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## EDITOR'S COMMENTS

Recently our issues have been dominated by the pressing contemporary "physics and society" issues concerning the nuclear aspects of energy, environment, and national security, as well as some discussion on the relationships between science and religion. These issues still predominate, as is evident in this issue, and will continue to do so. But we should not be ignoring "physics and philosophy" issues, especially when these also have significant impact upon our society. One such fundamental issue, fascinating to many of us, is the meaning of quantum mechanics. Fred Kuttner and Bruce Rosenblum illustrated public misperceptions based upon that topic in the commentary in our April issue. We have one possible follow-through in the article by Travis Norsen in this issue. We look forward to publishing further discussion on the subject.

*—A.M.S.*

IN THIS ISSUE

IN THE APRIL WEB ISSUE

# ARTICLES

## Intelligent Design in the Physics Classroom?

*Travis Norsen*

A dangerous enemy has infiltrated our science classrooms and is infecting our students' minds. The enemy is a profoundly unscientific theory masquerading as legitimate science. Its presence in the science classroom blurs the distinction between real science and arbitrary dogma and "makes students stupid" by leaving them less able to distinguish reasonable ideas from unreasonable ones — a skill that is surely one of the main goals of teaching science in the first place.

You probably suspect the enemy I'm talking about is Intelligent Design (ID). Yes, ID has infiltrated some science classrooms. Yes, ID is specifically designed to blur the distinction between real science and religious dogma. And yes, the phrase "makes students stupid" is straight out of Pennsylvania Judge John Jones' recent finding that "ID is not science" and shouldn't be taught in the biology classroom.[1] But, in part because of Jones' excellent analysis, I don't think ID is a terribly significant danger. It is too transparently unscientific, too widely recognized for what it really is: a thinly-veiled attempt to inject religious creationism into the science classroom.

The enemy I'm worried about is something else — something just as unscientific as ID, but more dangerous because it is not widely recognized as such: the Copenhagen interpretation of quantum mechanics.

The Copenhagen interpretation, so named because of the Danish roots of its main author Niels Bohr, grew out of the paradoxical nature of sub-atomic particles revealed by experiments in the 1920s: electrons sometimes acted like particles but sometimes like waves. This is a paradox because particles are, by definition, localized entities that follow definite trajectories while waves are not confined to any particular path or region of space. How could the same thing be both confined and not confined, both a particle and a wave? Paradox indeed!

Luckily, the two conflicting aspects never appear simultaneously. The experimental situations in which the particle and wave properties manifest themselves are, in a sense, mutually exclusive. The famous Heisenberg Uncertainty Principle codifies this separation: any experiment which reveals the precise particle character of an electron will necessarily obscure the wave character completely, and vice versa.

If one wants to achieve a coherent physical understanding of the nature of the electron, however, this is not very satisfying. Bohr's approach was not so much to resolve the paradox as to embrace it. Naming his philosophy "complementarity," he posited that the electron's wave and particle natures were mutually incompatible — yet still jointly exhaustive — perspectives. A complete theoretical description of the electron would have to include both wave and particle aspects; yet, like the experimental situations in which they are revealed, the very concepts of "wave" and "particle" could not be applied simultaneously. According to the Copenhagen view, physicists can never really understand the surprising experimental results or the real nature of the electron. We must simply embrace the paradox and quit looking for a coherent physical picture.

This is clearly all rather weird and philosophical, at least compared to what scientists normally consider scientific. One might think, therefore, that Bohr's ideas could have had little or no impact on the actual scientific theory of quantum mechanics. This, however, is definitely not the case. Bohr's ideas were tremendously influential in the development of the theory, and continue to be taught — in all the textbooks and in the overwhelming majority of classrooms — as an essential, ineliminable part of the formal textbook theory.

Indeed, Bohr's paradox-embracing philosophy has an exact counterpart in the theory's mathematics. It describes electrons as waves that obey Schrödinger's wave equation. So far so good. But this part of the dynamics only applies when nobody is looking. When somebody looks (i.e., when a "measurement" of the electron is made) it suddenly (one is tempted to say, magically) becomes a particle — a process governed, not by Schrödinger's equation, but by a different, incompatible bit of mathematics. According to the Copenhagen theory, the fundamental laws of nature governing electrons are thus deeply dependent on the human-centered concept of "measurement."

Bohr's colleague Pascual Jordan expressed the implications of the Copenhagen theory this way: "We compel [the electron] to assume a definite position; previously it was, in general, neither here nor there; it had not yet made its decision for a definite position. …we ourselves produce the results of measurement."[2]

Heisenberg explains that "we can no longer speak of the behavior of the particle independently of the process of observation. As a final consequence, the natural laws formulated mathematically in quantum theory no longer deal with the elementary particles themselves but with our knowledge of them. Nor is it any longer possible to ask whether or not these particles exist in space and time objectively." He concludes that "science no longer confronts nature as an objective observer, but sees itself as an actor in this interplay between man and nature."[3]

Bohr advocates complete surrender: "There is no quantum world... It is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we can say about Nature."[4]

I think that on some level, most physicists recognize the irrational and unscientific character of these sorts of statements – but also that they are reasonable extrapolations from the Copenhagen theory. This is probably why physicists have developed a kind of pragmatic, anti-philosophical attitude, and why they deliberately suppress discussion of the more philosophical aspects of the Copenhagen quantum theory. This attitude is best expressed in the popular slogan "Shut up and calculate," often wielded against students wishing to steer discussion toward these interesting (if disturbing) implications.

But if the textbook theory really has these crazy implications, isn't it rather pathetic to just ignore and suppress them while maintaining allegiance to the fundamental ideas at their root? Unscientific views should be openly identified, challenged, and rejected – even if they have, somehow, become scientific orthodoxy. Why haven't physicists been willing to critically analyze (and then reject) the Copenhagen philosophy?

Part of the reason is that they apparently think there is no better alternative. As Murray Gell-Mann once said, "Niels Bohr brainwashed a whole generation of physicists into believing that the problem [of interpreting quantum theory] was solved fifty years ago."[5] The orthodox dogma is that the Copenhagen approach is the only way to deal with the paradoxes. Physicists were allegedly forced — by incontrovertible experimental data — to accept Bohr's interpretation. This is the premise behind physicists' pathetic and evasive strategies for dealing with the Copenhagen theory and its implications.

But, in fact, this premise is a complete fabrication. The Copenhagen philosophy is not the only possible conceptual framework for quantum theory. There exists a completely normal, scientific, common-sensical alternative – a theory that agrees with all of the experiments but avoids completely the unscientific philosophical baggage and subjectivist implications of the Copenhagen approach. This alternative theory gives no special dynamical role to "measurement," in no way implies that the world doesn't exist until somebody looks at it, and completely undermines the case for mind-over-matter anti-realism, channeling, the magical healing power of crystals, and all the other nonsense (as expressed, for example, in the bizarre recent movie What the Bleep do We Know?) that draws its lifeblood from the Copenhagen philosophy. In short, it has none of the subjectivist-epistemological "human implications" which Kuttner and Rosenblum urged us, in the previous issue of this journal, to explore with our students.[6]

This alternative theory was first proposed in the 1920s by Louis de Broglie, who (tragically) abandoned his ideas in the face of tremendous peer pressure from the likes of Bohr and Heisenberg. De Broglie's theory was then independently rediscovered in 1952 by David Bohm, and clarified and elaborated in the 60's and 70's by John Bell.

How does this alternative theory resolve the basic wave-particle paradox which spawned such bizarre contortions in the Copenhagen approach? The solution is almost embarrassingly simple. Bell explains: "While the founding fathers agonized over the question 'particle' or 'wave,' de Broglie in 1925 proposed the obvious answer 'particle' and 'wave.'"[7]

And that's that. The paradox is resolved: there are two entities, a wave and a particle. The motion of the particle is affected by the wave according to a simple dynamical equation, and the resulting particle trajectories are completely consistent with what is observed in experiments. It is hard not to agree with Bell's judgment that "this idea seems to me so natural and simple, to resolve the wave-particle dilemma in such a clear and ordinary way, that it is a great mystery to me that it was so generally ignored."[8]

And it continues to be ignored. The theory is rarely mentioned in textbooks — or, when mentioned, usually dismissed as flawed, impossible, or inconsistent, all as part of a bogus proof that the Copenhagen view must be accepted. But the theory exists. It is possible; it is consistent; it is real. And there is no defensible reason that it should not be more widely known — i.e., more widely included in the quantum physics curriculum.

This may seem like a rather technical issue that physicists should straighten out for themselves, an issue that those outside of physics shouldn't or needn't worry about. But the wider academic community — and, indeed, society at large — has a legitimate interest and stake in this issue, just as it has a legitimate interest and stake in the debate over Intelligent Design. Like ID, Copenhagen quantum mechanics "makes students stupid." Like ID, it probably has no place in college science classrooms. If it is nevertheless to be given such a place, shouldn't the obviously more rational alternative theory of de Broglie and Bohm also be taught — "not as the only way, but as an antidote to the prevailing complacency? To show that vagueness, subjectivity, and indeterminism are not forced on us by experimental facts, but by deliberate theoretical choice?"[9]

This is a question physicists should have asked long ago. Given their stubborn refusal to do so, perhaps it is time for their colleagues and administrators — and any willing Pennsylvania judges – to provide the necessary wake-up call. Because, if you ask me, our physics students deserve a more intelligently designed curriculum.

### *Further Reading*

"Bohm's Alternative to Quantum Mechanics" by David Albert: Scientific American, May 1994

"Bohmian Mechanics" by Sheldon Goldstein: http://plato.stanford.edu/entries/qm-bohm (and many references therein)

Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony by James Cushing: University of Chicago Press, 1994

"A Suggested Interpretation of the Quantum Theory in terms of 'Hidden' Variables" by David Bohm, Physical Review 85, 166 (1952)

Speakable and Unspeakable in Quantum Mechanics by J. S. Bell: Second Edition, Cambridge University Press, 2004

### *Footnotes*

[1] *Jones' 140-page finding in the Tammy Kitzmiller et al. vs. Dover Area School District et al. case is available online at http://www.pamd.uscourts.gov/kitzmiller/kitzmiller_342.pdf*

[2] *quoted in J.S. Bell, "Bertlmann's socks and the nature of reality" in Speakable and Unspeakable in Quantum Mechanics, second edition, Cambridge University Press, 2004*

[3] *W. Heisenberg, The Physicist's Conception of Nature, Arnold Pomerans, trans., Harcourt Brace, 1958*

[4] *see N.D. Mermin, "What's Wrong with this Quantum World?" Physics Today, February 2004*

[5] *Murray Gell-Mann, The Nature of the Physical Universe: the 1976 Nobel Conference, Wiley, 1979*

[6] *F. Kuttner and B. Rosenblum, "Social Responsibility and the Teaching of Quantum Mechanics," Forum on Physics and Society of the American Physical Society, Vol. 35 No.2, April 2006*

[7] *J.S. Bell, "Six possible worlds of quantum mechanics" in Speakable and Unspeakable, op cit.*

[8] *Ibid.*

[9] *J.S. Bell, "On the impossible pilot wave", in Speakable and Unspeakable, op cit.*

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# Drilling for Oil in the Arctic National Wildlife Refuge

*Richard J. Wiener*

### *Introduction*

To drill or not to drill? That is a question I will not attempt to answer. The answer requires weighing the benefits of 10 billion barrels of oil against the costs of damaging an ecologically significant pristine wilderness. This quandary is part of the much greater problem of supplying energy for an increasing world population while simultaneously limiting environmental degradation to an acceptable level. Ultimately, physical scientists are no better (or worse) prepared to make the value judgments needed to solve this problem than philosophers, artists, economists, theologians, or politicians. But scientists often do have a critical contribution to make by analyzing the factual claims that are made in debates over energy versus the environment.

Thus, I will address one misleading argument that is frequently made by proponents of drilling in ANWR. Proponents often claim that drilling in this great northern wildlife refuge will reduce U.S. dependence on foreign oil. This claim is true in the narrow sense that any additional U.S. oil used to meet a given U.S. demand means that less foreign oil is used to meet that demand. However, even if all the oil from ANWR is consumed domestically, it would only slow the rate of increase of U.S. dependence on foreign oil. Extraction of oil from ANWR cannot reverse the overall downward trend in U.S. oil production, and U.S. dependence on foreign oil will continue to grow unless U.S. demand for oil is substantially reduced. I arrived at this conclusion by making a "back of the envelope" estimate of the effect that drilling in ANWR would have on future U.S. oil production. The remainder of this essay explains how the estimate was made and what it implies.

