Vol. 31, No 2 April 2002

PHYSICS&SOCIETY

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

IN THIS ISSUE

Statement From the Chair

It has been half a year since that hellish day in September which brought to our doorsteps the murderous anger of those who hate what the US values and represents. In the brief span of tens of minutes, our sense of our place and role in the world -- how we define ourselves personally, politically, and professionally – changed profoundly.

As physicists in the US, we have proudly characterized ourselves as working in a borderless world of free inquiry, inviting colleagues from all lands to join in this humanizing avocation, and using this fellowship of the mind as a means for greater sharing and understanding among all peoples. Yet at the same time, our science has been sustained by an imperative from our leaders to enhance the safety of our country through the application of knowledge to national security, be it military or economic. Many physicists are keenly attuned to this balancing act in which we navigate between openness without bounds and patriotic duty. Recently, our leaders – our neighbors, our mail carriers(!) – have renewed the national security imperative. The war on terrorism is being fought on several fronts, but the message has been delivered that this war will be waged not only with guns, but also technology. At home, as we work to protect ourselves from threats known and unknown, we have seen a remarkable deployment of physics-based technologies by law enforcement, airports, and postal distribution centers. Clearly, physicists who are so inclined will have the opportunity to align their professional objectives with the call to serve, by applying their skills to the national defense. Yet we all should continue to strive to maintain the balance that humanizes our profession, works toward peace, and shapes our world into an open and livable place.

It is in this context that I conclude with much pride my year as Chair of the Forum, for we have made progress in strengthening the influence of the Forum as a locus for connecting physics and physicists to the society we serve. Specifically, we have strengthened our position within the APS through the APS Council's approval of a designated FPS seat on the APS Panel on Public Affairs. The person filling this position will be elected by the Forum membership, thus providing a grass-roots FPS voice on POPA as it advises APS on a broad range of important issues at the intersection of physics and policy.

The Forum also continues to educate and shape the policy debate through our highly-acclaimed newsletter, *Physics and Society*. P&S is a unique venue for physicists to publish their analysis on a range of issues in a manner that is scholarly, accessible, and broadly disseminated. Recognizing the importance and potential of P&S, the Forum Executive Committee continues a vigorous discussion on the proper balance between paper and electronic publication. We have also been working with APS to broaden access to P&S through more visible placement of links to P&S from the APS web site. Given the scholarly nature and outward perspective of P&S, we feel strongly that access to and visibility of P&S should and will improve in the coming months. Success should also provide some relief from our concerns about the negative impact of the transition to 50% electronic publication. I am happy to report that the APS leadership has strongly supported our efforts and is working with us on a solution.

We have also made progress in connecting the interests and activities of FPS to those of other APS units, primarily the Forum on Education, the Forum on Industrial and Applied Physics, and the new Forum on Graduate Student Affairs. We have done this mainly through co-sponsorship of invited sessions at the APS March and April Meetings. These sessions,

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

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along with our newsletter, are at the heart of our intellectual contribution to the APS, and we continuously strive to sponsor or co-sponsor interesting and timely symposia.

As Program Chair and Chair of the Executive Committee, I encouraged different perspectives on invited symposia. My favorite was "Physics in Seattle/The Seattle in Physics," where we invited speakers to demonstrate the importance of physics to the Pacific Northwest (volcanoes and earthquakes, and the physics of foam – think capuccino) or discussed how the region influences what physicists do (work at Microsoft or Boeing). This slightly whimsical session attracted great speakers, good audience, and some good coverage in the press, and it illustrated the broad influence of physicists at work.

When I ran for Chair-elect two years ago, I expressed concern for the health of physics. My concern was not so much for our intellectual health, for if the programs of the March and April Meetings and the various unit meetings are any indication, physics remains a vital and nimble source of knowledge and insight with an ever-expanding sphere of application. My concern is more for the health of our field as an institution, particularly on campus. Specifically, I am deeply troubled by the precipitous fall off in undergraduate physics majors and what this portends for the future of the profession. In my opinion, the exodus of students is symptomatic of a growing perception that there is a gap between 1) physics education and applicability, 2) the expectations and goals of students, and 3) the needs of society, employers included. I took office with a goal to help change this perception. My focus has been on physics departments who, as the main social unit of the physics community, have the power to tackle this perception problem directly at it source. I have argued that physics departments need to re-enlighten students, parents, employers, and policy makers about the societal necessity of physics and physicists; and I have urged that departments need to enlighten and persuade by example and outreach.

In the post-September 11 world, we have the opportunity to strengthen our message to students and society at large in more profound ways. Our field provides us with the intellectual tools and international colleagues to work for peace and security through applications of knowledge and human outreach. The Forum has an important role to play as we enter this next year. Many issues beyond terrorism are also on the table, and these require the careful analysis of physicists: climate change, arms control, missile defense, and energy production and conservation, to name just a few. Through P&S, symposia, outreach, and now POPA, we have many instruments at hand to influence the spectrum of policy debates.

It has been a true honor to serve APS and the Forum. I will value this next year as past-Chair, for I will have the privilege of working with your new Chair, Laurie Fathe, and her future successors, Andy Sessler and your newly-elected Vice-Chair, Michael Rosenthal. I thank you for this opportunity.

Bo

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ELECTION RESULTS

The winners of the 2002 Forum on Physics and Society elections are as follows:

Vice-Chair: Michael Rosenthal

Executive committee: Antonia Herzog, Tina Kaaarsberg.

The race was very close – though non-Floridian – and we hope that the non-winning candidates for this year's elections will offer themselves in future elections as well as for non-elective services to the Forum. We are all grateful to our Secretary-Treasurer, Andrew Post Zwicker, and our Electronic-Media-Editor, Marc Sher, for conducting another smooth, efficient election.

ARTICLES

Advanced Fast Reactor: A Next-Generation Nuclear Energy Concept

Yoon I. Chang

Adapted from a talk delivered at Argonne National Laboratory on September 28, 2001

There is a growing international consensus that to be broadly acceptable for the 21st century and beyond, the next-generation advanced reactor system must meet these five criteria:

1. It must provide a long term energy source not limited by resources.
2. It must be passively safe, based on characteristics inherent in the reactor design and materials.
3. It must reduce the volume and toxicity of nuclear waste.
4. It must keep nuclear materials unsuitable for direct use in weapons.

It must be economically competitive with other electricity sources.

The only currently known concept that can meet all five requirements simultaneously is the Advanced Fast Reactor (AFR), a system that includes a closed fuel cycle based on pyro-processing.

The AFR concept is being developed at Argonne National Laboratory, as an extension of earlier work done on the Integral Fast Reactor (IFR).[1] That work was undertaken specifically to resolve some pressing technical issues in safety, waste management, nonproliferation, and economics. Also important, however, was the fundamental fact that the efficient utilization of uranium resources is crucial to the long-term sustainability of nuclear energy.

Energy is the engine of the economy, and hence of prosperity. Figure 1 shows that in North America, we enjoy a very high per-capita GDP and a very high electricity generating capacity.

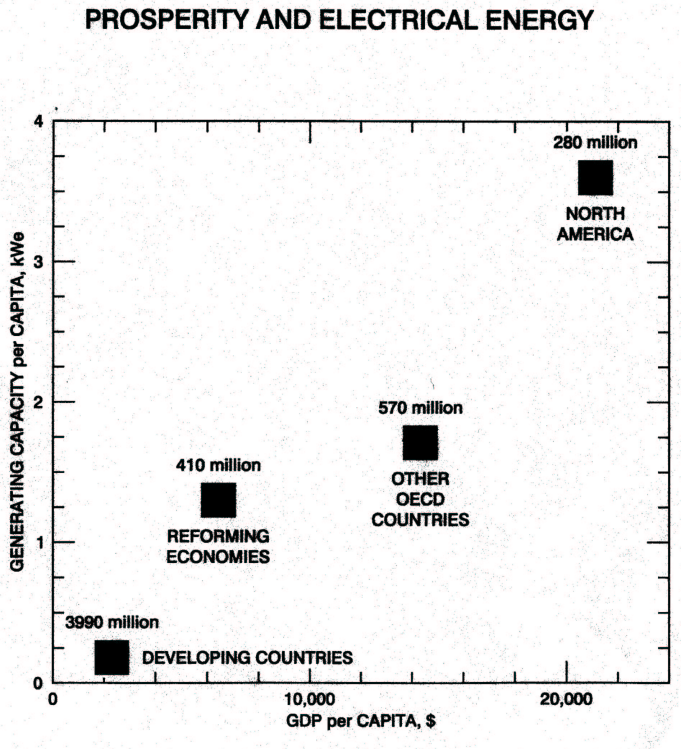

Figure 1

The per-capita electrical energy consumption in other OECD[2] countries is only half of ours, but it is very important to note that it is still an order of magnitude higher than that of more than three quarters of the world's population.

As we start the new millennium, growth in energy demand will become an acute problem, particularly outside North America. To meet the energy challenge, we have to exploit all energy options, including renewable energy sources. But the potential contribution of renewables is inherently limited. Fossil energy sources (coal, oil and natural gas) are the most readily available, but they raise concerns about global climate change and other forms of environmental pollution.

Nuclear energy today contributes almost 20% of the electrical energy around the world. Over the past decade, nuclear plants have improved their operational reliability, safety records, and economic competitiveness, and nuclear energy is now recognized as the only power technology that can generate large amounts of electricity without producing greenhouse gases and other atmospheric pollutants. It is the technology of choice to meet the ever-expanding demand for electrical energy.

But today's commercial thermal-spectrum reactors do not have the characteristics necessary to make nuclear a long-lasting energy source. Even with reprocessing, as is done in Europe and Japan, such reactors can utilize little more than one percent of the total energy potentially available from the mined uranium.[3] The U.S. once-through mode extracts considerably less than one percent. The unused energy is discarded as tailings in the enrichment process or as spent-fuel waste.

On the other hand, fast-spectrum reactors can utilize essentially all of the uranium resources through recycling (and breeding, when called for in the future), making nuclear energy resources comparable to all fossil energy sources combined.

