quickly as possible, and to make as much money as they can doing so. There are no production quotas for any of these organizations, and indeed there is intense, cutthroat competition to find new oil deposits and begin extraction with deliberate speed. Profits are derived almost entirely from exploration and production, while refining and distribution of petroleum products are much less lucrative, so that there is an intense focus on successfully locating new oil deposits.

Clearly, given the market rules under which non-OPEC producers operate, a peak in non-OPEC production means that it is physically impossible for these organizations to increase oil production either from new conventional discoveries or using improved technologies to extract previously inaccessible conventional oil.

Non-OPEC Decline Rates: the Hidden Killer

Discovery of new fields is necessary not only to meet rising demand, but also to compensate for declining production in mature discoveries. New offshore fields found, for example, in the Gulf of Mexico or offshore Brazil, are often announced in press releases that are propagated around the world. Hydraulic fracturing of oil-rich impermeable shale has enabled significant extraction from such formations in North Dakota and Texas, and has been widely portrayed as a bonanza for the U.S and heralding a revolution in world oil production.

There is unfortunately an elephant, or perhaps a herd of elephants, in the room. What is never spoken about is that production from all these new resources is now just compensating for an approximately 7.1 percent per year decline of non-OPEC fields, according to a study published by the International Energy Agency in 2008. This corresponds to a production drop of about 3 million barrels per day per year for non-OPEC fields. Moreover, decline rates can be expected to increase as the large, easy to discover fields are exhausted and smaller, harder to find deposits are exploited.

Oil from unconventional deposits9 will not alter the situation substantially. Production from Canadian tar sands in 2011 averaged about 1.35 million barrels per day and has been increasing slowly; oil production from tight shale deposits in the U.S. (mainly Texas and North Dakota) is currently around 1.2 million barrels per day and is projected to increase to 4.2 million barrels per day by 2020. Yet even though U.S. oil production has increased by about 1.8 million barrels per day and tar sands production by about 0.35 million barrels per day between 2006 and 2011, non-OPEC oil production has remained essentially flat over this period. Thus, it appears that crude oil from these unconventional sources will only help to lengthen the plateau in liquid fuel production and not significantly increase the overall rate of production.

Increased extraction from these new resources should be compared to the minimum production decline of conventional crude oil over this same period (2012-2020) of at least 24 million barrels per day. Thus, while some oil companies stand to profit handsomely from these new reserves, market fundamentals remain unchanged.

OPEC Producers

In contrast, OPEC, which supplies 43 percent of crude demand, is formally committed, as described in its founding statue, to maintaining a stable market; this is something that non-OPEC producers cannot and do not worry about. OPEC keeps demand and supply in balance, and prices within a band that it deems reasonable. In order to accomplish this it will not only increase, but also will decrease production as needed. Each member country has a production quota which is based roughly on the member states' proven reserves, as well as on many other factors such as need for revenue. However, these quotas are mostly for public consumption, and members may or may not abide by them since the only result that matters is a tranquil market.

OPEC always maintains what is termed "spare capacity," which is the ability to add additional supply to markets on short notice in case of unforeseen developments. One recent demonstration of OPEC's capability in this regard occurred following the loss of Libya's output of 1.79 million barrels per day as a consequence of the Libyan civil war which began in January, 2011. By August, increased production from Saudi Arabia, Kuwait, Iraq, Qatar and the UAE had replaced the Libyan output with negligible disruption to the world economy. (Of course this implies that this much production was being withheld from the market to maintain high prices before the Libyan collapse.) In another example, OPEC decreased production by about 3 million barrels per day between July 2008 and January 2009 following the near collapse of the world financial system and the onset of the Great Recession; non-OPEC production was virtually flat during this period. Had OPEC not cut production, prices would have dropped to the low single digits, driving many non-OPEC producers to bankruptcy in the process.

Although never mentioned in discussions of oil prices today, the existence of spare capacity and control of marginal, or swing production gives OPEC control of the market price, or more properly speaking, the market price band. This is set far above the cost of extraction, which for OPEC oil is a few dollars per barrel.

It is important to note that day to day or week to week prices on commodity exchanges are influenced by all market participants. This includes businesses such as airlines or oil refineries that need to protect themselves from changes in prices as well as speculators who place bets on future price directions. For example, if a refinery has an accident, an oil tanker is attacked, or a there is a report of an excess of oil stocks in the U.S., speculators moving in or out of the market can immediately increase or decrease the market price. Longer term prices are set by the supply and demand balance controlled by OPEC10: too much supply on the market means prices will drop slowly but steadily, and too little supply means prices will rise. In either case there can be significant fluctuations within or outside the price band since there is no official cooperation between consumers (oil importers) and producers to balance the market. Indeed, price fluctuations can be viewed as an integral part of the price setting mechanism in that they help to mask the real reason for price increases.

The Oil Weapon: Unmentioned But Potent

To complicate matters still further, OPEC sets prices11 for geopolitical as well as economic considerations and never announces or explains its decisions. Nonetheless, one can make reasonable guesses about the motivation behind some short term price movements. For example, OPEC might not want gasoline prices to be an issue in U.S. presidential elections so would adjust production to insure stable prices for such events.