*Hubbert Peak modeling*

Hubbert pioneered the idea of using logistic growth to model oil production.[1] The logistic growth curve satisfies the logistic differential equation $P = r(1 - Q/Q_{tot})Q$, where $Q$ is the quantity which is growing, $P$ is the derivative of $Q$, $r$ is the initial rate of growth, and $Q_{tot}$ is the value to which $Q$ is asymptotically growing. Logistic growth is a first approximation to any growth process in which the per capita growth rate, $P/Q$, decreases as $Q$ increases. The logistic differential equation specifies that the per capita growth rate decreases linearly as $Q$ increases. In the case of oil production, $P$ represents the production (e.g. in barrels per year), $Q$ represents the cumulative oil produced, and $Q_{tot}$ represents the total recoverable oil that ultimately will be produced from a reservoir or, more broadly, from an oil producing region. $Q = Q_{tot}/(1 + \exp(r(t_m - t)))$ is the logistic growth curve, where $t_m$ is the midpoint time at which $Q$ has grown to half its asymptotic value (which is determined by the conditions of the problem). $P = rQ_{tot}\exp(r(t_m - t))/(1 + \exp(r(t_m - t)))^2$ is the logistic production curve. The logistic growth curve has an S-shape with the midpoint time $t_m$ corresponding to the inflection point of the S, and the logistic production curve is bell-shaped with the midpoint time $t_m$ corresponding to the peak. In 1956 Hubbert fit data for U.S. oil production using a logistic production curve and correctly predicted that U.S. production would peak in 1970. The phenomenon of a peak in oil production in an oil producing region has since come to be known as *Hubbert's Peak.*

There are several ways to justify the use of logistic growth to model oil production. On heuristic grounds, one expects that oil production in an oil producing region will initially grow exponentially, since more wells will be drilled as more oil is produced and the most easily recoverable oil is often produced first. However, since there is a finite quantity of recoverable oil in any region, the production per cumulative production, $P/Q$, will ultimately decline as the cumulative production, Q, grows and the fraction of remaining recoverable oil, $1 - Q/Q_{tot}$, declines. If the relationship between $P/Q$ and Q is approximately linear, then the production is well modeled by the logistic production curve. Alternatively, one might consider a physical model for the pressure-driven extraction of oil from a finite reservoir and show that logistic growth arises for plausible conditions under which oil is produced.[2] Laherrère has argued that for many countries, and the world as a whole, oil production is better modeled using multiple logistic production curves.[3] One must separate production into several cycles with each cycle modeled with its own production curve. Then the overall production is modeled with a sum of the individual curves. The approach can be justified if one considers that many countries have oil regions that are developed at different times.

*Estimating future U.S. oil production*

The U.S. Energy Information Administration publishes data for U.S. oil production from 1859 through 2005. The data is available at http://tonto.eia.doe.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm. Figure 1 is a plot of this data. The solid line is a fit to this data extended to 2050 as an estimate of future U.S. oil production. In order to construct the fit to the data, I divided U.S. oil production into two cycles—production from the North Slope of Alaska and production from the rest of the U.S. The data for North Slope Alaska oil production which is available on the EIA web site only goes from 1981 to 2004, although there was some production prior to 1981. However, since almost all production of North Slope Alaska oil is after 1981, the lack of data for production before 1981 does not have much effect on the estimate of future U.S. oil production. I fit individual logistic production curves to each of the cycles. The three parameters in a logistic production curve are the initial growth rate r, the total recoverable oil $Q_{tot}$, and the midpoint year of peak production $t_m$. Figure 2 is a plot of the production per cumulative production, $P/Q$ versus cumulative production, $Q$, for U.S. oil production without North Slope Alaska oil production. I only show data from 1951 to 2005, the range over which the plot is approximately linear. The deviation from linearity prior to 1951 indicates that the growth is only approximately logistic. Figure 3 is an analogous plot for North Slope Alaska oil production. The three parameters for the logistic production curve can be estimated from a straight line fit to the data for $P/Q$ versus $Q$ for each cycle. The y-intercept for each linear fit is approximately the initial growth rate $r$, and the x-intercept is approximately the total recoverable oil $Q_{tot}$. The year that production peaked is determined by finding the year in which $Q$ surpassed $Q_{tot}/2$. For the U.S. (without the Alaska North Slope) the estimates are: total recoverable oil, 201 billion barrels; initial growth rate, 0.063; and year peaked, 1972. For the Alaska North Slope the estimates are: total recoverable oil, 14 billion barrels; initial growth rate, 0.18; and year peaked, 1991. The actual peak years are 1970 and 1988 for U.S. and North Slope Alaska oil production, respectively. Laherrère has noted that North Slope Alaska oil production is less well fit by a logistic production curve than production in many other regions, perhaps because a large amount of production came online at once with the opening of the Trans-Alaska Pipeline System.[3] I found that a logistic production curve with the above parameters underestimates the data for North Slope Alaska oil production prior to peak production but fits post peak production reasonably well.

The solid line fit to total U.S. production in Fig. 1 is a sum of the two individual production curves and it fits well for purposes of estimation. The secondary peak in the early 1980s appears to be due to North Slope Alaska oil production and this effect is captured by summing the two logistic production curves, whereas a secondary peak cannot be modeled by a single logistic production curve. The fit underestimates the data after 2000, which might indicate a fluctuation or this might be due to new oil regions being developed such as offshore drilling. Regardless, the overall trend is apparent—U.S. oil production has been declining for 35 years since 1970, with only a small temporary reversal when the Alaska pipeline was opened.

### *The effect of drilling for oil in ANWR*

To estimate the effect of drilling in ANWR on future U.S. oil production I added a hypothetical logistic production curve to represent what will be a new production cycle. I used the United States Geological Survey's mean estimate of 10 billion barrels for ultimately recoverable oil $Q_{tot}$ in ANWR.[4] My order of magnitude estimates for the midpoint year $t_m$ and initial growth rate r are 2030 (with recovery beginning in 2010) and 0.12, which is halfway between the rate for the U.S. and the rate for the Alaska North Slope. The estimate of the year recovery begins assumes a few years will be needed for the infrastructure of oil production to be built even if the U.S. Congress gives the go ahead in 2006. The result is a hypothetical production curve for ANWR in which over 8.3 billion barrels of oil will be extracted by 2050. The peak production is 300 million barrels per year which is roughly equal to the USGS mean peak production estimate of 325 million barrels per year. The dashed line after 2010 in Fig. 1 is the sum of all three logistic production curves, i.e. one for U.S. production without the Alaska North Slope, one for Alaska North Slope production, and one for the hypothetical ANWR production. There is a noticeable effect from adding the hypothetical oil production from ANWR, as would be expected from 8.3 billion barrels of oil. But the key point is that recovering this oil from ANWR cannot stop the overall downward trend in U.S. oil production. Therefore, recovering this oil is highly unlikely to stop U.S. dependence on foreign oil from growing. At best it will slow the rate of increase of this growing dependence.

Indeed, we cannot reasonably expect to end our dependence on foreign oil by increased access to a new supply of U.S. oil. There just isn't enough oil left in the U.S. The discovery of new oil in the U.S., despite large fluctuations in the data, clearly peaked decades before oil production peaked in 1970. As the 21st century unfolds we will become more and more dependent on foreign oil unless we almost completely eliminate U.S. demand for oil.

### *Acknowledgment*

I would like to thank Danny Abrams for helpful suggestions on the manuscript and useful discussions on the topic of oil production and logistic growth.

### *Endnotes*

[1] *Marion K. Hubbert, "Nuclear Energy and the Fossil Fuels", American Petroleum Institute Drilling and Production Practice, Proceedings of Spring Meeting, San Antonio (1956), pp. 7-25.*

[2] *Richard J. Wiener and Daniel M. Abrams, "A Physical Basis for Hubbert's Decline from the Mid-Point Empirical Model of Oil Production", in preparation.*

[3] *Jean H. Laherrère, "The Hubbert Curve: Its Strengths And Weaknesses", Oil & Gas Journal (April 17, 2000), p. 63.*

[4] *"Analysis of Oil and Gas Production in the Arctic National Wildlife Refuge", Service Report prepared by the Energy Information Administration (March 2004).*

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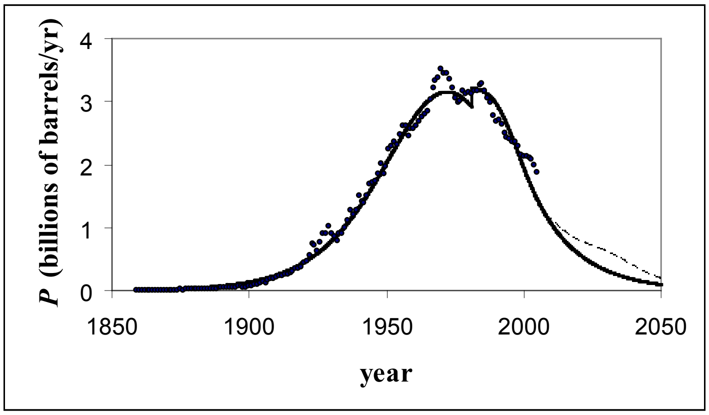

*Figure 1. U.S. production of oil in billions of barrels per year from 1859 to 2005. The solid line is a fit to the data projected to 2050. The dashed line after 2010 is an estimate of total U.S. oil production if oil is extracted from ANWR.*

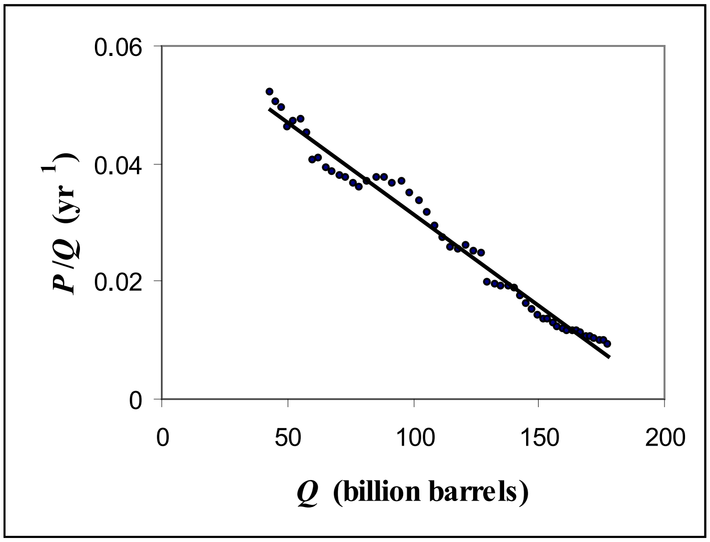

*Figure 2. Production per cumulative production, $P/Q$, plotted against cumulative production, Q, for U.S. oil production other than North Slope Alaska oil production. The straight line is a fit to the data. The y-intercept estimates the initial growth rate r and the x-intercept estimates the total recoverable oil $Q_{tot}$.*

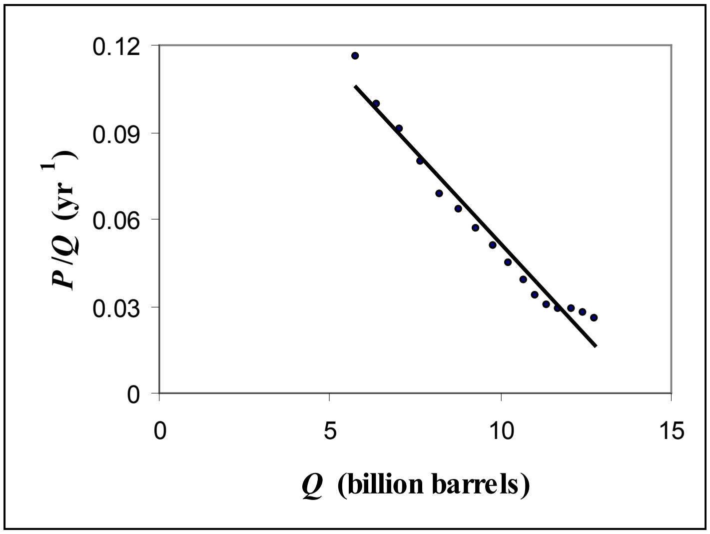

*Figure 3. Production per cumulative production, $P/Q$, plotted against cumulative production, Q, for North Slope Alaska oil production. The straight line is a fit to the data. The y-intercept estimates the initial growth rate r and the x-intercept estimates the total recoverable oil $Q_{tot}$.*

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# Should the U.S. Reprocess Spent Nuclear Fuel?

*Robert Vandenbosch and Susanne E. Vandenbosch*

The U.S. administration as part of its Fiscal Year 2007 budget submission has put forward a proposal to abandon the plan to dispose of untreated spent fuel directly in a geological repository and initiate a closed fuel cycle involving reprocessing and burnup in fast reactors. This proposal is part of an initiative called the Global Nuclear Energy Partnership, GNEP[1]. In this article we will discuss the considerations involved in deciding between direct burial and reprocessing, and the timeliness of this particular proposal.

We first outline the proposal as put forward by the Department of Energy. We will concentrate on the part of this proposal dealing with the fuel cycle for U.S. nuclear reactors. The initiative also has other components, including making fuel available to other countries and returning spent fuel from these countries.

The proposed fuel cycle starts with the reprocessing of spent fuel using an aqueous approach being developed at the Argonne National Laboratory called UREX+ (for uranium extraction). Although there are a number of variants of UREX+ [2, 3] , the particular one being considered would lead to three product streams; a uranium stream comprised of much of the mass of spent fuel, a transuranic stream comprised of plutonium and other transuranic elements, and a fission product stream.[4] The uranium would be stored for eventual enrichment or as fuel for future fast reactors. The transuranic stream would be “burned” in a fast reactor. A fast reactor (with neutrons having an energy of the order of an MeV rather than of the order of eV as in conventional thermal power reactors) is required to fission Np-237 and several other transuranic elements as they have fission thresholds that exceed the energy obtained from capturing thermal neutrons. The spent fuel from the fast reactors that are used to burn up much of the transuranic elements would be reprocessed using pyrochemical techniques. (An aqueous scheme such as UREX is less suitable for the chemical form of fast reactor fuel elements.) The fission products would be disposed of in a geological repository. The UREX + reprocessing scheme differs from the PUREX reprocessing scheme in that Pu is never isolated in the UREX + scheme as it is in the PUREX scheme. PUREX was originally developed for production of Pu for weapons, and is presently used by countries such as France and Britain in their reprocessing of spent fuel from civilian power reactors.