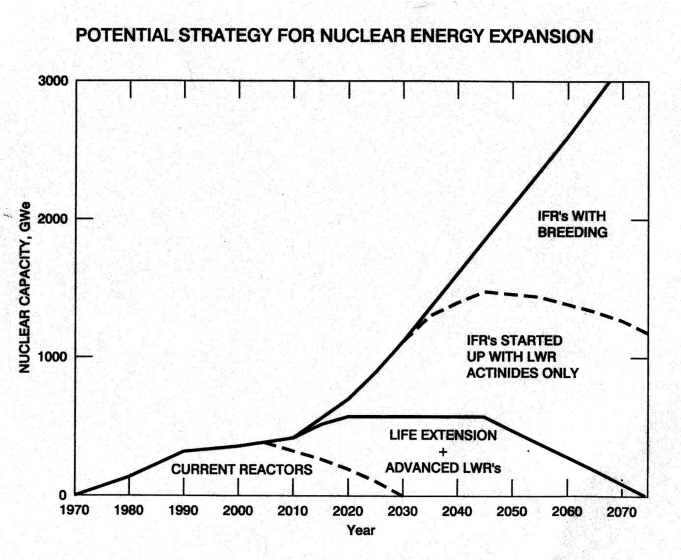

Figure 2

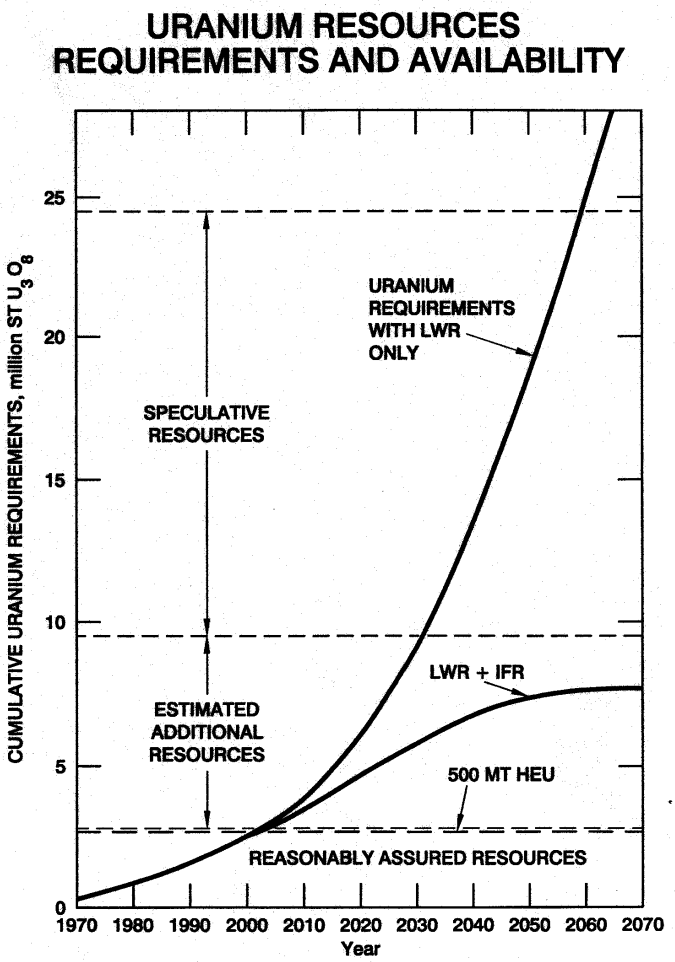

Figure 3

Uranium resources. To explore the uranium resources issue, let us look at the potential scenario for nuclear energy expansion that is depicted in Figure 2. The figure assumes a nominal growth in the next 10 years, followed by one-third of new demand to be met by nuclear, which translates to growth by about a 5% per year, through 2030, then a linear growth of 50 GWe/yr. This is a conservative assumption, to illustrate the resource implications.

The current total world-wide nuclear capacity is 350 GWe. We assume that life-extension of current reactors and 560 GWe of new LWRs will be the second-generation providers of nuclear energy. The AFRs that can be started up with actinides recovered from LWRs are shown by the dotted line; the remaining demand will have to be met by breeding in AFRs.

It is widely believed that there is a lot of cheap uranium, but this is illusory. Most utilities have long-term uranium supply contracts. When there are gaps in these long-term contracts, small quantities are purchased in the spot market. At present five hundred tonnes of highly enriched uranium from excess Russian weapons material are being blended down, flooding the uranium spot market. But the entire 500 tonnes represents only about a year and a half's-worth of uranium for the reactors currently operating, which has no significance in the global context, as a glance at Fig. 2 reveals.

Figure 3 shows that, with the AFR introduced, the uranium requirements can be capped well below the *estimated additional resources* category, which is, in effect, the limit of uranium resources that could be economically recovered to feed a fuel cycle based on thermal reactors. But if we continue with that

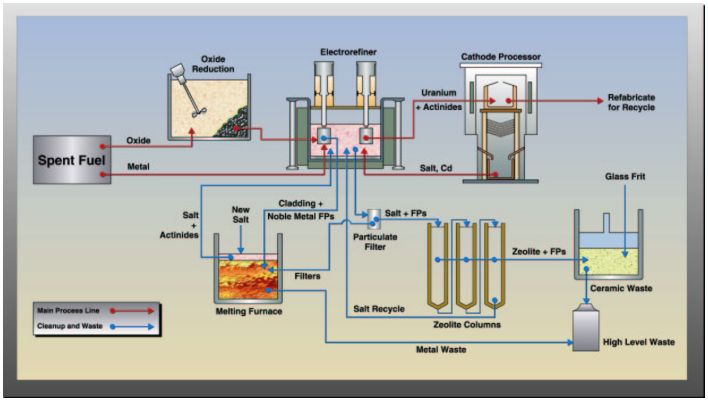

Figure 4

type of reactor, the uranium requirements rise even beyond the *speculative resources* category, which consists of uranium that is thought to exist mostly on the basis of indirect evidence and geological extrapolations. As the term implies, the existence, size, and recovery cost of such resources are guesses. (There is also a great deal of uranium in sea water, but it is so dilute that it is economically out of reach for use in the very inefficient thermal reactors.)

Safety. Today's reactors are very safe, but if there are going to be thousands of reactors around the world, they should have a higher level of *passive* safety, that is, safety should be inherent in design and materials, and not dependent on engineered safety systems or operator actions. The AFR can be designed for such, as was demonstrated in two landmark tests conducted with the EBR-II experimental reactor in 1986.

Those tests showed that even most the severe accident-initiating events would not lead to reactor damage or release of radioactive material. In one test, we shut off the power to the pumps that circulate coolant through the core, and in the other we cut off all active heat removal. In both tests the reactor safely shut itself down without human or mechanical intervention. In any other type of reactor, either of these occurrences would initiate a reactor-disabling accident.

Passive safety is uniquely achieved in the AFR by combining three factors:

- *Sodium coolant.* Because sodium has a very high boiling temperature, the cooling system can operate at essentially atmospheric pressure. Sodium is also non-corrosive to structural materials used in the reactor. These unique characteristics of a sodium-cooled system result in superior reliability, operability, maintainability, and long lifetime, all of which contribute to low life-cycle costs.
- *A pool type of cooling configuration.* The AFR core sits in a large pool of liquid sodium, combining high thermal inertia with convective removal of decay heat in the event of loss of forced coolant flow. Most of the previous fast-reactor designs used a cooling loop, which does not have those safety advantages.
- *Metal fuel, rather than oxide.* This is a major safety advantage. In all reactors there is a A Doppler reactivity effect, which causes the reactivity to increase if the temperature rises. Metal's high thermal conductivity means that there is only a small temperature gradient along the radius of the pin, so that there is much less heat stored in the fuel. In the AFR, as a result, there is only a small temperature rise upon loss of coolant, limiting the Doppler reactivity rise.

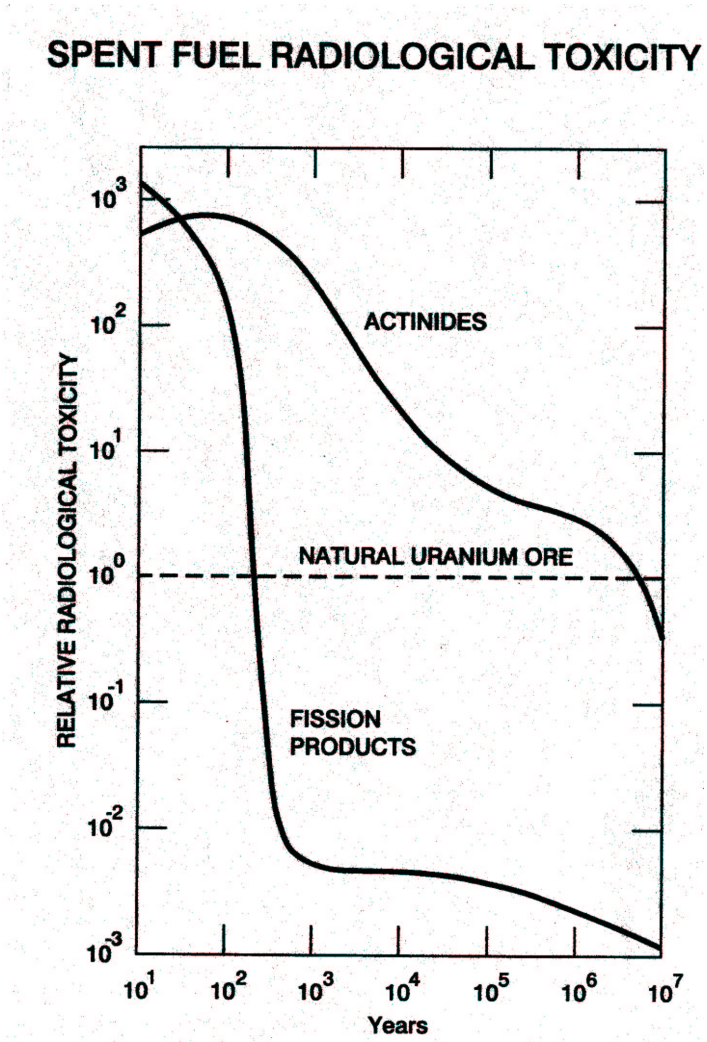

Figure 5

The fact that the fuel is metallic is what makes it practical to use pyrometallurgical processing (pyroprocessing for short, discussed next).

Pyroprocessing. The most innovative feature of the AFR is pyroprocessing, which promises revolutionary improvements in waste management, nonproliferation characteristics, and economics. With oxide fuel, reprocessing is done by the PUREX process, which produces chemically pure plutonium. Pyroprocessing not only does not do that, it cannot. This is a big part of the AFR's overriding non-proliferation advantage.

Figure 4 is a simplified pyroprocessing flow sheet. The key element of pyroprocessing is electrorefining. Spent fuel rods chopped into small pieces are loaded into the anode basket. One type of cathode recovers uranium and the other one recovers all other actinide elements together: Pu, Np, Am, Cm, and also some U.

The anode basket, which retains the cladding hulls and noble-metal fission products, is melted to produce high-level waste in metallic form.

The electrolyte salts, containing most of the fission products, are passed through zeolite columns where the fission products are immobilized by incorporation into the zeolite molecular structure through ion exchange and occlusion. The zeolite powder is then mixed with glass frits and melted at high temperature to form a stable ceramic waste form called sodalite.

Originally developed for the IFR, pyroprocessing works with metallic fuel. However, with the addition of a front-end step to reduce the oxide to metal it can treat spent fuel from today's commercial reactors.

Waste. The radioactive isotopes in spent fuel are of two types: fission products and actinides. The fission products as a group have an effective half-life of about thirty years. As shown in Fig. 5, it take only about 500 years for their toxicity to drop below that of the natural uranium ore from which their parent atoms came.

