

# PHYSICS & SOCIETY

A Publication of *The Forum on Physics and Society* • A Forum of *The American Physical Society*

## Editor's Comments

In this issue of *Physics & Society*, we continue our series on the risks of nuclear weapons after the Cold War. In their article *Illicit Trafficking of Weapons-Usable Nuclear Material: Facts and Uncertainties*, Lyudmila Zaitseva and Friedrich Steinhausler have provided us with a very detailed look at what is known about the smuggling of fissile materials. They have also provided a rather sobering estimate of how much of the smuggling may have remained undetected, as well as an analysis of the sources of uncertainties in our current knowledge. We are also very pleased to publish an analysis, by Steve Fetter, of the financial feasibility of space solar power (SSP), i.e., the collection of solar energy by

photovoltaics in orbit and the transmission of that energy to Earth. Dr. Fetter's analysis was motivated, at least in part, by a recent publication from Arthur Smith (*Physics and Society*, October 2003) that argued strongly in favor of SSP.

On a different tack, we publish several pieces about the role of physicists in government. Two, by Stephan and by Hafemeister, recount experiences as scientific fellows in the present Federal Government. One, by Hammer, is an account of an early scientist deeply involved at the heart of American governmental affairs.

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*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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## EDITOR'S COMMENTS continued..

The temporary Federal service of scientists has also been lauded in Congress as recounted in our News Section.

In September, one of us (JM) wrote to Senators Dianne Feinstein and Pete Domenici with an invitation to conduct a formatted debate, within the pages of P&S, regarding the issue of the development and deployment of small-yield nuclear bunker-

busters. (These issues are also touched upon in our News Section.) In recent senatorial debates, the two senators had been among the most vocal proponents against and for, respectively, such development. However, neither senator responded to the invitation.

*Alvin Saperstein & Jeffrey Marque*

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# ARTICLES

## 30 Years of APS Congressional Fellows: Looking Back and Looking Forwards based on remarks during the APS April 2003 meeting

*Sherri G. Stephan*

The American Physical Society Congressional Fellowship Program celebrated its 30<sup>th</sup> Anniversary the same way fellows participate on Capitol Hill: modestly, with due appreciation of the past and an optimistic view of the challenges ahead.

I began my fellowship in September 2000 in the middle of a heated presidential race. I joined the Senate Governmental Affairs Subcommittee on International Security, Proliferation, and Federal Services on the staff of the ranking Democrat on the Subcommittee, Senator Daniel K. Akaka of Hawaii. I worked on all things of interest to the Subcommittee that dealt with science, engineering, technology, and math. This included, but was not limited to, missile defense, geographical information system issues, weapons of mass destruction proliferation, defense, and terrorism, disaster mitigation and management, stockpile stewardship, nuclear testing, and space weapons.

I was an active member of the staff and contributed to many pieces of legislation. I also learned the quirks of Congress and how science and policy intersect. I gained an appreciation for the importance of procedure and politics in forming our national policies, and, in the end, I realized that Congress works just the way it was designed. It is not pretty or efficient, but that is the way it was meant to be.

The fellowship program has added a science perspective to this process. Current and former fellows work as ambassadors, raising the profile of science policy to scientists and the importance of science to policy makers. While current fellows provide most of the

in-house scientific expertise available on the Hill, past fellows are now high in the ranks of policy leaders, including Congressman Rush Holt in the House of Representatives and Jane Alexander in the Office of Naval Research.

The greatest challenge ahead for all Congressional science fellowship programs and Society policy offices is to decide upon the long-term policy goals of the science community. We need to look beyond increased funding for physics research. One comprehensive long-term goal is to change the way science is perceived in the legislative process. Currently, the science community is but one special interest. While Congressional staff has respect for scientists and their presumed intelligence, they still are seen to represent their own, rather than society's, interests. As a community, we should take steps to make science as fundamental to any policy debate as economics or national security. Imagine if along with the question, "What did the Congressional Budget Office say it will cost?" staff also asked, "What do the scientists say?"

To expand our interests in physics funding to include broad policy concerns, the science community will have to use some of their limited lobbying time on Capitol Hill to raise the appreciation of all science to policy makers. Scientists also need to increase science literacy efforts in the general public, the constituency base of every politician.

Both are difficult tasks. Some 30 % of Americans still believe that astrology is somewhat scientific and not enough people understand what a molecule is or are capable of defining

fundamental scientific terms and concepts (National Science Board, *Science and Engineering Indicators 2000*). Science literacy is more than definitions and specific theories. Scientists must help the public appreciate what science is, how it is done, and what it can do for society.

James Randi, in *The Mask of Nostradamus*, describes science as the “careful, disciplined, logical search for knowledge about any and all aspects of the universe, obtained by examination of the best available evidence and always subject to correction and improvement upon the discovery of better evidence.” Science is done through a never-ending search for better data and a better fit of our theories to the data. However, it is this uncertainty and ongoing quest for better evidence that makes the public and policy makers uneasy. The science community must do a better job at explaining uncertainty and the constant validation of current theories to lay audiences to help them recognize it as something to embrace rather than fear.

The public will need to understand uncertainty if they are to have reasonable expectations of what science can do for them and society. In a survey of scientists, policy makers, and the general public on attitudes towards science and its impact on society, close to 40 % of the general public agreed with the statement that science is becoming dangerous and unmanageable (National Science Board, *Science and Engineering Indicators 2000*). Thankfully, close to 80 % of scientists and 70 % of policy makers disagreed with this statement. The difference is telling—some of the public’s mistrust of science is due to the popular media’s unfortunate portrayal of scientists, especially physicists. The science community must share some of the blame. We need to put a face on science, reaching into the community and helping people understand what science is and how it is done.

The Fellowship Program and other policy groups within APS reach out to policy makers and legislators but need the assistance of Society members to make long-term and lasting changes to science policy. Physicists need to build a relationship with their Representatives and Senators. This requires a firm understanding of the difference between science and science policy. To illustrate the distinction using the analogy from George Philander (*Science*, vol. 294, 12/7/01, pg. 2105), suppose we are in a raft, drifting towards a waterfall. To avoid calamity, we must answer two questions: how far is the waterfall, and when should we get out of the water? The first question is a matter of science. The second is a matter of policy.

Answering the latter question becomes more difficult when the answer to the former has some uncertainty. There are additional considerations and there may be other questions. We may need to ask if we should get out of the water or off the raft at all. What if someone on the raft cannot swim or there is something more dangerous on the shore? All these other considerations, the politics and the procedures required in order to make a decision form the world of the policy maker. The first question, the science, is very important, but it may not be the deciding factor.

Through understanding these issues, scientists can appreciate the complex policy process and communicate effectively with legislators and their staff. Congress has 535 members and just as many points of view. Statements judging a member of Congress’ understanding of science widen the gap between scientists and Congress. Indeed, there are many people on the Hill who understand these issues: some are scientists, many are lawyers, others may be economists, historians, or physicians. Congressional staff are intelligent, dedicated, poorly paid, motivated by a desire to do good and deserve your respect.

I left the Subcommittee in March 2003, serving one year as a fellow and another year and a half as a professional staff member. I would offer that there is no “typical” tenure on Capitol Hill, but my two and a half years were full of historic, albeit some horrific, events. Through all these times, I was grateful to work for a terrific Senator and with a great staff. I am proud to say the personal and Subcommittee staff I worked with now have an increased awareness of science and what it can do for them.

I find the policy world becoming more complex and less predictable with every new corner I discover. However, like many of my colleagues and fellow Fellows, I enjoy sharing my experiences and offering advice on communicating with Congress and other policy makers. We hope this 30<sup>th</sup> anniversary celebration of the Fellowship Program will build interest in science policy and encourage others to take the plunge.

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## **Revolving Door Scenario for Congressional Fellows\***

*David Hafemeister*

I am grateful to have participated in the Science Congressional Fellowship program. This experience profoundly affected my professional (and personal) life. In particular, I am thankful for the guidance and friendship of Dick Scribner, who, as the founding Director of the AAAS Science Congressional Fellowship Program launched a thousand science and public policy careers.

In 1973, Scribner told the new fellows that there are two preferred paths in order to maximize the effectiveness of the program:

- stay in Washington and rise in the system to continually affect the system, or
- return to your home university or company and transfer to

those institutions what you have learned of science and public policy.

I will describe a third path, which is a combination of Scribner’s two desired paths. Namely I would like to address a “DC-Academia revolving door” scenario which alternates between presence and absence in Washington. In my case, I adopted this hybrid by spending about 1/2 of my time at my campus and 1/2 in Washington at university science and public policy programs.

My 12 years in Washington was divided among the Senate Offices of Senator John Glenn, the Foreign Relations Committee and the Governmental Affairs Committee, and among the

Department of State Offices of the Under Secretary of State (T), Office of Nonproliferation Policy (OES/PM) and the Office of Strategic Nuclear Policy (SNP/PM), the Bureau of Strategic and Eurasian Affairs (START) of the Arms Control and Disarmament Agency, and as a study director for the Committee on International Security and Arms Control of the National Academy of Sciences. In addition two years were spent at MIT, Stanford, Princeton and Lawrence-Berkeley Laboratory, working on national security and energy matters. For those who love acronyms, it has been my pleasure to work on EPCA, ECPA, NNPA, Glenn-Symington, INFCE, NASAP, terminating Clinch River and Barnwell, spent-fuel return, IAEA, ABM/D&S, INF, START, CFE, TTB/T/PNET, Open Skies, CWC, NPT, verification and compliance, minimum deterrence, verifiability of the CTB, stockpile stewardship, warhead monitoring, triad planning (1976-93), plutonium and HEU in Russia, Nunn-Lugar, and authorizations for ERDA(DOE) and ACDA.