It is not clear from the presently available information on the GNEP initiative what the plans are with respect to the present inventory of spent fuel and Yucca Mountain. The Department of Energy says it remains committed to Yucca Mountain, and that it will be needed whether or not the U.S. decides to adopt a closed fuel cycle with reprocessing. At a briefing on GNEP Deputy Secretary of Energy Clay Sell said "Getting Yucca Mountain licensed, getting it opened and getting spent fuel moved is critical, we think, to the nuclear renaissance which we are on the cusp of in this country".[5] During testimony before the Energy Subcommittee of the Senate Appropriations Committee, Sell responded to a question from Senator Domenici saying that "we believe that up to 90 percent of commercial spent fuel could be recycled before going to Yucca Mountain".[6] In furtherance of the Yucca Mountain project the Department has proposed legislation that would withdraw land from other uses and ease the regulatory hurdles the project faces.[7] It now anticipates a construction license application to the Nuclear Regulatory Commission in 2008.

We turn now to a discussion of the possible considerations involved in putting forth a closed fuel cycle at this time. We can roughly divide these into five categories, although there is overlap between them. The considerations that have been discussed or implicitly considered are economic savings, nuclear waste disposal simplification, proliferation resistance, public acceptance, and extending uranium fuel resources.

With regard to an economic comparison between a fuel cycle with reprocessing to that of direct burial of spent fuel, all independent studies have concluded that reprocessing is not competitive taking into account present and likely future uranium prices.[8, 9] A recent study of costs in Japan concluded that, integrated over the next 60 years, reprocessing would be about 50% more expensive than direct disposal of waste.[10] (In Japan nuclear power generators are charged about 0.2 cents per kWh to defray waste handling costs). There is one U.S. DOE analysis summary of several years ago suggesting that reprocessing would be less expensive[11].

With regard to nuclear waste disposal simplification, the situation is more complex. It is sometimes stated that there is almost a factor of 100 reduction in the amount of waste to dispose of if one reprocesses.[12] This is based on the fact that spent fuel is mostly uranium-238 that was not consumed in the reactor. This neglects the fact that the difficulty of disposing of nuclear waste involves both the heat liberated by the radioactive decay of the waste and the radio-toxicity of the waste. These latter two factors play a more important role in repository design and performance than does the volume of the waste. Both the heat liberated and the radioactivity of spent fuel is dominated by fission product decay during the first 100 years or so. Reprocessing does not ameliorate this problem. More serious analysis of the waste disposal problem suggests that the reduction in repository space required to dispose of nuclear waste is more like a factor of 10 than of 100 if reprocessing is employed. The handling of the waste is more complicated with reprocessing which involves many steps. Also the aqueous UREX + procedure generates liquid waste that has to be vitrified before being placed in a repository.

There are no proliferation advantages for reprocessing compared to direct disposal of spent fuel. Any separation of the different elements of the waste makes the fraction containing the plutonium less complex and simpler to work with. Similarly reprocessing makes the highly radioactive components of spent fuel that might be used to make a dirty bomb more accessible to terrorists. It is true that the UREX+ procedure makes the plutonium less accessible than the PUREX procedure used in earlier US weapons production and presently in Britain and France, but that is irrelevant if one is comparing the proposed reprocessing scheme with the present US direct disposal plan.

An underlying assumption in the GNEP proposal is that the public will accept the siting of reprocessing facilities.[13] It has been mentioned in presentations of the GNEP proposal that reprocessing could delay the need to search for a second geological repository site for a century. It seems to us that public resistance to accepting a nearby reprocessing plant will be as large as for a geological repository. The U.S. record on cleaning up both military and civilian spent fuel reprocessing facilities is not good. All of the high-level waste produced by reprocessing at the Hanford, WA plutonium production site is still being stored as liquid waste in tanks. A plant for vitrification of the waste is only now being built, and is still being designed as construction is in progress. The estimated cost is continuing to escalate. Similar problems are being encountered in the attempt to clean up reprocessing waste at the Savannah River Site in South Carolina.[14] The West Valley, NY facility was built to reprocess civilian spent fuel, but ceased operation in the 1970's. It is still not fully cleaned up, and the State of New York is suing the Department of Energy in an attempt to get the cleanup completed.

The final motivation for reprocessing is to extend the uranium fuel supply. This is the only motivation that has a valid underpinning. Unless human society makes drastic changes in its demand for energy, fossil fuel supplies such as gas and oil will become quite limited within a few centuries. Although renewable sources such as wind, solar cell, and geothermal can contribute, none of these sources can provide energy on the scale of that derived from fossil fuels. While uranium is reasonably abundant on the earth's crust, at some point as higher-grade ore is used up the cost and the energy required to extract the uranium becomes prohibitive if only the U-235 component is used. Fast breeder reactors with reprocessing can exploit the U-238 component comprising more than 99% of natural uranium.

This brings us to our final topic, the timeliness of the reprocessing proposal. The Department of Energy proposes studying reprocessing, particularly the aqueous UREX+ scheme, for two years and then deciding on whether to proceed with a pilot-plant demonstration of the scheme. This seems to us an unrealistically short time to sufficiently study the reproducibility, separation efficiency and waste stream purity of any new procedure. Pyrochemical processing is even more in its infancy, and decades of research and development will probably be needed to determine its viability and cost. Finally, there is a lot of work to be done on developing reliable fast reactors to burn the transuranic fraction from the first reprocessing step. There is no point in doing this first reprocessing step if one cannot burn the transuranics in a fast reactor. There are presently no fast reactors operating in the US. In France the most ambitious attempt, Super-Phenix, was terminated due to operational difficulties. Similarly a fast reactor built in Monju, Japan, has been shut down for decades due to an accident. (This reactor may however be restarted in the near future.)

We conclude that it would be very unwise to make a decision soon on whether to switch from a once-through fuel cycle with direct disposal of spent fuel to a closed cycle involving reprocessing and fast reactor burnup. This view has also recently been expressed[15] by Ernest Moniz, a former Department of Energy undersecretary. Considerably more research and development needs to be done. This should be done in an open and transparent manner, with significant independent peer review. The recent decision[16] of Secretary of Energy Bodman to dismiss his department's top science advisory board is a step in the wrong direction. We also think it would be a mistake to let an over-emphasis on reprocessing divert attention and funding from completion of a geological repository. The public needs to be assured that there is a safe, permanent solution to the nuclear waste disposal problem.

### *Footnotes*

[1] *http://www.gnep.energy.gov*

[2] *G. F. Vandegrift et al., "Design and Demonstration of the UREX+ Process Using Spent Fuel", http://www.cmt.anl.gov/science-technology/processchem/Publications/UREX.pdf*

[3] *C. Pereira et al., "Lab-Scale Demonstration of the UREX+2 Process using Spent Fuel" , WM'05 Conference, Feb. 27-Mar.3, 2005, Tucson, AZ, accessed 3/14/06 at http://www.wmsym.org archives.*

[4] *Clay Sell, March 2, 2006 testimony before the Energy Subcommittee of Senate Appropriations Committee, http://www.tmcnet.com/usubmit/2006/03/03/1428217.htm, accessed 3/23/06*

[5] *"Federal Budget: New front for Yucca argument", Steve Tetreault, Stephens Washington Bureau, Las Vegas Review Journal Feb 7, 2006.*

[6] *Clay Sell, March 2, 2006 testimony before the Energy Subcommittee of Senate Appropriations Committee, p. 10. http://www.tmcnet.com/usubmit/2006/03/03/1428217.htm, accessed 3/23/06.*

[7] *http://www.ocrwm.doe.gov/newsroom, accessed 4/8/06.*

[8] *"The Economic Future of Nuclear Power", a Study Conducted at the University of Chicago, August 2004 http://www.anl.gov/Special_Reports/ Accessed 11/29/04.*

[9] *"The Future of Nuclear Power: An Interdisciplinary MIT Study" J. Deutch and E. J. Moniz, co-chairs. Massachusetts Institute of Technology, 2003. web.mit.edu/nuclearpower/*

[10] *UPI, Oct. 6, 2004; Washingtontimes.com/upi-breaking/20041006-041809-9259r.htm*

[11] *"Advanced Fuel Cycle Initiative (AFCI) Comparison Report, FY 2003" U. S. Department of Energy, Office of Nuclear Energy, Science and Technology, Oct 2003 http://www.ne.doe.gov/pdf/AFCICompRpt2003.pdf*

[12] *Clay Sell, March 2, 2006 testimony before the Energy Subcommittee of Senate Appropriations Committee, http://www.tmcnet.com/usubmit/2006/03/03/1428217.htm, accessed 3/23/06.*

[13] *"Federal; Budget: New front for Yucca argument" Steve Tetreault, Stephens Washington Bureau, Las Vegas Review-Journal, Feb. 7, 2006.*

[14] *S. Fretwell, "Delay, cost hits SRS Plant", The State (Columbia, SC), Jan. 25,2006, p. B5.*

[15] *"Reprocessing plans tied to Yucca delays, scientist tells panel", Steve Tetreault, Stephens Washington Bureau, Las Vegas Review-Journal, April 13, 2006.*

[16] *Eli Kintisch, "Profile: Samuel Bodman", Science 311, p1369, Mar. 10, 2006.*

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# Nuclear Proliferation Status, 2006

*Joseph Cirincione*

The nations of the world confront serious and immediate threats from the global presence of some 27,000 nuclear weapons. They also face the possibility that some nation or group still has or soon could have biological or chemical weapons. A wide variety of delivery mechanisms for these weapons exists, including ballistic missiles, cruise missiles, aircraft, artillery, ships, trucks, and envelopes. There is also now the added danger that terrorist organizations could kill thousands with these weapons or destroy or sabotage critical urban and industrial infrastructures.

While a terrorist attack on these infrastructures using conventional weapons is the most likely threat, the explosion of a nuclear weapon would be the most devastating. The formula of "risk times consequences" forces us to focus serious attention on this catastrophic possibility.

Nuclear threats lie along four axes, though development along one axis often influences developments along the others. The four categories of threat are nuclear terrorism, new nuclear weapon states and regional conflict, existing nuclear arsenals, and regime collapse. The greatest concerns are outlined here.

### *Nuclear Terrorism: The Most Serious*

While states can be deterred from using nuclear weapons by fear of retaliation, terrorists, who have neither land, people, nor national futures to protect, may not be deterrable. Terrorist acquisition of nuclear weapons therefore poses the greatest single nuclear threat. The gravest danger arises from terrorists' access to state stockpiles of nuclear weapons and fissile materials, because acquiring a supply of nuclear fuel (as opposed to making the weapon itself) remains the most difficult challenge for a terrorist group. So-called outlaw states are not the most likely source. Their stockpiles, if any, are small and exceedingly precious, and hence well guarded. (Nor are these states likely to give away what they see as the crown jewels in their security crowns.) Rather, the most likely sources of nuclear weapons and materials for terrorists are storage areas in the former states of the Soviet Union and in Pakistan, and fissile material kept at dozens of civilian sites around the world.

There is also a substantial risk of terrorist theft from the nuclear stockpiles in more than forty countries around the world. Many of these caches of materials consist of highly enriched uranium that could be directly used in nuclear weapons, or further enriched to weapons grade. There are also significant stockpiles of plutonium that can be used in a weapon, though with more difficulty.

### *New Nuclear Nations and Regional Conflicts*

The danger posed by the acquisition of nuclear weapons by Iran or North Korea is not that either country would likely use these weapons to attack the United States, the nations of Europe, or other countries. States are and will continue to be deterred from such attacks by the certainty of swift and massive retaliation. The greater danger is the reactions of other states in the region. A nuclear reaction chain could ripple through a region and across the globe, triggering weapon decisions in several, perhaps many, other states. With these rapid developments and the collapse of existing norms could come increased regional tensions, possibly leading to regional wars and to nuclear catastrophe.[1]

New nuclear weapon states might also constrain the United States and others, weakening their ability to intervene to avoid conflict in dangerous regions, as well as, of course, emboldening Tehran, Pyongyang, or other new possessors.

Existing regional nuclear tensions already pose serious risks. The decades-long conflict between India and Pakistan has made South Asia for many years the region most likely to witness the first use of nuclear weapons since World War II. There is an active missile race underway between the two nations, even as India and China continue their rivalry. In Northeast Asia, North Korea's nuclear capabilities remain shrouded in uncertainty but presumably continue to advance. Miscalculation or misunderstanding could bring nuclear war to the Korean peninsula.

In the Middle East, Iran's quest for nuclear weapons, together with Israel's nuclear arsenal and the chemical weapons of other Middle Eastern states, adds grave volatility to an already conflict-prone region. If Iran were to acquire nuclear weapons, Egypt, Saudi Arabia, or others might initiate or revive nuclear weapon programs. It is possible that the Middle East could go from a region with one nuclear weapon state, to one with two, three, or five such states within a decade—with existing political and territorial disputes still unresolved.[2] This is a recipe for nuclear war.