The actinides, on the other hand, have long half-lives, and their toxicity level is orders of magnitude greater for millions of years. In pyroprocessing, the actinides are easily recovered and recycled back into the reactor. This reduces the effective lifetime of the waste from tens of thousands of years to a few hundred, and meanwhile energy is generated by fissioning the actinides.

A repository is still needed, but its performance specifications can be much less stringent without the long-lived actinides. Furthermore, the repository's capacity is increased substantially because the long-term heat source is eliminated. And the disposal site does not become a geological plutonium deposit, waiting to be mined by a would-be bomb-maker in the distant future, when the isotopic suitability of the plutonium for weapons will have improved considerably.

Nonproliferation. The nuclear materials in the AFR's closed fuel cycle cannot be used directly in weapons, because pyroprocessing is unable to separate pure plutonium. Instead, the plutonium is mixed at all times with uranium, other actinides, and fission products. The mixture is protected against theft or unauthorized diversion because it is dauntingly radioactive and must be handled remotely with sophisticated, specialized equipment.

Pyroprocessing systems are compact, and the fuel-cycle facility can easily be collocated with the reactor, all but eliminating the need to transport nuclear fuel.

Further, AFRs could be used to eliminate the existing stockpile of separated plutonium as well as the huge and growing amount of plutonium *arisings*[4] that are in spent fuel now in storage. Figure 6 shows that the plutonium arisings can reach thousands of tons. With enough AFRs in service, the entire plutonium inventory could be put into the reactors and their collocated fuel cycle facilities, generating more energy in the process.

Economics. The economic competitiveness of the AFR has not yet been established. While the plant operating costs might be somewhat higher than for today's LWRs and cheap uranium, there are a number of offsetting factors:

- The unique properties of the sodium coolant, mentioned above, help lower the life-cycle costs.
- Improved fuel-pin design permits much higher burnup per fuel cycle, an important economic benefit.
- A major long-run economic advantage of the AFR is its ability to exploit essentially all of uranium's natural energy, about a hundred times as much as is possible with today's commercial reactors, even with recycling (see footnote 3).
- Because the AFR is so efficient and can use all the actinides for fuel, the large quantities of spent fuel and depleted uranium that are already on hand eliminate the need for further mining of uranium for many decades.

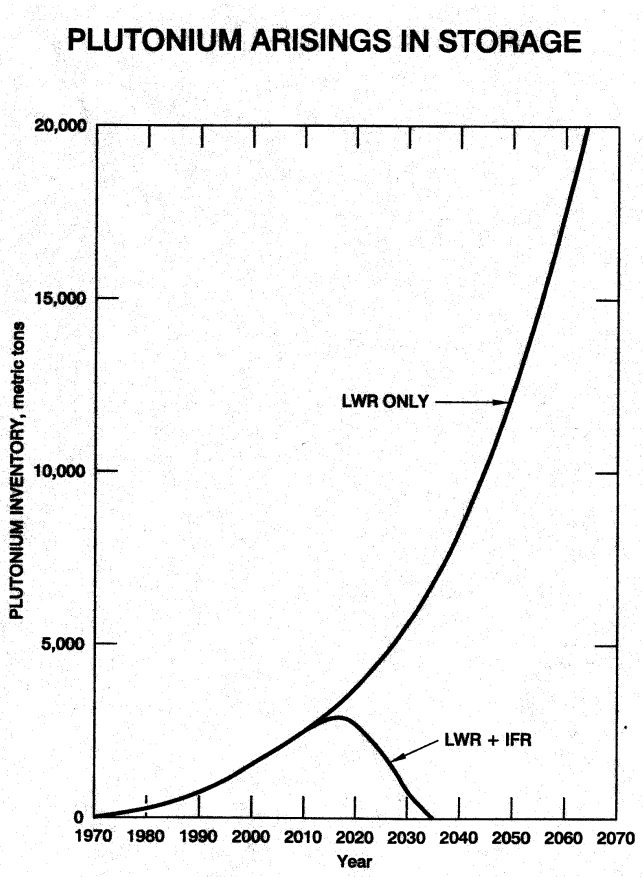

Figure 6

- With no uranium mining, there is no need for uranium milling.
- Even when resumed mining of uranium eventually becomes necessary, the need to identify and exploit high-cost uranium resources will be pushed far into the future.
- As observed above, waste disposal will be markedly cheaper.

A non-economic factor that deserves some weight is the nonproliferation value of the AFR, notably its ability to consume plutonium rather than create it. It can eventually create a world where the only existing plutonium is sequestered behind barriers and shielding in a highly radioactive power plant.

What's new and different? The idea of sodium-cooled fast breeder reactors has been around for many years, and so has elementary pyroprocessing. What's innovative in the AFR is a combination of technological advances and integration of techniques into a coherent system.

The fast reactor was passed over, early on, for reasons that were not always technical, and its technical problems were not fundamental, but part of the development process. More than twelve fast reactors of various types have been built and operated, with varying degrees of success. Standouts have been EBR-II in Idaho (a low-power, experimental reactor that ran for thirty years), Phenix and Superphenix in France, and BN-600 in Russia. Of those four, two are still running (Phenix and BN-600), and the other two were shut down for non-technical reasons.

Past breeder designs did not necessarily fail all of the five desiderata listed at the beginning of this piece. However, they did fall somewhat short on the second (passive safety) and the fourth (proliferation resistance), in both of which the AFR excels.

The novel proliferation-resistance features of the pyrometallurgical fuel cycle deserve emphasis:

- The collocation of reactor and reprocessing virtually eliminates, eventually, commerce in plutonium and transportation of spent fuel. In time, the only existing plutonium can be what is sequestered in AFR plants.
- The plutonium never has the chemical purity needed for weapons.
- The plutonium is extremely inaccessible, being at all times in an extremely radioactive environment behind thick shielding.

* * * *

Encouragingly, the near-term, high-priority benefits of pyroprocessing, nonproliferation, and waste reduction have been recognized by Vice President Cheney's National Energy Policy Development Group, which makes this recommendation: AIn the context of developing advanced nuclear fuel cycles and next-generation technologies for nuclear energy, the United States should reexamine its policies, to allow for research, development and deployment of fuel conditioning methods (such as pyroprocessing) that reduce waste streams and enhance proliferation resistance.

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[1] The AFR concept incorporates many of the features of the IFR, whose development was nearing completion when the program was terminated in 1994.

[2] *OECD*: Organization for Economic Cooperation and Development, consisting of 30 member statesC26 from the West, plus Australia, New Zealand, Japan, and Korea.

[3] It is impractical to recycle the fuel for thermal reactors more than two or three times, mainly because buildup of the higher actinide isotopes seriously degrades reactor performance.

[4] *Plutonium arisings*: the plutonium that is inevitably created in today's thermal-spectrum reactors.

Humanitarian De-mining and the Quest for Better Ways of Locating Buried Non-Metallic Objects

Surajit Sen and Ronald L. Woodfin

1. Introduction

Land mines are scattered across many countries. Most of these countries are poor and developing countries with meager resources to develop technologically sophisticated solutions for mine detection and removal. These mines are leftovers of conflicts, both large and small. Some land mines have been in place for as much as half a century. One such nation is Egypt, where millions of mines remain from World War II. Others have been placed very recently, as in some central African nations. Most of these mines are buried in soil at depths of less than 15 centimeters. The removal of these land mines is a mandatory requirement for using the affected land. Until they are removed, people are in danger and millions of acres of potentially productive land lies fallow and/or unavailable for grazing. Thousands of people including children are killed or injured each year by these mines.

Mines are difficult to detect and remove. De-mining is mostly a manual process. Metal detection and hand prodding remain the widely used approaches for locating mines. We still lack technological expertise when it comes to low risk, non-invasive, stand-off detection of mines. At the current rate of removal, several centuries will elapse before minefields become usable. The Ottawa Treaty of 1997 designed to ban the introduction of new mines has no effect on the existing minefields. Some nations (e.g., the US) have not joined the Treaty; furthermore, the absence of inspections and enforcement makes the possibility of violations rather likely.

Any nation that has a land mine problem has already been disrupted to its core by conflicts that led to the placement of mines in the first place. The presence of mines leads to loss of agriculture, as well as infrastructure such as roads, bridges and sanitation systems. Often there has been displacement of population with related problems of unemployed and homelessness. While these structural problems are visible and quantifiable, the social effects of the tragedy inflicted by land mines in the post-war period upon these citizens who are trying to reconstruct their lives cannot be measured and are seldom publicized.

In this article, we discuss the magnitude of the mine infestation problem and attempt an assessment of the state of mine detection technologies that are currently under development or are already available.

2. Mines, Mines and Mines ...

The number of land mines[1] that need to be cleared to restore land for civilian usage is not exactly known. There are more than 750 varieties of known land mines. The US GAO[2] and the International Campaign to Band Land mines estimate that there are some 127 million land mines that must be neutralized in as many as 88 countries. Some of the heavily mined nations with estimates of mines in parentheses in alphabetical order are:[3] Afghanistan (~ 10^7), Angola (1.5×10^7), Bosnia-Herzegovina (3×10^6), Cambodia (6×10^6), China (10^7), Croatia (3×10^6), Egypt (2.3×10^7), Eritrea (10^6), Ethiopia (0.5×10^6), Iran (1.6×10^7), Iraq (Kurdistan) (10^7), Mozambique (3×10^6), Rwanda (0.25×10^6), Somalia (10^6), Sudan (10^6), Ukraine (10^6), Vietnam (3.5×10^6).[4]

3. Mine Casualty Data

The global average number of casualties per year resulting from mine accidents is unknown. An estimate of total number of casualties per year is between 15,000 and 20,000.[5] The casualty data for calendar year 2000 as released by the International Campaign to Ban Landmines (ICBL) reveal the following numbers: Angola – 840, Bosnia-Herzegovina – 92, Chad ~ 300 over the past 24 months, Democratic Republic of Congo – 189 since 1997, Eritrea – 49 in May and June 2000. Lebanon – 113, Somalia – 147 in just two central regions, Sudan –321 between September 1999 and March 2001, Tajikistan – 58 between August 2000 and early May 2001. Thailand – 350 over the past 24 months.

4. Challenges of Exploring a Complex System

Our understanding of the mechanical and electrical properties of complex granular materials such as soil is limited (Bonner et al. 2001, Liu and Nagel 1993, Rogers and Don 1994, Sinkovits and Sen 1995, Muir 1954, Hoekstra and Delaney 1974, Wang and Schmugge 1980, Campbell 1990, Wensink 1993). High resolution imaging of shallow buried objects in soil remains an unresolved problem. It is not a surprise that small AP mines are most difficult to detect using available technologies. As stated above, most humanitarian de-mining operations rely upon the use of metal detectors and hand prodding. De-mining operations occasionally employ specially trained dogs to sniff out explosives. Besides, there are at least 20 different kinds of technologies specifically aimed at detecting buried mines that are currently either under development or are potentially available.[6] However, all of these technologies have their limitations and none of them can be used alone as a reliable mine detection tool. Further, de-mining is not only about digging out mines (King 1998). It also includes detection of ground based trip wires and of clearing vegetation and other elements that can potentially render many technologically sound methods practically useless (King 1998).