### **Good Aspects of This Revolving Door:**

One might ask whether the revolving door is a good path for a Congressional Fellow? As I see some of my friends rise in the system, I have wondered whether it wouldn't have been better to stay put, become an "expert" and get promoted to "boss-in-charge." Since we can't do our life experience twice, I can only write on what happened to me and not what might have been. First of all, the good side of my revolving door:

Flexibility, variety and timeliness: I have been able to work on what I thought was current and important. In most of my Washington offices, I have been the only technically trained person, given opportunity to quantify the issues at hand. By working on a great variety of arms and energy issues, I have had the luxury of often working at the steepest part of the learning curve, and thus I have been continually challenged. Since I have often been brought into the government to address a new topic for a "big push," or to create the idea for such a push, this has often given a timeliness to the work.

What you write is what you sign: In Washington, it appears that those who write, don't have the status to sign, and those who have the status to sign, don't write the major portion of their signed products. When back at the university, we must take responsibility for what we write by signing our names. Many of the Congressional Fellows have learned a public policy issue that should have been written up, but, alas, they haven't had the time and/or the freedom to put their thoughts to paper. And, of course, re-entry to the university allows the teaching of courses on science and public policy.

Lies and damn Lies: Each one of us can write a list of science and public policy issues which have been distorted by "politics" and bad press. A revolving door allows one to address these "damn lies" both in the government and outside the government. If a busy executive branch desk officer does not know the relevant "open" literature which goes above and beyond a current inter-agency study, then a revolving door can bring this data into the process. The biggest "fibs" I witnessed while in the executive branch were on SDI, treaty compliance issues, and the military significance of potential cheating by the former Soviets. On the other hand, public debate in the university or professional societies can lack the reality of decisions based on all the issues; it is the obligation of people such as former congressional fellows to bring a sense of reality to the campus. The biggest "fibs" I witnessed while on the campus were on discussions of relative risks in society and the neglect of practical economics.

An independent, but loyal voice: Congressional fellows are, by definition, hand-maidens to the powerful above them. When part of a government bureaucracy, it does not help ones career to be too contrary to what is perceived as the conventional wisdom. If one has a tenured position in another city, this can give one confidence to speak up when your Senator or Under Secretary is about to do something that you perceive is less than wise. It is the duty of the former congressional fellows to maintain the highest levels of honesty and objectivity in order not to be corrupted by the party line of the home university or government office.

### **Downsides to Becoming a Revolving Door:**

What might have been: 'Aw shucks, we all might have been Under Secretary if we had only stayed the course. It takes about two weeks to adjust to the lack of phone calls from Washington.

Out of date, out of loop: Upon re-entry to the government, have we missed or forgotten those details which used to be at our fingertips? The challenge is get back on the learning curve to "get up to speed."

Family chaos? Moving back-and-forth every few years can be stressful. Do you and your spouse flourish in two environments, one in Washington and one at your home university? If you have children, does change prepare them for real life, or is an incubation in a quaint college town a preferred route? (In my family, my wife has been mostly supportive and very adventuresome.)

### **Jargon in DeeCee:**

Rather than write an essay on the interaction of NPT renewal with CTB negotiations and IAEA enhancement, I would like to close by examining some Washington, DeeCee jargon:

*Pipelines in are pipelines out,  
Loose cannon on the deck,  
Nice up and nasty down,  
OBE.*

Pipelines in are pipelines out: In the interagency process on arms control, essentially all the working papers are marked "secret," no matter how trivial the essay. When a former congressional fellow arrives into the inner sanctum of the interagency process, he is initially viewed with suspect because he has too many contacts with the Congress and the public. Some in the Executive Branch have (accurately) referred to Capitol Hill as the "torture place" since they perceive it as an overly politicized body. However, the Constitution wisely gave the Congress the power to oversight the Executive Branch since concentrated power can go astray. With this power the Congress can assist the Executive branch to consider the wider issues, for example a CTB, rather than a more limited testing ban. Ultimately, good government has to have pipelines that flow in two directions. If the Congress and the public are surprised by sudden executive branch policy shifts without consultation, there is bound to be a great deal of trouble. On the other hand, telling EVERYTHING could undercut the policy. Good government requires flow in both directions.

Loose cannon on the deck: When carrying on negotiations with foreign delegations or with the Congress, it is not useful for a negotiator to raise issues incorrectly or outside a planned framework (unless it is a walk in the woods) because then the negotiating partner can use this error or exaggeration as a means to derail useful discussion. This kind of negotiator is called a "loose cannon on the deck" because his/her heavy movements can splinter the wooden structures of the ship of state, much as loose cannons have done on real ships.

Nice up and nasty down: The road map of power in the Congress and the Executive Branch is a starting point to see how science enters into public policy making. These flow charts are often treated with too much respect. When you get inside a bureaucracy, you often see that effective power, influence and jurisdiction don't quite follow these neat boxes and flow diagrams. Furthermore, other — less than nice — bureaucratic behavior often influences the way work gets done. For example, these diagrams imply a status between an under secretary and an office of policy and planning. If the director of an office takes too much credit for the work done by his office and if he is overly fond of those above him and not very nice to those in his office, he is then referred to as “nice up and

nasty down.” I met very few office directors who actually gained leadership this way, because these kinds of people are ultimately thrown overboard at sea.

OBE: This paper may be OBE by the time you read it, that is it probably will be “overtaken by events.” In that case, please bring it up to date.

\*This is updated, Chapter 10, *From the Lab to the Hill*, edited by Tony Fainberg, AAAS. Washington, DC. 1994.

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## Illicit Trafficking of Weapons -Usable Nuclear Material: Facts and Uncertainties

*Lyudmila Zaitseva and Friedrich Steinhauser*

### 1. The danger of perceived vs. actual threats

In the recent past the issue of covert trade in nuclear material gained public prominence when it was erroneously claimed by British intelligence sources that the former Government of Iraq under Saddam Hussein had tried to obtain uranium from Niger. The far reaching consequences of such assessments for society were clearly demonstrated by US President George W. Bush in his speech on January 28, 2003, using this incorrect information as one of the reasons why terrorists and countries belonging to the “Axis of Evil” posed a potential nuclear threat.<sup>1</sup> In view of the occurrence of such significant errors even in the intelligence community, it is not surprising that information in the media on the topic of illicit trafficking of nuclear material is frequently flawed by errors. Examples of such errors include failure to differentiate nuclear weapons-usable material<sup>2</sup> from other radioactive material, incorrect use of physical units of activity and dose rate, and misquotation of isotopic characteristics and enrichment levels.

Since the terror attacks on September 11, 2001, many publications envisaged doomsday terrorism scenarios, including the deployment of a nuclear device as a potential threat to society. Although this possibility can no longer be excluded, the probability for it to actually happen is relatively low and, in any case, significantly lower than that for a radiological dispersal device to be used in a future terror attack.<sup>3</sup>

Nevertheless, the issue of losing control over weapons-usable nuclear material has gained prominence in the debate on national security in several countries. Positions in this debate are frequently based on questionable intelligence rather than facts. This undesirable situation is largely due to the fact that information on illicit trafficking of nuclear material is often associated with a high level of secrecy.

In addition, there is a noticeable lack of sharing of relevant information among all parties involved due to the security-sensitive nature of the data and the justified concern by the security community not to reveal any weakness in the physical protection system for nuclear material.

The probability for losing control over nuclear material depends on the amount of material to be secured, the number of storage sites, and the level of physical protection provided by the facility operators.

Large quantities of nuclear weapon-usable material are stored at each of several hundred facilities worldwide. About 1,665 tons of highly enriched uranium (HEU) and 147 tons of plutonium are stored for military uses worldwide.<sup>4</sup> Comparable amounts are stored at facilities under civilian control. Physical protection practices at these facilities vary significantly, ranging from dedicated nuclear weapon storage facilities under military control, to commercial reprocessing facilities under civilian control, and some research reactors with completely inadequate control.<sup>5</sup>

In order to avoid the pitfalls of evaluating important security-related decisions from questionable sources of information, this paper discusses only the most reliable currently available data on illicit trafficking of weapons-usable nuclear material, contained in the Database on Nuclear Smuggling, Theft, and Orphan Radiation Sources.

### 2. Illicit trafficking of weapons-usable nuclear material

The Database on Nuclear Smuggling, Theft and Orphan Radiation Sources (DSTO), which combines state-confirmed information with unconfirmed open source data, contains 25 highly-credible trafficking incidents involving weapons-usable nuclear material, i.e., highly-enriched uranium (uranium enriched to 20% U-235 and more) and plutonium-239. Seventeen of these incidents were confirmed by member states to the International Atomic Energy Agency (IAEA) (Table 1). Eight other highly-credible cases were not officially reported to the IAEA Database Program for reasons unknown to the authors, although they have been publicly confirmed by state officials and described in detail by non-proliferation experts and investigative journalists (Table 2).

According to the IAEA state-confirmed reports, the total amount of weapons-usable material seized by law-enforcement authorities is about 9 kilograms. In other credible cases, it amounts to 30 more kilograms. Thus, a total of 39 kg of HEU and plutonium were intercepted during illicit transit, sale, and diversion attempts since 1992. In addition, a cache of 90% HEU reportedly disappeared from a research facility in Abkhazia, a break-away province of Georgia, during the military hostilities between 1992 and 1997. According to different accounts, between 655 g and 2 kg of HEU had been present on site before the conflict broke out and the staff had to leave the facility unguarded. When the specialists from the Russian Ministry

of Atomic Energy were finally allowed to enter the facility in 1997, they found no HEU remaining on site. The whereabouts of the material are still unknown and concerns have been raised whether it could have fallen into the hands of criminals or terrorists.