### *The Risk from Existing Arsenals*

There are grave dangers inherent in the maintenance of thousands of nuclear weapons by the United States and Russia and the hundreds of weapons held by China, France, the United Kingdom, Israel, India, and Pakistan. While each state regards its nuclear weapons as safe, secure, and essential to its security, each views others' arsenals with suspicion.

Though the Cold War has been over for more than a dozen years, Washington and Moscow maintain thousands of warheads on hair-trigger alert, ready to launch within fifteen minutes. This greatly increases the risk of an unauthorized launch. Because there is no time buffer built into each state's decision-making process, this extreme level of readiness also enhances the possibility that either side's president could prematurely order a nuclear strike based on flawed intelligence.[3]

Recent advocacy by some in the United States of new battlefield uses for nuclear weapons could lead to new nuclear tests. The five nuclear weapon states recognized by the Non-Proliferation Treaty have not tested since the signing of the Comprehensive Test Ban Treaty in 1996, and no state has tested since India and Pakistan did in May 1998. New U.S. tests would trigger tests by other nations, seriously jeopardizing the CTBT, which is widely regarded as a pillar of the nonproliferation regime.

### *The Risk of Regime Collapse*

If U.S. and Russian nuclear arsenals remain at Cold War levels, many nations will conclude that the weapon states' promise to reduce and eventually eliminate these arsenals has been broken. Non-nuclear states may therefore feel released from their pledge not to acquire nuclear arms.

The Non-Proliferation Treaty is already severely threatened by the development in several states of facilities for the enrichment of uranium and the reprocessing of plutonium. Although each state asserts that these are for civilian use only, supplies of these materials potentially puts each of these countries "a screwdriver's turn" away from weapons capability. This greatly erodes the confidence that states can have in a neighbor's non-nuclear pledge.

Additionally, there appears to be growing acceptance of the nuclear status of Pakistan and India, with each country accruing prestige and increased attention from leading nuclear weapon states, including the United States. Some now argue that a nuclear Iran or North Korea could also be absorbed into the international system without serious consequence.

If the number of states with nuclear weapons increases, the original nuclear weapon states fail to comply with their disarmament obligations, and states such as India gain status for having nuclear weapons, it is possible that Japan, Brazil, and other major non-nuclear nations will reconsider their nuclear choices. Most nations would continue to eschew nuclear weapons, if only for technological and economic reasons, but others would decide that nuclear weapons are necessary for improving their security or status. There is a real possibility, under these conditions, of a system-wide collapse.

### *The Nuclear Nations*

Today, only eight nations are known to have nuclear weapons. Five nuclear-weapon states are recognized by the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and enjoy special rights and privileges under international law. Listed in order of the size of their nuclear arsenals, they are: Russia, the United States, China, France, and the United Kingdom. This group acquired their arsenals during the twenty years after World War II and remained remarkably stable from 1964, when China tested its first nuclear weapon, until 1998, when India and Pakistan both detonated nuclear devices and declared their intention to deploy weapons. India and Pakistan have not yet openly deployed any weapons, but both are capable of configuring aircraft and missiles with tens of weapons over the next few years if they so desire. Israel is widely believed to have approximately 100 nuclear weapons but neither acknowledges nor denies their existence. India, Pakistan, and Israel are not parties to the NPT.

Apart from these eight countries, two others are known to be actively pursuing nuclear weapon programs. North Korea may have accumulated enough material to construct as many as ten weapons. The 1994 agreement that had frozen the nation's plutonium program broke down in 2002 and North Korea announced its withdrawal from the NPT. Iran is slowly but steadily pursuing an open civilian nuclear power program and may be covertly developing expertise for nuclear weapons.

Since the signing of the Non-Proliferation Treaty in 1968, many more countries have given up nuclear weapon programs than have begun them.[4] There are fewer nuclear weapons in the world and fewer nations with nuclear weapon programs than there were twenty years ago.[5]

In the past twenty years, several major countries have abandoned nuclear programs, including Argentina and Brazil, and four others have relinquished their nuclear weapons to join the NPT as non-nuclear-weapon states. Ukraine, Belarus, and Kazakhstan gave up the thousands of nuclear weapons deployed on their territories when the Soviet Union dissolved, thanks in great measure to the dedicated diplomacy of the Bush and Clinton administrations. Similarly, South Africa, on the eve of its transition to majority rule, destroyed the six nuclear weapons the apartheid regime had secretly constructed. President Nelson Mandela agreed with the decision, concluding that South Africa's security was better served in a nuclear-free Africa than in one with several nuclear nations, which is exactly the logic that inspired the original members of the NPT decades earlier. Iraq gave up its nuclear program after the 1991 Gulf war and subsequent UN disarmament efforts, though the United States led a coalition of nations to invade Iraq on the mistaken belief that the country still had major programs for nuclear, biological and chemical weapons. Libya gave up its nuclear and chemical weapons programs and long-range missile program in December 2003 after negotiations with the United States and the United Kingdom.

Radiological weapons, although not as destructive as nuclear explosive weapons, also pose a serious danger, particularly as a terrorist threat. These are weapons that use conventional explosives, such as dynamite, to disperse radioactive materials, including the highly radioactive waste material from nuclear power reactors or other nonweapon sources. They may be attractive weapons for terrorists owing to the relative ease of their acquisition and use and mass disruption potential.

### *Effective Policies Prevented Worse Dangers*

President John F. Kennedy worried that while only the United States, the Soviet Union, the United Kingdom, and France in the early 1960s possessed nuclear weapons, by the end of the decade 15 or 20 nations would have them. The concern was not that developing countries would acquire the bomb, but rather that the advanced industrial nations would do so, particularly Japan and Germany. Several European nations were already actively pursuing nuclear weapon programs. Neutral Sweden, for example, was then developing plans to build 100 nuclear weapons to equip its air force, army, and navy.

Kennedy moved aggressively to counter those trends. United States diplomacy and international efforts to create legal and diplomatic barriers to the acquisition of nuclear weapons, codified in the Treaty on the Non-Proliferation of Nuclear Weapons in 1968, dramatically stopped the rush toward nuclear weapon status. Twenty years after Kennedy's warning, only China (with Soviet help) had openly joined the ranks of the new nuclear nations while India had exploded a so-called peaceful nuclear device and Israel was building a secret nuclear arsenal. All the other nations that had studied nuclear programs in the 1950s and 1960s had abandoned their pursuits. The treaty did little at that time, however, to constrain the nuclear arms race between the two superpowers in the 1960s and 1970s that was sometimes known as vertical proliferation.

Non-proliferation efforts have steadily advanced over the past two decades, but never easily and never without serious setbacks. Although nuclear, biological, and chemical arsenals in the United States and the Soviet Union once grew to enormous levels and the technology of these weapons has become increasingly accessible, the world has not been devastated by a thermonuclear war. Moreover, the number of new prospective nuclear nations has shrunk dramatically over the past 20 years, not increased, and the international norm has been firmly established that countries should not, under any circumstances, possess or use either biological or chemical weapons. Global expectations are that the existing stockpiles of nuclear weapons will be greatly reduced, even if their eventual elimination seems but a distant hope.

Only four nations since 1964 have overcome the substantial diplomatic and technical barriers to manufacturing nuclear weapons. The proliferation of biological and chemical weapons is broader, but it is still mainly confined to two regions of the world: the Middle East and Northeast Asia. Most of the world's biological weapons have been destroyed, and the bulk of the global chemical weapon arsenals will likely be eliminated over the next ten years.

With all the serious challenges that exist, the non-proliferation regime has still had a remarkable record of success. But can it hold? Or are international conditions so different today that the regime can no longer work?

### *Twenty-first Century Proliferation*

The Bush administration implemented a radically new non-proliferation approach. Previous presidents had treated the weapons themselves as the problem and sought their elimination through treaties. President Bush framed the issue differently in his 2003 State of the Union address: "The gravest danger facing America and the world is outlaw regimes that seek and possess nuclear, chemical, and biological weapons." (italics added) The administration changed the focus from "what" to "who," seeking the elimination of regimes rather than weapons.

The first direct application of this theory was the war with Iraq. Since 2000, however, proliferation problems have grown worse, not better. Libya is an unqualified success, as that nation abandoned decades of work on nuclear and chemical weapons and missile programs. But Iran has accelerated its program – whether peaceful or not –in the past few years. So has North Korea. Globally, the threat from nuclear terrorism has grown as U.S. intelligence officials conclude that the Iraq war made the terrorism problem worse, and supplies of weapons and weapon materials remain dangerously insecure.[6] While U.S. attention focused on the three "axis of evil" states, the nuclear black market of Pakistan's A.Q. Khan spread nuclear weapon technology and know-how around the world. It is not clear if this network has shut down or merely gone further underground. Meanwhile, the United States and Russia have ended the process of negotiating reductions in their nuclear arsenals and the reductions themselves are proceeding at a slower pace than previous administrations planned. Finally, there is growing concern that the entire non-proliferation regime is in danger of a catastrophic collapse.

The strategy, or some modified variation, could still prove its worth. But a combination of approaches may offer the best chance of success. The European Union has crafted its own strategy that includes tying all EU trade agreements to observance of non-proliferation treaties and norms. This "soft power" approach could meld with the "hard power" of the United States to replicate the U.S-UK success with Libya. The Libya model could emerge from and prevail over the Iraq model: change a regime's behavior rather than change the regime. The critical importance of the NPT and other treaties is that they provide the necessary international legal mechanism and establish the global norms that give nations a clear path to a non-nuclear future. Military solutions cannot work alone. No nation has ever been coerced into giving up a nuclear program–but many have been convinced to do so.

These historic lessons must be remembered anew, lest in our haste to construct new solutions we tear down the very structures we need only repair.

## *Footnotes*

*[1] This is the danger President Kennedy warned of in 1963. "I ask you to stop and think for a moment what it would mean to have nuclear weapons in so many hands, in the hands of countries large and small, stable and unstable, responsible and irresponsible, scattered throughout the world," he said. "There would be no rest for anyone then, no stability, no real security, and no chance of effective disarmament. There would only be the increased chance of accidental war, and an increased necessity for the great powers to involve themselves in what otherwise would be local conflicts." John F. Kennedy, "Radio and Television Address to the American People on the Nuclear Test Ban Treaty," July 26, 1963, available at http://www.jfklibrary.org/jfk_test_ban_speech.html (accessed December 10, 2004).*

*[2] Several countries in the Middle East are capable of pursuing nuclear weapon programs or otherwise acquiring nuclear weapons, including Saudi Arabia, Egypt, and Turkey. Saudi Arabia might seek to purchase nuclear weapons from Pakistan, or invite Pakistan to station nuclear weapons on its territory. Other countries have at least the basic facilities and capabilities to mount a nuclear weapon program, albeit not without significant political and economic consequences. Egypt and Turkey could probably acquire enough nuclear material to produce a nuclear weapon within a decade of launching such an effort.*

*[3] Former U.S. Senator Sam Nunn argues, "The more time the United States and Russia build into our process for ordering a nuclear strike the more time is available to gather data, to exchange information, to gain perspective, to discover an error, to avoid an accidental or unauthorized launch." Speech to the Carnegie International Non-Proliferation Conference, June 21, 2004, available at www.ProliferationNews.org.*

*[4] Six nations abandoned indigenous nuclear weapon programs under way or under consideration in the 1960s: Egypt, Italy, Japan, Norway, Sweden, and West Germany. Since the late 1970s, Argentina, Australia, Belarus, Brazil, Canada, Iraq, Kazakhstan, Libya, Romania, South Africa, South Korea, Spain, Switzerland, Taiwan, Ukraine, and Yugoslavia have abandoned nuclear weapon programs or nuclear weapons (or both) on their territory. North Korea and Iran are the only two states that began acquiring nuclear weapon capabilities in this later period and have not ceased the effort.*

*[5] In 1970, the year the NPT entered into force, there were about 38,000 nuclear weapons in global arsenals, mostly in the stockpiles of the United States and the Soviet Union; by 1986, the number of weapons had increased to a peak of 65,000 worldwide; in 2004, there were approximately 27,000.*

*[6] See testimony of Central Intelligence Director Porter Goss and Defense Intelligence Agency Director Admiral Lowell Jacoby before the Senate Intelligence Committee, February 16, 2005, http://intelligence.senate.gov/0502hrg/050216/witness.htm.*

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# Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities[1]

*Steve Fetter and Ben Rusek*[2]

## *Introduction*

Previous studies by the National Academy of Sciences' Committee on International Security and Arms Control (CISAC) emphasized the key role of transparency, monitoring and verification, both for the future of arms limitations among the nuclear-weapon states and for keeping nuclear-explosive materials (NEM)[3] away from proliferation-prone states and terrorists. In 2000, the U.S. Department of Energy requested that CISAC study the potential for a more comprehensive approach to nuclear-arms control. The report, Monitoring Nuclear Warheads and Nuclear Explosive Materials, explores the extent to which current and foreseeable approaches to transparency and monitoring can support verification for all categories of nuclear weapons – strategic and non-strategic, deployed and nondeployed – as well as for the nuclear explosive components and materials that are their essential ingredients. Increasing the categories of items subject to transparency and monitoring would be valuable – and may ultimately be essential – as the United States and the world attempt to address the urgent and interrelated goals of reducing the dangers from existing nuclear arsenals, minimizing the spread of nuclear weaponry to additional states, and preventing the acquisition of nuclear weapons by terrorists.