Also, while certain OPEC members might not favor a nuclear armed Iran, even less desirable would be a U.S. or especially an Israeli attack on that country; unexplained higher oil prices – the oil weapon - are the perfect way to send a message. It could well be that the spikes in oil prices in 2007-2008 and 2011-2012 were directly related to the threat of an attack on Iranian nuclear facilities.

Finally, oil prices dropped significantly following the financial panic in 2008, not because OPEC was unable to decrease production sufficiently to support higher prices but perhaps because OPEC did not want to be seen as contributing to the strain on Western economies. This is all mere conjecture, but given the circumstances is the best that can be done. The important point to understand is that OPEC controls the market price band and is willing to use this to achieve its own economic and geopolitical goals.

To the average U.S. gasoline consumer, price signals are totally confusing over the short or intermediate term, while memory fails completely for long term trends, that is changes taking place over more than three to six month periods. However, it is precisely these longer term trends that are most relevant for understanding the second part of ExxonMobil's forecast, that of increased crude oil production by OPEC.

OPEC's Choice: Increase Supply or Increase Price

Once non-OPEC production reached a maximum, OPEC, contrary to what was stated in ExxonMobil's report, actually had a choice. It could increase production, maintaining the prevailing price band; this was the expected and desired outcome. On the other hand it could limit its own production, keeping the market well supplied, but increase prices to bring demand and supply in balance. This latter course of action had and has many advantages. It requires minimal investment in new fields, conserves what is now obviously a finite resource, and allows income to rise much faster than from a production increase.

In addition, raising prices rather than production serves to put a cap on a major source of greenhouse gas emissions, and by encouraging the owners of other fossil fuel reserves to raise prices and thus reduce demand, reduces emissions still further. This is totally irrelevant as far as the petroleum industry is concerned, but of seminal importance for understanding how to persuade the world's consumers to reduce fossil fuel consumption.

OPEC chose to increase prices rather than production. World crude oil production reached a peak of 73.7 million barrels per day in 2005 and has remained near this value through 2011[12]. In contrast to the peak in non-OPEC production, which is caused by real physical limitations in the ability to extract more oil, OPEC members, especially Saudi Arabia, Iraq, Iran and the UAE, are believed to have very large proven and undiscovered reserves and could increase their output significantly if they decided to make the necessary investments. OPEC production limits are consciously chosen rather than dictated by available resources, and have been of enormous benefit both to OPEC and non-OPEC producers as well as to the overall health of the planet.

Since petroleum is a fundamental requirement for a modern industrial society, raising prices is a delicate matter. Consumers would like prices to be as low as possible and based on the finding and extraction cost, which for the Middle East is well under $5 per barrel[13]. Resource owners would like prices to be set as high as possible, and based on what value is extracted from oil by the user. For example, it is well known that people everywhere will pay very high prices for personal mobility; gasoline prices in Europe are predominantly determined by imposed taxes, even today with crude oil prices about $105 per barrel ($2.50 per gallon of crude oil; with tax, gasoline prices of $8 per gallon in Europe). This demonstrates that much of the value[14] is captured by European governments rather than the producers and indicates a crude oil worth of at least $250 per barrel ($6 per gallon).

In addition, abrupt price increases should be avoided since consumers and industry will need time to adapt, either with new technology or changes in lifestyle. Demand must always be restrained by gradual price increases, not by reducing supplies; indeed, the threat of a supply interruption must never be mentioned or in any way suggested.

It seems that OPEC began increasing prices in 2003, and has continued to do so since then (with a pause due to the onset of the Great Recession). In 2002, the year before the U.S. invasion of Iraq, the annual average OPEC crude oil basket price[15] was $24.36 and OPEC spoke openly of increasing or decreasing its production to maintain oil prices within a band[16] of $22-$28 per barrel. However, after the U.S. invasion of Iraq in March, 2003, mention of this approach became less and less frequent and finally disappeared completely.

The attack on Iraq halted oil production from that country, which at the time amounted to about 2 million barrels per day, most of which was exported. OPEC made up for the shortfall by increasing production (Cavallo, 2004); indeed, anything less would probably have been used as justification for retaliation and retribution. However, the invasion provided the perfect opportunity to begin raising prices, given the uncertainty and violence in the region that is the major source of the world's petroleum; the average annual OPEC basket price increased by about 15 percent in 2003, to $28.10 per barrel; by December 2003, prices had risen to about $30 per barrel.

The U.S. was thoroughly preoccupied and distracted first by its successful invasion, and then by the intractable problems of a failed occupation. It appears that OPEC, far from being cowed into submission by the shock and awe display of overwhelming military force, took the opportunity to increase prices gradually. Using craft and guile, it orchestrated a masterful campaign of misinformation and pretended innocence. Between 2002 and 2012, the OPEC annual average basket price increased from $24.36 to about $105 per barrel, or about a factor of 4.3 (3.3 adjusted for inflation) an astonishing accomplishment. This far exceeds the rate of inflation over this period (approximately a factor of 1.3) and has had a relatively tolerable impact[17] on the world economy; the gradual change has allowed consumers to adapt while the Great Recession has cut demand in the developed world.