5. The Global Budget for Humanitarian De-mining

According to ICBL,[7] the total investment (including equipment purchase, maintenance, salaries, R&D, etc.) on "humanitarian mine action" in 1999 was $211 million. However, this amount is meager when one considers the overall cost of de-mining, some $1-2 million/sq. km (Trevelyan 1998). The stated amount includes the costs of operating an overall de-mining program in a typical third world environment. Hence, it would be incorrect to associate the $211 million figure with resources available for developing improved approaches to the problem of mine detection, deactivation and certification.

6. A Brief Survey of the Technologies

Electromagnetic Approaches

There are some eleven distinct technologies that are based upon sending electromagnetic energy into soil for mine detection.[2] There are four technologies that are based upon reflecting electromagnetic energy off the mine. These

technologies are radar, light detection and ranging (LIDAR), Terahertz imaging and X-ray backscatter. There are two technologies that rely on detecting an electromagnetic field. These technologies are a conductivity/resistivity based approach and metal detectors. In addition there are five different technologies that somehow react with the explosive contained in the mine. These technologies are electromagnetic radiography, gamma ray imaging, microwave enhanced infrared, quadrupole resonance, and X-ray fluorescence.

Mine detection using electromagnetic radiation is based on the difference between the electromagnetic properties of the target and the ground. We first mention the approaches that rely upon the reflection of electromagnetic energy off the buried mine. Usually, shorter wavelengths that afford higher resolutions attenuate rapidly in soil. The strength of each technology relies upon penetrability versus resolution for specific soil conditions. The radar-based technology relies on the microwave part of the spectrum and hence can penetrate some distance into the soil. However, because of the rather large wavelength, ground penetrating radars offer limited spatial resolution. They are also unable to penetrate water-saturated soils. The LIDAR, terahertz imaging and X-ray backscatter approaches use shorter wavelengths and hence suffer from significant limitations in soil penetration (typically a few centimeters).

Among the electromagnetic radiation based approaches that involve interaction with the explosives, the one based on quadrupole resonance appears to hold promise. Many of these approaches do not have the drawback of getting too many false positives due to clutter and debris content of the soil. The quadrupole resonance approach is already used to detect explosives at airports. In this technique a long wavelength pulse causes nitrogen nuclei to emit a pulse of energy that is characteristic of the molecule (e.g., nitrogen in TNT emits a unique pulse). The primary limitation of the quadrupole resonance approach is that the detector head must be very close to the target and the procedure is slow. In addition, it may not be easy to identify the signatures from specific suspect molecules. Quadrupole resonance is a mature technique and the Naval Research Laboratory has played a major role in developing this approach. Electromagnetic radiography scans the ground with long wavelength microwaves and excites target molecules at certain atomic levels, which in turn results in a spectrographic signature of the target substance. The electromagnetic radiography approach appears to be in a relatively early stage of development. In the microwave enhanced infra-red approach, the thermal signature and infra-red spectra of chemical explosives can be detected. One limitation of this approach is that it cannot detect metallic mines because microwave energy cannot penetrate metal. In addition, the speed and standoff distance at which this method can operate are concerns. In illuminating the ground with X-rays, one causes a series of changes in the electron configuration of the target atoms that results in X-ray fluorescence. This approach detects molecules of explosives that are emitted from the mine and the amount of fluorescence depends upon the target molecule. Standoff and penetration remain serious issues in the application of this technology to mine detection. Finally, gamma-ray imaging is a fourth technology being explored under this category. In this approach, an electron accelerator produces gamma rays that interact with the chemical elements in the explosives to generate a unique signature. Due to the short wavelength of this approach, proximity to the target is essential.

In the category of approaches that detect electromagnetic fields, metal detectors are most widely used for de-mining. These detectors generate a magnetic field that reacts with the electrical or magnetic properties of the target. This reaction causes the generation of a second magnetic field, which is received by the detector. Metal detectors are not very reliable when detecting low metal mines and must be operated at close range. In the conductivity/resistivity based approach, a current is applied to the ground using a set of electrodes. Then the voltage is measured between various other sets of planted electrodes. The voltage measured is affected by objects in the ground including landmines. This technique was originally developed to locate minerals, oil deposits and groundwater supplies. The need to place the electrodes in or near the ground is a concern for landmine detection.

In addition to the eleven technologies referred to above, there are four passive electromagnetic technologies that do not actively illuminate the targets but are based on detecting energy emitted or reflected by the mines. These technologies spot either a contrast between the energy emitted or reflected from the mine and that of the background or the contrast between the disturbed soil immediately surrounding the mine and the top layer of the soil. Infra-red, millimeter wave and microwave based technologies typically provide good stand-off. Multispectral infra-red approaches gather information in several infra-red wavelength bands at the same time. These approaches are, however, strongly sensitive to temperature variations during the day. A fourth passive approach that detects energy produced by the circuitry in advanced mines that contain sophisticated fuses is also under development.

Acoustics Based Approaches

A long history of theoretical and experimental work dating back to the 1950s shows that a mine sized object in soil causes persistent measurable changes in the local elastic properties of the ground, which can be detected by acoustic probing.

The acoustics based attempts at mine detection fall into three categories, "ground sonars," i.e., Rayleigh wave based forward propagation and echo technique, low frequency (typically in the range between 150 and 300 Hz or so), a resonance based attempt in which a selected low frequency is transmitted such that it resonates with the natural vibration of the soil-shell interface of a buried compliant object, and impulse backscattering based approach, in which signals are sent through the granular contacts for directly imaging buried metallic and non-metallic objects using backscattered signals.

In the ground sonar approach, the shallow depths of soil (meaning a floppy three dimensional network of air channels and soil grains) is insonified with low frequency vibration pulses. This can be accomplished by using speakers. The buried mines, which possess mechanical impedance contrasts relative to the undisturbed soil, generate backscattered waves that reach the surface. Eventually, the entire soil column above the object will be set into vibration. The surface vibrations can be sensed by a spatially distributed array of sensors/receivers or via more sophisticated analyses such as one involving how light rays incident on a vibrating surface will get scattered as in laser Doppler vibrometry. The measurements are typically done in "near-field," meaning within a few centimeters from the target. Typical depths that can be probed by this technique do not exceed 15 cms. A different approach currently under investigation, proposes to send two differing frequencies from a transmitter and bounce them off a buried object such that the

difference frequency is received by a receiver. The key idea is that the frequency difference can be crafted in such a way that a specific material of known geometry can respond to the transmitted signal while other objects would not. The method has the potential to discriminate different materials in soil. However, it is not appropriate for imaging and its usefulness in de-mining operations is unclear. The propagation of mechanical impulses in soil exhibit very different behavior compared to sound propagation. Unlike sound propagation in soil, which disperses as it travels horizontally or vertically through soil, impulses travel as weakly dispersive energy bundles. The velocity of an impulse depends upon the amplitude of the impulse and impulses backscatter efficiently from any object that possesses a density contrast with respect to that of the soil grains. The backscattered signals can be received at the surface using appropriate ground contact sensors, which in turn can allow one to reconstruct an image of the buried object.

Neutron Activation

Explosives in mines possess a much higher concentration of nitrogen and hydrogen than do naturally occurring chemicals. In this approach, a continuous or pulsed neutron source emits bursts of neutrons sent into the ground. A detector is used to characterize the outgoing radiation, which is predominantly gamma rays that result from interactions of neutrons with soil and substances such as explosives. The main limitation of the neutron activation approach is that it cannot be used in stand off mode. The neutron source and detector must be directly above the target. It is also unclear as to how deep the neutrons can penetrate and as to whether the approach would be capable of detecting small antipersonnel mines. The neutron activation detector is likely to be used as a confirmatory detector.

Biological sensors

All biological systems such as mammals and insects exploit the possibility of direct sensing of explosive compounds. This is, of course, the most direct route to exploring whether an object is an explosive and hence potentially dangerous. The commonly encountered difficulty in biological systems concerns translating relevant information from the dog, rat, bee or some other animal to the de-miner. Dogs are perhaps more reliable than others and are used routinely in de-mining operations. However, even with meticulous training and significant experience the information flow from the dog to the de-miner is not perfect. In addition, biological systems are very different than machines. The animals must be kept healthy, have fixed duty cycles and efforts must be made to keep them undistracted.

There have been several attempts to artificially accomplish the detection of explosive molecules by analyzing air samples in the vicinity of explosives. These attempts have exploited three distinct themes, the surface acoustic wave (SAW) devices, chemical resistor devices and ion-mobility spectroscopy. The SAW devices capture samples of the materials being sought and classify them by molecular mass. These devices capture the molecules of interest on a membrane. The membrane's vibrational response spectrum is altered by the captured molecules. Appropriate signal processing techniques allow classification into molecular groups, from which the identification follows. The chemical resistor devices capture samples and classify the samples based upon how they affect the resistivity of the sampling probe. These devices are able to distinguish between closely related molecules with considerable precision. However, both the SAW devices and the chemical resistor devices need a substantial amount of any sample for reliable performance. In ion mobility spectroscopy, the samples are classified according to molecular mass, size and shape as all of these characteristics affect the drag forces on a molecule in a moving stream of gas. All of these chemical sensors can potentially be sensitive devices for mine detection. However, it is necessary to miniaturize these devices appropriately and improve their sensitivities for use in the context of de-mining. Some of that work is currently in progress.

7. Conclusion

In conclusion, the issue of automated detection of land mines in various kinds of soils and terrains remains an outstanding challenge to scientists and engineers. In many ways, this challenge is related to the fact that we still have much to learn when it comes to describing the propagation of electrical and mechanical energy in complex materials such as soil.

A suite of cost effective and reliable technologies is likely to be a crucial factor in humanitarian de-mining. To this end, a balanced collaboration between scientists, engineers, de-miners and social scientists is required. Humanitarian de-mining, a subject of great importance and enormous complexity, could profit from such an approach.

We are indebted to Professor Sharmistha Bagchi-Sen, Dr. Irving Lerch and Dr. Andrew M. Sessler for their comments on this article. We acknowledge Professor Bernd Crasemann and Professor Daniel C. Mattis for their interest in this work. SS acknowledges the National Science Foundation grant NSF-CMS-0070055 for research support.

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1 Land mines can be anti-tank mines, anti-personnel (AP) mines and unexploded ordnance (UXO), which refers to any explosive device found in an apparently abandoned condition. A large portion of the anti-personnel and anti-tank mines are devices in plastic casings with very low metal content. Among the most difficult to detect are mines with low metal content, which are abundant. A typical plastic AP mine costs less than $ 3 to make. Estimated cost of retrieval/mine is ~ $1,000 or more.

2 US General Accounting Office Report to the Chairman, Subcommittee on Military Research and Development, Committee on Armed Services, House of Representatives, "Land mine Detection - DOD's research program needs a comprehensive evaluation strategy," US GAO-01-239 (2001).