In addition to understanding the transparency and monitoring possibilities and requirements for more ambitious arms control regimes, the study also focuses on potential applications to the continuing challenges of keeping nuclear weapons out of the hands of proliferant states and terrorists. To give one prominent example, the United States has emphasized the need for verification as part of an agreement to eliminate North Korea's nuclear weapons program. Likewise, as the United States continues to work with Russia to ensure that nuclear materials are adequately protected and accounted for, the partners will continue to require transparency measures to facilitate the process.

The study addresses the technical and institutional approaches and capabilities in transparency and monitoring that could be applied to declared stocks of nuclear weapons, nuclear weapons components, and nuclear-explosive materials. The study also evaluates methods that could be used to detect clandestine stocks or covert production of nuclear weapons or NEM. Although the study does not make recommendations about U.S. arms control and nonproliferation policies, such policy choices will continue to shape the context within which monitoring approaches and capabilities might be applied.

## *The Magnitude of the Monitoring Challenge*

More than 30,000 nuclear weapons remain in the world. The United States and Russia possess about 95 percent of existing nuclear weapons, with the remainder held by the United Kingdom, France, China, Israel, India, Pakistan, and possibly North Korea. In addition, stocks of NEM—high-enriched uranium (HEU) and separated plutonium—sufficient to make more than 100,000 additional nuclear weapons exist in military and civil nuclear facilities worldwide. HEU and plutonium are difficult to produce. Access to these materials is the primary technical barrier to the acquisition of nuclear weapons. These stockpiles of NEM, in addition to presenting a ready resource for further production of weapons by the states holding them, also constitute a potential source for the fabrication of nuclear weapons by non-nuclear weapon states and even terrorist groups.[4] Any assessment of the potential future availability of NEM, moreover, must include not only military stocks of these materials but also the NEM in research reactors and the growing quantities of it in civilian nuclear power programs.

The monitoring challenge is further compounded by the physical characteristics of nuclear weapons and NEM (e.g., radioactivity, toxicity, etc.), and by the tension that exists between sharing stockpile information and maintaining the security of these stockpiles against attack, sabotage and theft.

The extent to which transparency and monitoring measures should be enshrined in formal agreements remains a point of contention. The 2002 Treaty of Moscow commits the United States and Russia to reduce operationally deployed strategic offensive nuclear weapons to 1700-2200 each by end of 2012. The Treaty does not cover nonstrategic weapons or non-deployed strategic weapons, and it includes no transparency or monitoring provisions. In addition, the declarations and monitoring mandated under START I expire in December of 2009. Negotiation of agreements with formal transparency and monitoring measures may be difficult and protracted, but may be needed for the most stringent measures and for assurance of sustainability.

## *Nuclear Weapons and Nuclear Weapons Components*

A comprehensive weapons monitoring regime would have many elements. The necessary technical tools are either available today, or could be available with some additional development, to support significantly enhanced transparency

**Table 1. World Stocks of NEM (metric tons)**[5]

| | Military | Civil | Total |
|---|---|---|---|
| HEU | 1840 | 60 | 1900 |
| Plutonium (unirradiated) | 260 | 230 | 490 |

The International Atomic Energy Agency (IAEA) definition of a "Significant Quantity" (SQ) – enough for a weapon – is 25 kilograms of HEU or 8 kilograms of Plutonium. Global NEM stocks are greater than 100,000 SQ.

and monitoring for declared stocks at declared sites throughout the nuclear weapon life cycle.

- Developments in cryptography now widely used in banking and other commercial transactions offer a way to exchange and grant selective access to sensitive information about nuclear weapons that countries would not be willing to share more openly and comprehensively because of security concerns.
- Methods are available to examine from a short distance the radiation from a nuclear weapon or to interrogate a declared weapon container with an external radiation source. The radiation signature can be matched against templates of actual nuclear weapon signatures, or some portion of the radiation signatures can be singled out to identify attributes that confirm that the object is indeed a weapon. These techniques permit identification without revealing sensitive weapon design information. For example, table 2 gives data from a demonstration of the Trusted Radiation Identification System (TRIS). A comparison of the radiation signature of a weapon with a template taken from a weapon of the same type consistently produces a score (reduced chi-square) of about one, indicating a match, while the signatures of other types of weapon or weapon component clearly do not match.
- A wide array of tags and seals, ranging from bar codes and tamper-indicating tape to electronic chips, can be applied to weapons containers and storage rooms. Some such systems can be interrogated remotely to check their status.
- Monitored perimeter-portal systems, which exploit radiation and other distinctive signatures, can confirm that what enters and leaves any given facility is consistent with declared activities.
- Facilities and areas within facilities can be equipped with appropriate sensors and accountability systems to monitor declared activity and detect undeclared activity, the recordings from which can either be examined during periodic inspections or uploaded via the Internet or satellites for transmission to a monitoring center.

This array of tools makes it possible to contemplate a set of transparency and monitoring measures that would give a high level of confidence in the accuracy of declarations of weapon stocks. These measures could be undertaken unilaterally or through formal agreements. In general, tools and measures that provide a higher degree of confidence come at the cost of greater intrusiveness and potential impact on normal operations and require more effort to protect sensitive weapon design information.

Even a modest subset of the measures outlined here could provide a degree of openness concerning weapon stockpiles and a framework for access to weapon sites that would greatly ease the difficulties of cooperation to improve security of nuclear weapons everywhere against theft or unauthorized use. For the more demanding purpose of monitoring agreements to control or reduce the stocks of nuclear weapons held by nuclear weapon states, the more intrusive measures would also be required.

### *Nuclear-Explosive Materials*

Nuclear-explosive materials are readily convertible by nuclear weapon states (or other states or groups that have knowledge of nuclear weapon technology) into the components of actual weapons. The size of the NEM stock determines, to a reasonable approximation, how many weapons of particular types could be made. The difficulty of producing such materials means, moreover, that their acquisition is and will remain a limiting factor for states or subnational groups aspiring to make such weapons.

The basic structure of transparency and monitoring for NEM is parallel to that for nuclear weapons and nuclear weapons components. A NEM monitoring system could include comprehensive declarations of fissile material quantities and locations that include information on chemical forms and isotopic composition, NEM surplus to military and civilian needs, and provisions for inspection of all declared facilities as well as of any undeclared suspicious activities.

Transparency and monitoring can be made easier by reducing stocks and flows of NEM throughout the fuel cycle. This can be accomplished through the accelerated downblending of excess HEU for use as reactor fuel, replacing HEU fuels in research reactors and the disposition of excess plutonium by conversion to mixed-oxide fuel for civil reactors or immobilization with radioactive waste. An international cutoff of NEM production for weapons and designing nuclear fuel cycles for civil reactors that minimize or eliminate the vulnerability of NEM would greatly reduce the risk of NEM loss, as would the centralization under international control of all facilities capable of enriching uranium or separating plutonium.

Related measures that would assist international efforts to increase transparency and monitoring for NEM include the continued substantial improvements in national systems of Material Protection Control and Accounting (MPC&A) and strengthening the IAEA safeguards regime, including the universal application of the Additional Protocol and increasing the IAEA's manpower and funding.

Improved management and decreased inventories of NEM would become increasingly crucial if lower limits were agreed on total warhead stocks. The lower such limits became, moreover, the greater would be the need for reduced NEM stockpiles and high confidence in monitoring the remaining stocks. While technologies exist to achieve greatly improved monitoring for NEM, a strengthened international consensus on the value of doing this will be needed to solve associated problems cooperatively.

### *Clandestine Stocks and Covert Production*

As noted above, methods are available to verify with high confidence declarations of nuclear weapons and NEM stocks. But undeclared weapon stocks could exist, either through the clandestine retention of existing nuclear weapons, or through the clandestine production of nuclear weapons from hidden stocks of NEM. In addition, NEM for weapons might be produced clandestinely or diverted covertly from peaceful nuclear power programs. Tools for detecting clandestine stocks include National Technical Means (NTM), human sources, audits of records, and other physical evidence ("nuclear archaeology"). A state might confidently hide enough NEM for tens (China) to hundreds (Russia) of weapons. The potential for clandestine activities in these categories poses the largest challenges to efforts to strengthen transparency and monitoring for nuclear weapons, components, and materials on a comprehensive basis.

Production of NEM is difficult to hide. The ability of U.S. intelligence agencies to identify the emergence and evolution of nuclear weapon programs is one indication of the likelihood of future success in detecting covert production. Historically, U.S. intelligence has become aware of programs to develop nuclear weapons relatively early and well in advance of the production a weapon. U.S. intelligence has detected every program and identified production facilities, before significant quantities of NEM were produced in the Soviet Union, China, Israel, India, Pakistan, South Africa, Iraq, North Korea, and Iran. Estimates of the date of the initial fabrication of an actual nuclear device and future inventories of materials and weapons have often underestimated or overstated actual capabilities, however. Methods for detecting and evaluating clandestine efforts—in particular, NTM and environmental sampling—have improved over time and should continue to do so.

Given the already extensive knowledge of existing nuclear programs, the additional information that would result from the process of verifying declarations, the new inspection capabilities provided by the IAEA Additional Protocol, and the demonstrated capabilities of NTM, it is unlikely that any state could develop or reconstitute a complete and covert nuclear weapon production program that would not be discovered over time. If, however, undeclared stocks of NEM exist or can be diverted without detection from civilian stocks or production facilities, then it is much more likely that the assembly of new weapons could escape detection. Where concerns about compliance exist, the synergistic effect of multiple technical and management measures, supported by increased transparency and robust national technical means of intelligence collection, could reduce the risk that significant clandestine activities would go undetected and over time could build confidence that verification was effective.

### *Conclusion*

Current and foreseeable technological capabilities exist to support verification at declared sites, based on transparency and monitoring, for declared stocks of all categories of nuclear weapons—strategic and nonstrategic, deployed and nondeployed—as well as for the nuclear-explosive components and materials that are their essential ingredients. Many of these capabilities could be applied under existing bilateral and international arrangements without the need for additional agreements beyond those currently in force.

**Table 2. Trusted Radiation Identification System (TRIS) Template Identification Demonstration**

| | Template for Weapon Type | | | | |
|---|---|---|---|---|---|
| **Object** | **A** | **B** | **C** | **D** | **E** |
| Weapon Type A, #1 | 0.8* | 92 | 32 | 7.7 | 42 |
| Weapon Type A, #2 | 0.9 | 90 | 31 | 8.2 | 45 |
| Weapon Type A, #3 | 0.8 | 91 | 32 | 8.5 | 45 |
| Weapon Type B | 496 | 0.8 | 140 | 336 | 491 |
| Weapon Type C | 63 | 43 | 0.9 | 34 | 128 |
| Weapon Type D | 11 | 102 | 26 | 0.6 | 46 |
| Weapon Type E | 55 | 174 | 86 | 31 | 1.0 |
| Pit, Type A | 558 | 91 | 319 | 547 | 794 |
| Pit, Type E | 858 | 203 | 566 | 821 | 1071 |
| CSA, Type A | 52 | 118 | 88 | 64 | 66 |
| CSA, Type E | 27 | 156 | 77 | 22 | 6.4 |

[*] The “reduced chi-square” is a measure of the goodness-of-fit between the object’s spectrum and the template. The gamma-ray spectrum between 80 and 2,750 keV was divided into 16 groups (two of which are discarded) and the number of counts in each group for the object and the template was computed; the reduced chi-square is the sum over all groups of the squared difference in the number of counts for the object and template divided by the variance, divided by the number of degrees of freedom.

SOURCE: D.J. Mitchell and K.M. Tolk, “Trusted Radiation Attribute Demonstration System,” *Proceedings of the 41st Annual Meeting of the Institute of Nuclear Materials Management* (Northbrook, IL: Institute of Nuclear Materials Management, 2000).

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## *Footnotes*

*[1] The paper is adapted from the Executive Summary of Monitoring Nuclear Weapons and Nuclear-Explosive Materials: An Assessment of Methods and Capabilities, Committee on International Security and Arms Control (2005). Available at: http://www.nap.edu/catalog/11265.html.*

*[2] Steve Fetter is Professor and Dean of the School of Public Policy Affairs at the University of Maryland, a member of the National Academy of Sciences’ Committee on International Security and Arms Control (CISAC), and co-chair of the study. Ben Rusek is a Research Associate with CISAC, the Committee on International Security and Arms Control at the National Academy of Sciences.*

*[3] A “nuclear-explosive material” is a mixture of fissionable nuclides in which the proportions of these are such as to support an explosively growing fission chain reaction when the material is present in suitable quantity, density, configuration, and chemical form and purity. Uranium containing more than 20 percent U-235 or more than 12 percent U-233 (or an equivalent combination of proportions of these two nuclides) is considered NEM, as are all mixtures of plutonium isotopes containing less than 80 percent Pu-238.*

*[4] Other concerns include the increasing number of weapons in nuclear-weapon states, the acquisition of nuclear weapons by states that don’t yet have nuclear weapons but do have NEM (so-called “latent” nuclear states); and the illicit transfer to or theft by other states or sub-national groups intending to make nuclear weapons.*

*[5] Adapted from: David Albright and Kimberly Kramer, “Fissile Material Stockpiles Still Growing,” Bulletin of the Atomic Scientists, November/December 2004, pp 14-16. See also the underlying analysis on the website of the Institute for Science and International Security, available as of August 20, 2004 at: http://www.isis-online.org.*

# Advances in Nuclear Monitoring Technologies

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*Abstract:* This article is based on an invited presentation by Brent Park of Los Alamos National Laboratory on March 13, 2006, at the American Physical Society meeting in Baltimore. The presentation focused on recent efforts in new detector materials and detector systems, as well as improving existing systems for homeland security.

