Public Interest Report

THE FEDERATION OF AMERICAN SCIENTISTS Volume 60, Number 2 Spring 2007

PLUTONIUM RECYCLING

While the Global Nuclear Energy Partnership has the potential to revolutionize nuclear power, it may also turn into the greatest technological fiasco in U.S. history. Ivan Oelrich, Vice President of the FAS Strategic Security Program, summarizes the pros and cons of this proposal.

More on page 12.

RESPONSES TO A DIRTY BOMB ATTACK

Four experts reviewed current policies for dealing with the detonation of a dirty bomb at the AAAS Annual Meeting in San Francisco, CA. Much work remains to be done to better determine how U.S. first responders should prepare to act.

Read more on page 13.

DIGITAL PROMISE

The U.S. education system needs to join the digital age. At a time when technology is an integral part of daily activities, the traditional "test and tell" model of instruction is still being used in the classroom.

To learn more, *go to page 15.*

About FAS

The Federation of American Scientists (FAS), founded on 8 December, 1945 as the Federation of Atomic Scientists by Manhattan Project scientists, works to ensure that advances in science are used to build a secure, rewarding, environmentally sustainable future for all people by conducting research and advocacy on science public policy issues. Current weapons nonproliferation issues range from nuclear disarmament to biological and chemical weapons control to monitoring conventional arms sales and space policy. FAS also promotes learning technologies and limits on government secrecy. FAS is a tax-exempt, tax-deductible 501(c)3 organization.

FAS
PUBLIC INTEREST REPORT

Spring 2007, Volume 60, Number 2

ADDRESS SERVICE REQUESTED

FAS Public Interest Report

FAS Public Interest Report,
USPS No. 188-100
is published quarterly at:

1717 K Street, NW, Suite 209
Washington, DC 20036.

Periodicals postage paid at
Washington, DC

POSTMASTER:
SEND ADDRESS CHANGES TO

FAS Public Interest Report
1717 K Street, NW, Suite 209
Washington, DC 20036

Annual subscription is $25/year.

Archived FAS Public Interest Reports are available online at www.fas.org

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PRESIDENT'S MESSAGE

A Changed Environment for FAS

New leadership in Congress creates possibilities for a new policy agenda of intense interest to FAS. Much of our most important work over the past few years has been easy to characterize by what we were against: blocking dangerous developments in nuclear weapons, new constraints on government information, and cuts in research spending. We now have, with a fiscally restrained but politically more receptive Congress, the challenging task of helping construct positive solutions to fundamental problems. During the next few months we will seek the counsel of the FAS board, advisors, and members on where best to focus our efforts. I will take this opportunity to present some thoughts to start the conversation.

Economic changes over the last century resulted in a tightly coupled world economy. Economic change has increased living standards around the world, but the gap separating rich and poor is growing both among nations and within nations—including the US. This is shameful in itself but economic inequality, rather than conflicts over political ideology or religion, are likely to be the real engines of international turmoil for the foreseeable future. The danger is compounded because the free flow of information and goods has made it possible for countries with weak governments and non state terrorist groups to obtain terribly lethal powers — from access to sophisticated small arms, like shoulder-fired anti-aircraft missiles, to weapons of mass destruction including nuclear weapons. The fact that all nations live in the same atmosphere and biosphere has been underscored by frightening forecasts of the harm our accelerating industrial economy may have on our shared environment.

None of these challenges can be resolved without strong international collaboration or without coherent U.S. leadership. This begins by taking aggressive actions to get our own house in order. It's essential to restore America's reputation as a place that can encourage both creativity and justice, that celebrates freedom, growth, and change while taking care to ensure that everyone can benefit from progress, and that attention is paid to the environment and other non-market consequences of economic activity as a matter of routine.

These priorities assume that the U.S. must maintain strength and vigilance to defend ourselves. But this does not imply leadership by intimidation and pursuit of unfettered freedom of uni-lateral action that seems to have been the consensus view of the U.S. governing class for the past six years. It's a peculiar irony that the groups placing the greatest value on US unilateral freedom of action seem least concerned by the terrible constraints placed on US freedom of action by the need to maintain good relations with oil suppliers – few of whom share our values.

