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IN THIS ISSUE

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

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ARTICLES

Counterproliferation and Nonproliferation Backgrounder

Charles D. Ferguson

Nonproliferation refers to political, diplomatic, and economic measures, such as export controls, inspections, and treaty commitments, to prevent the spread of weapons of mass destruction (WMD). WMD encompasses nuclear, biological, and chemical weapons. Unlike chemical and biological weapons, which have been outlawed by the Chemical Weapons Convention and the Biological Weapons and Toxins Convention, nuclear weapons have had a norm established through the nuclear Nonproliferation Treaty (NPT) against their proliferation and non-possession, but not a time bound commitment for their complete elimination.

When the NPT entered into force in 1970, a majority of the world's nations banded together to endorse the prevention of nuclear proliferation. (Presently, all but four nations – India, Israel, Pakistan, and North Korea - belong to the NPT. North Korea left the treaty regime in early 2003.) At its heart, however, the NPT embodies a double standard in which five nations - the United States, Russia, China, Great Britain, and France - are designated as nuclear weapons states and the rest of the states signatories are not permitted to possess or acquire nuclear arms. Nonetheless, the treaty struck a grand bargain. The nuclear-haves agreed to pursue general and complete nuclear disarmament, while the have-nots have committed to not acquire nuclear arms in exchange for the "inalienable right" to peaceful nuclear technology. Failure to achieve nuclear disarmament has led many have-nots to accuse the nuclear weapon states as not living up to their commitment, but the NPT does not specify when disarmament is to be completed. Similarly, attempts by Iran to construct a complete nuclear fuel cycle have raised alarm among the United States and its allies that Iran, a member of the NPT, intends to use its civil nuclear program as a cover for nuclear weapons production.

Some have charged that the NPT regime is failing to stop proliferation. So-called rogue states, such as Iraq, Iran, and North Korea, have sought nuclear arms while remaining members of the NPT. (As noted above, North Korea has recently renounced its membership.) By exploiting access to dual-use technologies that could fuel both civil and military nuclear weapons programs, Iraq, for example, was able to come close to building a nuclear bomb. Iraq's defeat in the 1991 Gulf War, however, exposed just how near Iraq came to becoming a nuclear-armed state. Analysts have assessed that Iraq only needed to produce or purchase sufficient amounts of bomb-usable fissile material, either highly enriched uranium or plutonium. The complexity of the pre-1991 Iraqi nuclear weapons program lay largely hidden from the prying examination of inspectors and intelligence experts because only nuclear facilities declared by Iraq were then open to inspection.

To correct this inspection gap, several International Atomic Energy Agency member states acted after the 1991 Gulf War to implement a tougher inspection regime, called the Additional Protocol. Presently, only a small fraction of the member states belong to the Additional Protocol, but with the recent action by the United States to sign and ratify this enhancement, there is a renewed push to bring more and more member states into the strengthened inspection system.

In tandem to implementation of the Additional Protocol, the United States has placed increased emphasis on using intervention to prevent proliferation of WMD. Intervention can take the forms of interdiction of shipping, preventive war, and other military methods such as attacks against nuclear facilities and developing "bunker buster" weapons to hold at-risk deeply buried and hardened facilities that may contain WMD. Use of nuclear bunker busters in a preemptive role would represent an ironic twist because the ultimate weapon of mass destruction would be unleashed to prevent the employment of an adversary's WMD.

Strengthening interdiction, the United States and about ten other partner states have forged the Proliferation Security Initiative (PSI), which reserves the right to stop suspicious shipments that may contain WMD or components to support WMD programs. Critics have raised concern that PSI needs to adhere to the requirements of international law and that it should not be applied in a lopsided fashion, perpetuating a double standard betwee haves and have-nots.

According to the Air War College (What is Counterproliferation?, from the Web site of the Air War College at www.au.af.mil.), counterproliferation can be defined as:

"The military component of nonproliferation, the same way that military strategy is a component of foreign policy. Counterproliferation refers spcifically to Department of Defense activities, both in the actual employment of military force to protect U.S. forces, and in their support of overall U.S. nonproliferation policies and goals."

Although counterproliferation methods have been available to the military for several decades, the 1991 Gulf War, in particular, began to shift counterproliferation to center stage. The Clinton administration established a counterproliferation initiative in 1993, but this effort played a supporting role to the primacy of nonproliferation policy. In contrast, while not eschewing traditional methods of nonproliferation, the Bush administration has acted on its belief that military force or the threat of that force can prevent the further spread of WMD. This conviction ostensibly spurred the United States to launch a preventive war in Iraq in 2003. Despite the commitment of substantial intelligence, military, and U.S. inspection resources, the United States and its Coalition partners have uncovered, to date, no WMD caches in Iraq. The continued failure to find WMD in Iraq could undermine the credibility of the United States in future endeavors to use force to bring about the end goal of no WMD.

Bush administration officials have cited additional reasons in their decision to launch war in Iraq. They sought the removal of Saddam Hussein, a dictator who had tyrannized his people. Moreover, some Bush officials are driven to democratize the Middle East and hope that Iraq will serve as their model project. The implication for the prevention of WMD is that counterproliferation, in this case and perhaps in the future, could serve as a fig leaf for another agenda.

Many have credited the American and British military buildup in the Persian Gulf region prior to September 2002, when President Bush made his case before the UN General Assembly, as being instrumental in compelling Saddam to allow the renewal of UN and IAEA inspections in Iraq. Critics, however, have charged that the American and British arms buildup was too fast and too massive and, therefore, gave the United States and its allies too little time to let inspections run their course. In effect, the military appeared to be in a use or lose situation. Fears were raised about operating in the desert heat, thus accelerating the requirement for Iraq's complete, demonstrated WMD disarmament by early spring 2003. In parallel, the United States displayed a lack of trust in the inspections process while Iraq could not convince the Coalition that it had already disarmed as it claimed to have done. In hindsight, the UNSCOM inspections and disarmament efforts from the 1990s appear to have achieved the intended effect of ridding Saddam of WMD. Perhaps a more modest and more gradual military buildup could have applied sufficient pressure and allow enough time for inspections, thus avoiding the rush to war.

If a "rogue" state is strongly suspected of already possessing WMD or powerful conventional forces, it could deter the United States or its allies, and, therefore, counterproliferation smacks into barriers. For example, the credible threat posed to Seoul, South Korea, by the North Korean conventional military forces and the postulated threat to the United States and allied states from North Korea"s nascent nuclear weapons program place severe restrictions on the use of the U.S. military in rolling back the North Korean regime. From the North Korean viewpoint, these weapons provide an important means of leverage to North Korea to lift it to greater security. The United States, on the other hand, perceives a serious threat to the nonproliferation norm if North Korea maintains a nuclear weapons program. Ultimately, a comprehensive security package, with nuclear weapons disarmament as only part of the agreement, will be needed to convince North Korea to renounce nuclear weapons.

Most worrisome of all, Pakistan, the world's biggest nuclear proliferator, has developed immunity to both nonproliferation and counterproliferation methods. It remains outside the NPT regime and will not renounce its nuclear weapons at least for the foreseeable future. Moreover, as a key ally in the "War on Terror," it will not likely suffer forceful interdictions from the United States or the PSI. As for the reported brains behind the proliferation hemorrhage, Dr. A. Q. Khan, a Pakistani metallurgist and the "father" of Pakistan's nuclear bomb, had his wrist slapped recently when he was revealed to have orchestrated a nuclear technology bazaar, which catered to Libya, North Korea, and Iran as well as possibly other states to be identified. Was he the real mastermind behind this nuclear black market or do the roots go deeper into the bedrock of Pakistani politics?

Will nonproliferation and counterproliferation work hand-in-hand? Does the world need both methods to prevent proliferation of WMD? Will over-reliance on one method versus the other lead to a renewed proliferation of WMD? Does the threat of military force stimulate the proliferation of WMD? Is sole reliance on nonproliferation techniques too lacking in teeth and muscle to stop the spread of WMD? These are the types of questions that the world community needs to confront if it is to bring about a more secure globe.

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National Academy of Sciences Study on the Comprehensive Nuclear Test Ban Treaty

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[Paper presented at Montreal APS Meeting, March 22, 2004]

After the 51-48 defeat of the CTBT in the Senate, the National Academy of Sciences was commissioned by General John Schalikashvili (Former Chair, Joint Chiefs of Staff) to examine technical issues relating to the CTBT. The issues reviewed in this paper are as follows:

Verification: Seismic monitoring of tamped, underground nuclear explosions with the International Monitoring System is better than what was originally stated (1 kton), to about 0.1 kton. When the NAS panel took all the factors into account by the NAS, muffled explosions detonated in cavities can be detected down to 1~2 kton. The advent of interferometric synthetic aperture radar compliments the CTBT monitoring technologies (seismic, infrasound, hydroacoustic, radionuclide) and NTM methods by measuring surface subsidence to 0.1 cm.