Initially, industry analysts and commentators explained increased oil prices by saying that the markets were reacting to the unrest in the Middle East by adding a "war premium" or a "terrorist premium" or a "fear premium" onto prices[18]. There were even attempts to quantify this by conjuring up a sum to be added to what analysts thought the real price should be. There was absolutely no basis for such an assignment and any "premium" charge was in effect pulled out of thin air; one might as well have proposed a "leprechaun premium" to explain the escalating prices. At one point an OPEC spokesperson simply stated that he did not understand why oil prices were so high since the markets were obviously well supplied.

Most recently the favored causative agent cited by OPEC and others has been "speculators," a brilliant choice given the terrible damage banks, hedge funds and other such financial buccaneers and their enablers have inflicted on the world economy. This is the perfect scapegoat, and serves to distract consumers, politicians and environmentalists from the OPEC managers controlling the market, as well as from the root cause of the problem which is the real limits on petroleum resources.

Anyone familiar with how oil markets function in practice should be able to see through such fantasy, yet this charade has been a complete success in that OPEC has remained nearly invisible and is virtually never cited in the news media as having anything to do with setting oil prices. Western and other non-OPEC oil companies will not challenge this narrative since they have profited enormously from it. Environmental groups and consumer organizations lack the expertise or the will to penetrate the misleading rhetoric from authoritative sources, and in any case are totally focused on the problem of climate change. To a casual observer it would seem that prices are indeed determined by what appears to be free markets since large volumes of oil are traded daily on commodity exchanges. These markets do serve useful functions, but setting the price band for oil is not one of them. There should be no doubt that OPEC can and does control oil prices based on what it regards as its own economic and strategic best interests.

The Climate Connection

OPEC's decision to increase oil prices and thereby limit demand, rather than to increase production, has another important consequence: It puts a cap on a major source of greenhouse gas emissions and, by encouraging the owners of other fossil fuel reserves to raise prices and thus reduce demand, reduces emissions still further. The question is whether demand will continue to increase so the price hikes can be maintained, and whether there is any possibility of satisfying the increased demand from available oil resources.

Increased Demand

Given the large and growing decline rates for non-OPEC oil fields, one should expect oil prices to have significant fluctuations and a strong upward bias. Yet there is another factor that puts still more pressure on prices, and that is increased demand in places like China and India. These two nations have a population of about 2.5 billion people and are moving rapidly to adopt more comfortable lifestyles. To understand what this means it is useful to compute how much oil would be needed to elevate their standard of living to a level enjoyed by Europeans (Table 1).

Current world crude oil production has been nearly constant at about 74 million barrels/day (26.9 billion barrels per year), since 2005; it is clear that a world oil production increase of 20 billion barrels/year is out of the question. The world is indeed on the threshold of a fundamental transformation in energy consumption, but the primary driver has remained deliberately obscured.

Both China and India are diligently following Western development templates and seem completely unaware of the unfeasibility of the "business as usual" model. It appears that we are on a collision course not only with limits on petroleum resources but also with limits to conventional growth patterns fueled by increased oil supplies. China and India cannot consume petroleum at the same level as Europe much less the U.S. (average U.S. consumption is about 22 barrels per person per year.): the resource base just does not exist. (On top of this, Africa and Latin America are following this same path and hope to improve their standard of living in precisely the same way.)

This most certainly means that nobody will be able to consume petroleum or other fossil fuels, even at current, modest European rates, for much longer, and we will all be forced to adapt to significantly higher fuel prices. Fortunately, it does appear that while renewable energy supplies and new technologies19 are more expensive than fossil fuels, they are certainly affordable and will allow people to live comfortably; the world is not going to freeze in the dark without fossil fuels.

Running out of oil

OPEC is thus sensibly using increased prices to limit demand, a classic case of "demand destruction." For all practical purposes, the world will never run out of oil: Price will be used to ration a scarce commodity, and there will be oil for sale at, for example, $500, or $600, or $800 per barrel. Moreover, natural

Table 1
Annual Petroleum Supply Needed to Raise China/India Living Standards To European Levels

Average European Petroleum Consumption	~10 barrels/person /year
Final China/India Petroleum Consumption	25 billion barrels/year
Current India/China Petroleum Consumption	5 billion barrels/year
Increased World Oil Production Needed	20 billion barrels/year
Current World Oil Production	32.5 billion barrels/year

gas prices are linked to oil prices everywhere outside the United States, so a similar process is taking place with this fuel.

Policy implications

It has become evident over the past decade that most consumers are incapable of voluntarily reducing their fossil fuel consumption, even when told that the stability of the Earth's climate is threatened. It is therefore important to explore all possible means of motivating people to move away from fossil fuels.

It is generally agreed that a zero-net-revenue carbon surcharge is the fairest, simplest, and most effective way to reduce fossil fuel consumption. While there is strong resistance to such a surcharge, it should be noted that the $2-per-gallon price increase OPEC imposed between 2002 and 2012 is approximately equal to a carbon tax of $200 per metric ton. 20 This indicates another way to persuade people to move away from fossil fuels: immediate economic necessity due to high fossil fuel prices demanded by the owners of the resource.

While an effective carbon tax imposed by the resource owners is infinitely better for the climate than no tax at all, it is far from ideal. The resource owners in this scenario collect all of the revenues; a far better approach would be to recycle at least a portion of the effective tax to consumers, to subsidize new technologies. It remains to be seen whether politicians are willing to acknowledge resource limitations and use this as a justification to impose, for example, a zero-net-revenue surcharge21 on fossil fuels.