It should be noted that since 1992 HEU has been subject to diversion and smuggling to a much higher degree than plutonium. Intercepted plutonium accounts for less than one percent of the 39 kg. About 380 g of this material were seized since 1992, of which 363

**Table 1. Government-confirmed cases involving weapons-usable material<sup>6</sup>**

| Date of Seizure | Location of Seizure          | Type and Amount of Material          |
|-----------------|------------------------------|--------------------------------------|
| 24 May 1993     | Vilnius, Lithuania           | 100 g of 50% HEU                     |
| 10 May 1994     | Tengen, Germany              | 6.2 g of Pu-239 (99.75%)             |
| June 1994       | St. Petersburg, Russia       | 2.972 kg of 90% HEU                  |
| 13 Jun 1994     | Landshut, Germany            | 795 mg of 87.7% HEU                  |
| 25 Jul 1994     | Munich, Germany              | 240 mg of Pu-239                     |
| 10 Aug 1994     | Munich airport, Germany      | 363 g of Pu-239                      |
| 14 Dec 1994     | Prague, Czech Rep            | 2.73 kg of 87.7% HEU                 |
| 6 Jun 1995      | Prague, Czech Rep.           | 415 mg of 87.7% HEU                  |
| 7 Jun 1995      | Moscow, Russia               | 1.7 kg of 21% HEU                    |
| 8 Jun 1995      | Ceske Budejovice, Czech Rep. | 17 g of 87.7% HEU                    |
| 28 May 1999     | Rousse, Bulgaria             | 4 g of 72.65% HEU                    |
| 2 Oct 1999      | Kara-Balta, Kyrgyzstan       | 1.49 g of Pu                         |
| 19 Apr 2000     | Batumi, Georgia              | 920 g of 30 (±3)% HEU                |
| 16 Sep 2000     | Tbilisi airport, Georgia     | Pu (0.4 g)                           |
| 2 Jan 2001      | Liepaja sea port, Latvia     | 6 g of Pu in Pu/Be sources           |
| 28 Jan 2001     | Tessaloniki, Greece          | 3 g of Pu-239 in anti-static devices |
| 22 Jul 2001     | Paris, France                | 2.5 g of 72.57% HEU                  |

**Table 2. Other highly-credible cases involving weapons-usable material**

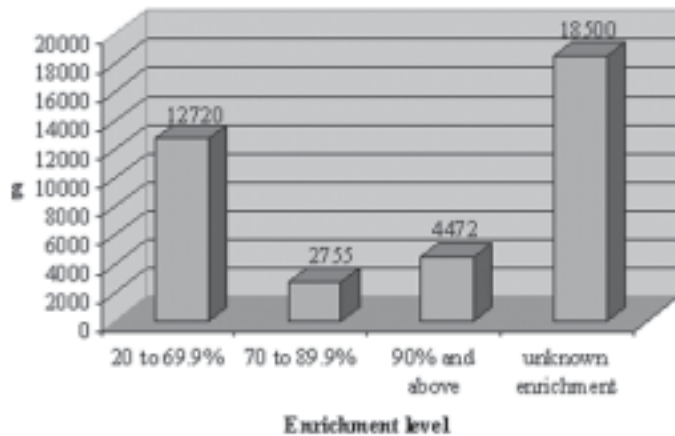
| Date        | Name of Incident           | Type and Amount of Material    |
|-------------|----------------------------|--------------------------------|
| 3 Feb 1992  | Munich, Germany            | Pu (115 mg) in smoke-detectors |
| 6 Oct 1992  | Podolsk, Russia            | 1.5 kg of 90% HEU              |
| 29 Jul 1993 | Andreeva Guba, Russia      | 1.8 kg of 36% HEU              |
| 27 Nov 1993 | Sevmorput, Russia          | 4.5 kg of 20% HEU              |
| 1992-1997   | Sukhumi, Abkhazia, Georgia | 655 g of 90% HEU               |
| 1998        | Chelyabinsk region, Russia | 18.5 kg of HEU                 |
| 2000        | Electrostal, Russia        | 3.7 kg of 21% HEU              |
| 2001        | Erlangen, Germany          | 0.8 g HEU                      |

g were part of a mixed uranium oxide batch, 10 g were contained in radioactive sources, and only 6 g were weapons-grade material with a purity of 99.75%. The enrichment level of the remaining 38.6 kg of HEU varies from case to case (Figure 1). At least 4.5 kg were weapons-grade (enriched to 90% and more), which would be insufficient for building a nuclear weapon. However, if the 18.5 kg of HEU intercepted during the attempted diversion from one of the Russian nuclear weapons laboratories in the Chelyabinsk region in 1998 were weapons-grade, this batch alone might have been enough for an advanced nuclear device.

As demonstrated by several known thefts (*Luch-Podolsk 1992, Electrostal-St. Petersburg 1994, Electrostal-Moscow 1995*), significant amounts of fissile nuclear material disappeared from Russian facilities without being noticed by the facility accounting systems. Therefore, it is possible that more nuclear material has been successfully diverted since the collapse of the former Soviet Union in 1991. It is also likely that gram amounts of HEU and

plutonium seized in a number of cases (*e.g., Tengen 1994, Rousse 1999, Paris 2001*) were only samples of larger quantities of already diverted material. Such a possibility was demonstrated by the four linked cases involving 87 % HEU (*Landshut 1994, Prague 1994, Prague 1995, and Ceske Budejovice 1995*). A small sample of the HEU was handed over to a German undercover policeman in Landshut, and a follow-up investigation led to the seizure of a large cache (2.73 kg) and two more samples of uranium in the Czech Republic. Subsequent analysis revealed that the material seized in all four cases was identical and likely of the same origin. A similar scheme was used in Germany in 1994, when a 240 mg sample of plutonium transferred to an undercover German intelligence agent in July, was followed by 363 g of the same material delivered on an ordinary Lufthansa flight from Moscow in August. The arrested smuggler claimed he could deliver several more kilograms of already stolen plutonium from Russia. Additional amounts of HEU and plutonium were reportedly promised in several other cases, although

**Figure 1. Amounts of seized uranium with various enrichment levels (in gram)**



the validity of such claims is difficult to corroborate. Therefore, the cumulative amounts of the seized weapons-usable HEU and plutonium may represent only a fraction of the material already diverted from nuclear installations. In this sense, nuclear smuggling is often compared to drug trafficking. For example, the US law enforcement authorities admit to being able to stop between 10 to 40 % of the drugs illegally imported into the country.<sup>7</sup> These figures are likely to be even lower in developing countries due to poorer border protection. Assuming that the detection rate for HEU and plutonium before they reach the end-user is similar to that of drugs, the quantity of the material that has been successfully diverted and possibly smuggled to the final destination may be 3 to 10 times higher than what has been interdicted so far.

In most of the 25 incidents, the material was stolen or is suspected to have originated from nuclear facilities in Russia. Nuclear research institutions, fuel production facilities, and naval fuel depots have been the most frequent sites for successful material diversion. Russian weapons laboratories located in closed nuclear cities appear to have been guarded better over the past decade. There was only one diversion attempt that can be referred with a certain degree of confidence to a closed nuclear city, and it was successfully interrupted by the Russian security services in the Chelyabinsk region in 1998.

The first theft of weapons-usable material was noted in Russia in 1992, soon after the collapse of the former Soviet Union, accompanied by an economic downturn and impoverishment of the nuclear sector. An engineer involved in the material weighing and accounting procedures at Luch Scientific Production Association diverted almost daily gram amounts of 90% uranium, which were below the detection limits. Over a four month period he had accumulated 1.5 kg of the material. He was arrested by pure chance at a train station in Podolsk on his way to Moscow, where he intended to find a buyer for the HEU. The thief admitted that he had hoped to sell the material for about US\$500, so he could buy a new stove and a refrigerator. Once an elite of the Soviet society, nuclear scientists were suddenly faced with dramatically decreased funding, low wages delayed for months, and bleak prospects for the future. As a result, the security of nuclear material became very vulnerable to the so-called "insider" threat from facility employees, who wanted to improve their financial situation by stealing the material and trying to sell it. In all credible thefts of weapons usable material known to date (*St. Petersburg 1994, Moscow 1995, Podolsk 1992, Andreeva*

*Guba 1994, Sevmorput 1994, Erlangen 2001*), the material was diverted by insiders with access to fissile nuclear material acting both on their own initiative and upon requests by other individuals (e.g., relatives, middlemen). It should be noted that although the identities of the individuals apprehended in the 1998 diversion attempt in the Chelyabinsk region have not been revealed to the public, Minatom officials in Russia confirmed that they were conspiring facility employees. In five out of the six cases, the material was stolen with the purpose of selling it for profit, although, like in the Podolsk case, the perpetrators had only vague ideas as to where to find a buyer.

Involvement of organized crime groups could be a key factor in a successful transfer of diverted weapons-usable material to the end-user in view of their logistical capabilities in the smuggling of weapons, drugs, and people. Therefore, it is very encouraging that no apparent links to organized crime have been identified in any of the 25 smuggling cases. Also, no hard evidence has been found to link any of these cases to specific end-users, such as rogue nations or terrorist organizations, which remain the least known link in the nuclear smuggling chain.

### **3. Inherent uncertainties in the current knowledge about illicit trafficking**

In order to judge the validity of the current threat assessment, it is essential to also address the inherent uncertainties in the data used for the analysis, such as:

•**Corruption to defeat the physical protection system:** The black market value of weapons-usable nuclear material ranges from a few hundred to several thousand US dollars per gram, which is the equivalent of at least several months' wages for nuclear scientists and security guards in the former Soviet Union or in developing countries. Since corruption is officially acknowledged as a serious problem in many of these countries, it is safe to assume that corruption among personnel guarding and working at nuclear facilities cannot be excluded.