### *I. Introduction*

The problem of detecting an attempt to smuggle a nuclear weapon into the United States has not been solved and the detonation of such a device would be a catastrophe that would dwarf the terrible tragedy of September 11, 2001. It is estimated that annually ~7 million cargo containers enter the United States by sea and ~9 million by land.[1] Twice in recent years, 7-kg chunks of depleted uranium (DU) — harmless itself but massive enough to resemble threatening quantities of weapons-grade uranium — are known to have passed border inspection without detection.[2, 3] Clearly we need to substantially improve nuclear monitoring technologies, while acknowledging the extreme challenges of monitoring nuclear and radiological materials and differentiating the bad (weapons-useable) from the good (medical, industrial). In March 2006, major news outlets carried such headlines as "Dirty bomb test exposes security lapses: False radiation alarms are common – sometimes occurring more than 100 times a day," describing how the Government Accounting Office was able to smuggle radioactive sources through multiple ports of entry into the United States without detection.[4] The gamma radiation emitted by a threat is not readily distinguished from that emitted by many innocent items of commerce, and, as in this example, such signals are frequently ignored. Thus, reducing the false alarm rate is essential for a robust detection system.

### *II. Discussion*

Protecting the United States against terrorists bringing in weapons-useable nuclear and radioactive materials requires advanced, robust detector systems that provide maximum detection efficiency with low false alarm rates, in addition to accurate radiation identification capabilities. Additional constraints include the need for detectors that are inexpensive, wide-area ranging, field ruggedized, and capable of near real-time data acquisition and analysis. In this paper, we provide a brief overview of recent efforts on nano-composite scintillators, quantum dots as detector materials, a microcalorimeter array for ultra-high-resolution spectrometry, and ongoing improvements to CdZnTe and high-pressure Xenon detectors. We comment on the limitations of Compton imagers for passive detection of nuclear signatures. We also examine active interrogation techniques and algorithm development work aimed at reducing false-alarm rates.

### *II-A. Advanced detector materials*

To make passive gamma-ray detectors ubiquitous and useful, it is necessary to substantially reduce their cost while increasing detector volume and energy resolution. Improved energy resolution enables reliable isotope identification, thus separating threats from non-threats in a variety of situations. Many types of gamma and neutron-detector materials are available: Ge, CdZnTe, NaI, Plastic, and other scintillator materials. In Table 1 we summarize different detector material performances and costs.

A key goal is to combine the performance characteristics shown in bold face with in a single material. One way to

| Detector Material | Energy Resolution (% @ 662 keV) | Density (g/cc) | Estimated Cost ($/cc) | Maximum Volume (cc) |
|---|---|---|---|---|
| Ge | **0.13** | 5.3 | 150 | 750 |
| CdZnTe | **1.7** | 6.0 | 4400 | 3.4 |
| NaI | 6 | **3.7** | 2 | 4200 |
| Plastic Scintillator | Very Poor | 1.0 | 0.16 | **14000** |

*Table 1. Comparison of commonly used detector materials. Numbers are approximate since performance/cost depend on specific detector design.*

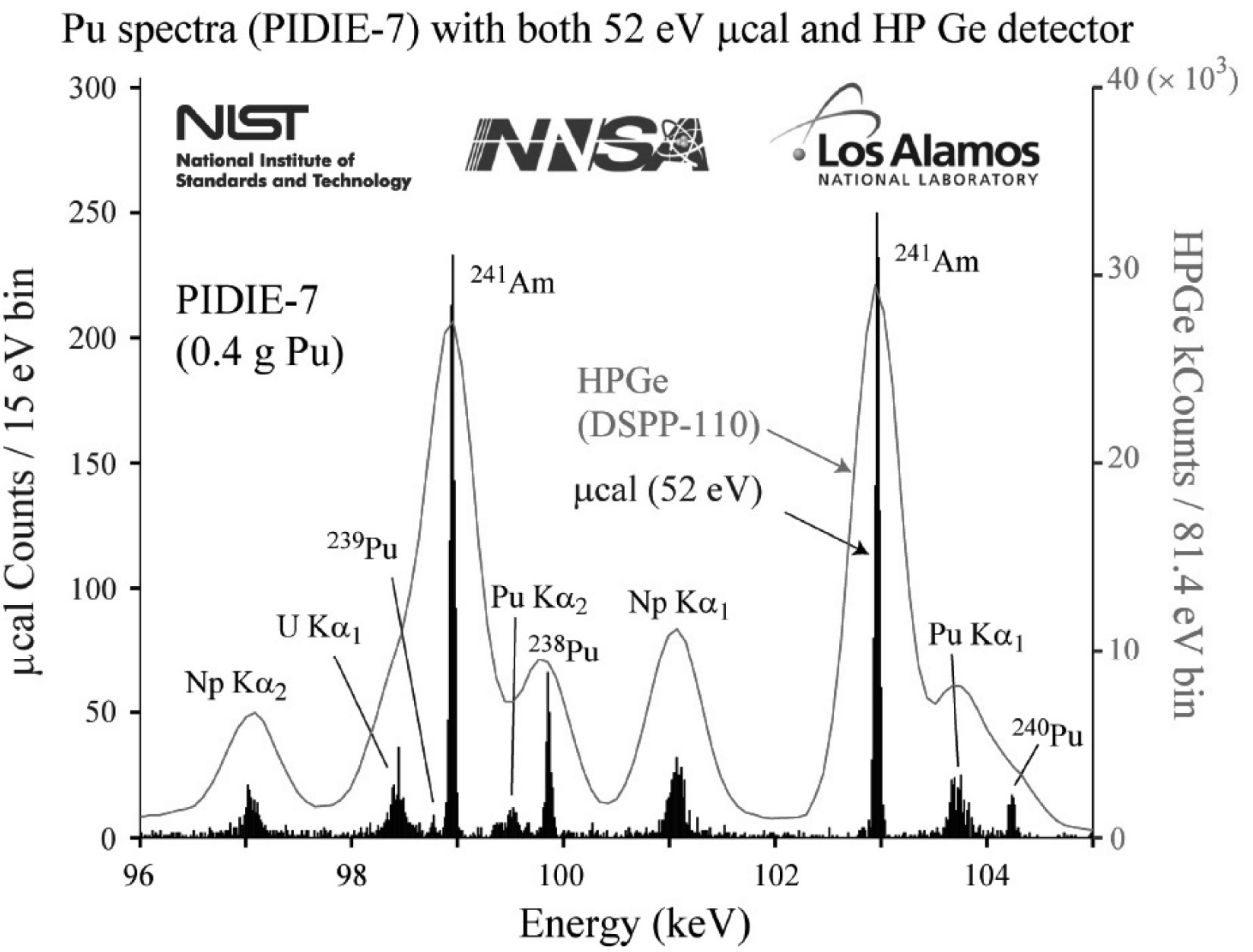

*Figure 1. Microcalorimeter (black) and high-purity germanium (red) spectra of a mixture of plutonium isotopes.7 Minimal thermal noise is achieved at 100 mK. High sensitivity is due to use of a superconducting quantum interference device.*

achieve this is to create a composite scintillator, where the materials are synthesized by industrial chemical means, with processing similar to plastic scintillators. Nano-composite material is one such example. Nano-sized particles of known insulating and semiconducting scintillators may be used as components of composite materials. Nano-composites can be used for passive detection and active interrogation and may offer improved energy resolution, due to the fact that nano-composites have reduced self-absorption and enhanced light-yield from reduced dimensionality, along with fast lifetime. Because nano-materials are synthesized in a scalable way, significant cost savings compared to bulk materials should be possible. Recently LANL developed techniques to produce nano-particle material.[5] Several transparent pieces of a few-millimeters diameter were successfully manufactured, optically characterized and tested. Transparent samples have been produced with dimensions up to about 1 mm. We plan to scale up the production process to larger sizes of more practical interest and are evaluating the possibility of fabricating high-quantum-efficiency, large-area, low-cost organic photodiodes.

Another effort seeks to develop a new class of radiation-detection materials — composite inorganic semiconductor quantum dot/organic semiconductors — that possess the cost and processing advantages of organic scintillators and the ionization characteristics of inorganic semiconductors. Organic scintillators are widely used in radiation-detection applications due to their low cost, ease of fabrication, and fast response times. However, because their large and nonlin-

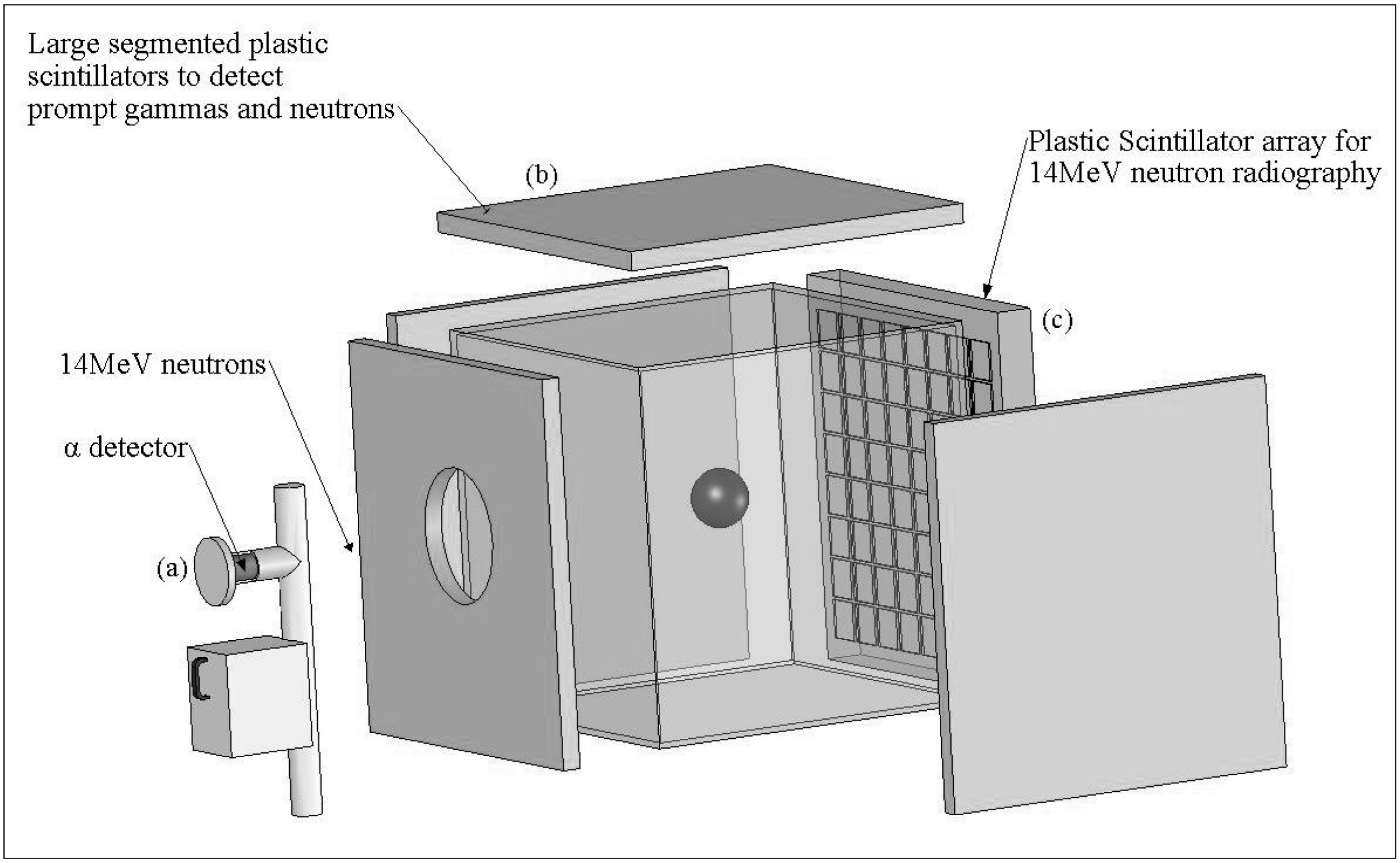

*Figure 2. A schematic illustration of a field measurement using TANIS.11 The neutron generator (a) creates 14-MeV neutrons with a precisely known start time and direction. Plastic scintillator detector modules (b) are arrayed about the sample as geometry permits to detect induced-fission neutrons and gamma rays. A 2-dimensional plastic scintillator array (c) detects 14-MeV transmitted neutrons for neutron radiography. Delayed emissions are measured immediately after the neutron generator is turned off.*

ear ionization energy make them unsuitable for applications that require high-energy resolution or detection of strongly ionizing particles. The ionization energy of a semiconductor quantum dot is expected to be less than the bulk material and may approach the energy gap of the quantum dot.[6]

Microcalorimeters and bolometers made from thin superconducting films cooled to temperatures near 100mK provide unprecedented energy resolution (see Figure 1). A research team from LANL and the National Institute of Standards and Technology (NIST) has accurately measured the x- and gamma-ray spectra of plutonium samples with a pin-size calorimeter, achieving an energy resolution of 42 eV FWHM at 103 keV, roughly 10 times better than high-purity germanium detectors.[7] Such measurements are valuable for non-destructive assays of radioactive isotopes mixed in with other materials. Successful development and implementation of the detectors is directly relevant to problems in nuclear forensics, international and domestic safeguards, attribution, and analysis of environmental samples. LANL and NIST plan to develop a microcalorimeter-based gamma-ray spectrometer with a count rate > 2- kHz and a sensitive area of 10 cm$^2$. Such an instrument would provide new capabilities for analyzing such nuclear materials as mixed plutonium isotopes. Over the next two years, the collaboration seeks to make the detector system portable and ruggedized for field use.