Stockpile Stewardship: All scientific review groups agree that nuclear testing is not needed at this time, and the NAS concludes that it is unlikely to be needed in the future. Plutonium decay in the primary stage does not greatly limit the Pu pit lifetime, which NNSA determined to be a minimum of 45~60 years. The most likely weapon components to suffer degradation are the non-nuclear components, which can be monitored without the need of nuclear testing.

Benefits of Cheating: After an evaluation of the weapons programs of other nations, the NAS concluded that "Very little of the benefit of a scrupulously observed CTBT regime would be lost in the case of clandestine testing within the considerable constraints imposed by the available monitoring capabilities… The worst-case scenario under a no-CTBT regime poses far bigger threats to U.S. security - sophisticated nuclear weapons in the hands of many, more adversaries - than the worse-case scenario of clandestine testing in a CTBT regime, without the constraints posed by the monitoring system."

1. CTBT in Context

Building on the experience of three previous nuclear testing treaties (1), the Comprehensive Test Ban Treaty (CTBT) bans all nuclear tests of any yield in all places for all time. This requires the fulfillment of complete bans in terms of four parameters (number, yield, location and time). The CTBT is an arms control measure that constrains the five nuclear weapons states from developing new weapons. In the past, the US tested the most at 1,030 times, followed by the Former Soviet Union with 715 tests, which is much more than the tests of other states; France (210), UK (45) and China (45), as well as India and Pakistan at about five each. The CTBT is also a nonproliferation measure since the test ban raises a barrier to the development of first-time nuclear weapons. The 1998 tests by non-NPT (Nuclear Nonproliferation Treaty) parties, India and Pakistan, highlighted the need for a universally accepted CTBT and NPT. The CTBT also affects the long-term stability of the NPT. The agreement by the five nuclear weapon states (China, France, RF, UK, US) to join the CTBT was the quid pro quo accepted by the five nuclear weapon states in 1996 to gain the acceptance by 183 non-nuclear weapon states to extend the NPT for all time. The Council of the American Physical Society approved statements strongly supporting the CTBT on April 19, 1997 and April 4, 2003 (2).

The CTBT has been signed by 169 nations (December 2003), which amounts to all the nuclear capable nations, except for India, Iraq, and Pakistan (North Korea has announced that it possesses nuclear weapons and it has been widely reported that Israel also has a stock). Of the signatory nations, 107 have ratified the CTBT, including three nuclear weapons states (Russia, France, United Kingdom). In October 1999, the US Senate rejected the CTBT by a vote of 51 to 48. (China stated it will ratify the CTBT only after the US ratifies it.) After the defeat of the CTBT, the National Academy of Sciences was asked by the Clinton administration to convene a panel of experts (3) to examine technical issues that could affect the viability of a test ban. The results of the NAS study, Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty, were published in 2002 (4). The Academy decided early on not to evaluate the net benefit of the CTBT to the United States, but rather the NAS examined the following three technical issues:

- ability to monitor a test ban, including evasion scenarios.
- US capacity to maintain a safe and reliable nuclear stockpile without testing.
- ability of nations to increase nuclear prowess by cheating and its effect on US security.

NPT-CTBT Connection. As stated above, the non-nuclear weapons states view the CTBT as the quid pro quo that fulfills the requirement of the five nuclear weapons states to balance their CTBT obligations to the 183 non-nuclear weapon states. This balancing act was very apparent to the 5 nuclear weapon states in 1996. The NPT would not have been renewed by the 183 states for all time, without a time limit, unless all five nuclear weapon states declared they would join the CTBT. The continuation of the NPT is of fundamental importance to all nations, as it is the legal capstone that constrains the nuclear rogue states (President Clinton) and the axis of evil (President George W. Bush). On December 8, 2003 the General Assembly of the United Nations passed a resolution that urged all nations to maintain the nuclear testing moratorium, urged all nations to sign the CTBT and urged all nations that had signed the CTBT to ratify it. The gap between the US and the rest of the world could not be more apparent from the following. The vote in the General Assembly was 173 in favor, 1 against (U.S.) and four abstentions (Columbia, India, Mauritius, Syria), while Iraq and North Korea were absent. The intensity of the global diplomatic opinion on the CTBT/NPT connection is not understood by the US populace.

2. Monitoring the CTBT

The Senate debate on the CTBT was marred by claims that cheating could take place without detection at yields up to 70 kilotons. The NAS report strongly contradicts this claim. The CTBT Organization's International Monitoring System (IMS) deploys 300 monitoring stations that use seismic, hydroacoustic, radionuclide, or infrasound sensors. These facilities are operating today without the CTBT having entered into force. The IMS network consists of 50 primary and 120 auxiliary seismic stations. In addition the IMS deploys 60 infrasound stations (less than 0.5-kton global atmospheric threshold detection), 11 hydroacoustic stations (less than 100-kg global oceanic detection) and 80 radionuclide stations (less than 1-kton, global atmospheric detection). In addition, the US uses satellite optical bhangmeters, particle detectors and EMP detectors to monitor atmospheric tests. Lastly, US National Technical Means (NTM) monitors with other technologies, including satellite reconnaissance, human intelligence (humint) and other "ints." The IMS and NTM technologies combine to make intelligence gathering a synergistic operation that is greater than the sum of its parts. The fear of being spotted by the IMS and NTM deters most nations from cheating, and these measures will be buttressed by on-site inspections. Since the signing of the CTBT, a potent new technology, interferometric synthetic aperture radar (ISAR), has been disclosed, which we will discuss at the end of this section.

The US, Russia and UK have only tested in underground locations since 1963, and they have been joined in this by France (1974), China (1980), India (1974, 1998) and Pakistan (1998). Seismographs are the primary tool for monitoring underground tests, with the other technologies supplementing this data. Seismic traces from nuclear explosions differ from earthquake traces in several ways. Nuclear explosion seismic data have higher-frequency components than those from earthquakes because the duration of an explosion is much shorter than the duration of an earthquake. In addition, the ratio of the short-period, pressure body wave magnitude (mb) to the long-period, surface wave magnitude (MS), is larger for weapons than for earthquakes. The zero-threshold limit for the CTBT was chosen because a finite limit legalizes testing below that limit and because accurately determining a threshold adds a source of error (5).

The International Monitoring System (IMS) has the capability to detect explosions with high confidence (90% certainty) to an mb level of 3 (less than 2.5 for Russia's Novaya Zemlya), which corresponds to a tamped explosion of about 0.1 kton in hard rock throughout Eurasia and North Africa. The contours in Fig. 1 are in tons (not kilotons). These results are from the Defense Department's Center for Monitoring Research, which agrees with calculations from the national laboratories and universities. The limit of 0.1 kton for tamped explosions is a factor of ten better than the 1 kton limit that was originally projected for the IMS. Even this estimate can be too cautious in that it does not take into account the possibility of close-in, regional stations. A concerned state could place regional seismographs close to a suspected region to improve monitoring. Finally, chemical explosions are usually identifiable as they are not spherical explosions, but they are often ripple-fired along a line to reduce costs. The required notification threshold for chemical explosions is 0.3 kton, which reduces suspicions about chemical explosions.

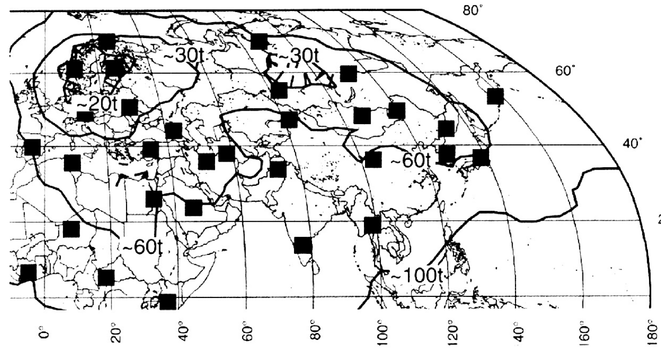

Fig. 1. IMS seismic monitoring limit (tons). Projected 90%-probable, 3-station detection thresholds in tons of explosive yield for the IMS network of 50 primary stations. The IMS detection threshold is below 0.1 kton for all of Eurasia and below 0.5 kton for all continents worldwide. The 1999 IMS system with 33 stations detected 0.1 kton underground chemical explosions and a 0.025-kton explosion at the former Soviet Semipalatinsk test site in Kazakhstan. [Center for Monitoring Research, Nuclear Testing Programs, Department of Defense, in Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty, National Academy of Sciences, National Academy Press, 2002]

Explosion in a Cavity. There are very little data on nuclear tests exploded in cavities. If a nuclear weapon is placed in a cavity of sufficient size, the blast pressure on the cavity wall falls below the material's elastic limit, which avoids cracking and nonlinear effects, reducing the effective seismic yield by a theoretical factor of 7 at 20 Hz and 70 at lower frequencies. The only fully decoupled test took place in 1966 when the 0.38-kton Sterling explosion was exploded in a Mississippi salt cavity with a 17-m radius (from the 5.3-kton, Salmon explosion); it minimized the observed yield by, at most, a factor of 70. The Soviets carried out a 9-kton test in a cavity at Azgir in 1976, but it was only partially decoupled, as the weapon was too large for the cavity's 36-m radius (from a 64-kton previous test).