•**Flaws in the material accounting system:** Accounting practices for nuclear material face two major limitations: (a) The mass of radioactive material is derived indirectly from counting events of radioactive decay with its inherent statistical uncertainties. This is generally acknowledged in the fuel production by defining a certain percentage of the nuclear material involved in the process as "material unaccounted for" (MUF) – a potential loophole for covert diversion of material which has already been successfully used in Russia; (b) containers holding nuclear material are equipped with seals of various degree of sophistication. Irrespective of the type of seal, these seals can be successfully faked, i.e., material can be diverted without any apparent tampering with the seal.<sup>8</sup> Provided that material accounting practices rely predominantly on checking the integrity of such a seal rather than the actual content of the container, diversion of nuclear material may remain undetected for extended periods of time.

•**Inadequate equipment for detecting trafficking:** The characteristic radiation emitted by nuclear material (mainly alpha particles, together with neutrons) is of a type that most border guards and customs officers cannot detect. Provided that they are equipped with a detection device at all, it is usually a simple gamma radiation detector. The situation is more dire still in case of traffickers familiar with the technical specifications of suitable radiation shielding, since their knowledge enables them to successfully bypass even the checkpoints equipped with alpha- and neutron radiation detectors.

•**Limited prevention of illegal border crossings:** Despite major technological and logistical efforts, no country has been able to stop the illegal flow of drugs, immigrants, weapons, or stolen art across its borders. Since the physical amount of nuclear material subject to smuggling is comparatively small, it can be safely assumed that illicit trafficking of the amount of nuclear material needed for a crude nuclear device – about 50 kg of 90% HEU – can be achieved by transporting it across borders on foot or boat using the services of illegal immigrants.

•**Deliberate underreporting of diverted material:** Any report about diversion or interdiction of nuclear material highlights the fact that local and national authorities had lost control over the material due to inadequate material accounting and/or physical protection. This fact in itself may be sufficient reason for some countries not to report each and every such incident. Table 2 above shows several incidents involving HEU that had happened in Russia, but were not officially reported to the IAEA. This suggests that there might have been other such incidents, which were not reported by states and therefore went unnoticed by the general public.

#### 4. Conclusions

Until now, only 25 highly-credible cases of illicit trafficking in nuclear material have become known since recording of such incidents was started in 1991. By comparison, there have been over 800 cases involving illicit trafficking in *other nuclear and radioactive material*, such as low-enriched uranium, yellowcake, medical and industrial radiation sources, during the same period of time. The inherent uncertainties in our current knowledge on nuclear smuggling make it difficult to judge whether trafficking in weapons-usable nuclear material is really such a relatively rare phenomenon, or whether it was and still is carried out in such a clandestine, professional – in criminal terms – manner, that it remains largely undetected. In either case, it is essential to improve our current understanding of the true magnitude of illicit trafficking in nuclear material, since national security and international stability heavily depend on the correct threat assessment.

*Lyudmila Zaitseva established- jointly with the co-author Friedrich Steinhausler-the Database on Nuclear Smuggling, Theft and Orphan Radiation Sources (DSTO) as a Visiting Fellow at the Center for International Security and Cooperation (CISAC), Stanford University.*

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#### (Endnotes)

<sup>1</sup> US President George W. Bush, “...The British Government has learned that Saddam Hussein recently sought significant quantities of uranium from Africa...”, quote from the State of the Union address, 28 January 2003.

<sup>2</sup> Fissile material with an enrichment level of 20% or more is considered usable for a nuclear weapon according to the definition by the International Atomic Energy Agency (IAEA). However, it should be pointed out that the actual amount of nuclear material needed for building a “crude” nuclear device increases significantly with enrichment levels below 90%.

<sup>3</sup> Steinhausler, F., “What It Takes to Become a Nuclear Terrorist”. American Behavioral Scientist, 1February 2003, vol. 46, no. 6, pp. 782-795(14), Sage Publications.

<sup>4</sup> Institute of Science and International Security (ISIS) at [www.isis-online.org](http://www.isis-online.org).

<sup>5</sup> Bunn, G., Steinhausler, F., “Guarding nuclear reactors and material from terrorists and thieves,” Arms Control Today, Vol. 31, No. 8, October 2001, pp. 8-12.

<sup>6</sup> IAEA Office of Physical Protection and Material Security, “Comprehensive List of Incidents Involving Illicit Trafficking in Nuclear Materials and Other Radioactive Sources: Confirmed by States”.

<sup>7</sup> Phil Williams and Paul Woessner, “Nuclear material trafficking: An interim assessment”, Working Paper 95-3, Ridgway Viewpoints (Matthew B. Ridgway Center for International Security Studies, University of Pittsburgh: Pittsburgh, Pa., 1995), p. 2.

<sup>8</sup> Johnston, R., “Effective vulnerability assessment for physical security devices, systems, and programs,” Austrian Military Journal (OMZ), Special Edition “Nuclear Material Protection” (2003), pp. 51-55.

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## COMMENTARY

### Benjamin Franklin – America’s First Civic Scientist Summary of April, 2003 APS Meeting Session

*Bo Hammer*

The April 2003 Meeting of the APS was held in Philadelphia. Appropriately, the Fora on Physics and Society and on History of Physics, co-organized a session on Benjamin Franklin: America’s First Civic Scientist, to reflect on the impact of Franklin as a scientist immersed in public service. The session was inspired by Neal Lane of Rice University, who, as President Clinton’s science advisor, coined the term “civic scientist” as an appeal to scientists to become engaged in the policy process. A little reflection on the life and career of Franklin reveals that he left his mark in a way that can be

idealized as that of the prototypical civic scientist. The session co-organizers were Michael Riordan of the Forum on History of Physics, who served as chair; and Bo Hammer, of FPS, who served as a discussant.

The session began with a wonderful reflection on Franklin’s personality and friendships by Claude-Ann Lopez, former editor of the Franklin Papers project at Yale. Franklin’s was a life lived through the written word. His legacy persists because so much of what he wrote remains accessible to the public. It was Franklin’s scientific



accomplishments that gave him entrée into the courts of Europe, making him one of the most well-traveled Americans of his time. His journeys and his *joie de vivre* left him with friends throughout America, Britain, France, Russia, and elsewhere in Europe. He maintained his friendships through correspondences, which now provide insight into the workings of Franklin's mind including his thinking on all topics of the day from politics to science, and the great degree to which he valued human contact as a way to propagate and refine his thoughts.

The next speaker was Nobel Prize-winner and science historian Dudley Herschbach, who established Franklin's scientific bona fides and his life-long calling to public service. Herschbach characterized Franklin as a "curiosity-driven scientist and a service-driven citizen." Indeed, Franklin's science was inspired by a combination of inquisitiveness, skepticism of accepted wisdom, a need to constantly improve things, and a deep sense of social responsibility. Herschbach emphasized Franklin's primary profession as a printer. Upon retirement in his early 40s, Franklin turned his full attention to science and public life.

James McClellan, a science historian from Stevens Institute of Technology, reminded the audience that the term, "scientist," was not in use in Franklin's day and that a career in "science" was much different then than it is now. Rather, in the 18<sup>th</sup> century today's scientists would be labeled as "natural philosophers". McClellan asked the audience to take a step back and consider that, despite Franklin's remarkable contributions to the understanding of natural phenomena and the enthusiastic reception he received from the community of natural philosophers, Franklin really was not a scientist in the sociological sense of the profession. He did not, as McClellan put it, "enter the fray." He was not fully engaged in the give and take of scientific discourse. And, while he published his work, he essentially ignored his detractors instead of engaging them in scientific debate in order to resolve disagreements on theory, observation, and conclusions.

The last speaker, Neal Lane, provided detail to his concept of the civic scientist, which he originally promoted as President Clinton's science advisor as a way to encourage scientists to become more engaged in the policy process. Lane described the civic scientist and characterized Benjamin Franklin as America's first scientist to fit this description: According to Lane, a civic scientist should be a practicing scientist with sufficient professional standing to have credibility among colleagues, policy-makers, and the public. This individual must possess the wisdom and judgement necessary to understand when it is appropriate to apply scientific authority to policy issues and where the boundaries of this authority exist. A civic scientist should be able to communicate effectively with a variety of audiences in order to convey his or her message most effectively. A civic scientist must not expect to persuade by virtue of scientific authority; rather, he or she should understand the nature of political discourse and decision-making, and realize that progress is made incrementally through a process of compromise and consensus building. Finally, a civic scientist is one who is committed to applying scientific knowledge and experience to the benefit of the public.

## Discussion

Biographer H.R. Brands entitled his biography of Franklin, *The First American*. Among his contemporaries abroad, Franklin was the prototypical American, with his somewhat rustic attire, his independent tendencies, his entrepreneurialism, and his creative

and tireless drive to forge a new nation. Franklin was the first American, in the sense that he played such an important role in defining our national character. Not only was he instrumental in crafting the Declaration of Independence, the Constitution, and the Bill of Rights, but through his involvement in founding civic organizations, he shaped the role that citizens play in the civic life and governance of our cities and nations. His organizational activities as one of Philadelphia's leading citizens led to the creation of universities, hospitals, libraries, fire companies, and learned organizations — and their associated philanthropic support — that functioned outside of government or church control. As a result, Philadelphia became the prototype of the great American cities that persist today. These cities are uniquely American because their strength resides primarily in organizations and people outside of the government and church. In this sense Franklin represented what it means to be American, individually and institutionally.