3 Data quoted from Annex A of "Hidden Killers 1998: The Global Landmine Crisis" available in http://www.state.gov/www/global/arms/rpt_9809_de-mine_nxa.html

4 The available data is incomplete. It is known for instance that much of Falkland Islands is heavily mined yet such information is not easy to come by in many publications. For details see the following on-line article by J.C. Ruan and J.E. Macheme, "Landmines in the sand: The Falkland Islands" in the Journal of Mine Action, http://maic.jmu.edu/journal/5.2/focus/falklands.htm.

[5] http://www.icbl.org/lm/factsheets/va_sep_2001.html

[6] http://www.humanitariandemining.org/catalog/fcover.htm

[7] http://www.icbl.org/lm/2000/keyfindings.php3

COMMENTARY

Gaps in APS Position on Nuclear Energy

Gerald E. Marsh and George S. Stanford

The American Physical Society recently issued a position paper entitled ÒNuclear Energy: Present Technology, Safety, and Future Research Directions: A Status ReportÓ (<www.aps.org/public_affairs/popa/reports/nuclear.shtml>). It is an excellent snapshot of the current status and future potential of nuclear energy -- but there are a few matters that should have been more carefully addressed.. As noted in the Preamble, the earlier, 1993 APS position on nuclear energy called for Òthe development and implementation of programs for the safe disposal of spent fuel and radioactive waste.Ó We have some comments on voids that the current report leaves in those areas, and others.

Economics. In the section subtitled *Advanced LWR Designs*, the report states that "the cost of electricity from these plants has also been improved and is estimated to be lower than today's nuclear plants by about 20%. Yet, the capital cost is still too high to be competitive with gas-fired plants in the U.S. rate deregulated market, assuming present gas prices." Fair enough as stated, but this is a red herring. Gas plants now are used mainly for peaking. If U.S. electric utilities ever turned to gas-fired plants to supply base load on a large scale (which is what advanced LWR designs are all about), the demand for natural gas would balloon, and with it the price of gas-fired electricity and the cost of heating homes.

Safety. In the subsection *Economics and Safety*, the report states that "the safety of operating reactors has been excellent since the TMI and Chernobyl accidents." This is true, but the two accidents should have been distinguished. TMI was scary, and caused some panic, but hurt no one except the pocketbooks of local rate payers. A Chernobyl type accident (a graphite fire) could not happen to civil reactors in the U.S. -- none uses a graphite moderator. This distinction is important.

Reprocessing. The last sentence of the "Security" section maintains unequivocally that "reprocessing separates out plutonium, which is a serious proliferation concern." While this is true for the aqueous "Purex" process that is used to treat thermal-reactor fuel, it is simply not a valid generalization -- a startling blunder by the authors of the APS evaluation.

For one example, it is no secret that pyrometallurgical processing, as developed at Argonne National Laboratory for use with metal-fueled fast reactors, is *incapable* of producing plutonium of the chemical purity needed for weapons. If the starting material is spent oxide fuel from thermal reactors, the initial reduction step also can be done by a process that does not involve separated plutonium.

Indeed, the whole issue of reprocessing should be reexamined by the APS. Perhaps the foremost reason has to do with waste disposal.

Yucca Mountain. The problems associated with waste disposal stem primarily from the notions that spent reactor fuel is waste, and that this waste must be isolated for 10,000 to 20,000 years. Change the assumptions and the problem disappears.

In the light of new technologies, past reasons for not reprocessing spent fuel are no longer convincing. Anyway, the issue is moot, because other nations are already reprocessing their fuel (using Purex). With fast reactors and proliferation-resistant pyroprocessing, the time the actual waste needs to be isolated drops to less than 500 years. Geological disposal for that long is almost trivial.

Appropriate reprocessing, coupled with advanced fast reactors, can extract from the mined uranium over 100 times the energy that is obtained without reprocessing. While this may not be important in the current market with its glut of enriched uranium, that will change. As we understand it, current plans are to keep the spent fuel stored in Yucca Mountain retrievable for 100 years. That is certainly prudent -- our generation has no moral right to deny that rich energy source to future generations. Yucca Mountain should be thought of as an interim spent fuel repository.

As for the safety of the waste, that's another red herring. Already there is far more radioactive waste under the ground at the adjacent Nevada nuclear test site than would ever be expected to leak from the Yucca Mountain repository (even in the absence of recycling). At least four tons of plutonium remains at the test site as bomb residue, along with a much greater quantity of radioactivity due to fission products. The safety of this totally unconfined residue has never become an issue – evidence that concern over the repository is not really about public safety, either now or thousands of years from now.

The debate over Yucca Mountain is really a surrogate for the disagreement between those who see nuclear power as essential to meet the burgeoning energy needs of the world, and those who see it as an evil genie that should be stuffed back into the bottle.

While technological advance will continue, the reassuring outlook for the safety and proliferation-resistance of nuclear power would be more apparent if the implications of even the current state of the art were more widely understood. The APS has been helpful in this regard, and would be even more so if it were to round out its analyses.

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Nuclear Terrorism

Donald D. Cobb

A radiological dispersal device, or RDD, commonly called a "dirty bomb," is a device other than a nuclear explosive device intended to cause damage to the environment and to the public health by dispersing radioactive material.

An improvised nuclear explosive device, or IND, as the name implies, is a device that produces explosive fission energy release (yield). Such devices are called "improvised" to distinguish them from the highly sophisticated nuclear weapons found in the arsenals of the nuclear weapon states. Depending on the sophistication of the developer and access to the requisite nuclear material, highly enriched uranium or plutonium, the yield of an IND could range from a few pounds of TNT equivalent (a "fizzle") to several kilotons.

For four decades the principal nuclear-related threat has been the proliferation of nuclear weapons to countries other than the five nuclear weapon states, as codified in the Nuclear Nonproliferation Treaty (1970). The United States has invested substantial resources for many years in guaranteeing the security of weapon usable nuclear materials and has been a leader in establishing international controls. Nuclear terrorism, while of concern, was generally put in the "too hard" category for international terrorist or sub-national groups. It was thought that the controls on nuclear materials and nuclear weapon technology would be sufficient to discourage terrorists. Since September 11 this assessment has changed. The threat that terrorists might use RDDs or INDs must now be considered more credible. Furthermore, the possibility that terrorists might obtain access to a stolen nuclear weapon cannot be completely ruled out. It is clear that Al Qaida, the Aum Shin Rykyo cult in Japan, and the Chechen rebels all wanted access to nuclear materials or weapons to inflict maximum damage on their targets while causing mass hysteria among the population.

The attack on the World Trade Center released an amount of energy equivalent to about 140 tons of TNT. If this same amount of energy had been released as the result of an IND the Towers would likely have collapsed immediately with even more catastrophic loss of life, and the fallout from such a device, depending on how much radioactive material was lofted into the prevailing winds, could have contaminated much of lower Manhattan and beyond. This contaminated area would have required years and tens of billions of dollars to clean up.

The first line of defense against nuclear terrorism is to deny the terrorists access to the required nuclear materials. The International Atomic Energy Agency (IAEA) definition of **direct use material** (that, is nuclear materials directly usable in a nuclear explosive device) consists of highly enriched uranium (HEU, >20% U235) and plutonium (Pu, <80% Pu238). The IAEA defines **significant quantities** of these materials as 25 kg HEU and 8 kg Pu. While "significant quantities" are not the same as "weapon quantities," they set a threshold for safeguards timely detection of theft or diversion. Clearly, intensive effort is required to control and account for nuclear materials in such small quantities.

Nuclear weapons and weapons-usable nuclear materials tend to be held under tight government oversight. Protection of radiological sources, on the other hand, has more to do with safe use than with security against theft or diversion. Isotopic sources (for example, Cs137, Co60) ranging from much less than one curie to hundreds of curies are in common use for medical and industrial applications. There are no international safeguards or export control regimes for the possession and use of such sources comparable to IAEA safeguards or the Nuclear Suppliers' Group.

Following the collapse of the Soviet empire, serious concerns were raised regarding the security of Russia's nuclear weapons, weapons usable materials, and nuclear weapons experts. It is generally believed that Russia's nuclear weapons are more secure than its weapons usable materials. But there is much more weapons usable material **not in** weapons than **in** weapons. Hundreds of tons of these materials are stored at dozens of sites across Russia. The amount continues to grow as more and more Russian nuclear weapons are dismantled and the nuclear materials recovered. Meanwhile, production reactors in Russia continue to produce plutonium. There are also considerable quantities of weapons usable materials, for example left in Soviet era research reactors, in countries other than Russia that were formerly part of the Soviet Union.

There have been several reported cases of the theft of weapons usable materials within Russia, and several documented cases of nuclear smuggling out of Russia. The total amount of weapon usable materials successfully smuggled out of Russia cannot be accurately known. There are also documented cases of the theft of radioactive isotopic sources, including within the United States. Again, the actual numbers and types, and where the sources finally ended up, cannot be accurately known.

Since 1992 the Nunn-Lugar program has financed cooperative efforts to dismantle Russian nuclear weapon delivery systems and secure nuclear weapons and materials. Since 1994 the Department of Energy (DOE) and the National Labs have worked with their counterparts in Russia to secure nuclear materials and weapons under the Materials Protection, Control and Accounting (MPC&A) program. Today, under the DOE National Nuclear Security Administration (DOE NNSA), this and related programs such as the HEU purchase agreement, have helped secure amounts of weapons usable nuclear material equivalent to thousands of nuclear weapons. The magnitude of the problem is daunting. DOE NNSA estimates indicate approximately 600 tons of weapons usable materials located at 95 sites, or, considering the IAEA definition of significant quantities, enough material to make more than 40,000 nuclear explosive devices. Rapid progress is being made to increase the security of these materials, but completing the effort will take several more years of intensive work.

Another DOE NNSA sponsored program, called the Second Line of Defense, is working to install detection systems at transit points in Russia and neighboring countries to detect smuggled nuclear materials. These systems include monitors for air, rail and ship cargo looking for concealed nuclear materials.

Since September 11, the DOE NNSA has been working with its Russian counterpart, the Ministry of Atomic Energy (MINATOM), to extend the MPC&A and Second Line of Defense programs to include radiological sources as well as weapons usable materials. In general, the intention is to find new ways to work together to combat nuclear terrorism. Clearly, securing Russia's nuclear materials and enhancing security at borders and transit points are important elements of a comprehensive approach to combating nuclear terrorism, based

on a protection strategy that is multi-layered and provides defense in depth.

One key to enabling such a multi-layered, defense-in-depth strategy is improved detection technology. The underlying physics of detecting the presence of nuclear materials has been known for decades. Measurable signatures include gamma rays from radioactive decay, and both gamma rays and neutrons arising from spontaneous fission. Isotopic and accelerator based sources of energetic X rays, gamma rays, and neutrons can be used to detect the presence of weapons usable materials by measuring the emanations from induced fission. Today, building on the availability of new detector materials, advances in electronics, and miniaturization of processors and memory, sophisticated hand held and portable sensors and detection systems are becoming available. Based on these advances, many U.S. Customs agents are equipped with hand held radiation pagers, small devices that can detect sources of radiation, if in sufficiently close proximity. New, more sensitive detection technology is being evaluated at entry points into the U.S. to look for nuclear contraband carried by people, hidden in luggage, within vehicles, or in cargo. While the state of technology can support the eventual wide deployment of such systems, the cost will be high and, of course, no system can ever be foolproof.