If blast pressure exceeds the elastic limit of the cavity's wall material, sufficient energy is absorbed to crack the wall, increasing coupling to the wall, giving an increased seismic signal. Critical cavity size depends on explosion depth, but it is usually assumed to be about 1 km. One expects that R_c is proportional to $Y^{1/3}$ since the energy to fill the volume of the cavity to a critical pressure is proportional to the yield, or $Y \alpha$

$P\Delta V \alpha R_c^3$. The *critical radius for decoupling* increases with yield to the third power, according to

R_c = (15–20 meters)$Y^{1/3}$,

with Y in kton. From this, a 70-kton explosion needs a cavity radius of 70 m (a 20-story building) to achieve full decoupling – an extraordinary engineering challenge when one considers the secrecy requirements.

We derive the coupling constant from first principles for a 1-kton blast in salt. Because explosion occurs very rapidly, little heat is transferred during the compression. This dictates an adiabatic expansion with PV^γ= C, a constant. The yield Y to compress air to the elastic limit of salt is

$$Y = - P\ dV = - CV^{-\gamma}\ dV = CV^{1-\gamma}/(\gamma - 1) = P_o(4\pi R_c^3/3)/(\gamma - 1) = P_oV_c/(\gamma - 1),$$

where P_o is the elastic limit of the wall material and V_c is minimum cavity volume.. Using Y = 1 kton, γ = = 1.2 (very hot air) and P_o = 440 bar for salt's elastic limit, we obtain the minimum cavity radius R_c = 16 m. The critical radius is 30 m at a depth of 600 m (6).

Monitoring Limit with Cheating. The NAS panel concluded that "The only evasion scenarios that need to be taken seriously at this time are cavity decoupling and mine masking." The NAS panel considered many issues that affect the probability of successfully hiding a nuclear test in a cavity. For example, covert testing is complicated by the possibility of venting of radioactive gases from the explosion, which can easily be detected. The Soviets had 30% of its tests vent, and the US had severe venting problems during its first decade of underground testing. Venting from smaller tests is often harder to contain than venting from larger ones, as the last four US tests that vented had yields of less than 20 kilotons. This tendency to vent at lower yields can be explained by the hypothesis that smaller explosions may not sufficiently enclose cavities with glassified rubble, and they may not rebound sufficiently to seal fractures with a stress cage. The NAS panel considered six other issues as follows:

- Violators need to make accurate yield estimates to avoid yield excursions.
- Violators need to hide removed materials from satellites.
- Crater and surface changes from testing are observable.
- Regional seismic signals at 10 Hz improve detection.
- A series of tests is needed to develop significant weapons.
- Human and other intelligence can give information.

Because the total success probability for hiding a covert test is the product of the individual-task success ($P_{success} = \Pi_i P_I$), the NAS panel did not use a decoupling factor of 70 times the 0.1-kton limit to obtain a maximum cheating limit of 7 kton. Rather, it concluded the following: "Taking all these factors into account and assuming a fully functional IMS, we judge that an underground nuclear explosion cannot be confidently hidden if the yield is larger than 1 or 2 kton."

Interferometric Synthetic Aperture Radar. Signatures from underground nuclear tests can be obtained using accurate satellite radar interferometry (7). By combining synthetic aperture radar data (European Space Agency) from before and after a nuclear test, crater subsidences as small as 0.1 cm can be measured. The radar data has a horizontal resolution of better than 10 m, which is much smaller than a typical crater subsidence radius of about 100 m. A typical radar frame covers 100 km by 100 km, sufficient to search wide areas. The ISAR data can also determine the slow subsidence relaxation over longer times. This allows ISAR to locate past explosion locations for which there was no radar data prior to the explosion. Interferometric radar has some limitations, but it is a very positive addition to CTBT monitoring.

3. Stockpile Stewardship

The NAS panel examined many factors in its analysis on the US ability to maintain a safe and reliable nuclear weapon stockpile without testing:

- Confidence requires a high-quality workforce and adequate budgets.
- Stockpile stewardship and enhanced surveillance must examine components of weapons.
- Remanufacture to original specifications is the preferred remedy for age-related defects.
- A highly disciplined process is needed to install changes in nuclear designs.
- Primary yield that falls below the minimum level needed to drive a secondary is the most likely potential source of nuclear-related degradation.
- Based on past experience, the majority of aging problems will be found in the non-nuclear components, which can be fully tested under a CTBT. (NNS has stated that nuclear Pu pits have a minimum lifetime of 45-60 years with "no life-limiting factors.")
- In the past, confidence tests were limited to one per year, as most tests were carried out to critique new designs.
- New stewardship programs, using the Dual Axis Radiographic Hydro Test (DAHT) facility and Advanced Simulation and Computing (ASC), are already valuable

During the technical briefings, potential problems for existing warheads (8) in the enduring stockpile were raised. The NNSA was asked if testing was needed to resolve these issues and the answer was always "no". From all of these results, the Academy panel concluded the following:

"Although a properly focused stockpile stewardship program is capable, in our judgement, of maintaining the required confidence in the enduring stockpile under a CTBT, we do not believe that it will lead to a capability to certify new nuclear subsystem design for entry in the stockpile without nuclear testing – unless by accepting a substantial reduction in the confidence in weapon performance associated with the certification up until now, or a return to earlier, simpler, single stage design concepts such as gun-type weapons."

"It seems to us that the argument to the contrary – that is, the argument that improvements in the capabilities that underpin confidence in the absence of nuclear testing will inevitably lose the race with the growing needs from an aging stockpile – underestimates the current capability for stockpile stewardship, underestimates the effects of current and likely future rates of progress in improving these capabilities, and overestimates the role that nuclear testing ever played (or would be ever likely to play) in ensuring stockpile reliability."

4. NAS Conclusion on Potential Impact of Foreign Testing

Section 2 of this paper showed that explosions of tamped weapons can be detected with high confidence in Eurasia for yields over 0.1 kton, and explosions in a cavity can be detected above 1–2 kton. What can nations learn from cheating at these levels? Nations with lesser prior-testing experience can carry out equation of state studies, high-explosive lens experiments, certification of bulky inefficient unboosted fission weapons (gun-type), one-point safety tests, limited improvement of unboosted fission weapons, proof tests of compact weapons with yields up to 1–2 kton (with difficulty and without an excursive yield). Nations with greater prior-testing nuclear test experience could partially develop primaries for thermonuclear weapons. The CTBT prevents the development of low-yield boosted fission weapons, and the full testing of primaries (over 1–2 kton) and thermonuclear weapons. The NAS study commented on what Russia, China and other nations could gain from cheating on a country-by-country basis.

Of course cheating on the CTBT would be a blow to the political aspects of the nonproliferation regime. However, the NAS panel concluded the following: "But potential undetected Russian and Chinese evasive testing is not relevant to the maintenance of US nuclear weaponry. As noted in Chapter 1 (on stockpile stewardship), we judge that the United States has the technical capability to maintain the reliability of its existing stockpile without testing, irrespective of whether Russia or China decides they need to test in order to maintain the reliability of theirs…."

"Very little of the benefit of a scrupulously observed CTBT regime would be lost in the case of clandestine testing within the considerable constraints imposed by the available monitoring capabilities. Those countries that are best able to successfully conduct such clandestine testing already possess advanced nuclear weapons of a number of types and could add little, with additional testing, to the threats they already pose or can pose to the United States. Countries of lesser nuclear test experience and design sophistication would be unable to conceal tests in the numbers and yield required to master nuclear weapons more advanced than the ones they could develop and deploy without any testing at all."

"The worst-case scenario under a no-CTBT regime poses far bigger threats to U.S. security – sophisticated nuclear weapons in the hands of many more adversaries – than the worse-case scenario of clandestine testing in a CTBT regime, without the constraints posed by the monitoring system."