Franklin's career had three phases. Remarkably, he worked nearly to the day he died in 1790 at the impressive age of 84. Franklin began his professional life as a printer, and throughout his life considered himself to be, above everything else, a printer. Franklin was successful as printer and leveraged his success by providing capital to other printers in Philadelphia and other cities. Income from his own business and from his partnerships was such that he was able to retire in his early 40s so that he could pursue other interests, the foremost of which were his investigations into the nature of electricity. The impact of Franklin's discoveries and inventions made him an international celebrity, so that when he was sent to London as the agent of Pennsylvania, he was received enthusiastically at the highest levels of government and science. Indeed, his scientific reputation and correspondence were such that upon his arrival in London he had an extraordinary network of well-placed friends and colleagues. He exploited this network skillfully on behalf of Pennsylvania and other Colonies.

It was Franklin's scientific reputation that enabled his success as diplomat and public man, his third career. Then, as today, scientific success and the reputation that attends it, can, under the right circumstances of motivation, connection, and interest, endow one with considerable authority. Franklin recognized this, and combined his authority with his keen mind, quick wit, and good cause, in order to effect great change on behalf of the colonies, and later the fledgling United States.

Public policy is infused with scientific and technical issues, perhaps more now than ever before. This may be especially true considering the impact of the questions at hand, such as the potential for global climate change, the need for energy alternatives to fossil fuels, the new ethics of biotechnology, nonproliferation of weapons of mass destruction, and appropriate science education. Franklin's blending of curiosity, questioning of nature, and civic-mindedness provide an example for scientists to follow today, and we are fortunate that the [Forum on Physics and Society](#) provides a locus of activity for physicists interested in these issues and motivated to act. For those who are interested but not quite yet motivated, consider these motivational factors: because of the predominance of public funding that enables our livelihood, scientists have an obligation to account for the public impact of their work. Accordingly, because of the public trust accorded to scientists, scientists are in a position to have a relatively high degree of influence on policy makers.

There are many avenues open to those who wish to become more involved. For example, the Forum always seeks volunteers to

organize sessions, write for this newsletter, and become involved in Forum leadership. Additionally, APS, AIP, OSA, AAAS, MRS, AGU, ACS, and many other professional societies sponsor policy fellowships that enable scientists to work as staff in Congressional or Executive branch offices. On a local level, members of Congress or state legislatures are open to well-reasoned advice and would probably appreciate hearing from a professor or industrial scientist living in their district. And for those who really want to get their hands dirty, school boards are, in many ways, the great political finishing school, and can have significant influence on science education matters.

Benjamin Franklin was, as America's first civic scientist, not only an instrumental figure in our nation's founding, but he also provided a model of personal action and habits of mind that are worthy of study and perhaps emulation. His curiosity and love of his fellow humans are infectious, and his words displayed a remarkable breadth of learning, wisdom, and inquisitiveness. Franklin's tercentenary in 2006, presents an opportunity to reflect on his legacy and consider how we can strive to use the privilege of our profession to improve the world beyond our laboratories.

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## Space Solar Power: An Idea Whose Time Will Never Come?

Steve Fetter

Arthur Smith laments the lack of attention to space solar power (SSP),<sup>1</sup> but SSP cannot compete with solar power based on earth. The advantage of SSP is a large and constant solar flux—1.37 kW m<sup>-2</sup> or 12,000 kWh m<sup>-2</sup> y<sup>-1</sup>. This is about five times higher than the average flux on a sun-tracking surface in sunny areas on the earth's surface, such as the American southwest.<sup>2</sup> The larger solar flux in space cannot compensate, however, for the cost of placing systems in space and transmitting the electricity back to earth.

Smith correctly states that earth-based systems suffer from the day-night cycle and cloud cover, and the consequent need for energy storage or very-long-distance transmission. But earth-based solar systems could supply up to 20 percent of U.S. electricity demand<sup>3</sup>—the fraction currently provided by nuclear or hydro—without significant storage or long-distance transmission. Even if solar was used to meet all electricity demand—an unlikely scenario—only about half of the solar electricity produced by earth-based systems would have to be stored or transmitted over intercontinental distances. By comparison, 100 percent of SSP electricity would have to be transmitted wirelessly to earth, at efficiencies optimistically estimated at 40 percent. Moreover, SSP transmission is very likely to be less efficient and more expensive per kilowatt-hour than storage or transmission of electricity generated by earth-based stations.<sup>4</sup>

To see that SSP cannot compete with earth-based solar power, consider only the costs of the photovoltaic arrays. In order for SSP to be less expensive than earth-based systems

$$\frac{C_{pv} + C_L M}{\epsilon S} < \frac{C'_{pv}}{[1 - f(1 - \epsilon')] S'} \quad (1)$$

where  $C_{pv}$  and  $C'_{pv}$  are the installed unit costs of the photovoltaic arrays in space and on earth ( $\$/kW_p^{-1}$ ),<sup>5</sup>  $C_L$  is the unit cost of placing mass in orbit ( $\$/kg^{-1}$ ),  $M$  is the unit system mass in orbit ( $kg kW_p^{-1}$ ),  $S$  and  $S'$  are the annual solar fluences on arrays in space and earth ( $kWh y^{-1}$ ),  $\epsilon$  is the end-to-end transmission efficiency of the SSP system,  $\epsilon'$  is the end-to-end transmission efficiency or round-trip storage efficiency for earth-based generation, and  $f$  is the fraction of earth-based solar generation that is transmitted very-long distances or stored. Assuming  $S/S' = 5$  and solving for  $C_L$ , we have

$$C_L M < 5pC'_{pv} - C_{pv} \quad (2)$$

where  $p$ , the efficiency ratio, is given by

$$p = \frac{\epsilon}{1 - f(1 - \epsilon')} \quad (3)$$

The fraction of electricity generated by earth-based stations that is stored or transmitted very long distances,  $f$ , depends on  $\epsilon'$  and the fraction of total electricity demand met by solar. If the later is small (<20%), then  $f \approx 0$  and  $p \approx \epsilon$ . If solar supplies all U.S. demand, then a comparison of the time correlation between U.S. demand and sunshine in the southwest gives  $p \approx \epsilon/\epsilon'^{0.55}$ . If we assume  $\epsilon = \epsilon' = 0.4$  (an optimistic assumption for wireless transmission efficiency and a pessimistic one for earth-based storage or transmission), then  $0.4 < p < 0.65$ .

Space-based photovoltaic systems cannot cost less than the same systems based on earth systems, so  $C_L M < C'_{pv}(5p-1)$ . In order to be economically competitive with other sources of electricity generation, it is widely agreed that  $C'_{pv} \approx \$1000 kW_p^{-1}$ . Thus  $C_L M < \$1000$  to  $\$2300 kW_p^{-1}$ , where the lower limit is considerably more realistic than the upper limit.

The current state-of-the-art for solar arrays for spacecraft is  $M > 10 kg kW_p^{-1}$ . Although improvements are possible using flexible materials and/or concentrating lenses, it is unlikely that the total system mass, including platforms, power handling and transmission hardware, could be less than  $5 kg kW_p^{-1}$ . Launch costs therefore must be less than  $\$200$  to  $\$460 kg^{-1}$ . For comparison, the current cost to low-earth orbit is about  $\$10,000 kg^{-1}$ . Thus, even the most optimistic analysis requires that launch costs fall by a factor of 20 to 50 simply to allow SSP to break even with terrestrial solar power.

If space-based systems cost more than earth-based systems, as seems almost certain, the comparison becomes even less favorable for SSP. As indicated by equation (2), if space-based photovoltaic arrays cost two to three times more per peak kilowatt than earth-based systems, SSP would not be cost-effective even if launch costs were zero. Today, space-based arrays cost about 500 times more than earth-based arrays per peak kilowatt.<sup>6</sup>

If the costs of transmission and operation and maintenance are higher for space-based systems, the situation for SSP is worse still. If  $c_T$  and  $c_{OM}$  are the costs of transmission and operation and maintenance per kilowatt-hour of delivered electricity ( $\$/kWh^{-1}$ ) for SSP and

$c'_T$  and  $c'_{OM}$  are the corresponding costs for earth-based systems, equation (2) becomes

$$C_L M < 5pC'_{PV} - C_{PV} - \frac{S}{F}(c_T - fp c'_T) - \frac{S}{F}(c_{OM} - \rho c'_{OM}) \quad (4)$$

where  $F$  is the fixed charge rate ( $y^{-1}$ ). Assuming, as above,  $S = 12,000 \text{ kW}_s \text{ h m}^{-2} \text{ y}^{-1}$  and  $C_{PV} = \$1000 \text{ kW}_p^{-1}$ , and also that  $F = 0.12 \text{ y}^{-1}$  (corresponding to an interest rate of  $10\% \text{ y}^{-1}$  and an array lifetime of  $20 \text{ y}$ ) and  $c_T = c_{OM} = c = \$0.01 \text{ kWh}^{-1}$  (very optimistic assumptions for SSP)

$$C_L M < 1000 \left( 5p \frac{C'_{PV}}{C_{PV}} + fp \frac{c'_T}{c} + \rho \frac{c'_{OM}}{c} - 3 \right) \approx 1000\chi(6p + fp - 3) \quad (5)$$

where  $\chi$  is the cost ratio of earth-based systems to space-based systems (assumed to be equal for the array, transmission, and operation and maintenance costs).