In any case, it may well be that in the very near future price increases dictated and collected by resource owners alone22 will be sufficient to move society toward a more sustainable economy and to avoid the worst consequences of our insatiable demand for fossil fuels.

A new approach to oil pricing and taxes

It appears that oil companies as well as automobile manufacturers, hedge fund operators and investment houses are aware of the immediate reality of finite oil resources. This scarce commodity will be rationed through prices set by OPEC, the owner of the largest and lowest-cost reserves. Higher prices will encourage the development of alternatives, such as new technologies and lifestyle changes. OPEC leaders seem well aware of the challenges they face and so far have carried out their strategy of price rationing with consummate skill. This set of circumstances also presents an opening for others who wish to limit fossil fuel consumption to mitigate climate change; hopefully, they can use the facts related to oil supplies and pricing to persuade citizens and, particularly, leaders of developed countries that they must deal with petroleum differently if they are to maintain an acceptable standard of living on a crowded planet.

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Notes

1 Warnings that the U.S. was about to run out of oil have a long and checkered history. To this author's knowledge the oldest such statement came in 1874, just fifteen years after "Colonel" Drake's first oil well, from a Pennsylvania geologist who projected that we would run out of oil by 1878 (Anderson, 1984). New oil discoveries in Indiana immediately voided this forecast, but similar warnings regularly occurred from this point on. Forecasts of scarcity would be followed by new discoveries and overabundance, a characteristic boom and bust cycle for which the oil industry became infamous. After the 1973 oil embargo stories of decline and oil famine became almost a cottage industry; end of oil proponents might be termed oil doomsters, eager catastrophists or anti-industrial romantics, describing or implying the end of civilization and mass destitution following the exhaustion of oil reserves. Until very recently such attitudes might be excusable since the mechanisms of petroleum formation, migration and accumulation were not understood and credible estimates of oil resources and reserves were lacking. It was only with the acceptance of the theory of plate tectonics and advances in geophysics, geochemistry and geology that a scientific approach to the problem became possible. As will be shown, we now have reasonable estimates of world petroleum resources that can be used to project the evolution of the oil industry with acceptable uncertainty; assuming that petroleum resources are infinite is not a justifiable input in any model of the evolution of a modern industrial society or of how carbon emissions are likely evolve.

2 http://www.exxonmobil.com/corporate/files/news_pub_eo_2010.pdf. This report is updated each year; the 2004 version is no longer available. On p42 of the 2010 version there is a plot entitled Liquids Supply versus Time (1980-2030); non-OPEC crude oil production appears to decline slightly after about 2004 but remains flat out to 2030. That world crude oil production has not increased since 2005 and that prices have increased substantially as well is not mentioned.

3 OPEC producers strictly restrict access to and control of their oil resources. International oil companies such as BP, ExxonMobil or Shell may be hired as contractors but are never allowed to take ownership of the reserves. This is the reason for ExxonMobil's interest in the peak in non-OPEC production: for all practical purposes OPEC reserves are not accessible to non-OPEC companies.

4 Presentation by Scott A. Nauman, Corporate Planning, ExxonMobil Corporation, October 20, 2005, Washington, DC.

5 http://pubs.usgs.gov/dds/dds-060/; U.S. GEOLOGICAL SURVEY WORLD PETROLEUM ASSESSMENT 2000 – DESCRIPTION AND RESULTS. The report provides estimates of the amounts of conventional oil, natural gas and natural gas liquids outside the U.S. that can be added to proven reserves between 1995 and 2025. The report does not analyze the implications of these findings and specifically states that these data can be used for additional environmental, geologic, geopolitical and environmental studies.

6 OPEC set up its own research group and began producing Monthly Oil Market Reports in 2001. These are high quality, detailed, publically available monthly evaluations of the oil industry.

7 Hydraulic fracturing is an excellent example of a technology that was much more successful than most observers believed possible. It has certainly had a huge impact on the U.S. natural gas industry, but is unlikely to have a similar effect on the world petroleum industry.

8 See http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=50&pid=57&aid=1&cid=&syid=2008&eyid=2012&freq=Q&unit=TBPD. The EIA website is excellent and can be used to examine details of world crude and world liquids production.

9 http://digital.ogj.com/ogjournal/20140106?sub_id=LqhvjCW6dypr#pg50; Gaswirth S and Mara K, Bakken Three Forks Largest U.S. Continuous Oil Accumulatiion, 48-53; The USGS estimates U.S. total recoverable reserves of shale oil as 13 billion barrels. This should be compared to current U.S. consumption of about 7 billion barrels per year.

10 Current OPEC oil production figures are somewhat uncertain. See for example: http://www.opec.org/opec_web/static_files_project/media/downloads/publications/MOMR_December_2012.pdf, p53. Two sets of OPEC production data are shown, one from secondary sources, which are used by all those following the oil industry, the other from direct communication with OPEC producers; there is a differential of about 1.3 million barrels per day between the two sets of figures. Most of the difference is due to Iran, which claims about 1 million barrels per day more production than is recognized in secondary sources. This might indicate significant oil smuggling by Iran to circumvent the U.S. led campaign to restrict Iran's oil sales and thus cripple its nuclear program. Ignoring this subterfuge allows the U.S. to satisfy domestic supporters of Israel while avoiding drastically increased prices resulting from an effective blockade which would damage the world economy. It is clear that what is of primary concern is the maintenance of an orderly petroleum market.