* D. Hafemeister was the technical staff lead for nuclear testing for the State Department (1987), the Senate Foreign Relations Committee (1990ñ92) and the National Academy of Sciences CTBT Study (2000ñ02). dhafemei@calpoly.edu.

(Endnotes)

[1] The Limited Test Ban Treaty, entered into force (EIF) in 1963, bans nuclear tests in the atmosphere, outer space and under water. The Threshold Test Ban Treaty bans underground nuclear tests of over 150 kilotons. Its 1988 protocol added on-site inspections (OSI). (Signed 1974, EIF 1990.) The Peaceful Nuclear Explosions Treaty limits PNEs to underground explosions to a maximum of 150 kton for individual PNEs and 1500 kton for group explosions. (Signed 1976, EIF 1990.)

[2] http://www.aps.org/statements/index.cfm

[3] J. Holdren (chair), H. Agnew, R. Garwin, R. Jeanloz, S. Keeny, C. Larson, A. Narath, W. Panofksy, P. Richards, S. Sack, A. Trivelpiece with staff of J. Husbands and D. Hafemeister.

[4] Technical Issues Related to the Comprehensive Nuclear Test Ban Treaty, National Academy Press, Washington, DC, 2002. Further details can be found in D. Hafemeister, *Physics of Societal Issues*, Springer Verlag and AIP Press, New York, 2004.

[5] Monitoring the 150-kton threshold yield of the TTBT was complicated by geological differences in the US and USSR tectonic plates at the test sites. The magnitude of a body pressure-wave seismic wave is

$$m_b = a + b + c \log Y,$$

where m_b is the magnitude of a 1-Hz body wave, a is the 4.1 magnitude of a 1-kton explosion, b is the bias correction for a test site, c is the slope of 0.74 and Y is the yield in kton. A 150-kton yield at the Nevada Test Site has an m_b of

$$m_b = 4.1 + 0.74 \log 150 = 4.1 + 1.61 = 5.71,$$

while a 150-kton explosion at the Soviet site with a bias of 0.4 is 6.11. The US initially and incorrectly assumed there was no bias between the two sites (b = 0), which gave a false impression that a Soviet explosion at 6.11 mb was a violation with

$$Y = 10^{[(6.11 - 4.1 - 0)/0.74]} = 520 \text{ kton}.$$

Later a value of b = 0.2 was used, but this was also too low. The incorrect designation of "likely violation" on Soviet compliance to the TTBT greatly hindered negotiations on the CTBT.

[6] L. Sykes, Public Interest Report 53, no. 3, Fed. Amer. Sci., Washington, DC, www.fas.org/faspir/v53n3.htm

[7] P. Vincent, et al, Geophysical Research Letters, 30, 2141 (2003).

[8] B61/B83 (bombs), W80 (cruise missiles), W62/W78/W87 (ICBMs) and W76/W88 (SLBMs).

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PUREX AND PYRO ARE NOT THE SAME

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Introduction

In the early days of civilian nuclear power, it was assumed that PUREX -- an aqueous reprocessing method that was used in weapons programs to produce plutonium of the chemical purity needed for bombs -- would be suitable for recycling the fuel. The countries that had the most advanced civilian nuclear power programs already had PUREX plants to service their nuclear weapons programs.

In 1970, as nuclear technology and civilian nuclear power plants were beginning to spread to additional countries, the Nuclear Non-proliferation Treaty was put in place. Skepticism remained, however, as to whether that treaty was adequate to stem the increasing availability of separated plutonium. So in 1977, attempting to limit the availability of separated plutonium and the associated potential for proliferation of nuclear weapons, the Carter administration accepted the recommendation of the preceding Ford administration, and banned the reprocessing of commercial reactor fuel.

At that time, "reprocessing" meant PUREX. PUREX works well for thermal-reactor fuel, but it is not well suited for a fast-reactor fuel cycle, and it is very expensive. Consequently, a "dry" (nonaqueous) pyrometallurgical method was developed -- a process that cannot by itself produce plutonium of weapons-quality purity. With pyrometallurgical processing it's a new ball game.

Fast reactors have advantages in addition to a proliferation-resistant fuel cycle. They can consume plutonium and other long-lived actinides, reducing to less than 500 years the required isolation time for waste in a repository, postponing indefinitely the need for more repositories. They can get more than 100 times as much energy from uranium as the profligate once-through fuel cycle, and more than 50 times as much as thermal reactors with aqueous recycle.

The Union of Concerned Scientists, an eminent public-interest group, has issued the following statement: "UCS calls upon the Bush administration to pull the plug on reprocessing and encourage U.S. allies to do the same." However, advances in fast-reactor technology have made it inappropriate to use the word "reprocessing" generically, as though fuel cycles based on PUREX and pyroprocessing have equivalent proliferation potential. They don't. Continuing to prohibit recycling in the United States only aggravates the disposal problem and encourages the profligate waste of uranium resources. We therefore suggest that, to be consistent with its goals and values, UCS should modify its position to the following:

"UCS calls on the Bush administration to pull the plug on aqueous reprocessing and encourage U.S. allies to do the same. Further, UCS also calls for initiating deployment of proliferation-resistant fast reactors, since they can consume virtually 100 percent of the low-quality plutonium produced by thermal reactors, along with the high-quality plutonium from weapons."

Discussion

We all agree that the threat of nuclear terrorism is a matter of serious national and international concern. Today, any group with sufficient resources, along with access to current technology and to readily available materials, can make any of a variety of nuclear terrorist devices. There is also a wide range of terrorist threats involving WMD that are far more credible than nuclear terrorism. (We use the term "WMD" in its popular, all-inclusive sense, realizing nevertheless that the only true weapons of mass destruction are atomic bombs – the others, including radiological weapons, being more properly characterized as "weapons of mass terror.")

The relevant question is this: *Is technology available that can reduce the threat of nuclear terrorism, or that can improve our energy posture or environment without increasing the threat of nuclear terrorism or of nuclear-weapons proliferation?*

Note that this question is posed as a comparison, not an absolute. Any claim that a particular technology can guarantee that there will be no future nuclear terrorism threat or no potential for proliferation of nuclear weapons to more countries is either disingenuous or terribly naive.

A well-conceived program of nuclear recycle can reduce the threat of nuclear terrorism without significantly affecting the potential for nuclear proliferation. It can greatly improve our energy independence, and drastically reduce the environmental challenges involved in energy production. The most notable benefit is in waste management: only the true waste will be left, whose activity will be below background in less than 500 years.

It is important to realize that the nuclear fuel cycle can be "closed" (essentially all of the energy in the mined uranium exploited) only by consuming the actinides (uranium and transuranics) in a fast neutron spectrum.

Part I: Proliferation and Terrorism

Let's consider whether closing the nuclear fuel cycle by means of an advanced recycle technology such as pyrometallurgical recycle combined with fast reactors would properly addresses the above comparative question. Safety and economics are also relevant, but are not discussed here.

Nuclear terrorism could involve dirty bombs or even nuclear weapons. Presumably they would be rather basic devices, unless the terrorists got more sophisticated weapons from a new or established nuclear-weapons state. Each possibility should be considered.

Dirty Bombs. To many, dirty bombs are the most likely nuclear terrorist threat, even though they can do little physical damage. A dirty bomb could trigger panic, and could cause significant economic disruption due to the need to clean up the resultant contamination. To the extent that large-scale recycle would affect this threat, it would reduce it. Spent nuclear fuel would have economic value (perhaps minimal, at first)[1] , which would provide the basis for improved accounting for spent fuels.

Today, such accounting is unreliable, even worse than the world-wide accounting of more sensitive nuclear materials. Very significant is the fact that fast-reactor recycle would, in the long run, dramatically reduce the stores of old spent fuel, which, although only mildly self-protecting, would still be disruptive if used in a dirty bomb.

Terrorist Atomic Bombs. For a terrorist trying to construct a basic nuclear bomb, one of the main challenges is to acquire the weapons-grade uranium or plutonium. Enriched uranium is a serious concern because of the availability of centrifuge technology, even if the potential for subnational groups to use this technology is remote. Recycle (other than for consumption of excess weapons quality uranium) is irrelevant for a uranium-based device.

The prospect of a terrorist group constructing a plutonium-based bomb is even more remote, because of the task's complexity. Nevertheless the possibility cannot be ignored. As Carson Mark points out, use of a poor grade of plutonium could well result in a "fizzle," but even this would be an effective terrorist weapon. Consequently the stewardship of nuclear materials in general, including recycle activity, must be subject to appropriate safeguards. This is discussed below.

A far more credible threat is that a nuclear-weapons state could provide a surrogate group with weapons. Here again recycle is irrelevant.