In the most optimistic case for SSP, solar supplies all electricity demand and  $\epsilon \approx \epsilon' = 0.4$ , and  $\rho \approx 0.65$  and  $fp \approx 0.45$ . If  $\chi = 1$  (i.e., earth-based systems are no less expensive than space-based systems), then  $C_L < \$270 \text{ kg}^{-1}$  for  $M = 5 \text{ kg kW}^{-1}$ . If, however,  $\chi < 0.7$  (i.e., capital, transmission/storage, and O&M costs are more than 30 percent cheaper for earth-based systems), then  $C_L M < 0$  and SSP cannot compete regardless of launch costs. Moreover, if solar supplies less than 20 percent of total electricity demand, then  $\rho = 0.4$ ,  $fp \approx 0$ , and  $C_L M < 0$  for all cost ratios less than one.

In summary, SSP could compete with earth-based solar power only if *all* of the following conditions are met:

- solar supplies  $\sim 100\%$  of total electricity demand;
- the cost of space-based solar arrays is reduced to  $\$1000 \text{ kW}_p^{-1}$  and that earth-based arrays do not cost less than space-based arrays;
- SSP transmission costs no more than  $\$0.01 \text{ kWh}^{-1}$  and is no less efficient and no more expensive than storage or intercontinental transmission of electricity generated by earth-based systems;
- SSP operation and maintenance costs no more than  $\$0.01 \text{ kWh}^{-1}$  and is no more expensive than operations and maintenance of earth-based systems; *and*
- launch cost to low-earth orbit (currently about  $\$10,000 \text{ kg}^{-1}$ ) is reduced by a factor of 40, to less than  $\$250 \text{ kg}^{-1}$ .

Much of the discussion surrounding SSP has focused on the last of these conditions. A launch cost of  $\$250 \text{ kg}^{-1}$  corresponds to a cost of only  $\$3$  to  $\$5 \text{ kg}^{-1}$  for a disposable launcher—comparable to the cost of the propellants alone.<sup>7</sup> Propellant for a reusable vehicle is likely to cost more than  $\$50$  per kilogram placed into orbit;<sup>8</sup> achieving a total cost of  $\$250 \text{ kg}^{-1}$  would therefore require a total-to-fuel cost ratio of no more than 5:1. Given that the total-to-fuel cost ratio for the U.S. air freight industry is about 4:1, launch costs below  $\$250 \text{ kg}^{-1}$  are probably unachievable with chemical rocket technology.

The probability the SSP could produce electricity more cheaply than solar arrays on earth is so small that any expenditure of federal funds for research and development on this concept would be unwise and unwarranted.

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## (Footnotes)

- <sup>1</sup> Arthur Smith, “Energy for Society from Space,” Physics and Society, October 2003; Arthur Smith, “Letters:

Energy Possibilities: Windows, Windmills, and Satellites,” Physics Today, October 2002.

<sup>2</sup> Nearly all of Arizona, Nevada, New Mexico, and Utah, and significant portions of California, Colorado, and Texas, receive more than  $2400 \text{ kWh m}^{-2} \text{ y}^{-1}$  of solar radiation on a sun-tracking surface, as do vast areas of northern and southern Africa, west Asia, and Australia, and significant areas in Chile and Argentina. See NASA, “Surface Meteorology and Solar Energy,” <http://eosweb.larc.nasa.gov/sse>.

<sup>3</sup> H. Ishitani, T.B. Johansson, et al., “Energy Supply Mitigation Options,” in Robert T. Watson, Marufu C. Zinyowera, and Richard H. Moss, eds., *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change* (Cambridge: Cambridge University Press, 1996), p. 617.

<sup>4</sup> Many options exist for energy storage, including batteries, pumped hydro, compressed air, hydrogen production, and superconducting storage rings. Substantial room also exists for improvements in load management to better correlate electricity supply and demand, such as smart appliances and thermal storage in buildings. Intercontinental transmission is possible using existing technologies (e.g., between Africa and Europe) at efficiencies that are higher and costs that are likely to be lower than SSP transmission. SSP transmission technologies would, in any case, serve as a backstop for intercontinental transmission between earth-based stations via reflectors in orbit, ensuring that SSP transmission could not be cheaper than storage or transmission of electricity generated on earth.

<sup>5</sup> Photovoltaic costs typically are given in dollars per peak kilowatt, where “peak kilowatts” is the electrical power output when the incident solar flux is  $1 \text{ kW}_s \text{ m}^{-2}$ ; it is equal to cost per unit area ( $\$ \text{ m}^{-2}$ ) divided by efficiency ( $\text{kW}_e \text{ kW}_s^{-1}$ ). Thus,  $\$ \text{ kW}_p^{-1} = \$ \text{ kW}_s \text{ kW}_e^{-1} \text{ m}^{-2}$ .

<sup>6</sup> The solar arrays for the International Space Station cost about  $\$2.4 \text{ million kW}_p^{-1}$  ( $\$450 \text{ million}$  for about  $250 \text{ kW}$  or  $180 \text{ kW}_p$ ); the installed cost of large earth-based arrays is currently about  $\$5,000 \text{ kW}_p^{-1}$ .

<sup>7</sup> Placing an object in a polar orbit at  $1000 \text{ km}$  altitude requires a burn-out velocity of  $8.4 \text{ km s}^{-1}$ . Achieving this velocity requires  $50$  to  $90$  kilograms of disposable launcher per kilogram placed in orbit. The lower limit corresponds to a two-stage liquid propellant launcher ( $f = 0.93$ ,  $v_e = 3.1 \text{ km s}^{-1}$ ,  $\Delta v_{ag} = 1.7 \text{ km s}^{-1}$ ); the upper limit to a three-stage solid propellant launcher ( $f = 0.88$ ,  $v_e = 2.7 \text{ km s}^{-1}$ ,  $\Delta v_{ag} = 1.0 \text{ km s}^{-1}$ , where  $f$  is the fraction of launcher that is propellant,  $v_e$  is the exhaust velocity, and  $\Delta v_{ag}$  is the velocity lost to air resistance and gravity).

<sup>8</sup> The propellant-to-vehicle mass ratio for a single-stage-to-orbit vehicle  $m_p/m_v = \exp(\Delta v/v_e) - 1$ , where  $\Delta v$  is about  $10 \text{ km s}^{-1}$  for a  $1000\text{-km}$  altitude near-polar orbit (including losses due to gravity and air resistance) and  $v_e$  is the exhaust velocity. Assuming  $v_e = 3.8 \text{ km s}^{-1}$  for  $\text{O}_2/\text{H}_2$ ,  $m_p/m_v = 12.6$ ; assuming  $v_e = 2.9 \text{ km/s}$  for  $\text{O}_2/\text{RP-1}$ ,  $m_p/m_v = 29$ . If 20 percent of the vehicle mass is payload, the propellant-to-payload mass ratios are 63 and 145, respectively. Assuming an  $\text{O}_2/\text{H}_2$  mass ratio of 6 and  $\text{O}_2$  and  $\text{H}_2$  costs of  $\$0.25$  and  $\$4 \text{ kg}^{-1}$ , the propellant cost is  $\$50$  per kilogram of payload. Similarly, assuming an  $\text{O}_2/\text{RP-1}$  ratio of 2.5 and RP-1 cost of  $\$1 \text{ kg}^{-1}$ , the propellant cost is  $\$70 \text{ kg}^{-1}$ .

## Congressional Fellows Program Honored by Congress

In an October 28 speech on the House floor, Rep. Fortney “Pete” Stark (D-CA), called the Congressional Science and Engineering Fellowships “a shining example of a collaborative program that benefits all who participate.” The fellowships, he said, are “a remarkable partnership between Congress and the 30 or so participating professional societies that select and fund the Fellows.” Rep. Vern Ehlers (R-MI), who introduced the resolution, described the fellowships as “a truly valuable educational program that gives scientists a wonderful opportunity to step out of the lab and into the political process.”

The above remarks were made during debate on a congressional resolution honoring the 30th anniversary of the Congressional Fellowship program of the American Association for the Advancement of Science (AAAS) and pledging continued congressional support for the program. AIP and three of its Member Societies (APS, the American Geophysical Union, and the Optical Society of America) all sponsor Congressional Fellows under the auspices of the AAAS program. In fact, APS was one of the original societies to participate in the program. The resolution, which has now been referred to the Senate, finds that “Fellows bring to the Congress new insights and ideas, extensive knowledge, and perspectives from a variety of disciplines.”

The AIP and APS Fellowships enable qualified members of APS or any of the nine other AIP Member Societies to spend a year on Capitol Hill, working in the office of a Member of Congress or for a congressional committee. Fellows work with personal offices and congressional committees to select an assignment that interests them. They do not act as representatives of AIP or APS during their time on Capitol Hill; their only responsibility is to the congressional office in which they choose to serve.

Some Fellows accept permanent positions on Capitol Hill or in federal agencies after their Fellowships, while others return to academia or industry, to share their experience of the legislative process with others in the science community. The APS 1982-1983 Congressional Science Fellow, Rep. Rush Holt (D-NJ), was elected to the U.S. House of Representatives, where he is now serving in his third term.

During discussion of the resolution, several Members of Congress spoke in praise of the Fellowships. Selected portions of the discussion are provided below:

REP. VERNON EHLERS (R-MI): “This resolution...recognizes a truly valuable educational program that gives scientists a wonderful opportunity to step out of the lab and into the political process.... [T]hey get a behind-the-scenes look at how our laws are made, writing speeches, developing legislation, and serving as liaisons to committees on which a Member serves. At the same time Members of Congress and other policy makers gain a valuable new resource to help them better understand the scientific and technical issues underpinning complex policy debates.... After 30 years, this program is still going strong. Over 800 scientists have now served Republican, Democratic, and Independent Members of Congress

and many are currently working for Congress and the administration. These individuals have contributed not only their scientific expertise, but also a fresh perspective to policy making.”