11 The OPEC basket price, available at www.opec.org, will be used as the benchmark (or standard reference price) in this discussion. The normally quoted WTI (West Texas Intermediate, Cushing, OK) price is no longer representative of world oil markets due to the rapid increase in unconventional oil production in North Dakota and the lack of pipeline capacity at the distribution point in Cushing, OK, depressing the WTI price artificially.

12 For the first three quarters of 2012 world crude oil production was about 75.5 million barrels per day (computed using the lower Iranian production figures). Non-OPEC production is virtually unchanged at 42.4 million barrels per day in spite of significantly increased shale oil production in the U.S. so that almost all of the increase in world crude oil extraction is attributable to OPEC.

13 Finding and extraction costs are much higher for new non-OPEC conventional and especially unconventional oil. While such costs are generally regarded as proprietary, information on oil and gas company acquisitions and asset sales is available in the Oil and Gas Financial Journal (www.ogfj.com). This indicates that proven U.S. conventional on-shore oil reserves are currently valued at about $20/barrel. North Dakota oil shale is profitable at a West Texas Intermediate (WTI) price of less than $60/barrel while Canadian tar sands requires a WTI price of $60-$100/barrel, depending on the extraction method used (information from OGFJ, July 2012, p 34). These figures should be regarded as for guidance only since there can be wide variations in profitability due to resource quality ("sweet spots"), advances in technology (especially for oil shale), operator skill and luck, and taxation and royalty regimes. Given the current WTI price of above $90/barrel it is clear that the oil business is immensely profitable for competent producers.

While OPEC profits are rarely discussed in the open literature, Iraq's need for outside assistance in reviving its oil industry after decades of war and U.S. imposed sanctions has provided some indication of development and extraction costs in the Gulf. Foreign oil companies were invited to bid on contracts to restore and expand Iraqi production in existing fields or to establish production from new fields; these companies would not receive production sharing agreements, as is often the case, but would be rapidly reimbursed for their investments and receive a minimal fee for each barrel produced. Iraq will then sell the oil at the market price, currently about $105/b.

In 2009 a group led by CNPC (Chinese National Petroleum Company) signed an agreement for the development of the supergiant Halfaya field (4.1 billion barrel reserves) (http://www.ogj.com/articles/2010/01/group-signs-halfaya.html; http://www.ogj.com/articles/2009/12/shell--cnpc-groups.html; http://www.bloomberg.com/apps/news?pid=newsarchive&sid=ai2RXfGm2.EU;). Development costs of about $7 billion will be reimbursed and a fee of $1.40/b paid for oil produced above a threshold of 70,000 b/d. ExxonMobil led a group that promised to expand production from the West Qurna 1 field (8.7 billion barrel reserves) with reimbursement of expenses (unspecified) and a fee of about $1.60/b. And BP won a bid to increase production from the Rumalia field (17.6 billion barrels reserves) from 1.05 million to 2.875 million barrels per day for reimbursement of expenses ($25 billion) and a fee of about $2.00/b.

Although the agreed-upon fees seem quite low, BP and ExxonMobil claim to be confident that they will achieve returns of nearly 20 percent (S. Harbison, B. Montalbano and L. Pugliaresi, Oil and Gas Journal, vol. 109.12, May 2, 2011, pp 24-36).

These contracts are notable for several reasons. The most obvious is the low fees allowed the oil companies, insuring that Iraq will retain almost all of the advantages of increased oil output. Another is that the overwhelming majority of these bids was won by non-U.S. companies, portending a minimal U.S. involvement in the revived Iraqi oil industry and in the Iraqi economy. The contracts also mandate a 25 percent local working interest in the projects, insuring that Iraqi personnel will be trained to eventually manage these efforts. While the capital expenditures are large, over $100 billion, relative to the increase in production they are perhaps one-fifth of what would be expended elsewhere on a per barrel per day basis, demonstrating the extraordinary low cost of exploiting Iraqi deposits. The specified increase in production, about 10 million barrels per day, is significant relative to OPEC crude oil production, currently about 30 million barrels per day. While this production level may never be achieved for many reasons such as political instability, security issues, technical challenges moving the oil to market or the desire to conserve resources, it is clear that in the near future Iraq will be a much more significant oil producer and a more important member of OPEC. Currently, Iraqi production has increased modestly from 2.45 million barrels per day (average, 2009) to about 3 million barrels per day (2/2013).