Proliferation at the Nation Level. Any nation that is determined to acquire nuclear weapons can and will do so, regardless of U.S. recycle policy. What the U.S. can and must do is promote an international environment that reduces the incentive to proliferate and enforces international safeguards.

Part II: Safeguards Against Nuclear Terrorism

Safeguards involve physical protection, technical steps, and information control, including intelligence measures. This discussion is limited to technical matters. It is perhaps legitimate to ask whether the technical aspects of various recycle technologies should be classified, but that is beyond the scope of this discussion (anyway, it may already be too late).

The current IAEA approach to controlling nuclear terrorism is inadequate. The system is based on international verification of the signatory states' compliance and rigid commitments of intent. There are vast quantities of weapons-usable materials spread around the world, and in some cases these materials are under very lax controls. Even obtaining estimates of the quantities of such materials, let alone their location and security, is almost impossible. The most credible nuclear terrorist threat, a dirty bomb, requires only access to spent nuclear fuel, and the controls on this material in various parts of the world are minimal. Thus we are seriously dependent on additional information from intelligence and surveillance.

The advanced separation technologies that have been studied and shown to be feasible present a minimal increase in risk. Such technologies constitute a considerably smaller proliferation or terrorism threat than the centrifuge. While they could be used by a well-funded and well-protected terrorist organization in doing part of the separation of plutonium from spent fuel, the facilities required for such a separation would be complex. The terrorists or proliferators would need, for example, to have a reasonably well shielded facility with remote manipulators (depending on how willing the operators were to accept high radiation doses).

They also would need a staff with expertise in chemcal separations. To produce weapons-usable materials, the facility would have to have equipment for complex chemical separations that would not be present in a recycle application, whether it contained an aqueous separations unit or not. Even if the recycle system included an aqueous unit for the initial separation, the operating parameters for extracting weapons-useable plutonium would have to be significantly different, and therefore detectable under a suitable verification regime.

Because of the evident differences between using an elecrtorefining facility for recycle and using it for extracting materials for a weapons program, the technology would be susceptible to rigorous monitoring (although the monitoring method has not yet been adequately demonstrated).

For a plutonium-based weapon, possession of the fissile material is far from the only prerequisite: the device's design and construction are extremely demanding, and the ancillary equipment is critical.

Advanced technologies should be deployed under the most rigorous safeguards, and appropriate monitoring technologies should be an integral part of the development. There should be some form of physical control over the verification process, which should not be subject to veto by the inspected party. Planned and controlled deployment of nuclear power in the United States (under conditions that need to be developed) is far preferable to waiting for others to develop such technologies. In promoting the establishment of such a system, the Union of Concerned Scientists could play an important catalytic role.

Part III: A Bit of History and the Current Situation

The peaceful use of nuclear power has moved forward in major and somewhat disjointed steps, driven by clearly identifiable events or situations. The development of civilian nuclear power was initiated by President Eisenhower's Atoms for Peace program. The large-scale deployment in the United States was largely driven by economics, in response to the almost total dependence on coal as our basic energy resource, and the effective monopoly control over supplies of coal by John L. Lewis and the United Mine Workers. Nuclear power, supplemented by a modest contribution from domestic oil, broke the coal monopoly in the United States.

At about the same time, the Suez Canal crisis deprived England of its supply of oil, leaving it also totally dependent on coal and on the miners, who sought to exploit the situation to improve their economic condition. Nuclear energy provided the bridge until super-tankers made the Suez bottleneck irrelevant, and North Sea gas gave the U.K. an additional option. Similarly, France's nuclear power program, which today is a major factor in its economic well being, was undertaken in response to its loss of control over Algeria and its oil.

In today's economy, energy is used primarily for transportation, space heating, electricity, and industrial processes. In the United States, transportation is almost totally dependent on oil; heating is done largely by natural gas (along with some oil and coal); and electricity comes mainly from burning coal, with contributions from nuclear power (~20%), natural gas (~18%), and rivers and miscellaneous (including oil) (~11%). Industry is powered by all of the above.

With the notable exception of land and air transportation, virtually all energy demands could be satisfied with non-fossil sources, with electricity as the main means of delivery. That includes ocean transport, for which well-managed nuclear power is ideally suited, as the U.S. navy has amply demonstrated. Pending break-throughs in battery technology or in the generation and management of hydrogen, land and air transportation will continue to depend mainly on oil. But in the longer term, given the needed technology, even there nuclear power can help change our dependence on a near-monopoly energy source that we do not control. Removing this issue, and the gluttonous demands of the U.S. economy for imported oil, would reduce both the motivations for terrorism, and the resources to support it.

Much of the recently installed electric generating capacity in the United States is powered by natural gas, driving the price skyward. Since natural gas will for some time be used for heating (it makes cities far more healthful than they used to be), it is foolish to use this resource to produce electricity. The choice for electricity in the future comes down to nuclear or coal, and even with the most advanced technologies, coal is and will remain far more environmentally harmful than nuclear power.

Part IV: Other Benefits of Closing the Fuel Cycle

With fast-reactor recycle there will be better accounting for, and ultimately a reduction in, inventories of spent nuclear fuel; there will be a rethinking of technical safeguards approaches; and there will be a much greater incentive to have rigorous accounting of all nuclear materials.

There will be dramatic reductions in the toxicity of wastes to be disposed of. Best current estimates are that fast-reactor recycle will reduce net long term toxicity by something like two orders of magnitude. The final wastes can easily be tailored to an appropriate form for optimum security: long-lived isotopes in a metallic waste form (which can be highly corrosion resistant in the repository), shorter lived materials in ceramic waste forms. Radioactivity in a repository will reach background levels in less than 500 years.

With recycle integrated within a power generation complex, there will be a substantial reduction in transportation of nuclear fuel, both fresh and spent, with a concomitant reduction in opportunities for theft and sabotage.

There will be no need for uranium mining or milling for the foreseeable future. Now enrichment needed, ever. (Possession of a plant for isotopic separation, cetrifuge or otherwise, would be ipso facto evidence of intention to proliferate.) Residues of depleted uranium from previous weapons programs become valuable resources, not waste that is difficult to handle and dispose of.

Increased use of nuclear power will significantly reduce the atmospheric emissions associated with power generation, reducing both air pollution and greenhouse gases.

Part V: Electrochemical Separation Technologies

The advanced recycle technology that is closest to commercialization uses electrochemical methods. Both Argonne National Laboratory in this country, and Dmitrovgrad in Russia, have considerable experience, and have demonstrated the technical feasibility of separating heavy metals from highly enriched (fast reactor) fuels.

These techniques are effective in separating the heavy metals in fast reactor spent fuel from the bulk of the fission products – most notably, the cesium and strontium. This offers considerably increased flexibility in designing waste forms that are tailored to the hazards posed by the wastes. The recovered heavy metals are well suited for recycle into a fast reactor, either for consumption or for regeneration (breeding).

With further processing, such materials could also be used in a dirty bomb. In principle, they could even be used to construct a crude nuclear bomb, but the technology for this is surely beyond all but the most competent designers and technicians. Carson Mark has pointed out a few of the complexities of such an undertaking. Since terrorists cannot be counted upon to be realistic, this threat, however remote, is justification for rigid safeguards on electrochemical separation facilities.

Part VI: Weapons Usable?

Since the matter comes up over and over again, we now consider the weapons usefulness of reactor grade plutonium.

In policy circles, one of the great fears about nuclear power is its supposed connection to the spread of nuclear weapons. The usual statement is that "all plutonium is weapons usable," encouraging the inference that all plutonium is equally dangerous as a material for making nuclear weapons, which is incorrect.

While it is possible, using very sophisticated nuclear weapon designs, to get an explosive yield from reactor-grade plutonium, no country seeking nuclear weapons would use such material. As mentioned above, it is extremely difficult to design a weapon with reactor-grade plutonium. One problem, for example, is that so much heat is generated by that plutonium that when it is surrounded with high explosive to make a bomb, the explosive will decompose unless the assembly is equipped with very elaborate heat-removal features. Unsophisticated designers would not succeed. Furthermore, even with such problems solved, weapons made from reactor-grade plutonium have a yield that is highly unpredictable – they would be very likely to "fizzle," producing no mushroom cloud at all. Thus their usefulness as a military weapon is questionable to say the least, and even as a terrorist weapon that will definitely fizzle, they are technically beyond the reach of subnational terrorist organizations.

To our knowledge, a test carried out by the United States in 1962 is the only one ever performed that incorporated reactor grade plutonium. Unfortunately the details of that test are still classified. We are not told, for example, what fraction of the bomb's fissile content was "reactor grade," nor are we told the isotopic composition of the "reactor grade plutonium," nor the fabrication complexities.