### *II-B. Efforts to improve existing detectors and materials*

CdZnTe is a semiconductor material used to detect various energy levels of radiation. CdZnTe detectors produce high-quality data in portable systems that are not sensitive to extreme variations in temperature or environment.[8] Using such a detector, operators can identify whether a radiation source is near, its proximity, its constituent radioactive materials and their quantities, based on data collected by the detector and analyzed by an on-board microcomputer.[8] One challenge to wider use of CdZnTe is its limited size and volume of a few cm. New configurations of CdZnTe detectors recently have been evaluated for nuclear material monitoring applications. A LANL team used two CdZnTe detectors, mounted side by side in a single housing behind slit collimators, and achieved about 3.5 % energy resolution in unattended monitoring of UF6 enrichment.[9] For this application, measurements of gamma-ray lines at 143 and 186 keV are used to deduce gas pressure. Due to their relatively high sensitivity coupled with low-power requirements, it may be possible to use CdZnTe detectors for remote monitoring of nuclear signatures for extended periods.

High-Pressure Xenon (HPXe) Detector: A recent demonstration at LANL showed HPXe detector performance may be superior to that of NaI, plastic scintillators, high-purity germanium, or lanthanum halide/bromide detector materials for many homeland security applications. A prototype HPXe detector showed good temperature stability. Its statistical energy resolution limit is better than 1% and it can provide real-time isotope identification capabilities and push the low-level detection limits.[10] There are challenges in the handling and transporting of pressurized Xe gas. Such a detector shows a huge potential for accommodating unusual shapes for special applications as well as scalability to large sizes, but it is not yet cost-effective for wide use.

Compton Gamma-Ray Imager/Camera: Development of a passive gamma-ray imager includes efforts to use the Compton effect to diagnose the internal details of a suspicious device by passive detection alone. Although Compton cameras have been successfully used in astrophysics, using Compton cameras to detect passive nuclear signatures is a difficult challenge due to the inherent inefficiency of a device that requires double scattering. Most Compton imagers use several-hundred-micron-thick layers of pixilated silicon detectors followed by an array of CsI scintillators. The probability of gamma-ray interaction in the silicon layers is very low, resulting in low detection efficiency. A Compton camera might be more useful as part of active interrogation system, especially with an extremely low-dose source.

### *II-C. Active Interrogation of HEU*

Clandestine transport of nuclear materials is an enormous challenge to current detection methods. Passive sensing can be rendered largely ineffective through the use of shielding, which easily blocks the low-energy gammas emitted from highly enriched uranium (HEU), for example. To make things worse, HEU emits almost no neutrons. The solution is active interrogation, defined as bombardment with neutrons or gammas to induce fissions that in turn induce nuclear materials to self identify via fission signatures. Utilization of the prompt-induced emissions from an active interrogation measurement for detection of SNM is essential to any high-throughput screening strategy for inspection of items and containers entering the United States. A screening technique that combines neutron radiography with measurement of prompt- and delayed-induced emissions can reduce the frequency of false alarms toward zero. With the added capabilities of active-interrogation measurement come additional operational risks, such as increased occupational dose to operators and increased radiation exposure to cargo. Current research efforts have focused on high-dose, fixed-facility systems, which, even if successful in detection, will have limited application due to the inherent complexities and safety issues associated with accelerator operations.

Another effort seeks to develop a portable, low-dose, tagged-active-neutron interrogation system (TANIS) for the detection and characterization of SNM such as HEU in cargo.[11] The key to this approach is using time-of-flight and directional coincidence gating on alpha-tagged 14-MeV neutrons from the d + t → 4He + n reaction to improve the signal-to-noise ratio in transmission and induced fission measurements. TANIS uses three distinct measurement methods: prompt emission measurements of neutrons and gammas, 14-MeV stereoscopic neutron radiography imaging, and delayed emissions. As shown schematically in Figure 2, a cargo container is scanned in a plastic scintillator neutron and gamma-ray detector array, surrounded by a tagged-neutron (d,t) generator. Small items can be inspected all at once, while larger containers can be inspected in stages.

### *II-D. Other improvements*

Improved analysis algorithms using Material Basis Set (MBS): There are already thousands of hand-held detectors used by first responders for radiation monitoring. Many commercially available radioisotope identifiers perform poorly. Tests by Blackadar et al. revealed that these radioisotope identifiers worked only 38% of the time.[12] Performance of these hand-held units improved drastically when we introduced much-improved algorithms. One such algorithm, Material Basis Set (MBS), compensates for shielding impacts on gamma spectra, providing more accurate isotope identification.[13] Running these algorithms does not impact detector performance in that typical calculation take only one second on the Motorola 64K series. When MBS was added to CdZnTe- and NaI based radioisotope identifiers, false alarms dropped to ~8%.

Many activities do not involve new detection principles. Instead, performance enhancements due to digital techniques and computational power result in more useful detectors and detector systems. For example, LANL is working on a portable neutron spectrometer in which a liquid scintillator packaged with digital electronics is placed into a hand-held portable unit with low power demands. Pulse-shape discrimination is applied to separate the contributions of neutrons from those of gamma rays. Both experimental calibrations and computational modeling have been used to derive response functions over a wide range of neutron energies that are needed in the deconvolution of fast-neutron spectra. A feasible next step would extend the instrument to the accurate measurement of radiation dose from fast neutrons. By incorporating tables of fluence-to-dose factors for neutrons as a function of their energy, on-board calculations from the measured energy spectrum could give accurate measurements of neutron dose in varying neutron fields that are difficult to obtain using other means.[14]

## *III. Summary*

Homeland security requires low-cost, large-area detectors that can locate and identify weapons-usable nuclear materials and monitors for radiological isotopes that are more robust than current systems. Potential improvements can result from recent advances in electronics materials and nanotechnology, specifically nano-particle composite materials, organic semiconductors and inorganic quantum dots. This overview presented some recent initiatives in radiation detection using these new materials in the design of new device structures. Detector improvements demand not only new materials but also enhanced data-analysis tools that reduce false alarms, thereby increasing the quality of decisions. Additional computing power on hand-held platforms should enable the application of advanced algorithms to radiation detection in the field, reducing the need to transmit data and thus delay analysis. The need is for detectors that are bigger and more robust, not to mention cheaper, yet approach the theoretical efficiency and resolution limits of the component materials more closely than existing materials.

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## *Footnotes*

[1] *U. S. Customs and Border Protection:*

*http://www.cbp.gov/xp/enforcement/international_activities/csi*

[2] *http://abcnews.go.com/sections/wnt/DailyNews/sept11_uranium020911.html*

[3] *http://abcnews.go.com/sections/wnt/PrimeTime/sept11_uranium030910.html*

[4] *Liz Sidoti, ABC News, http://abcnews.go.com/Politics/wireStory?id=1774306*

[5] *Ed McKigney et al., "Composite Scintillators for Radiation Detection and Nuclear Spectroscopy," to be presented at SORMA XI and published in the proceedings (2006)*

[6] *Ian H. Campbell and Brian K. Crone, "Quantum dot/organic semiconductor composites for radiation detection," Advanced Materials, Vol. 18, Issue 1, pp. 77-79*

[7] *J.N. Ullom et al., "Development of Large Arrays of Microcalorimeters for Precision Gamma-ray Spectroscopy," IEEE-NSS conference, Puerto Rico, October, 2005*

[8] *Bill Murray et al., Patent US6781134*

*http://www.lanl.gov/news/releases/archive/03-150.shtml*

*http://www.lanl.gov/opportunities/techtransfer/dsp_technology.php?id=162*

[9] *Gary Gardner et al., "Miniature Self-contained CdZnTe Gamma Spectrometer for use in Unattended Nuclear Material Monitoring," IEEE-NSS conference, Puerto Rico, October, 2005*

[10] *Gary Gardner, private communication, March (2006)*

[11] *Bill Myers et al., "A Tagged Active Neutron Interrogation System (TANIS) For the Detection of Fissile Material in Cargo," 2007106DR, Directed Research proposal for the Laboratory Directed Research Development effort (2006)*

[12] *John Blackadar et al., RadAssessor, LA-CC-04-126 (2006)*

[13] *Robert Estep et al., "Methods For Generating MBS (Material Basis Set) Basis Spectra For Use In Mass-Produced Handheld Monitor Systems," Proc. INMM 46th Annual Meeting, July 10-14, 2005, Phoenix, AZ*

[14] *Mark Nelson, LANL, private communication, March (2006)*

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# COMMENTARY

## We Taught Them to Fish and They Are

*Harold M. Agnew*

There is an old saying if you give a person a fish he has one meal but if you teach him to fish he will have many meals. Many of us who opposed the Non Proliferation Treaty (NPT) called it a license to steal because it provides a signing nation any and all technical nuclear help it requests so it can develop its own completely peaceful nuclear capability. In return, the nation agrees not to use the technology to develop a nuclear weapon capability. But upon giving six months notice, after receiving all the relevant nuclear technology, it can do whatever it wishes with the technology which it has received with no penalty. It can really become a complete nuclear "fisher-man."

Iran since signing the NPT has received extensive nuclear technology available under the NPT. One aspect of the peaceful use of nuclear technology is to develop nuclear reactors for electrical power. Most nuclear reactors today use uranium which has been enriched to a few percent. So a nation wishing to develop nuclear reactors either has to contract for enriched uranium or develop the technology to enrich natural uranium to at least a few percent itself. Several reactors have been built and operated very well on highly enriched (weapons grade) uranium and even plutonium. But once a nation has developed the capability to enrich uranium to a few percent it is relatively easy to enrich the material to weapons grade. This is the concern today with regard to Iran.

If one is concerned with global warming and appreciates the need for electrical power, especially in developing nations, then one should support the development of safe modern nuclear power reactors in lieu of burning coal, oil or gas, all of which release carbon dioxide. In the case of coal fired plants, there is also release of mercury, lead, and even uranium to further pollute the atmosphere and contribute to global warming. If Iran develops its enrichment capability solely for low enrichment reactor fuel and allows full IAEA inspections then we should encourage its plan to develop nuclear electrical power and set an example for the Middle East nations.

In any event, if it doesn't allow full IAEA monitoring of its nuclear endeavors, just remember that the NPT allowed it to become a nuclear fisherman.

But if it does become a nuclear weapons capable nation, we should not follow the path which we followed with Pakistan and India. Sanctions are of no use. The real problem with new nuclear capable nations is that of preventing unauthorized use of their weapons. Their weapons are not under physical control of the nation's president or king. Somewhere a colonel or lieutenant or sergeant has actual physical control of the weapons. Until the early 70's even the U.S. President did not have a positive control system over our nation's nuclear weapons. If a nation develops a nuclear weapons capability, we should offer the technology to guarantee no unauthorized use. But under the NPT this is not allowed according to DOE legal council. So much for the license to steal.

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*Harold Agnew was born in Denver, Colorado in 1921 and is now an adjunct professor at the University of California at San Diego. In 1942, he was part of Fermi's group that constructed, and then operated, the first nuclear reactor. He subsequently moved to Los Alamos for work on the development of the atomic bomb. There, he became the Weapons Division leader (1964-1970), and then Director of LANL (1970-1979). He was scientific advisor to Supreme Commander Europe at NATO (1961-64), a member of the President's Science Advisory Committee (1965-73), and a White House science councilor (1982-89). He received the E.O. Lawrence Award in 1966 and the Enrico Fermi Award of the Department of Energy in 1978, and is a member of both the National Academy of Sciences and the National Academy of Engineering.*

# LETTERS

## More on Strawbale Construction

The January 2006 article in the FPS newsletter on strawbale construction summarized very nicely many of the general principles involved in using that material for building a house. I would like to add just a few additional points that pertain to a strawbale house my wife and I finished building a year ago.

To start with, the opportunity for encouraging community relations should not be underestimated when undertaking a project of this type. On the one hand there is the actual strawbale party one can have to invite neighbors to take part in the building of the house. At least in my experience, there was a tremendous amount of interest among various friends and acquaintances to help out just because it looked like it might be fun. Second, the qualities of the house have provided many opportunities to educate and to learn more about energy efficiency, embodied energy, solar energy and green building practices. It is also important to note that the initial building cost of the house was about $90/sq. ft., less than average for new construction.

An important goal of our house was to have a dwelling that uses less energy than a typical building. After one year of data, the result is that this house uses about 75% less electricity and natural gas than an average house in the Midwest. Although not a zero-net-energy house, the energy bills for the house have been the envy of the neighborhood this winter. While not for everyone, there are many reasons to consider strawbale construction as a reasonably sustainable, environmentally-friendly building technique.

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## Alternatives to "Global Warming"

In global warming, we do not usually find conclusions being supported by tests, with the standard deviations shown with each test result. And with such a science as global warming, there are many alternant possibilities. We do not often find tests to clearly indicate which of all these alternant explanations are the most viable, along with their individual error analysis.