14 *Who gets what from imported oil, November 2012; http://www.opec.org/opec_web/en/publications/340.htm.*

15 *For example, see http://www.ogj.com/articles/2003/12/market-watchbroil-prices-mixed-at-end-of-november.html.*

16 *A search of the Oil and Gas Journal (www.ogj.com) website for "oil price band" yields over 50,000 results, e.g.: http://www.ogj.com/articles/2003/12/market-watchbroil-prices-mixed-at-end-of-november.html. The target price band ($22-$28/barrel) is specifically mentioned, as is the "terrorist premium." Bear Sterns oil market analysts quoted in the article seem mystified by high oil prices ($28.45/barrel), citing a terrorist premium of $2/barrel and other fears adding $4-$6/barrel as the cause. Note that the price band represents a very substantial variation of ±12 percent around a central value of $25/barrel. This gives some indication of OPEC's willingness to tolerate large swings in price before adjusting production. As prices increase, the magnitude of the price variation increases proportionally.*

17 *The impact of this oil price increase is not well measured by the inflation rate. For example, higher income people can easily adapt to increased gasoline prices by buying a more efficient car or simply paying the greater price. On the other hand people trying to earn a living working for minimum wages are much more severely impacted, and a significantly larger fraction of their already small disposable income must now be spent for fuel. They generally drive older, less efficient cars and may be forced to commute longer distances from affordable housing to their workplaces.*

18 *A Google search of "fear premium oil prices" returned over 2 million results. A fairly representative article can be found at: http://www.chinadaily.com.cn/english/doc/2004-06/02/content_335812.htm. According to the article a fear premium of $10-$15 per barrel (or between $5-$12 per barrel, depending on the source), was in June of 2004 adding $0.36 per gallon to the cost of gasoline, then about $2 per gallon with crude oil at $42 per barrel. The story notes "Many oil industry analysts estimate that without the cloud of uncertainty posed by terrorists and the continued violence in Iraq, oil prices probably would be in the US$30 range. They say there's still plenty of oil available." None of the stories indicate that prices might be deliberately set or manipulated by OPEC.*

19 *These new technologies include compressed air energy storage to integrate intermittent energy sources onto utility grids, heat pumps for heating and cooling as well as battery powered cars and plug-in hybrid cars.*

20 *Between 2002 and 2012, OPEC increased prices by about $80 per barrel, or nearly $2 per gallon (there are 42 gallons in a barrel). Each gallon of gasoline burned releases about 0.009 metric tons of carbon dioxide (see http://www.epa.gov/cleanenergy/energy-resources/refs.html), so a $2-per-gallon price increase is almost equal to a carbon tax of $200 per metric ton ($200 x 0.009 = $1.80).*

21 *One example of such an effort is the Boxer-Sanders bill proposed in the Senate. The bill is not an ideal approach to a surcharge but is a step in the right direction. See http://www.sanders.senate.gov/imo/media/doc/021413-2pager.pdf.*

22 *Allowing the resource owners to set the market price to limit consumption means these owners collect all of the profits. This makes it economically feasible for them to extract oil from increasingly fragile and challenging locations, such as the Arctic Ocean. The amount of oil available in such areas is small relative to proven and undiscovered conventional oil resources, so the world resource limits remain. However, the risk of environmental degradation increases significantly for extraction of these marginal reserves.*

Alfred Cavallo is an energy consultant based in Princeton, New Jersey, and formerly was a physicist with the US Department of Homeland Security. He worked on nuclear fusion experiments at the Princeton Plasma Physics Laboratory, the Max Planck Institute for Plasma Physics in Munich, and the French Atomic Energy Commission in Paris. He later moved to the Center for Energy and Environmental Studies at Princeton University, working on indoor air quality and wind-utility system integration issues, including the analysis of compressed-air energy storage systems for intermittent wind power. In an attempt to understand how renewable energy can compete with fossil fuels, he became interested in resource limitations on petroleum and natural gas—and how those constraints affect US national security.

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***Physics and Society* can be found on the web at www.aps.org/units/fps.**

REVIEWS

The History and Science of the Manhattan Project

by Bruce Cameron Reed (Springer-Verlag, Berlin, 2014), ISBN 978-3-642-40296-8, 451p, $60.

In the prologue to *The History and Science of the Manhattan Project*, Bruce Cameron Reed asks the question with which I approached this review--why do we need another book on the development of the atomic bomb? As noted by Reed, there are many books including Richard Rhodes 1986 classic *The Making of the Atomic Bomb*. Reed argues that there has been new information in the last 25 years and that a somewhat different style book is needed for an individual familiar with physics, one that is addressed to an undergraduate student. To a large degree he has succeeded in describing the incredible magnitude, rapid progress, and success of the Manhattan Project (officially the Manhattan Engineering District) at an appropriate and interesting level. Problems, with answers, are provided at the end of many chapters to provide readers a chance to test their understanding.

The introduction and overview give an excellent summary of the fundamental issues and scope of the project, the majority of which took place from mid-1942 to August 1945. One could get a reasonable understanding by going no further; however, the details later in the book add significantly to the reader's understanding of the scientific and engineering challenges to be overcome and the pace at which activities were taking place.

The long second and third chapters on nuclear physics history can be skipped by people with a knowledge of nuclear physics. Although I found Chapter 2 in particular to be a diversion from the actual beginning of the project in Chapter 4, a student might find it useful. With Chapter 4 the book began to really become quite exciting. The book does not follow a strict time sequence so one is bounced back and forth to some degree. While this confused me at times, it does provide an impression of how much is happening in such a short time. The writing emphasizes the manner in which the necessary components and engineering came very quickly together shortly before the bombs, *Little Boy* and *Fat Man*, were dropped.