It is important that FAS seize this moment. Action on key issues in nonproliferation, energy, the environment, research, and education is badly overdue. The kinds of thoughtful, well researched concepts our community can offer have a uniquely receptive audience. It's time for us to move from defense to offense and develop concrete, actionable ideas that can be considered by a new Congress. I look forward to your thoughts about priorities and hope that you'll be willing to help us deliver. To start, I have outlined some specific priority areas in a table appearing later in this document. They are built around four themes:

1. **Enhancing the Nation's Security:** We must move beyond pork barrel projects left over from the Cold War and put our security resources where they matter the most. This includes making strategic investments in economic development, energy programs that could prevent conflict and setting an explicit goal of eliminating nuclear weapons.
2. **Improving the Natural Environment:** Technological advances increase productivity of resources use to a point where people worldwide can enjoy improved living standards and amenities with dramatically reduced envir-onmental harm.
3. **Promote Innovation and Discovery:** Innovation is the driving force of our economy; it is the only hope for continued US leadership in the global economy. This includes innovation in education. The freedom to explore the unknown is the ornament and obligation of an advanced society.
4. **Reform Government management of S&T:** Restore unbiased science and technology advice to the Congress and President and ensure that the actions of government and information available to government officials are accessible to voters except when restricted by clear, and challengeable, rules of classification.

The US scientific community has an obligation both to help the new Congress define an agenda in these critical areas and build a national consensus for action. It's clear that none of the critical challenges facing the federal government can be resolved unless creative, dedicated people are willing to take the time to engage in the debate and encouraged to take key administrative positions in the federal government.

Overview of Science and Policy Issues

FAS must take great care in choosing where to invest the time and resources of its members and supporters. It succeeds best when it works on critical areas that are not adequately covered by other groups or when it can collaborate or build on high quality work done by others. The following essay is intended to facilitate a discussion about FAS priorities by providing a broad review of key science policy issues facing Washington today.

Enhance the Nation's Security

The enormous debacle of the Iraq war has made it difficult to focus on the fundamental security issues facing US a decade after the end of the Cold War and simultaneously increased the urgency of addressing them. While the debate over Iraq deserves priority it would be a dangerous mistake to ignore deep structural problems in US defense priorities.

It's received wisdom in Washington that Reagan's massive defense buildup forced the Soviet Union into bankruptcy and collapse and there is an element of truth in this. Since the US won the Cold War decisively, we have never been forced to undertake a thoughtful review of security spending priorities. The momentum of cold war pork barrel spending continues unabated. Huge fleets of new submarines, fighter aircraft, and nuclear weapons designed to defeat the Soviet Union continue using justifications that would have to be considered delusional if they weren't in fact quite cynical. Efforts to close or consolidate bases or national laboratories or stop pointless weapons programs are frustrated. Indeed we have arrived at a point where any vote against defense spending, however egregious, is politically dangerous. Since few legacy programs can be stopped, innovations must be paid for with new money. But even with a tidal wave of red ink in national budgets, Iraq has strained defense budgets to the breaking point.

The decoupling of military spending from real defense priorities could be considered a comparatively harmless waste of money except for three problems:

- First we're finding that our military is not prepared to manage the wars that we actually need to fight. Our intelligence system is too often surprised and our troops are stunningly ill equipped when they actually have to defend themselves against poorly organized enemies equipped with primitive explosives and cell phones – let alone the sophisticated small arms that we and others have helped put into world circulation over the years.
- Second, programs like our nuclear weapons complex, supported at this point primarily as a pork barrel projects, have real and dangerous effects on US options for bringing these dangerous weapons under international controls.
- Most importantly, the politics of military spending blinds us to investments that might actually have the greatest impact on security. These include economic development that will provide jobs and hope to people now turning to fanatics for leadership. And they include research collaborations that could create alternatives to petroleum that could remove a force that has disfigured the foreign policy of the US, Europe, China, and many others by forcing alliances with distasteful governments.