When I see someone who calls their work scientific, and they have no tests and no error analysis to confirm their position, I do not accept too much of what they have to say. For these many reasons, I support the sentiments of Gordon Freeman as was expressed in a letter in your P&S April issue.

What we can assume is that this earth has previously seen rising and falling temperatures. And there is every reason to assume it is going to occur again no matter what man might do. Looking at the size of this earth, it would be unexpected for us to be able to actual control anything this earth does. For us to try to do this, by spending billions of dollars, by causing us all a lot of pain and suffering, by destroying much of our normal businesses, would very likely all be for nothing.

As Freeman wisely pointed out, what we should do, would be to prepare ourselves to make the most of any change that does occurs. If we have any money at all, let it be to produce better crops that can be grown under warmer conditions. We could use such crops whether global warming occurs or not. Let us find the best way to survive any rising of the oceans. Such studies will be useful no matter what really happens.

This way of responding will be beneficial, no matter what else might happen. Let us maximize the benefits of any efforts we make. We should not try to solve a problem when we do not really know that it is a problem. Why purposely hurt ourselves, just by guessing that it might be helpful.

We do live on an earth where there are yet vast areas that are too cold. Thus, if and when the earth warms up, there has to be as much good done as harm up to the point where there are no more areas that are too cold. We must know what all the options might be, and know the true uncertainties that might exist for each option that is available. I know that we can do better than going around hurting each other. This is not the way to be civilized.

I thank Freeman for his insights. I hope we are able to understand his better approach.

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# NEWS

## President Bush and Governor Schwarzenegger Crown Art Rosenfeld "Father of Energy Efficiency"

The APS Forum on Physics and Society has long recognized that Art Rosenfeld fathered the discipline of "enhanced end–use efficiency of energy." Many of us are proud to call Art one of the very best physicists to improve society. After the oil embargo of 1973–74, Art established the Center for Building Sciences at Lawrence Berkeley Laboratory, which created energy efficient light bulbs, DOE-2 building analysis, reflecting roofs, clean water using florescent tubes, coolth-of-the-night into heat-of-the-day buildings, the analysis that allowed appliance energy standards to save 75% electricity in refrigerators and great savings in all appliances, and much more. In 2001, the U.S. National Research Council estimated that the US saved $15 billion (1999 USD) from electronic ballasts and $8 billion from low-emissivity windows. The DOE–2 computer tool has saved 22 percent of building energy when compared to not using the tool.

Long ago Henry Kelly realized Art's greatness by defining an Art as one A/R deltaT (equals heat flow, dQ/dt). Over the years Art was given the APS Szilard and DOE Carnot awards. On April 27, President Bush gave the DOE Fermi Award to Art with the statement "His vision not only underpins national policy but has helped launch an industry in energy efficiency." This was followed by Governor Schwarzenegger, who proclaimed April 28th as "Arthur Rosenfeld Energy Efficiency Day." The proclamation had seven whereases, including "Whereas, his work sparked the global energy efficiency movement and reminds Californians to never take our resources for granted." On April 28, energy luminaries came from near and far to celebrate Art's 80th birthday. Not to be outdone, the California State Assembly and the Public Utility Commissions also passed resolutions praising Art. A good time was had by all, as the Chairs of the Public Utility Commission and the California Energy Commission lauded Art, who was appointed by Governor Davis and reappointed by Governor Schwarzenegger.

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## NRC Report Critical of NASA's Plans for Science

"The program proposed for space and Earth sciences is not robust; it is not properly balanced...and it is neither sustainable nor capable of making adequate progress toward the goals that were recommended in the National Research Council's decadal surveys."

— new NRC report, *An Assessment of Balance in NASA's Science Programs*

Based on its current budget request and future funding proposals, NASA's science programs can neither be considered robust nor sustainable, an expert National Research Council panel has concluded. It calls for NASA to "move immediately" to correct the funding imbalances in its small missions and research and analysis programs; to preserve important microgravity, life and physical sciences research needed for long-duration human spaceflight; to better evaluate the costs of current science missions; and to seek input on these issues from the science community through its advisory committees "as soon as possible." It further calls on Congress and the Administration to recognize and address the "mismatch" between NASA's responsibilities and its available resources, and urges that science funds be isolated so that they are not used to make up shortfalls in the human spaceflight program.

The panel's report, released on May 4, finds that at the time the president's space exploration initiative was announced in 2004, NASA's space and Earth science programs "were projected to grow robustly from about $5.5 billion in 2004 to about $7 billion in2008." But, it says, NASA's current plans for those programs "differ markedly from planning assumptions of only 2 years ago. "The FY 2007 request for the Science Mission Directorate is approximately $200 million less than the FY 2004 appropriation, and NASA proposes cutting the directorate's total available funding in the 2007-2011 period by $3.1 billion below what was projected in last year's budget request. Additionally, the report notes that between the FY 2006 projection and the FY 2007 request, some funds that had been designated for the Science Mission and Exploration Systems Mission Directorates were shifted to the Space Operations Mission Directorate "to compensate for the projected shortfall in support for the shuttle and the ISS [International Space Station] programs."

NASA Administrator Michael Griffin testified on Capitol Hill this spring that NASA "cannot afford to do everything that our many constituents" want it to, and that his highest priorities were to keep the shuttle operating while developing a Crew Exploration Vehicle and to complete the space station (seehttp://www.aip.org/fyi/2006/034.html).

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# REVIEWS

## Nuclear Shadowboxing, Vol. 1: Cold War Redux

*By Alexander DeVolpi, Vladimir E. Minkov, Vadim E. Simonenko and George S. Stanford, Fidlar Doubleday, Kalamazoo, MI, 2004.*

Recollections of the Cold War grow more distant with time and we are constantly losing our prospective. When our politicians tell the public that we need to go to war with Iraq because of unbearable danger, which can come in the form of a "mushroom cloud" (C. Rice) or in "45 minutes" (A. Blair), and the public goes along, we forget that this was the plight of most of humanity for more than thirty years, and it was real, not imaginary. As time passes, the attitudes of the participants on the winning side become more and more gung-ho.[1] Of course, history is always written by the victors, but if our recollections of the Cold War were true, then why were US policy-makers occupied for 50 years by confrontation with what turns out to be a piffling military power[2] run by pathetic incompetents?[3] Or was the far left right all along in suggesting that the Cold War was an American ploy to keep its vast military-industrial cabal from expiring?

The book "Nuclear Shadowboxing" written by a collective headed by Alex L. Volpi, goes far to dispel that persistent but self-contradictory mythology. In particular, I would recommend the book to history teachers in order to present a more balanced picture of the Cold War and its consequences to their school students all over United States, including my son. The book contains contemporary information free from the post-Cold War stratagems in service of current political agendas in Washington.

The authors' design to expose the Cold War in all its multi-faceted variety was over-ambitious from the start and could not be free from certain shortcomings. First, it is not clear who are the potential readers of the book; second, the organization principle of the book is obscure . If the readers are physics and engineering professionals, they do not need a discussion of U235 or the critical mass (Chapter I). If the readers are high school students and teachers of history, then the book needs to be structured to help them, for instance by arranging it alphabetically, like an encyclopedia. As presently written, it appears to be a thematically-organized handbook, which should mix popular introductions and lore with more specialized but condensed treatises written by experts in the narrow field of each chapter, but it does not. Yet, I doubt that the authors actually had that in mind.

Because of poor structuring, some of the material is repetitive. For instance, the material on the neutron bomb from Section C, Chapter III ("The Nuclear Priesthood") is repeated almost in the same terms in Section B, Chapter IV ("Arms-Control Issues") and this is only one example of dozens. I could learn who Herbert York was from at least three places in a book; one would be sufficient. Maybe, for a few prominent personalities, a short biographical note would be more appropriate than parts and parcels of information scattered here and there around the text.

Some of the book's statements are plainly stupid (or racist?): "The economic well-being of the Russian population is considered secondary. President Putin understands well that [Great Power] status cannot be returned through great economic achievements; there is no widespread entrepreneurial spirit of the Western type in Russian culture" (p. xii). For most of the charts and tables in the main text but, somehow, not in the Appendices, the references are absent or incomplete, making it unclear whether authors display their own estimates or somebody else's data. Text box inserts have different formats. The book does not have pass-through page numbers. The contents of Volume 1 and the Volume 2 are printed in different fonts. And the list of structural deficiencies can be extended.

However, the authors reassure us that this is not the final version (Version A3, as they call it). Even in its current, imperfect and awkward form—and what else would one expect from a first undertaking of this magnitude completed without public financing—"Nuclear Shadowboxing" deserves to be on the shelves of every public and school library in the United States. I look forward to the second volume with great interest.

*References*

[1] *See, e.g. Chris Adams,* Inside the Cold War: A Cold Warrior's Reflections, *University Press of the Pacific, 2004.*

[2] *David Miller,* The Cold War: A Military History, *St. Martin's Press, 1999. William E. Odom,* The Collapse of the Soviet Military, *Yale University Press, 1998.*

[3] *See, e.g., R. N. Lebow and J. G. Stein,* We All Lost the Cold War, *Princeton University Press, 1994, with a liberal standpoint, and a gamut of books written by Timothy Naftali and Konstantin S. Pleshakov from a neocon prospective.*

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## Reappraising Oppenheimer, Centennial Studies and Reflections

*Edited by Cathryn Carson and David Hollinger,University of California, 2005, $14, 413 pages, ISBN 0-9672617-3-2*

Recently there have been at least nine books devoted to the life and career of J.Robert Oppenheimer as 2005, the hundredth anniversary of his birth, arrived. The present volume is a collection of 18 essays, mainly by historians, covering different periods and interpretations of the Oppenheimer story. It originated from a conference held at the University of California in 2004.

The first two essays deal with Oppenheimer as a physicist before World War II. At Berkeley and CalTech he started the first US school of modern theoretical physics; before that all the best students, including Oppie (or Opje) as he was called, went to Europe to study. It is often said that he made no major contributions to theoretical physics; however, as described in some detail by Karl Hufbauer, his papers with Volkoff and Snyder showed that collapsing stars could lead to black holes, the great importance of which was only realized some 50 years later. In fact there was some other important work, which has been reviewed in an article by John Rigden[1].

The next three essays are devoted to the issue of whether Oppie was ever a member of the Communist Party (CP), a claim made by Greg Herken in a recent book[2] and in an essay here. In a long essay Barton Bernstein goes over all the evidence and discusses the general question of how to evaluate evidence. What has always been clear is that Oppie was a leader of a small group of intellectuals who met regularly between 1938 and 1942 and who followed the CP line. There is no evidence that he had a CP membership card or that he paid dues. The question as to whether he was a "closet Communist" ends up seeming almost semantic. A later essay by J. L. Heilbron suggests that in this same period Oppie's philosophy and even his physics style was greatly infuenced by his immersion in Hindu writings.

A most intriguing aspect of Oppie's career is his transformation from a prototypical outsider, a left-wing theoretical physics professor, to an insider leading a wartime laboratory under the overall direction of Gen. Leslie Groves. A fascinating essay by David Holloway compares Oppie's career to that of Julii Khariton who led the development of the Soviet bomb under the direction of Lavrenti Beria.

Five essays deal with the period between the end of the war and the infamous 1954 "trial" that stripped Oppie of his security clearance. Overall one gets the impression of an uneasy insider in a government in which the military had the real power. The Acheson-Lilienthal plan for international control, much of which was written by Oppie, was sabotaged by the appointment of Bernard Baruch as negotiator[3]. However after that, according to an essay by J. G. Hershberg, Oppie appeared as a hard-liner, in contrast to James Conant, and considered any agreement with the Soviets was impossible. As head of the General Advisory Committee (GAC) he opposed the H-bomb, not because it was "evil" as GAC members Fermi and Rabi wrote, but because the funds would be better spent building more useful fission bombs. Once the H-bomb proved "technically sweet" he never opposed it again.

As a participant in Project Vista in 1951, discussed in an essay entitled "Killing the Messenger" by W. Patrick McCoy, Oppie strongly recommended the development of tactical nuclear weapons, which led to the suppression of the project's report by the Air Force. It was the military's desire to eliminate unwanted scientific advice that led to the 1954 Oppenheimer "trial." In spite of Oppie's self-deprecation and naming of names at the hearing, he was denied his clearance. Richard Polenburg suggests that had he been cleared he would have been condemned by many for his apparent cooperation with his persecutors rather than having been heralded as a victim.

The last six essays relate Oppie to the historical and cultural context of his times and compare the images of him in films and books. He appears as a symbol in various ways: of the Faustian bargain of the scientist; of the modern Galileo, victim of the McCarthy era; of the tragedy of the physicist who finds himself "a stranger and afraid in this new world of his own making."[4] Yet, as Hollinger writes in the Afterword, "there is in the literature a persistent 'almostness'": Each symbol almost works but not quite. There is no simple J. Robert Oppenheimer.

*Footnotes*

[1] *John Rigden,* Scientific American*, July 1995, pp 76-81.*

[2] *Gregg Herken,* Brotherhood of the Bomb*, (Henry Holt, 2002).*

[3] *See, for example, Gregg Herken,* The Winning Weapon*, (Vintage, 1982)*

[4] *Lincoln Wolfenstein, "The Tragedy of J. Robert Oppenheimer,"* Dissent *Jan-Feb 1968, pp 81-85*

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