REP. EDDIE BERNICE JOHNSON (D-TX): “The AAAS Congressional Science and Engineering Fellowship Program has provided congressional committees and Members’ offices with scientific and technical expertise that has greatly benefitted governmental decision-making for three decades.... I know that many of my colleagues have repeatedly sought AAAS fellows for their personal offices because of the quality of the contributions they have made.... The presence of congressional fellows enhances the public policy formulation process. In addition, the program provides fellows with a window on the policy formulation process and the workings of Congress that they take back to their home institutions. It also provides a mechanism that many fellows have used to transition to careers in public service.... [T]he American Association for the Advancement of Science is to be congratulated for creating this successful and valuable congressional fellows program.”

REP. RUSH HOLT (D-NJ): “For 30 years, the fellowship program has brought together Members of Congress with leading scientific practitioners and scholars in a variety of scientific fields. And this has provided a level of scientific expertise not otherwise found on most congressional staffs, and it presents the congressional fellows with an intimate role in the process of decision-making in public policy.... I was an AAAS Fellow 20 years ago...and I witnessed firsthand the important role that scientific expertise can bring to policy decisions. “Since I have been a Member of Congress for the past 5 years, I have welcomed AAAS Fellows into my staff and fully integrated them into my staff because of the wealth of knowledge they provide and their ability to pose questions.... I have benefitted from their aptitude, their ability and their energy; and I will, as long as I serve in this body, continue to recruit these motivated and high-qualified experts and do everything I can to make this program a success. It has, in many ways, benefitted America.”

REP. VERNON EHLERS (R-MI): “I thank the gentleman from New Jersey [Rep. Holt] for his comments and his co-sponsorship on this resolution.... He and I, as most people know, are the only two physicists in the Congress and I am told are the only two that have ever served in this Congress. That, I think, is an indictment of the scientific community because we should have more scientists in the Congress, but most scientists tend to shy away from this particular type of activity. But the Fellows that we are honoring here have filled the gap, as the gentleman from New Jersey has so clearly outlined. They provide some very badly needed scientific advice.... [T]he Fellows are extremely important in maintaining the scientific competence of the Congress, both House and Senate. Many of the Fellows have returned to their laboratories where they serve as a good liaison between the scientific communities and the Congress. Many others have chosen to stay here.... [Y]ou will find many former science Fellows in the halls of Congress, in the administration, playing a very vital role in keeping this Nation’s

governing bodies current in science. So this has been a very valuable enterprise.”

REP. EDWARD MARKEY (D-MA): “I have welcomed over twenty AAAS Fellows into my office since 1979 and have been consistently impressed by their contributions to policymaking and advising. They have made a significant positive impact on the quality of life for the people of Massachusetts, the United States, and the world by instilling a measure of science and humanity into the decisions we are asked to make in these chambers every day.”

REP. FORTNEY “PETE” STARK (D-CA): “This program is a remarkable partnership between Congress and the 30 or so participating professional societies that select and fund the Fellows. At no cost to Congress, these Fellows offer their substantial expertise and experience to various personal offices and committees in return for the opportunity to be immersed in the legislative process. I have been fortunate enough to work with many AAAS fellows over my Congressional career. Without exception, they have been valuable additions to my staff. I especially appreciate the real world perspective they bring to us.... In my office, a fellow is treated exactly as other members of my staff. They have issue areas of expertise and perform all of the duties necessary to move those issues forward.”

REP. SHERWOOD BOEHLERT (R-NY): “The AAAS [program has made] literally incalculable contributions to this institution and the nation. It has enabled scientists to have a better understanding of the governing process - both the fellows themselves and scientists with whom they interact - and it has improved the governing process by enabling Congressional offices to better understand scientific information and scientists. The fellows program has also been an entry point for many of the best staff we have on Capitol Hill.”

*Adapted from the AIP Bulletin of Science Policy News  
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## Final Funding Legislation on Administration’s Nuclear Weapons Initiatives

Final legislation has been developed in the House and Senate that responds to the Bush Administration’s nuclear weapons initiatives. The FY 2004 Energy and Water Development appropriations bill contains language and funding supportive of the Administration’s requests regarding the development of the Robust Nuclear Earth Penetrator, Advanced Concepts, and the readiness posture of the Nevada test site.

The House and Senate versions of the Energy and Water Development appropriations bill were very different in their treatment of the Administration’s requests. Republican Chairman David Hobson (Ohio) and his fellow House appropriators’ committee report criticized congressional policymaking procedures, stating, “...this Committee will not assume that all of the proposed nuclear weapons requests are legitimate requirements.” The House bill provided only one-third of the Administration’s funding request

for the Robust Nuclear Earth Penetrator, and no money for Advanced Concepts definition studies or funding to shorten test readiness posture at the Nevada site. The House approved this bill, setting it on an eventual collision with the Senate bill, crafted by Senator Pete Domenici (R-New Mexico). Press accounts reported that one of the major points of contention in this bill’s conference committee was the language on the Administration’s nuclear weapons initiatives.

The final conference report language has been completed. In regard to the Administration’s \$15.0 million request for the Robust Nuclear Earth Penetrator, House Report 108-357 states:

“The conferees provide \$7,500,000 for the Robust Nuclear Earth Penetrator study, instead of \$5,000,000 as proposed by the House and \$15,000,000 as proposed by the Senate. The conferees remind the Administration that none of the funds provided may be used for activities at the engineering development phases, phase 3 or 6.3, or beyond, in support of advanced nuclear weapons concepts, including the Robust Nuclear Earth Penetrator.”

Concerning the Administration’s request of \$6.0 million for Advanced Concepts Definition Studies, such as low-yield nuclear weapons, the report states:

“The conferees provide \$6,000,000 for Advanced Concepts, as proposed by the Senate, of which \$4,000,000 is available for obligation only after the official delivery of a revised Nuclear Weapons Stockpile plan to Congress and a 90-day review period by the House and Senate Committees on Appropriations and the Committees on Armed Services. The revised Nuclear Weapons Stockpile plan should detail the Department of Defense and Department of Energy’s program plan and detailed schedule to achieve the President’s proposed inventory adjustments to the Total Strategic Stockpile, including the Strategic Active Stockpile and Inactive Stockpile, by weapon systems and warhead type.”

Responding to the Administration’s request to reduce the current 24-36 month test readiness posture at the Nevada test site, the report states:

“Within funds provided for program readiness activities the conference agreement provides \$24,891,000 for test readiness in Nevada, the same as the [Bush Administration’s] budget request. The conferees recognize that test readiness activities in Nevada were allowed to atrophy during the last decade under the current nuclear test moratorium as documented by the DOE Inspector General and the NNSA’s [National Nuclear Security Administration] internal assessments. However, the conferees expect the NNSA to focus on restoring a rigorous test readiness program that is capable of meeting the current 24-month requirement before requesting significant additional funds to pursue a more aggressive goal of an 18-month readiness posture. The conferees expect the House and Senate Appropriations Committees be kept informed on the progress of restoring the current test readiness program. The conferees remind the Administration that Congressional authorization must be obtained before proceeding with specific activities that support the resumption of testing.”

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# REVIEWS

## Win-Win Ecology

*By Michael L. Rosenzweig; Oxford University Press, 2003; 211 pages, \$27.00; ISBN 0-19-515604-8*

*Win-Win Ecology* deals with the problem of reduced biological diversity of animal and plant species due to their being driven to extinction by loss of habitat caused by humans taking over all but a small fraction of the Earth's available space. The author provides an elaborate scientific treatment to explain and quantify how very serious (and perhaps even devastating) this problem is, and will become in the near future, but this is done only in Chapters 8, 9, and 11 of the 12 chapter book. The downbeat character of this treatment is more than counter-balanced by the upbeat message of hopefulness in the rest of the book.

The author concedes at the outset that when ecological benefits come into conflict with human economic concerns, the economic concerns normally win. His solution is to find and implement ways in which ecologically-responsible activities result in economic and lifestyle benefits rather than penalties. He calls this "reconciliation ecology" which he defines as the science of inventing, establishing, and maintaining new habitats to conserve species diversity in places where people live, work, and play. The first seven chapters of the book are full of successful examples of this reconciliation ecology.

One such example is a U.S. program now in operation for making back yards of homes attractive to wild life and wild flora, while improving their attractiveness to people and saving on maintenance costs and efforts (e.g. lawn mowing). Another example is roof gardens on Berlin houses that do not need watering, fertilizing, or mowing. There is an extensive description of successful ecological improvement programs at Eglin Air Force Base in Florida without compromising the wide variety of military activities there; these programs also promote recreational activities, including fishing and hunting.

There are several examples where the benefits involve making money. A large cattle ranch in Utah utilized wild life (deer, elk, and moose) management to convert parts of the land into a hunting area bringing in substantial license fees from hunters. A program for saving the almost extinct vicuna in Peru has resulted in a flourishing population of vicunas yielding substantial income for their very valuable fleece. A salt marsh was created near Eilat in Southern Israel which has become an important stop for birds migrating between Europe and Africa, resulting in a flourishing and profitable tourist attraction.

There is a chapter on hidden costs that are avoided by ecologically beneficial procedures, even though such procedures may increase direct costs. One example is where the direct economic benefits of using chemicals in agriculture are more than balanced by loss of top soil that this causes. Other hidden costs discussed include air and water pollution, and building roads to accommodate forest exploitation. Ecologically devastating improvements in efficiency of coffee growing in Latin America led to collapse of coffee prices, with the result that coffee growers suffered large economic net losses. Social costs are also worthy of consideration; for example, large agro-businesses may be more

efficient than a system of family farms, but the author considers the loss of family farms to carry a social cost that far over-balances the benefits of the improved efficiency.