If the worst occurs and a nuclear-related terrorist attack becomes a reality, whether involving an RDD or an IND, it will be up to local, state and federal emergency response authorities to deal with the crisis. The DOE's Nuclear Emergency Support Team (NEST) will be in the vanguard. NEST actually consists of several interrelated capabilities, including assessing the credibility of the threat, searching for and rendering harmless a nuclear terrorist device, and helping to mitigate the consequences to public health and the environment. The men and women of NEST consist largely of volunteer experts from the National Labs. They represent a critical core of expertise for responding to a nuclear terrorist attack.

However, more capability to combat nuclear terrorism is needed, considering the urgency of the threat post-September 11 and the potentially disastrous consequences of a nuclear terrorist attack. Preventing a nuclear terrorist device from entering the U.S. or being placed in an urban area represent major challenges. If such an attack ever occurs, screening the health effects of potentially thousands of people exposed to radiation and cleaning up widely contaminated areas may represent even greater challenges. The scientific and technical base of the country is needed to address these challenges.

Historically, physicists have been in the vanguard of understanding "things nuclear", including technical measures on behalf of nuclear arms control and limiting nuclear weapons proliferation. It is now time for us to take on the challenge of combating nuclear terrorism.

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Radiological Terrorism

Steven E. Koonin

(Statement delivered before Senate Foreign Relations Committee, March 6, 2002)

The events of last fall have induced us all to give greater attention to the safety and defense of the civilian population. Unfortunately, this is a very difficult problem. Because the number of targets is virtually unlimited and the resources available to protect them are necessarily finite, hard choices have to be made about *what*, and *what not*, to protect, as well as what to protect *against*.

Of course, not all threats are equal. In allocating defensive resources, the factors to consider include the direct and indirect consequences of a successful attack, the likelihood of an attack, the vulnerability of the target, intelligence and warnings of potential attacks, and the availability of effective defense measures. I applaud the initiative of this Committee in defining and addressing these very important issues.

In that context, I want to call to your attention one type of terrorist attack that I believe to be a very serious threat: the deliberate dispersal of radioactive materials. These materials might be the weapons-grade metals used in nuclear weapons or the more common materials contained in radiation sources. The dispersal can be accomplished either through an explosive release (a nuclear device producing "fallout" or a conventional explosive that has been laced with nuclear material) or through a covert, and perhaps gradual, release of particulates, aerosols, or contaminated materials such as food. While the intent of the perpetrators might be to induce immediate or long-term casualties, far more widespread will be the intense psychosocial reactions associated with radiation. In any case, a large-scale release of radioactive material could well entail significant costs through both direct clean-up expenses and the economic disruption induced. My goal here is to describe for you the potential threat that I see and offer some possible steps that could be taken to reduce it.

My scientific credentials for this task are as follows. I am Professor of Theoretical Physics at the California Institute of Technology, as well as that institute's Provost. For more than 30 years, the focus of my teaching and research has been in nuclear physics and I am the author of some 200 refereed scientific publications in that field. I have also served as the Chair of the Division of Nuclear Physics of the American Physical Society. Beyond my academic credentials, I have been involved in National Security matters for more than 15 years. I currently chair the JASON group of academic scientists and engineers, which has a 40-year record of unbiased technical advice to the government on national security matters. I have also served on both the Pentagon's Defense Science Board and the Navy's CNO Executive Panel, and also chair the University of California's committee overseeing the national security aspects of the Los Alamos and Lawrence Livermore National Laboratories. More specifically related to counter-terrorism, I led a DARPA-chartered JASON study of Civilian Biodefense issues in 1999, and served this Fall on Defense Science Board panel looking broadly at terrorism vulnerabilities. While my testimony is informed by these experiences, particularly discussions with my JASON colleagues, the words and opinions expressed are my own.

Radioactive materials are common in society. Their importance in medical diagnostic and therapeutic procedures is well-known. Less well known, but equally important, is the use of intense radioactive sources to sterilize food and medical instruments and to image industrial equipment (including the logging of oil wells). Far less potent amounts of radioactive materials are used in smoke detectors, anti-static devices, and self-illuminating exit signs. Many of these sources are harmless and have no potential for terrorist misuse. There is also a very large amount of radioactivity contained in the spent fuel in the cooling ponds at nuclear power reactors.

Sources ranging from a few to thousands of Curies could be employed for terrorist purposes. If just three Curies (a fraction of a gram) of an appropriate isotope were spread over a square mile, the area would be uninhabitable according to the recommended exposure limits protecting the general population. While direct health effects would be minimal (for each 100,000 people exposed, some 4 cancer deaths would eventually be added to the 20,000 lifetime cancers that would have occurred otherwise) the psychosocial effects would be enormous.

I believe that radiological terrorism is a plausible threat. Gram for gram, radioactive material can be at least as *disruptive* as weaponized anthrax. Further, the material circulates broadly through society. There are tens of thousands of significant, long-lived sources in the US and many more abroad; they are produced, purchased, stored, and transported through ordinary channels. The expertise to handle them is widespread and/or readily acquired (radiation safety courses are offered regularly; you can sign up on the web). And the safety and security of these materials relies on the good faith and good sense of the end-users, who are licensed by the Nuclear Regulatory Commission. This array of facts does not leave me with a great deal of comfort.

One scenario of how a terrorist attack using radioactive material materials might play out is as follows. A several-curie source of a long-lived isotope is stolen and covertly released one evening throughout the business district of a major city. Acting on an anonymous tip the next morning, officials verify widespread contamination over a 100 block area at roughly three times the natural background level, well above the legal exposure limit protecting the general population. That area is immediately evacuated and sealed off as hundreds of thousands of people rush to hospitals demanding to be screened. Businesses in the area are shutdown during the many months of decontamination that follow; dozens of buildings are razed. Economic damage runs into the billions of dollars, but there are no direct fatalities.

Most important in thinking through the situation are the widespread fear of radiation and the low legal dose limits protecting the general population. These latter make the terrorists' task easier in at least two respects. First, even very low levels of contamination, comparable to the natural background level in many locales, will be very disruptive. Second, in decontaminating any site, the question of "How clean, at what cost, and in what time?" will eventually have to be answered; that will not be easy.

There are several kinds of measures that can be taken to prevent terrorist attacks using radioactive materials, or at least make them more difficult to carry out. Through various economic, regulatory, and technological mechanisms, one can encourage migration of legitimate users from radioactive sources to radiation sources that can be turned off, such as accelerators and electrically-driven neutron generators. However, this will not be possible for all applications. Strengthened controls on radioactive materials are therefore an important step; fortunately, some of the infrastructure is already in place through the NRC and the IAEA. Also important would be the establishment of pathways to retrieve, store, and dispose of unwanted radioactive materials. The tracking of personnel with radiation expertise also seems a good idea, as this would provide both a registry of trained responders in the event of an incident, as well as be of assistance in detecting terrorist preparations.

Widespread radiation monitoring to detect large sources as they are moved about would be very useful. One would start with ports of entry, transportation choke points, rail plane, and ship cargo, and mail. Going further, it is not difficult to imagine widely deployed radiation detectors ("one on every lamp post"). In contrast to detectors for biological and chemical agents, the monitoring technology is well-established, the power and maintenance requirements are likely to be minimal, and the specificity and robustness will be high. Whatever the character and extent of radiation monitoring, it will be important to significantly test and "red-team" the system.

Before an incident occurs, it is important to educate the first responders and the public as to the nature of this threat, the probable consequences an incident (*i.e.*, few casualties, maximal disruption), and how they can be managed. This will likely not be simple given the unease evident in many public discussions of radiation.

In summary, I believe that the deliberate dispersal of radioactive materials is a significant and plausible threat. However, it is very likely that the predominant effects will not be casualties, but rather psychosocial consequences and economic disruption. Fortunately, there are a number of steps that can be taken to reduce the likelihood and impact of such an attack, beginning with the strengthening of controls on radioactive materials.

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Does New Nuclear Posture Review Foster Proliferation of nuclear Weapons?

Kurt Gottfried

The Bush administration's new Nuclear Posture Review (NPR), which was leaked to the LA Times, proposes measures that, in the view or many physicists, would mark a dangerous step backward in nuclear weapon doctrine and policy.

During much of the Cold War, the US threatened to initiate use of nuclear weapons if conventional forces could not repel a Soviet invasion of Western. With the collapse of the Soviet Union, this policy lost whatever rationale it may have had. Never the less, the opportunity to adopt a No First Use policy was not exploited. Furthermore, the Clinton administration was deliberately ambiguous about whether it might use nuclear weapons in response to a chemical or biological attack.

The new Bush NPR goes much further. It would enlarge and amplify the role of nuclear weapons by intermingling nuclear and conventional forces and command and control; designing new nuclear weapons; and readying the Nevada test site for testing on much shorter notice.

The policies advocated in the Bush NPR pose a grave threat to the nonproliferation regime and the Nuclear Non-Proliferation Treaty (NPT) on which the regime is based. If the US were to resume testing, other states with far less mature, or none, should be expected to follow suit. Furthermore, in gaining the indefinite extension of the NPT in 1995 the US committed itself to the Comprehensive Test Ban Treaty, which the Bush administration opposes. The NPR proposes contingency plans for pre-emptive nuclear attacks on states that do not have nuclear weapons, which contradicts security guarantees that were provided by earlier administrations, and which were also key to the indefinite extension of the NPT.

Finally, while the NPR confirms the administration's plan to cut the number of deployed strategic warheads to about 2000, it also intends to keep a large portion of the withdrawn weapons in a ready reserve. The Russians, and many others, in the U.S. and abroad, proposed instead to render these cuts irreversible and verifiable.

In short, when the state with the world's most powerful nuclear and conventional forces announces that it must retain a huge nuclear arsenal into the indefinite future, still needs new nuclear weapons, and is laying plans to possibly use nuclear weapons against basically weak opponents who may not even have nuclear weapons, is it not constructing a compelling brief in favor of nuclear proliferation ?