The government has stated only that the yield was less than 20 kilotons. It could have been very much less. This information is almost useless, since neither the actual yield nor the yield to be expected with high-quality plutonium has been revealed. Without at least the ratio of those two quantities, one cannot determine the degradation in yield due to using reactor grade plutonium rather than weapons grade. Furthermore, the importance of heat generation in the assembly tested is unknown, but probably it was finessed in some way rather than handled as would be necessary in a real-life weapon that used only reactor grade plutonium.

In short, we are denied the information that would let one evaluate the practical difficulties.

In his 1993 paper, J. Carson Mark wrote: "The difficulties of developing an effective design of the most straightforward type are not appreciably greater with reactor-grade plutonium than those that have to be met for the use of weapons-grade plutonium." That was based on his calculations, and on his apparent opinion that the heat problem is trivial. However, to our knowledge no weapons program, anywhere, ever, has made another attempt to produce an explosion with reactor-grade plutonium. It is extremely likely that the 1962 test demonstrated that reactor grade plutonium is lousy material for making bombs, and that no nation, given the data from that test, would want to use the stuff.

While the difference in weapons potential is one of degree rather than principle, that difference is huge. The point is not that it can't be done, but rather that a would-be proliferator has far easier routes to nuclear weapons.

All reactors and all plutonium should be safeguarded, but reactor-grade material will be used only when all routes to higher fissile quality (uranium or plutonium) are cut off.

By the way, it has sometimes been asserted that the chemically impure plutonium produced by the pyrometallurgical process could be used to make a bomb without further separation. This has been convincingly refuted in an unpublished investigation by Livermore National Laboratory (1994),which concluded that the transuranic impurities render the material far too hot (thermally and radioactively), and with far too many spontaneous neutrons, to make it at all feasible.

Anyway, it is very much easier to make a bomb with highly enriched uranium than with reactor grade plutonium. That route would surely be taken by any organization that did not have access to weapons-grade plutonium.

Conclusions

No technology that involves the handling of nuclear materials, including the current once-through fuel cycle, can be totally immune to misuse. Regarding the current and short-term threat of nuclear terrorism, the status quo is not optimum. Relying solely on the current IAEA verification approach is adequate for controlling neither the inventory of nuclear materials nor any of the recycle technologies, current or advanced. Rigorous safeguards, including monitoring, surveillance, and accountancy, are necessary. The advanced recycle technologies offer no net additional potential for terrorist or proliferator, and appear to be adaptable to rigorous safeguards.

Since before the invention of fire, a new technology has always meant new risks. The genie, to be trite, cannot be put back in the bottle. In each case, society has learned to live with the risks in order to realize the benefits. All things considered, recycle of spent nuclear fuel to fast reactors will make a minimal contribution to the short-term risk of terrorism, provided that appropriate safeguards are instituted as an integral part of the process. In the longer term, recycle will significantly reduce the terrorist threat. Surely there can be no greater contribution to our national security than to lessen the tensions inherent in the world's massive dependence on oil.

Inevitably, nuclear power will supply a growing fraction of the growing global energy requirements. Although currently there is no shortage of uranium, continuing the profligate practice of treating spent fuel from thermal reactors as waste – throwing away more than 98 percent of the energy in the mined uranium – will swamp the waste-disposal facilities and exhaust the reserves of low-cost uranium. Fast reactors can run happily on that "waste," meeting the growing energy demand for decades before any more mining or milling of uranium is needed – and enrichment will never be needed. The basic technology is now in hand.

Those who would restrict the growth of nuclear power in the United States would deprive it of the ability to help set the guidelines and structure within which the spread occurs – an important recent example being the sale of Chinese reactors to Pakistan. We hope that UCS will decide to be part of the solution, rather than part of the problem

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(Endnotes)

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COMMENTARY

Comment on APS Hydrogen Report

Amory B. Lovins

Like several other well-publicized recent assessments, the March 2004 APS Panel on Public Affairs report "The Hydrogen Initiative" reaches erroneous conclusions about hydrogen economics and storage, due to three main fallacies:

1. By tacitly assuming today's heavy, inefficient vehicles, the panel concludes that "no material exists to construct a hydrogen fuel tank that meets the consumer benchmarks. A new material must be developed." In fact, those benchmarks (300-mile range, 3-5 minute fill, high safety, negligible leakage) are readily met by presently commercial filament-wound carbon-fiber tanks if used in very efficient and crashworthy fuel-cell vehicles made of ultralight advanced polymer composites. An illustrative 2000 virtual design for an uncompromised, cost-competitive midsize SUV [1] offers 330-mile range, 114-mpge EPA-adjusted efficiency, and excellent packaging using safe and cost-effective 350-bar hydrogen tanks now on the market. New manufacturing methods for carbon-fiber-reinforced thermoplastic vehicle structures appear capable of •80% of the performance of hand-layup aerospace composites at •20% of their cost, beating aluminum in cost per part and steel in cost per car, while offering automakers major reductions in required capital, parts, and assembly.

Such light, efficient vehicles remove any need either for a new hydrogen storage material or for liquid or solid storage, both of which are far costlier than simple compressed-gas storage. Compressed-gas storage does require compression energy, but it's minor and largely recoverable; and as the 2000 design demonstrates, combining good platform physics with fuel-cell efficiency overcomes hydrogen's inherent bulk. The panel's qualitative objections based on these old issues don't withstand quantitative analysis.

2. The panel concludes that the cost of natural-gas-reformed hydrogen must fall by at least 4x to compete with $1.50/gallon gasoline. In fact, distributed miniature reformers now being commercialized, or hydrogen piped from near-urban refineries used as merchant hydrogen plants, can compete well at the wheels of the car, net of fuel cells' 2-3x tank-to-wheels efficiency advantage over gasoline Otto engines. (Comparing cost per MJ of fuel rather than per unit of delivered traction – a mistake I made throughout the 1970s and 1980s – is of course fallacious when the desired end-use is moving the car.)

The more interesting question is how well fuel-cell cars and reformed-methane hydrogen can compete with gasoline in a gasoline hybrid-electric car like the doubled-efficiency 2004 Toyota Prius. (A Prius powertrain in the ultralight, low-drag SUV design just mentioned, but with a 0-60 mph time reduced from 8.2 to 7.1 s, would get 66 mpg.) It turns out that 5x-efficiency cars create a robust business case for hydrogen fuel-cell propulsion, while today's inefficient platforms don't. Thus hydrogen needs superefficient cars far more than vice versa – but once we have those cars, hydrogen clearly beats gasoline in cost per mile, using reformer technology now in service (centralized) or being commercialized (distributed). Cars with such good physics (low mass, drag, and rolling resistance) also make the fuel cell three times smaller, so it can be introduced many years earlier even at a threefold-higher price per kW.

The panel is correct that electrolytic hydrogen is too costly -- at least unless its electricity costs well below 2¢/kWh delivered to the filling station. But this means that electrolytic (or thermolytic) hydrogen can't justify further subsidies to or R&D investment in nuclear power, as the nuclear industry and Administration misrepresent, with the panel's apparent concurrence. Some renewables may ultimately be able to meet this stringent cost target, but nuclear technologies never can.

3. The panel omits the key strategy for an expeditious and profitable transition to hydrogen -- integrating fuel-cell deployment in mobile and stationary applications so that each helps the other happen faster [2].

How did these errors occur? The panel forthrightly states in its methodological appendix that "The authors did not carry out a new analysis of the scientific elements of the Hydrogen Initiative," but only "distilled" a rather narrow range of prior sources, nearly all governmental and many unquantitative and outdated. It's embarrassing to see APS issuing a me-too report pervaded by the same methodological flaws that undermined the similar reports lately issued by NAS/NRC, OTP, and others. POPA's distinguished panel and reviewers did not represent the range of knowledge needed to span the state of the art in key hydrogen-related technologies, and appear to have overlooked key evidence well-known to many active practitioners [3]. I fear the result, echoing the conventional wisdom of five or ten years ago, does no credit to APS and will unduly retard sound R&D planning for the hydrogen transition [4], even though POPA correctly emphasizes integrating hydrogen R&D with efficiency and renewables. The Administration's hydrogen and automotive strategies have important flaws [5], but POPA hasn't correctly identified them. This lost opportunity is unfortunate.

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(Endnotes)

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Radiation Detection at Borders for Homeland Security

Richard Kouzes

A Summary for Forum on Physics and Society Session at the April 2004 APS Meeting

The philosophy for the defense of the United States changed after the terrorist attack on September 11, 2001. The methods for delivery of weapons of mass destruction (WMD: nuclear, biological, or chemical) or weapons of mass disruption, such as radiation dispersal devices, expanded from military systems, such as missiles and bombers, to include transportation modes used by commerce and passenger carriers. Sophisticated military systems allow weapon delivery to specific targets at specific times and may be useful for destroying or deterring the use of other weapons. However, terrorist attempts to create psychological and ecnomic disruption do not require the precision or timing of such sophisticated delivery systems. As a result, defensive measures must include screening of cargo and passenger transportation modes for WMD or components thereof.