One chapter deals with small things people can do to accommodate wildlife living with them, and benefit from its presence. For example, the Eastern Bluebird in the U.S. is being saved by constructing nest boxes that they can use without interference from their starling and sparrow enemies. Analogous situations are described for saving leopard frogs, butcherbirds, and natterjack toads.

Another chapter deals with "happy accidents" where technological developments led to ecological benefits. Crocodiles in the U.S. were saved from extinction by warm water discharges from a Florida nuclear power plant. Draining lands to allow farming in the Czech Republic led to ponds which spawned a profitable fishing industry, with a side effect of saving a population of otters. An architectural design movement in Israel and a bridge design in Texas saved local populations of bats by providing habitats for them.

There is a chapter on "reservation ecology" - setting aside wild areas such as national parks to leave undisturbed or for limited use, and "restoration ecology" - restoring areas to their original wild condition. But these are characterized as "fighting for crumbs", not important enough to be truly effective.

As very much a non-expert, this book left me confused. If the situation is as grim as the author portrays it in Chapters 8, 9, and 11, I cannot understand how the counter-measures discussed in the remaining chapters can come close to resolving the problem. These remaining chapters describe the saving of a few local populations of selected species whereas the problem involves the extinction of millions of species - the prediction is that 95% of all species will soon become extinct. How, then, can the author exude so much upbeat optimism? The only avenues for optimism that I can see are that his estimates of extinction rates are perhaps greatly exaggerated, or that mankind can thrive with only 5% of the species our world now contains. But the author seems certain that neither of these provides an escape from the problem. He seems to believe that the measures described in the first seven chapters will be expanded to save the situation. It seems to me that this would require at least a million-fold expansion of these measures during the current century, which I would judge to be completely incredible.

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## Report of the American Physical Society Study Group on Boost-phase Intercept Systems for National Missile Defense: Scientific and Technical Issues

*By a Study Group: David K. Barton, Roger W. Falcone, Daniel Kleppner (Co-chair), Frederick K. Lamb (Co-chair), Ming K.*

Lau, Harvey L. Lynch, David E. Moncton, L. David Montague, David E. Mosher (Staff director), William C. Priedhorsky, Maury Tigner, and David R. Vaughan

Report available online at [http://www.aps.org/public\\_affairs/popa/reports/nmd03.html](http://www.aps.org/public_affairs/popa/reports/nmd03.html) Will be published later as a supplement to an issue of *Reviews of Modern Physics*.

Much delayed, the report of this American Physical Society (APS) study group was finally made available to the public on July 15th. Matching up with the long title is a bulk of over 400 pages—though for those with shorter attention spans, there are two levels of executive summaries available as well. Indeed, the news coverage of the report has not gone beyond the abstract. To wit, intercepting intercontinental ballistic missiles (ICBMs) shortly after launch (boost-phase) is technically difficult, requires interceptors of similar size to the ICBMs, is susceptible to simple countermeasures, and is likely to be obsolete by the time it is deployed as faster (solid-fueled) ICBMs become available. The three-year study is far more than its executive summary, however. It contains elegant condensations of the physics of rockets, radars, atmospheric beam propagation, and guidance command loops, just to mention a few of the topics considered. It is a thorough manual to the science and engineering of a boost-phase missile defense.

For the most part though, readers are concerned with the central conclusions of the report—that boost-phase intercepts of ICBMs from the chosen “rouge nations” of Iraq, Iran, and North Korea are highly problematic if not completely absurd. Other than sticking with the politically charged “Axis of Evil,” policy statements are studiously avoided. Most people reading the report can easily draw their own conclusions in that direction. Challenges to the report also are likely to be of a political nature, rather than of a technical nature. Since the study was initiated, the national missile defense plan (and budget) has become increasingly entrenched by the Bush administration, the Republican-controlled Congress, and a Pentagon confident in its expanding missile defense monies.

Returning to the technical issues that are at the heart of the study, the panel concluded that:

-Defense of the entire United States might be feasible against liquid-fueled ICBMs (such as the expected first generation North Korean ICBMs), but not likely to be practical against faster, solid-fueled follow-on missiles.

-Space-based interceptors might be technically possible, but would need to be very large and very numerous. Such an expensive system would also require space-launches far in excess of current and projected launch rates.

-Airborne lasers might have some utility against the vulnerable liquid-fueled rockets, but are unlikely to be effective against solid-fueled rockets.

-Even successful intercepts of inbound missiles present serious problems with the ballistic flight of the missile payload. That payload will fall short of its target, but that may well be onto (friendly) populated areas.

-The fundamental difficulty (beautifully illustrated in the study report with maps of missile defense launch areas) amounts to the short window of time to detect, commit to a launch against, and accelerate to reach an enemy rocket.

-The technical problems of any of these systems are large, so any boost-phase intercept system would take significant time to deploy. The study indicates perhaps 10 years before an effective system could be built.

-Within that time, the named opponent countries are expected to have solid-fueled ICBM technology, rendering the defense obsolete.

-The US Naval Aegis anti-air and anti-missile system (most famous for “successfully” shooting down an Iranian civilian airliner) has some capability against sea-launched missiles aimed at the United States, provided the Aegis destroyer or cruiser is within a few tens of kilometers of the ballistic missile launching ship or submarine.

Anyone with interest in the technical aspects of any of these issues is well advised to download the PDF file from the web and start reading. (Printing the tome takes most of a ream of paper and a three-ring binder.) It is difficult to imagine anyone but the savviest military insider not learning something useful or interesting from this work. The authors of the study have come from a wide range of backgrounds to produce this document, which draws on declassified military data and analyses but explains systems in the terms and style of physics publications. A serious reader could spend quite a few years with the references...

By limiting the scope of the boost-phase defense (for example, to only protect Hawaii against a North Korean rocket), it gets somewhat easier. Supporters of the missile defense programs are likely to latch onto these sorts of limited goals as “first steps.” It will be interesting to observe how this study report is used in the debate over missile defense. Do the serious technical problems carry weight with the President, the legislators, and the military-industrial complex? Do the mildly favorable comments about protecting limited areas, or the limited capabilities of an airborne laser and the Aegis system give supporters of national missile defense an “in?” How much does missile defense even have to do with the technical objectives? Does this report spell the end of boost-phase intercept enthusiasm? We know the answer to the last question only, and that answer is “no.” That may give us a hint as to how the other questions will be addressed over the next few years.

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## Freedom Evolves

By Daniel C. Dennett, Viking, New York, New York, (2003), 247 pp, \$24.95, ISBN 0-670-03186-0

Daniel Dennett sets out to prove that free will is real and has evolved over eons according to the laws of nature. Much of the book is devoted to defining free will—or rather, why the usual notion of free will is uninteresting—and its relationship to determinism. ‘From Dennett’s perspective, the traditional definition of free will as the ability possessed by a creature to willfully change the trajectory of its life—even in a deterministic universe—is a metaphysical definition which is no longer useful. He argues convincingly that the insertion of indeterminacy (quantum or otherwise) does not lead to free will as defined above.

To show this, Dennett goes over the arguments of Robert Kane (*The Significance of Free Will and Responsibility, Luck, and Chance: Reflections on Free Will and Indeterminism*) who argues that free will depends on the existence of self-forming acts (SFAs) that contain the essence of free will and ultimately stem from a fundamental indeterminacy as found in quantum mechanics. In

particular, for a genuine SFA to occur, there must exist alternative possibilities (AP's) at the moment that the SFA takes place, namely, the agent should have other real options that he chooses not to exercise. To achieve the SFA, there must also arise a random, indeterminate event in the agent's brain somewhere between the moment of input of all elements that contributed to the SFA, and the moment of output when the decision prompted by the SFA becomes evident through the agent's actions. Dennett points out that you can always make that time interval so small that no SFA can be found. Ultimately, the mechanisms producing SFAs and their identification become impossible to determine. Dennett doesn't prove that SFAs do not exist; rather he argues that their existence is irrelevant.

Dennett's ultimate goal is to show that notions of self and morality can emerge from evolution. Once a sense of self has evolved, an agent can be assigned responsibility for its actions performed out of its own free will. Dennett's discussion on the evolution of morality is largely based on game theory such as the prisoner's dilemma where two suspects under interrogation in separate rooms are each told that their partner has confessed. If the two suspects resist the temptation to squeal—i.e., if they are both “cooperators”—they will both get short jail sentences. If one of the prisoners implicates the other in a confession—making him a “defector”—while the other does not (the cooperator), the defector will go free while the cooperator will receive a long sentence. If they are both defectors and implicate each other, they will both get long sentences. Dennett argues that groups of

cooperators will tend to flock together and on average will have better chances of survival than groups of defectors or mixtures of defectors and cooperators. Morality will spring up from these groups of cooperators whose social interactions eventually lead to a sense of self and responsibility.

The point at issue in *Freedom Evolves* is never whether free will can exist in a deterministic world. Instead, Dennett explores how a sense of responsibility for one's action can evolve naturally. Indeed, in the last chapters of the book, Dennett attempts to show that a more naturalistic definition of free will is a sounder foundation on which to build a judiciary. However, he doesn't succeed in showing that this approach would result in a remarkable improvement in the dispensation of justice.

With regards to the writing style of the book, Dennett relies far too much on Socratic dialogue to make his points; asking four or five consecutive questions (a typical occurrence) made the book more difficult to read than if Dennett had simply laid out his arguments. On a related note, he spends too much time answering questions that he assumes the reader has, and in reading certain sections of the book, one gets the feeling of witnessing an argument between Dennett and invisible haranguers. In fact, many parts of the book are unnecessarily wordy and could have been presented in a simpler manner. This said, I do think this book a worthwhile read to anyone interested in questions of free will as seen in the light of modern science.

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