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1. Leaked sections from the Nuclear Posture Review are available at: http://www.globalsecurity.org/wmd/library/policy/dod/npr.htm
2. "Bunkers, Bombs, Radiation," Op-ed by Sidney Drell, Raymond Jeanloz and Bob Peurifoy, Los Angeles Times, March 17, 2002. Facts from weapons scientists on the feasibility of bunker-busters.
3. "Secret Plan Outlines The Unthinkable," Column by William Arkin, Los Angeles Times, March 10, 2002. The first unveiling of the NPR documents

LETTERS AND E-MAILS

Manufacturer's view of 'Customer's View

In the January 2002 issue there is an article about vehicle fuel efficiency "On the Road in 2020, a Customer's View" by Vince Fazzio. Mr. Fazzio is a leader at Ford Motor Co., and thus does not necessarily represent the "Customer's view". He claims that "although most customers say they want to improve the environment, they are unwilling to make many personal sacrifices for a public benefit." This is clearly untrue. We have taxes, voted by our representatives, which pay for what are perceived as public benefits: roads, education, the military, science research, environmental protection, food and drug safety ...". People are willing to pay for the public benefit if the costs are perceived as fairly distributed among the population. Perhaps what most people are unwilling to do is to sacrifice some of their own desires while others continue to freely despoil the environment.

The improvements in fuel economy and emissions for vehicles over the last decade was because of laws passed for public benefit. The SUV, escaped most of this regulation and now is a major cause of high fuel consumption and additional highway deaths (2000/year according to the next article in the same issue). Increasing the Federally mandated fuel economy standards so that all personal passenger vehicles must meet the same standards and increasing those standards meets the criteria of equitably distributed costs for all. Mr. Fazzio clearly shows in Figure 4 that under his assumptions, if the fuel efficiency of a mid-sized Sedan were doubled, it would save about $4000 in 10 years (150,000 miles) in fuel costs. By his numbers, this would more than match the added costs of producing such a car. However, he then claims that people's economic horizons are very short and only the first two years of savings should be considered. Perhaps Ford dealers only provide new car loans for a maximum of 2 years. Perhaps they no longer try to sell extended warranties for 5 or more years (Honda tries to sell a 7 year plan).

The article claims that American consumers "want their car to take them where they want to go, whenever they want, quickly and inexpensively". However, we do not get that with our present vehicles. Roads in most areas are congested and traffic is slow. Costs are high ($0.35/mile including $0.20/mile for depreciation of a $30K car over 150k miles). Clearly people in big cities like New York choose to take trains rather than cars because they are faster at many times during the day and cheaper. If consumers had those goals, we would all buy smaller, less expensive vehicles which are easier to park. If all we wanted was faster, there would be no speed limits on city streets.

We all may "want" many things, but you do not always get everything you want do to do because of monetary, environmental, safety and other constraints. In his entire "Customer's View" article, there is not a single mention that Ford and other manufacturers spend a lot of money on advertising trying to tell us that what we want are expensive, fuel guzzling SUVs that drive over and trash environmentally sensitive lands. If Ford really wanted to "have the least impact - or the most benefit - for the environment and for society in general" they would stop advertising SUVs, and use their lobbyists to encourage our government to increase the CAFÉ fuel economy standards.

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Criticism of a Criticism

I have often enjoyed reading articles in "Physics and Society" and have considered them a real contribution by the American Physical Society. I also was pleased to read the article by Prof. Cameron in your publication, (P&S,2001,30(4),14) entitled "Is Radiation an Essential Trace Energy?". Cameron is Emeritus Professor at the University of Wisconsin and has been a distinguished contributor to several journals. Cameron is noted for his originality and many contributions to the field of Medical Physics. Among other accomplishments, he is the inventor of the bone densitometer which is used daily in patients in hospitals and clinics around the world to determine local bone density.

I am surprised that you published a letter\ which was not entirely logical in its criticism and employed the term "obnoxious" to describe an article by an established scholar of radiation effects in man. As Editor of "Medical Physics" for nine years, I would never have published such a letter. Clearly, publication of a reply from Cameron is required for the credibility of "Physics and Society".

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Validity of Epidemiology

I don't believe that John Williams (P&S, 2002,31 (1),21) has a current understanding of epidemiology. See the web site on epidemiology at: http://www.pitt.edu/~super1/main/epi.htm . This is an internet course primarily for students in medical school.

We all know that epidemiology studies have lead to society's efforts to reduce smoking, studies of uranium miners in Czechoslovakia have led to our regulations for control of Radon to reduce deaths from lung cancer. Those studies are not purely statistical but involve investigations into the etiology of disease, with a limited population. I was involved in a small cluster study on cancer in children in our area which used some of these techniques. We used medical, physical and chemical tests for each person/family involved.

Another point of view about John Cameron's hypothesis of receiving a short burst of radiation (equivalent to about 50 x the annual background radiation) to extend one's life is to view it as a type of hormesis, i.e., using a small amount of a substance for benefit which is normally harmful in large doses. For example: one uses a little nitroglycerin to help with the pain of angina. The common blood thinner linoxin, is a rat poison.

How would you prove that a small amount of radiation might be able to extend one's life ? Cameron has given the references in valid studies to that end. Other ?

I have had an Oncologist tell me there are about 60 -70 cells that develop daily with the possibility of producing cancer. Our body handles those very nicely until for some reason a change occurs and one develops cancer. Certainly a study should be made to determine if this hypothesis is valid.

I ask students in an elementary physics course each semester if John Cameron's hypothesis were found valid, would they want to receive it? Approximately 50 to 60 % of the class, said they would opt for it. Especially those whose family has had a history of illness. So I know this topic is of interest to many.

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REVIEWS

Nuclear Energy: Present Technology, Safety And Future Research Directions: A Status Report from the APS Panel on Public Affairs

by *John Ahearne, Ralph Bennett, Robert Budnitz, Daniel Kammen, John Taylor, Neal Todreas,* and *Bert Wolfe*
Available at http://www.aps.org/public_affairs/popa/reports/nuclear.shtml

This Report, prepared under the auspices of the APS Panel on Public Affairs, provides an objective overview of nuclear power today with an emphasis on issues of reactor safety. The outstanding qualifications of its authors assure that the report is authoritative. As might be expected, its tone is more reportorial rather than editorial.

The starting point for the report is the 1993 APS Policy Statement that asserted: "A balanced energy policy…requires…strong programs to keep the nuclear energy option open." The Report's indicated purpose is to discuss "the current status of topics directly related to that 1993 APS position." About three-quarters of the document is devoted to nuclear reactors and their safety. Nuclear wastes and nuclear proliferation are also addressed, but less extensively.

Following a brief historical review of nuclear power, the report takes up two very general topics in the area of nuclear reactor safety. The first is an outline of the "key elements" in reactor design and operation that are necessary for safety. These elements are seen to be present in the nuclear programs of many countries, but for others - presumably some members of the former Soviet bloc - there are "significant gaps" that are now the subject of an international remedial effort.

The second general topic is the use of probabilistic risk assessments (PRAs) for evaluating reactor safety. There is general agreement that PRAs are useful for identifying weaknesses in reactor designs and evaluating the implications of changes in plant equipment and procedures, whether undertaken to improve safety or to improve economy. The report shows some ambivalence with regard to the absolute or "bottom-line" numbers given by PRAs for accident probabilities and consequences, indicating that these cannot be "highly accurate" but nonetheless that they can still be of "broad use." No direct mention is made of a particularly interesting use of the PRA method, namely the analysis of the rate of accident

"precursors," as pursued by the Nuclear Regulatory Commission to track gains in reactor safety since the 1970s.

A highly informative overview is given of the main new reactors that have recently been built or are in prospect:

Advanced Light Water Reactors. All operating power reactors in the U.S., and most of those elsewhere, are light water reactors (LWRs), either pressurized water reactors (PWRs) or boiling water reactors (BWRs). One group of advanced reactors builds on prior experience to achieve simpler and safer designs, without radical changes. The report describes four such reactor types: the Advanced BWR (two already operating in Japan), the System 80+ (becoming the standard in South Korea), the Sizewell-B PWR (one unit, operating in the United Kingdom since 1995), and a recently completed quartet of French PWRs. Other LWR designs, somewhat further down the road in development, incorporate more substantial changes, particularly an increased reliance on passive safety features.

Gas-cooled reactors. Two helium-cooled, graphite-moderated reactor designs are described. One is the Gas Turbine Modular Helium Reactor, originally designed by General Atomics in the U.S. and now being developed by an international consortium in Russia. The other appears to be the hottest, or at least the newest, game in town: the Pebble Bed Modular Reactor (PBMR), being developed in South Africa based on earlier German work and under consideration for possible licensing and construction in the U.S. Both feature small-size and also modular construction, and the possibility of passive cooling in case of an accident.[1]

Generation IV Reactors. The U.S. Department of Energy embarked in 1999 on an ambitious, if modestly funded, initiative to develop reactor designs that might be ready for deployment by 2030. The targets set for such reactors include safety, proliferation resistance, economical use of fuel, and low cost. The report provides an outline of the goals for these reactors.

Overall, the report indicates that advanced LWRs are safer and more economical than present LWRs, but still are not cost-competitive with natural-gas fired plants "assuming present gas prices and no environmental credits" – perhaps an important caveat. It cites some attractive features of the PBMR, but indicates that it is too soon for a definitive evaluation.

The report closes by addressing the chief concerns about nuclear power:

Reactor safety. The report states crisply that "the safety of operating reactors has been excellent since the TMI and Chernobyl reactors." New designs promise still greater safer.

Economics. This is subsumed under reactor safety, with lower construction costs anticipated for the new designs.

Nuclear Waste. The report briefly describes the present status of the handling of both high-level and low-level nuclear wastes, but does not undertake to consider the merits or weaknesses of the proposed Yucca Mountain repository.

Security. On-going efforts to increase plant security against terrorist attack are mentioned. In its discussion of weapons proliferation the report touches on the reprocessing of spent fuel, taking the position that reprocessing is not economical and creates "a serious proliferation concern."

Overall, this report is a very useful document, although one may regret that two significant topics were apparently outside its intended scope. One is a review of the technical issues surrounding the Yucca Mountain project—arguably the most immediately critical matter relating to nuclear power in the U.S. today. Another is placing the possible need for nuclear power in the context of a comprehensive energy strategy. A single report, however, cannot address all relevant matters. In the areas it does cover, the report gives a very good picture of the current situation, with an impressively balanced perspective.

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[1] A slightly different pebble-bed design is being independently developed by a Massachusetts Institute of Technology group. See Andrew Kadak, "A Renaissance for Nuclear Energy?" *Physics and Society* January 2002, pp. 13-17.

Hubbert's Peak: The Impending World Oil Shortage

by *Kenneth S. Deffeyes, Princeton University Press, ISBN 0-691-09086-6*

In 1956 M. King Hubbert, a geologist, made one of the very few good forecasts in the energy field.[1] He fitted US oil production to a bell-shaped curve (with hindsight, a Gaussian is best) which predicted that oil production from wells in the lower 48 states would start to decline about 1970; and it did. The prediction has continued to have astonishing accuracy. By the late 1990s production had fallen by half from its all-time high of thirty years ago, and is still roughly on the curve.