Countries around the world are deploying radiation detection instrumentation to interdict the illegal shipment of radioactive material crossing international borders at land, rail, air, and sea ports of entry. These efforts include deployments in the US and a number of European and Asian countries by governments and international agencies, such as the International Atomic Energy Agency (IAEA).

Items of concern to be interdicted include radiation dispersal devices (RDDs), nuclear warheads, improvised nuclear devices (INDs), and special nuclea material (SNM). The materials of concern include: plutonium (239Pu), enriched uranium (235U and 233U),other SNM, and any radioactive source that could be used for a RDD. All of these targeted materials produce a gamma radiation signature. Plutonium is also an emitter of neutron radiation, and a neutron signature is of particular interest if found at a border crossing. There are a few commercial neutron emitters used for soil and concrete density measurements and well logging, such as: californium (252Cf), americium-beryllium (AmBe), polonium-beryllium (PoBe), plutonium-beryllium (PuBe), and radium-beryllium (RaBe). Generally, the size of a source for an RDD of any consequence would be fairly large (kilocuries of activity) and thus relatively easier to detect than SNM. SNM massesof interest are on the order of the amounts designated by the IAEA as "significant quantities" of interest, i.e. 8 kg of plutonium and 25 kg of highly enriched uranium (HEU). Of these, plutonium emits higher energy gamma rays and neutrons and is thus somewhat easier to detect than HEU.

Generally, deployments utilize a layered defense where various technologies and people are used to interdict contraband. Intelligence may lead to targeting of certain vessels or cargo. Trained inspectors evaluate the attitude and behavior of those passing through control points.

The technology for screening of cargo and passenger transport for radiological threats is more advanced than that for chemical or biological weapons. Radiological screening instrumentation is being deployed broadly whereas chemical and biological screening is largely still in the research and development stage. Both passive and active techniques exist for searching for contraband. Active techniques include x-ray or gamma-ray imaging for hidden materials, acoustic testing for hidden materials, and neutron or gamma-ray induced signatures for explosives and special nuclear material. Passive techniques include various forms of mass spectrocopy for chemical or biological contraband and gamma-ray or neutron signatures for radiological materials.

Radiation portal monitors (RPMs) are used as the main screening tool for vehicles and cargo at borders, supplemented by handheld detectors, personal radiation detectors, and x-ray imaging systems. Pacific Northwest National Laboratory (PNNL) is deploying such RPM systems on behalf of U.S. Customs and Border Protection (CBP) at U.S. ports of entry. These RPMs are supplemented by handheld radio-isotope identifier devices that are used for limited area searches and personal radiation detection devices that are worn by personnel. ANSI standards have recently been developed for the certification of such radiation detection equipment for border security applications.

Some cargo contains naturally occurring radioactive material (NORM) that triggers "nuisance" alarms in RPMs at border crossings. NORM includes such materials as kitty litter, fertilizer, road salt, abrasives, and ceramics. Individuals treated with medical radiopharmaceuticals also produce nuisance alarms and can produce cross-talk between adjacent lanes of a multi-lane deployment. The operational impact of nuisance alarms can be significant at border crossings. Methods have been developed for reducing this impact of NORM without negatively affecting the requirements for interdiction of radioactive materials of interest.

Plastic scintillator material is commonly used in RPMs for the detection of gamma rays from radioactive material, primarily due to its efficiency per unit cost compared to other detection materials. The poor resolution and lack of full-energy peaks in the plastic scintillator material used prohibits detailed spectroscopy. However,the limited spectroscopic information from plastic scintilator can be exploited to provide some discrimination. Appropriately applied energy-based algorithms used in RPMs can effectively exploit the crude energy information available from a plastic scintillator to distinguish some NORM. Whenever NORM cargo limits the level of an alarm thresold, energy-based algorithms produce significantly better detection probabilities for small SNM sources than gross-count algorithms.

There has been a significant improvement in commercial radiation interdiction equipment available in the last few years, and a reduction in the cost of many of these systems. Ongoing research and development efforts are allowing for the fielding of new capabilities and integrated systems that will provide an even higher sensitivity to materials of concern.

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REVIEWS

Ivory Bridges - Connecting Science and Society

Gerhard Sonnert; The MIT Press, 2002; 239 pages, $30.00; ISBN: 0-26-219471-6

The lofty goal of this book is to evaluate “the contract between science and society.” Two ivory bridges between science and society are described; the first between science and state, where the justification of basic curiosity-driven research is studied, and the second between the scientists and society in conjunction with concerns about the implications of scientific research.

The volume is divided into four chapters and four appendices. Sonnert opens in Chapter 1 by introducing the concept of the ivory tower as a metaphor for an idealistic, and egoistic, struggle for knowledge. The supporting voices of those, such as Vannevar Bush, in favor of science for the sake of science, clash with those advocating greater social relevance, such as Joseph Rotblat. These contrasting views lead us to a third category of scientists that endeavour to “have their cake and eat it, too,” by building bridges from the ivory tower to society. This third category of scientists is divided into two subgroups, scientist-administrators and citizen-scientists.

The efforts of the scientist-administrators are detailed in Chapter 2, by following the development of science policy in the United States after the Second World War, a period of unparalleled scientific advance. The two familiar research camps, namely basic (curiosity-driven or Newtonian) research and applied (mission-oriented or Baconian) research, are complemented with a third Jeffersonian camp, which advocates basic research tied to a societal need.

Sonnert chronicles the “Press-Carter Initiative” as an example of science policy within a Jeffersonian framework. The evolution of this initiative is followed in some detail, from pre-natal events during the 1950’s, such as the establishment of the National Science Foundation, the domination of big science, such as the Apollo program, and the discussions of a Department of Science. Sonnert describes the enormous task of studying the case for federal funding of basic research given to Frank Press from the Carter administration. Part of this task entailed contacting the various departments in the government in order to gather basic research questions whose pursuit could be of vital interest to the United States. The answers of each department are presented with comments concerning the posed questions, as well as the willingness, or lack thereof, of the department to answer Press’s request. The second appendix presents a concentrated list of fundamental questions gathered by Frank Press in conjunction with the Press-Carter Initiative, while the third documents the master list of questions with references to the department of origin. This bank of questions offers an exceptional artefact of this time period. It also inspires us to ponder the great questions of today. The intricate political dance that Press performed in order to execute this assignment is not only impressive, it educates those of us without experience from these spheres of power, in the ways of influence.

The third chapter concerns voluntary public-interest organizations, which constitute the second ivory bridge. Once again the focus is on the period after World War II and three distinct waves of activism are identified. The first wave of citizen-scientist activism had its cradle in the Manhattan Project. Sonnert describes the development of scientist organizations, such as the Association of Los Alamos Scientists and the Bulletin of the Atomic Scientists of Chicago, and the growing struggle between collaboration and dissent with respect to the government. Sonnert continues to the 60’s and 70’s and portrays the growing interest in social movements for peace and environmental protection. Issues were more loosely connected to science, resulting in scientists reaping a less prominent position in the larger movements of this era. The third wave put forward by Sonnert is set in the Cold War years of the 80’s. Scientists regained some of their expert status in the questions du jour, namely environmental effects of nuclear energy and societal implications of research in biotechnology. Sonnert describes an increasing professionalism of special-interest groups that may endanger the influence of citizen-scientists. The fourth appendix represents a compilation of profiles of approximately ninety scientists' public-interest associations.

Sonnert ends his book with a brief social systems discourse into the area, where the transformation of science into an autonomous subsystem of society is described and evaluated.

For an early stage researcher, such as myself, this book offers an interesting, although perhaps not exciting, view into the complex relationship between science and society. What can and should be expected from scientists, with their unique technical knowledge, in societal activism? How should science justify itself and its public funding in the eyes of the public? The Jeffersonian framework, which the author puts forward as a viable and desirable mode of research, is indeed attractive. The question is whether it is novel or not?

A very positive facet of this book consists of the extensive referencing to other works and authors. Actually reading the seminal papers of Vannevar Bush or the Nobel Prize acceptance speech of Joseph Rotblat provided some of the most rewarding reading.

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Out of Gas: The End of the Age of Oil

by David Goodstein. W. W. Norton & Company, New York (2004). 140 pages, $21.95, ISBN 0-393-05857-3(hard cover).