We have the opportunity to redefine US defense priorities starting with the following.

1. Focus on prevention:

- *Rebuild the reputation of the US as a model of how a strong and prosperous society can operate with uncompromising ideals of justice, fairness, and tolerance.* A recent BBC poll showed that nearly half of the people polled in 25 countries thought that the US had a "mainly negative" influence on the world – and this fraction has been growing rapidly[1]. US leadership is plainly impossible unless this trend is sharply reversed.
- *Form collaborative research alliances with Europe, China, India and other nations on strategies for minimizing the role of petroleum consistent with global environmental goals.* This would include high efficiency transportation technologies, and clean alternative energy sources. It makes little sense to try to gain competitive advantages for US firms in this area since most vehicle manufacturers and energy companies are multinational. The benefits of reduced dependence on petroleum anywhere in the world would serve the interests of the US (more on this later).
- *Secure economic development in countries where we have a clear strategic interest.* Priority should be given to Mexico and Turkey. Both are on the brink of becoming modern economies but both are also at great risk of collapsing into the hands of radicals. A prosperous Mexico would greatly reduce immigration tensions and drive economic growth in the US. A prosperous Turkey could show how Muslem nations can be full partners in a modern world economy. Success depends on ensuring that all parts of their societies benefit from development. Failure by either nation would be catastrophic to US interests.
- *Move to an economic assistance program that builds capacity for modern economies.* This includes greater investment, setting priorities by the recipient country's need, not by which domestic firms benefit, and eliminating US and European agricultural subsidies.

2. Move beyond Cold War legacy programs and focus on contemporary defense needs

- *Seek the worldwide elimination of nuclear weapons.* In today's world, nuclear weapons are instruments of terror. Given the superiority of US conventional forces, nuclear weapons have no essential role in the US arsenal. Bunker busting bombs are pointless even given perfect intelligence since even the largest weapon can be avoided by digging deeper. Any nuclear use would inflict huge numbers of civilian casualty from fallout and other effects and instantly turn a conflict into a calamity. But the growing number of weapons states is a clear danger to US security. The administration should conduct a broad, imaginative review of US nuclear weapons policy with the intent of effectively and convincingly ending the Cold War nuclear posture. The US should act immediately to break the logjam on negotiations on proliferation by signing CTBT and offering to eliminate all US weapons if acceptable protocols for dismantlement and inspections are agreed to. An international agreement should put the entire nuclear fuel cycle under strong international inspection or control, including the US fuel cycle, and stop all production of fissionable material worldwide.

- *Ban weapons in space:* The recent Chinese test underscored the necessity of working to free space from weapons. The US has a huge, asymmetrical interest in open access to space both for its economy and for the operation of its security apparatus. Other nations are quickly following suit. Space assets ranging from GPS locaters to communications and weather forecasts are becoming a part of the infrastructure of a modern economy. Open access to space is central for research on climate, weather, and astronomy. The benefits of a weapons free space environment vastly outweigh any advantage in freedom of US unilateral action.
- *Restore the integrity of the Defense Research and Development Process.* A combination of budget cuts and pork barrel projects built around obsolete or misplaced objectives has endangered the future of US defense forces and intelligence and hobbled a critical part of the US research enterprise. DARPA and other key defense research organizations have been forced to shift to highly applied projects. The process of setting priorities for applied technology has been crudely distorted by political pressure to back projects like missile defense, hafnium bombs, and next generation fighter bombers to combat nonexistent threats while important ideas for strengthening intelligence and protecting soldiers in the field have gone begging.
- *Build a serious program for responding to a major outbreak of an infectious disease.* It is highly likely that the US will face a dangerous outbreak of a naturally occurring infectious disease during the coming decades and will be woefully unprepared. Programs to defend against natural disease outbreaks would be as effective in defending against malicious use of biological agents. Investment in infectious disease prevention and treatment should be accelerated. Immediate steps are needed to accelerate the development of vaccines and treatments and for creating stockpiles. Provision must be made for treating large numbers of patients through rapid expansion of medical facilities. Careful planning for quarantines and other activities need to be developed and practiced.