Based on Hubbert's success, Deffeyes, a petroleum geologist now retired from Princeton, applies this method to world oil production. He forecasts that oil production will reach its maximum and begin to decline in about 3 years (yes, in 2005, give or take a little)! If true, there would be shortages of oil and great increases in oil prices. That would shake US Mideast policies to the roots, turn on its head the marketing of huge gas-guzzling "trucks" to households, and more. This "Hubbert-type" forecast is based on the assumptions that cumulative oil production will eventually turn out to be about 2 trillion barrels, and that a smooth symmetric (bell-shaped) curve will describe the overall history of oil production. The US Geological Survey has predicted instead that cumulative oil production will be about 3 trillion barrels,[2] which would move the Hubbert-type peak to about 2025. These are both geologist's predictions. The language of economists is different. They say there is no limit to the resource, that production is only limited by the price people pay. On one point there seems to be general agreement: There are almost certainly no very large new oil fields left to discover. The most recent excitement concerns the Caspian Sea region of the former Soviet Union. But while the estimated resources are huge in dollars, they are modest in terms of annual world consumption.

Some feeling for these numbers is given by the total consumption to date of roughly 0.9 trillion barrels. Pessimists like Deffeyes say that just over half the eventually available oil is still in the ground, and optimists say 70%.

But the oil still in the ground is not the only controversial aspect of a Hubbert-type forecast. Hubbert's bell-shaped curve implies that production will begin to fall when cumulative production reaches half of the original resource. The assumed shape of the curve is a way of estimating how the economic

system and society will deal with the impending exhaustion of petroleum. Hubbert says that there will be a moderate decline in production starting long before exhaustion is imminent. The USGS and the US Department of Energy place the reversal about 5 decades in the future by assuming that production will continue to grow almost until the resource collapses. The reader's opinion is as good as the experts' on this.[3]

In my opinion, some feeling for the shape of the curve can be obtained by theorizing about the transition away from oil. Most of the oil is used for transportation, and, in the US, most of that by automobiles.[4] Four possibilities for fueling automobiles in the next few decades are: (1) development of unconventional oil resources such as tar sands from Alberta or very heavy oil from Venezuela or synthetic oil from coal; (2) the easier conversion of remote natural gas to a convenient liquid;[5] 3) switching to vehicles directly fueled with hydrogen; and 4) provision of household vehicles that are 50% to 100% more energy efficient than at present.[6] New supply technologies, like (1), (2) and (3) involve huge up-front costs and would take a lot of time. In the US, the scale of fossil fuel use is roughly 23 kilograms per person per day. The capacity to provide a substitute vehicle fuel could grow only gradually, probably only by a small fraction in 20 years. How would this slow development affect the shape of the curve? On the other hand new vehicles could be mass-manufactured in less than a decade and replace most of the fleet in another decade.

Deffeyes advises John McPhee on his series of popular books on geology. While he devotes the first chapter and chapters 7 and 8 to the Hubbert curve analysis, he also discusses how and where oil is formed, and how it is discovered and extracted. There are many interesting anecdotes about the oil industry, and many easy doses of geology along the way. He must have been a delightful lecturer.

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\1 The list of forecasts that were grossly in error includes virtually all energy quantities of interest. For example, a review in preparation by Jon Koomey at al. (Lawrence Berkeley National Laboratory), of forecasts made in the 1970s of US energy consumption, shows they were all too high. For 2000, many were too high by a factor of two or more.

2 This difference is due mainly to a contribution called "reserve growth" in already discovered fields, which has justification in the on-going improvements in mapping and extraction technology--although the size of the effect may have been exaggerated by the U.S. Geological Survey.

3 There are examples for production-until-collapse behavior, for example in whaling. In whaling it is claimed that the optimal business strategy is to exhaust the resource as fast as possible, followed by moving whatever capital is left to another business.

4 Making materials like plastics is an activity which would continue economically at oil prices much higher than at present; and substitutes could be found for by-product uses like power plant burning of "residual" fuel from refinery processes.

5 Fouda, Safaa A, "Liquid Fuels from Natural Gas," *Scientific American*, March 1998.

6 Ross, Marc, "New Automotive Technologies," *Physics & Society*, April 1999.

The Bulletin of Atomic Scientists

by Published bi-monthly by the Educational Foundation for Nuclear Science (not-for-profit),

edited by *Ms. Linda Rothstein*

This review is based on an exploration of *The Bulletin of Atomic Scientists* from 1995 to the present. By surveying selections from the past five years, I hoped to develop a sense of *The Bulletin's* common topics of discussion, the style of writing and the depth of coverage.

At first glance, the title, *The Bulletin of Atomic Scientists* , suggests a magazine that discusses topics that are germane to those who work on nuclear/atomic weapons or power-related issues. I was pleasantly surprised to see that *The Bulletin* contains discussions of a broad range of current affairs. I found articles on bioterrorism, chemical weapons, and primers on international relations for a diverse selection of countries in addition to discussions of nuclear-related issues.

The Bulletin is divided into different sections, which as a whole balance expert opinion with clearly presented information. These sections are: the main articles, "Bulletins," "Reports," "Opinions," book reviews, "The Nuclear Notebook," and "The Last Word." Each issue has a main topic of discussion that is covered by two or more main articles. The articles I read provided in-depth introductions to issues I had not read about before. Each article was a friendly primer on its respective subject. Shorter "Bulletins" read like news briefs on current, sometimes entertaining, events not mentioned in the mainstream press. "Reports" provided detailed exposition on specific political and technical issues. By construction, "The Nuclear Notebook," which is prepared by the Natural Resources Defense Council, is an almanac of international facts and figures regarding national nuclear stockpiles. Each entry in the notebook focuses on a specific nation, providing publicly the latest information available. These sections of *The Bulletin* were nicely balanced by opinion pieces found in "Opinions" (called "Perspectives" in past issues) and "The Last Word."

The style of the journal appears geared toward educating both technical and non-technical audiences about current affairs in international politics, nuclear-related or not. The articles that I read were not shallow in their coverage, in contrast to mainstream media. They were not filled with unnecessary technical details, but rather provided details as a means of understanding the issues at hand or expanding one's prior knowledge on a specific subject.

Many mainstream media sources are terse in their presentation, elementary in their vocabulary or writing style, and shallow in their coverage. Based on the material that I had read, I felt that *The Bulletin* covered topics in an intelligent and polished style. Overall, *The Bulletin* was a refreshing alternative to traditional news sources.

More information, including back issues, can be found on their website: http://www.thebulletin.org

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A Beautiful Mind

by *Sylvia Nasar* (Simon and Schuster, 1998; paperback reprint with new Epilogue, 2001)

a film directed by *Ron Howard* (DreamWorks-Universal Studios, 2001)

"*Insanity is often the logic of an accurate mind overtasked*" (Oliver Wendell Holmes, Sr.)

John Forbes Nash, Jr. is a brilliant mathematician who, remarkably, overcame paranoid schizophrenia and won the Nobel Prize in Economics in 1994. By now most readers are familiar with this story, largely due to the enormous success of the film which has garnered numerous awards including the Golden Globes' Best Picture and, by the time this review appears, perhaps the Academy Award. The film is based upon the book of the same title by Sylvia Nasar, a former NY Times economics reporter and now Professor of Journalism at Columbia University. The book, which won the 1998 National Book Critics Circle Award for biography, has now become a best seller. It also won the Communications Award of the Joint Policy Board for Mathematics (a collaboration of the three major American mathematics societies).

Nasar's biography is "unauthorized" in the sense that Nash did not cooperate in its writing ("I adopted a position of Swiss neutrality"). Nevertheless in the epilogue added to the 2001 reprint (which bears on its cover a picture of actor Russell Crowe, who portrays Nash in the film, rather than of Nash himself) he expresses satisfaction with the result, especially retrieving some of his past. It resulted from an enormous labor of hundreds of hours spent interviewing hundreds of people who knew Nash at various phases in his life (the footnoted acknowledgments run to 40 pages), sifting through correspondence and records, and assembling all into a coherent whole. What results is a fascinating portrait not only of Nash, but also of the nature of mathematical America in the 1940's and 50's, the Nobel process and, perhaps most importantly, of the mysterious mental illness called paranoid schizophrenia and how the medical establishment dealt with it. She contrasts the genteel anti-Semitism that blighted the paragons of American higher education, like Princeton and Harvard, with the dynamism of universities like MIT, NYU and CCNY. The Nobel Prize in Economics comes in for some withering criticism. Many leading mathematicians played roles in Nash's life and career and are portrayed here.

The film version is quite a different thing, although I must add that Nasar and Nash both approve of it. At the outset, let me say that the film is excellent entertainment, and I am told that the portrayal of schizophrenia is the best ever done in a major motion picture. The acting is excellent, except that I found that Russell Crowe, as Nash, tended to mumble too much--perhaps an accurate rendition of Nash or perhaps to mask the Australian actor's difficulty with the West Virginia accent. The problem I have with the film is that it is too far removed from the story as presented in the book. Some liberties reflecting the difference between the two media are to be expected. And, as screenwriter Akiva Goldsman has emphasized, they were not making a documentary.

The only real-life major characters in the film are Nash and his wife Alicia, played outstandingly by Jennifer Connelly. The film opens with Nash's arrival as a beginning graduate student at Princeton. We are introduced promptly to his roommate and lifelong friend--who does not exist in reality. The film implies that Nash's schizophrenia began much earlier than in Nasar's book. There is no record in the book of the early extremes of eccentricity at this stage, such as writing his calculations in soap on the windowpanes. The portrayal of the other mathematicians is perhaps too "over the top" as well. Hollywood has a perverse view of scientists in general, and especially of the cerebral mathematicians!

In reality, after Nash finished his Ph.D.--it was his dissertation on game theory that won the Nobel Prize--and spent a year at Princeton, he moved to MIT as a C.L.E. Moore Instructor. He spent a few summers at the RAND Corporation in California, doing classified research, spending much of his time applying his ideas on non-cooperative n-person games to military and geopolitical situations, until he lost his clearance after a homosexual incident. The film makes no hint of the homosexuality, and transplants the secret research to "the Wheeler Institute" on the MIT campus, so that the secret research can be an ongoing thread in the story. This aspect comes to dominate much of the film, giving it a pronounced cloak-and-dagger aspect that is quite exciting but entirely fictional.

The film accurately portrays the meeting of Nash and his future wife, Alicia. But one does not learn that Nash previously had an extended affair with a nurse, Eleanor Stier, who bore him an illegitimate son. Alicia is the long-suffering wife who stands by Nash through his tribulations. In actual fact they were divorced after six years of marriage, but remarried in 2001.

As for Nash's schizophrenia, while the film may be an accurate depiction of the illness and of the treatments Nash underwent, the delusions he suffers in the film are in many ways different. The real Nash saw himself in various bizarre roles: as a Palestinian warrior, as the "emperor of Antarctica," as someone in contact with extraterrestrials. He went to Europe and tried several times to renounce his U.S. citizenship. Like the majority of schizophrenics, his delusions were often in the form of voices. But auditory delusions are not very cinematic, so they become primarily visual in the film.

There are other items in the film absent in the book, such as a bizarre ritual involving pens among the Princeton faculty. I hope a reader will tell me that this is nonsense! But all in all, I would say that the film is worth seeing if you do not care about the real Nash story. If you do, the book is much more rewarding .

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