While there have been numerous accounts of the vital role of Robert Oppenheimer in leading the scientific aspects of the project at Los Alamos, the importance of having General Groves in overseeing the whole project was also absolutely vital. The huge engineering and logistics efforts would not have happened without someone of his capability. The three major facilities (Los Alamos, Hanford, and Oak Ridge) were so distant from each other that coordination and transportation from lab to lab was not trivial. The extensive logistics involved in setting up three "green field" sites were overcome in a remarkably short time. It was a dramatic example of how much can be accomplished if money is not a constraint and risks are accepted, but we must also note that we are still dealing with the legacy issue of nuclear waste, especially at Hanford.

The focus at Los Alamos was on the science of how to make an atomic (fission) bomb actually work. The scientists were remarkable not only for their talent but also for their youth, the most probable age being about 27. The physics considerations to make both the uranium-based Little Boy and the plutonium-based Fat Man actually work were quite different. Reed describes both in considerable detail. There was a need for a variety of cross section measurements. To provide the equipment to gather the necessary data, accelerators from various universities were packed up and shipped to Los Alamos. This posed logistical issues of dismantling and packing large equipment and then shipping and reassembling it at a remote location, but the logistics paled in comparison to those at Oak Ridge or Hanford.

The efforts at Oak Ridge and Hanford involved enormous amounts of engineering and construction, carried out by industrial firms. The construction of huge facilities at Oak Ridge to enrich uranium-235, quickly followed by operation, in less than 2 years is stunning when one compares with today's construction times. It included borrowing silver from the U.S. mint to make busbars. The construction of the first large production reactors at ORNL and Hanford were another feat. In particular, Hanford's 250 MW reactors to produce plutonium were constructed in less than a year. To add to the difficulties, upon startup there was a surprise as the enormous neutron capture cross section of one fission product, xenon-135, stopped the reactor (xenon poisoning), requiring post-hoc changes to the reactor to reach the required power level. In the end the three reactors at Hanford did not all come on line until March of 1945, just 5 months before the plutonium was used in *Fat Man*.

Reed describes more mundane, but important, considerations such as dummy drops that revealed that the bombs would not fall in a controlled way so their external design had to be modified. There was also an issue of accommodating the bombs' sizes with the bomb-bay doors of the B-29.

This is comprehensive and fast paced read that should be fascinating not only for students but for any physicist. There were a few issues that could be improved. Some of the pictures could be of higher quality and there are a number of typographical issues. I also found it distracting in the Introduction to be told numerous times what chapter would address which topic in more detail. I am aware of two statements that should be corrected. Ernest Rutherford's didn't die from a fall, but from an untreated umbilical hernia. And many physicists would challenge the statement that "nuclear physicists classify the parity of nuclei" according to the evenness or oddness of the number of nucleons. The context for the parity of nuclear states is much different.

These minor issues do not detract from the book capturing the scope Manhattan Project. It is well documented with an extensive list of references and copies of original documents.

One of these is a letter from Groves about the readiness of a third bomb; the letter contains a handwritten note from General Marshall that the third bomb is not to be dropped without the express order of the President. *The History and Science of the Manhattan Project* book is an interesting, informative and entertaining read.

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The Future

by Albert Gore, Jr. (Random House, 2013), 533 pages, ISBN 978-0-8129-9294-6.

The title of this book intrigued me because of the difficulty involved in making predictions about the future. The author avoids this problem by making very few predictions. Rather he describes where we are now concerning a number of critical issues, allowing the reader to decide what the future holds if we do not face the challenges and take advantage of the opportunities presented. The challenge in making predictions about the future is illustrated by a quote from Thomas Jefferson in the introduction to the book. Considering the progress he had witnessed during his life, Jefferson wrote, "And where this progress will stop no one can say. Barbarism has, in the mean time, been receding before the steady step of amelioration, and will, in time, I trust, disappear from the earth." Also in the introduction, Gore writes about short term predictions about the future; "…there is an unhealthy focus on very short-term goals, to the exclusion of long term goals."

In the chapter titled "Earth Inc." Gore writes about the problems associated with income inequality. He describes the Gini coefficient, which is a measure of income inequality nation by nation, on a scale of zero to one hundred. On the scale, a zero designation indicates that everyone has the same income, and a score of 100 indicates that one person has all the income of the nation. The Gini coefficient indicates that in the U.S. in the last quarter century, income inequality has risen from 35 to 45, and other developed countries have experienced similar changes. Gore writes "In the United States 50 percent of all capital gains income goes to the top 0.001%." Much later, when writing about climate change, Gore describes "The dominance of wealth and corporate influence in decision making" in the U.S. He describes a fact that overwhelms this reviewer, writing, "The carbon fuel companies hired four anti-climate lobbyists for every single member of the U.S. Senate and House of Representatives in their fight to defeat climate legislation." That statement certainly makes my voice seem insignificant, and my efforts futile.

Gore writes about the development of the "molecular economy," bioethics, "optogenetics," and transhumanism. Gore presents an interesting illustration regarding biotechnology. Oscar Pretorius, the Australian Olympian equipped with high tech prosthetics, performed well when he competed against able-bodied athletes. Two weeks later, Pretorius competed in the Paralympics, and complained that one of his competitor's prosthetic blades appeared to be too long for his height, giving him an unfair advantage.