David Goodstein is vice provost and Distinguished Teaching and Service Professor at the California Institute of Technology. In his slim and simple book, he claims that the supply of oil will probably reach its peak by the end of this decade and will decline thereafter. Unless the world can learn to live without fossil fuels, he foresees the end of civilization, as we know it, some time during this century.

The Introduction calls attention to the work by M. King Hubbert, a geophysicist working for the Shell Oil Company. In the 1950s, Hubbert predicted that oil production in the United States would peak around 1970 and decline thereafter. Hubbert was right. Oil production in America reached a maximum of about nine million barrels a day in 1970, and today is down to around six million barrels a day. Hubbert reached his prediction by extrapolating new finds of oil reserves and finding that around 1970, the United States would have used up around half of the oil. When that happened, he said, peak production would be reached.

This analysis has been applied recently by geologists to the world's oil reserves and has led to the prediction that the world will have used up around half of its oil by the end of this decade. But even if the geologists and Goodstein are wrong in detail, it is unlikely that they are wrong by more than a few years. The decline in the world's oil production is more likely to begin in ten years than in forty.

What can take the place of oil? Goodstein discusses a number of possibilities, including natural gas, coal, shale oil, solar energy, nuclear fission, and nuclear fusion. Other fossil fuels, especially coal, can be converted to oil at high cost, but although coal can prolong our dependence on fossil fuels, even coal production will decline before the end of the century. Moreover, turning to coal from oil will continue to cause an increase in the carbon dioxide emitted into the atmosphere, with consequences that cannot be foreseen.

As to the use of shale oil and nuclear fusion, Goodstein is pessimistic. He remarks, "It has been said of both nuclear fusion and shale oil that they are the energy sources of the future, and always will be." He is more optimistic for nuclear fission, although he states that if we go that route our available uranium supplies will decline in about twenty-five years unless the world turns to breeder reactors with the added risk of proliferation of nuclear weapons.

Goodstein doesn't think that hydroelectric power or wind power can do much to solve the world's problems. He discusses the hydrogen economy, and rightly points out that the use of hydrogen is not really a source of energy because it takes energy to produce hydrogen.

Goodstein likes to shock. For example, he says it is a myth that the "greenhouse effect and global warming are bad." What he means is that if it were not for the global warming caused by the greenhouse effect, Earth would be much colder than it is today, perhaps too cold for human beings to have evolved. He does not mean that the excess carbon dioxide in the atmosphere caused by burning of fossil fuels is OK. In fact, he states that we do not know the long-term effects of continuing to depend on fossil fuels. The result may be worse than bad---it may be catastrophic.

The book is not only about oil and its substitutes. The equilibrium of Earth in absorbing and emitting radiation is explained, and it is pointed out howfragile that balance is. There is a discussion of electricity, magnetism, and light. An historical approach is taken, from Franklin to Oersted to Faraday to Maxwell.

The first and second laws of thermodynamics are explained in simple ways without the use of any formulas, again from an historical perspective. Goodstein may not entirely succeed in making the concept of entropy easy to understand. I am not criticizing him on that account, because the concept of entropy is probably inherently difficult for the lay person.

Various kinds of engines are briefly discussed, including the standard gasoline engine based on the Otto cycle, the diesel engine, and the turbine. The theoretical Carnot engine, which gives the maximum efficiency that can be obtained in a heat engine operating between two given temperatures, is mentioned. Goodstein points out that the use of electrical energy is not limited by the Carnot efficiency, but if electrical energy is obtained from a turbine, the efficiency of the generation of the electrical energy is so limited. The alternative, of directly converting solar energy into electrical energy, is limited by the low density of solar energy.

In discussing alternative sources of energy, Goodstein does not omit remote possibilities, such as placing a huge device in outer space to catch solar energy and beam it to Earth in microwave radiation, which is not absorbed by clouds. He even mentions the possibility of cold fusion, although he does not really believe in the experiments purporting to have discovered it.

On the whole, Goodstein is correct in his discussion of physics principles, although he oversimplifies in some cases.

Occasionally he makes a mistake, as when he says that after a few years tritium "fissions spontaneously." It actually decays by beta-decay. Mistakes like this do not affect the main thrust of the book, which is to give us all a warning that time for the solution of our energy problem is running out much faster than we think. Whether the book is basically right depends crucially on whether Hubbert's method of analysis is valid when applied to the world's oil reserves. Goodstein argues impressively that it is.

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The Discovery of Global Warming

Spencer R. Weart, Harvard University Press, 2003, 228 pages, $24.95, ISBN 0-674-01157-0 and the associated web pages located at http://www.aip.org/history/climate/

The Discovery of Global Warming is a well-written, concise history of the science of climate change and the resulting discovery of global warming. From Arrhenius in 1896 breaking with the assumption of an unchanging Earth climate through to the politics of the Kyoto accords and New York Times headlines, Spencer Weart's book traces how science, often esoteric science, combines and builds a consistent overall view. Climate can and does change, and not merely over geological time scales but over the scale of a human lifetime. Understanding both the data and the models required to connect the data with natural processes has not been easy. The subtlety of data from ice cores, lakebeds, stratospheric winds, and local weather stations ultimately yields the punch line of "global warming" but it's the chase, not the capture, that is the heart of this book.

This chase has turned out to have far more twists, turns, and blind alleys than most would have guessed at the time. What controls the climate? Is it the variation of the Sun, as noted by Herschel in the eighteenth century? Is it the stability of the cold deep waters of the ocean? Or the transformation of old growth forests to grazing land? Greenhouse gases trapped in tropical forests? Or hidden away in blue-green algae? And what of the petrochemical haze of Los Angeles and the killing fog of London? What is a symptom and what is a cause? And further, what do the symptoms truly imply?

It might be glib to talk today about the good that might come of global warming—perhaps my Minneapolis winters won't be quite as harsh—but that is just one more lesson that we have learned, or are learning. Advances in modeling and in analyzing the data proceeded hand-in-hand. Atmospheric CO2 measurements (the "poster child" for global warming is the graph of Keeling's Mauna Loa CO2 measurements, see http://cdiac.ornl.gov/new/keel_page.html) could be explained by sufficiently complex simulations, but those computer models had to incorporate atmospheric methane, deal with the changing solar illumination, correct for the aerosols from the eruption of Mount Pinatubo, and be written by increasing large and sophisticated (and better funded) groups of scientists.

Combining information from disparate fields such as meteorology, vulcanology, atmospheric chemistry, and planetary science made the discovery of global warming difficult, and probably also prevented the history of the discovery from culminating in one single, glorious epiphany. Instead we find the gradual accumulation of knowledge and understanding with the occasional misstep or red herring, and with the background of political reluctance to act. There is no Moses, and no Newton, in this tale. Instead we have a succession of interesting characters, for instance Ed Lorenz and his butterfly wings, Nick Shackleton's million-year old deep-sea core, and Spencer Weart pulling it all together onto the page for you.

Weart, the director of the Center for History of Physics of the American Institute of Physics, has also made sure that the book will not quickly become out of date by producing a set of web pages (see top of article), which both go into additional depth and allow for updated information to be added. In fact, the web "book" adds many more layers, including technical ones, to the paper book. The online text is searchable and very well referenced through bibliographies sorted by both author and by year. The contrast between the two works, and the two media, is considerable. The 200-page (plus chronology and notes) book that I read on a couple of domestic airplane flights is a beautifully written, smooth narrative while the web pages have had me jumping around, following interesting leads, for several evenings in my office. It's hard to think of a pairing of book and web material that more clearly illustrates the relative advantages of the two media. Although the book is readable on its own, I suspect that the Physics and Society readership will feel the need to track at least a few of the historical or scientific developments through the web pages.

As physicists, the details of the history of climate change studies are likely to be as interesting as the broad storyline. These details, which make The Discovery of Global Warming a wonderful exercise in the "how science is actually done" school of the philosophy of science, also make for entertaining reading. The pumping of greenhouses gases into the atmosphere is, after all, a very human story and one whose importance will only grow with time.

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JST calls for nominations of research theme candidates and Research Director candidates who are capable of leading future ERATO projects. Please read through the guideline for nominators below. We hope that outstanding and competitive researchers will be nominated from a wide range of research communities. â—‹ Required information regarding the nomination of research theme candidates. ãƒ»What kind of scientific impact can be expected with the research theme? Our 2019 call for nominations is now closed. Important Dates. January 7, 2019 â€“ Nominations open online. March 31, 2019 (at 11:59 pm EDT) â€“2019 Nominations closed. April â€“ August 2019 â€“ Review and investigative process. September 2019 â€“ Honorees Announced.Â Individuals nominated for the Education, Health, Humanitarian or Protection Awards must have been doing this work with their organization for a minimum of 10 years. Nominees with less than 10 years of work will be disqualified.