The author spends very little time addressing education issues. In a section titled "Education and Health Care in a New World," he writes "In a world where all facts are constantly at our fingertips, we can afford to spend more time teaching the skills necessary to not only learn the facts but also learn the connections among them." Later in the same section he describes the Khan Academy as an "exciting and innovative breakthrough." This reviewer takes issue with this opinion. Having reviewed Khan Academy topics that I am familiar with, and as a teacher with 35 years of experience, I find the approach clumsy and confusing. Gore presents information about cyber security and cyber crime and cites data indicating that the global cost of cyber crime exceeds the annual global market for marijuana, heroin and cocaine.

Gore describes the impact of increasing population. He indicates that the problem of obesity on the planet creates what is equivalent to an additional one billion people. He lists a statistic indicating that the amount of waste produced on Earth each day exceeds the body weight of the global population. The population issue is closely tied to the economic impact of the increasing numbers of elderly people. Gore cites an eye-opening statistic: In 2012, the Japanese bought more adult diapers than baby diapers.

Bioethics is another issue that Gore indicates can not be ignored. The decrease in investment in biomedical research by the U.S., and falling numbers of Americans entering STEM careers, comes at a time when China has spent more than 100 billion dollars on life science research. Gore goes on to write of "optogenetics," telepathy helmets, transhumanism, 3D printing of pharmaceuticals, and genetic modification.

The remaining forty percent of the book addresses the issue of civilization versus climate. Towards the end of a chapter titled "The Edge," Gore includes a section describing "False Solutions" to our climate problems. These include carbon capture and sequestration, nuclear power, and geoengineering (described as "wackadoodle").

In the concluding chapter, Gore writes, "Our decision about how we choose to live will determine whether the journey takes us, or whether we take the journey." A section titled "So What Do We Do Now?" suggests addressing communications, global warming, economics, population, preserving human values in an era of technological development, and leadership based on the deepest human values. He states that we have reached a fork in the road and we must choose a path; one of those paths leads to the future, and the other to the possibility that civilization as we know it will come to an end.

The Future is well written and well researched. It is a valuable resource that dissects the effect technological advances have had on our culture and society.

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Saturday/Sunday, March 8-9, 2014 at the University of California, Berkeley

Sponsored by: American Physical Society (Forum on Physics & Society) • APS Topical Group on Energy Research and Applications • American Association of Physics Teachers • Lawrence Berkeley National Lab • Renewable & Appropriate Energy Laboratory, UC Berkeley

This third workshop on Physics of Renewable Energy continues the tradition begun by two successful predecessors, held in 2008 and 2011. Once again, experts will give the technical background to understand current energy issues. The talks will be aimed at college professors and students wanting to teach or do research in this field.
Organizers: Rob Knapp, Evergreen State College; Dan Kammen, University of California at Berkeley; Barbara Levi, *Physics Today*

Saturday, March 8

Welcome: Daniel Kammen (UC Berkeley) & Rob Knapp (Evergreen State College)

Session A: Global and Regional Issues
1. Global Carbon Balance – Ken Caldeira, Carnegie Institution
2. Energy and the Global Poor – Daniel Kammen, UC Berkeley

Session B: Renewable Energy Sources
1. Progress in Photovoltaics – Jennifer Dionne, Stanford U.
2. Solar Power Life Cycle – TBA
3. Biofuels—status and prospects – Chris Somerville, Energy Biosciences Institute, UC Berkeley
4. Wind – John O. Dabiri, Caltech
5. Synergies of Energy and Information Technologies – Eric Brewer, University of California, Berkeley

Session C: Efficient and Transformed Uses, part I
1. Buildings – Gail Brager, UC Berkeley
2. Energy Use in the Information Economy – Jonathan Koomey, Stanford
3. Industrial Ecology – Valerie Thomas, Georgia Tech
4. The Rebound Effect – David Goldstein, NRDC

Poster Session - Contact Rob Knapp (knappr@evergreen.edu) for information and proposal form.

Day 1 Evening Banquet Keynote – Amory Lovins, Rocky Mountain Institute

Sunday, March 9

Session D: Sustainability and Nonrenewable Energy
1. ARPA-E – searching for breakthroughs – Arun Majumdar, Google, Inc
2. Replacing Coal with Gas and Renewables – Vikram Rao, Research Triangle Energy Consortium
3. Nuclear Power after Fukushima – Robert Budnitz, LBNL

Session E: Efficient and Transformed Uses, part II
1. The Science of Smart Grids – Duncan Callaway, University of California, Berkeley
2. Micro-grid and Off-grid – TBA
3. Toward Oil-free transportation – Amory Lovins, Rocky Mountain Institute
4. Batteries – George Crabtree, Argonne National Laboratory

Session F: From Lab to Market
1. Government Initiatives – Cyrus Wadia, Office of Science and Technology Policy (White House)
2. Private Sector Initiatives – Todd Strauss, Pacific Gas & Electric

Session G: Non-Energy Climate Initiatives
1. Adapting to Climate Change – Ann Kinzig, Arizona State Univ.
2. Geoengineering – Alan Robock, Rutgers University

Final Comments / end of main conference

Monday-Tuesday, March 10 & 11: Optional field trip visits available: Optional field trip visits available: LBNL FlexLab, The Biosciences Institute, and local cleantech companies, including Enphase, Natel Energy, Sunpower, and more.

To register go to
www.aps.org/units/fps/meetings/energy/