Protect the Environment

There is no serious doubt that human activity is altering the earth's climate in potentially catastrophic ways. Even skeptics are forced to admit that the risk is real and that prudence demands action if only as an insurance policy, the only serious debate is about how best to respond. This is a global problem demanding global solutions and international collaborations on research and policy are essential to ensure that remedies do not adversely affect the competitive positions of the US or other nations. But in the near term the US has an essential role to play in demonstrating how a prudent policy based on innovation can combine strong economic growth with reduced impact on the environment.

The core problem, of course, is that the most obvious answer to energy issues is also the most difficult to implement: ensuring that consumers pay the full cost of energy when they purchase gasoline, electricity, or other energy products. Energy production and use is responsible for the vast majority of air emissions including greenhouse gas emissions. An avalanche of studies has estimated the huge hidden costs of US energy consumption, but without visible impact. Clear price signals that include these costs are the best way to ensure that funds flow to the most efficient investments for providing energy services – automatically balancing investments in supplies and demand. It is also the best way to ensure that private research funds flow to the most promising areas. The obvious political problem is that the benefit of avoiding wars or climate catastrophes is distant and uncertain while prices at the gasoline pump are instantly understood and loathed. This political paradox has spawned a huge industry of second best solutions. One obvious casualty of a policy keeping energy prices artificially low is privately supported energy research. Aggressive federal investment in research essential and presently less than half what would be needed to mount a serious program.

Energy has its own federal agency because we can't solve this problem. We pay a huge price for decoupling energy policy and the many domestic economic issues that are entangled in energy issues. Policies dealing with innovation, housing, urban development, transportation, agriculture, and many others can have a greater benefit than any new energy production technology. Approaches to revitalizing innovation include the following:

1. Rebuild Energy Research around a DARPA model

Energy research has become bogged down in decades of pork barrel spending, ideological struggles, and federal laboratories unable to keep pace with commercial innovation. The need for a fresh start in energy research is well understood. In testimony before the Senate Energy Committee, Dr. Charles Vest, former President of the Massachusetts Institute of Technology (MIT), recently told the Congress: "On the whole, in recent decades, many of our best minds were not attracted into the science and technology of energy. We in universities allowed energy to slip into academic backwaters, and neither our energy companies, nor our national laboratories, nor the entrepreneurial community have applied enough intellectual and financial muscle to it. We have grown complacent in the face of a monumental challenge."

A creative response to this challenge now being considered by the Congress deserves strong support – building energy research around a model established by the Defense Advanced Research Projects Agency (DARPA). The classic DARPA style is simple. They define what they call "DARPA-hard problems," challenges of enormous importance to national security, but present technical problems so heroic that standard engineering can't begin to address them. These projects, along with a considerable amount of money, are assigned to managers chosen because of their well-respected grasp of the relevant subject matter, their ability to manage complex projects, and their creativity in searching for precedent-shattering ideas. When DARPA was in its prime it gave managers freedom and three to four years to attack the problem, using talent and ideas wherever they can be found. DARPA has been unusually effective in building teams from university faculty, people from innovative startup firms, and researchers in large businesses who have never met each other, often making them an offer they can't refuse – the chance to work on a fascinating problem with enough money and enough time to make a difference.

This is obviously a high risk approach. DARPA projects have crashed and burned in spectacular—occasionally embarrassing—ways. But the payoffs can be huge. Author Michael Dertouzos estimated that DARPA was behind "between a third and a half of all the major innovations in computer science and technology." Many of the people involved in these projects went on to launch major businesses including Sun Microsystems, Silicon

Energy research challenges: safe, affordable, practical technologies for:

- carbon sequestration
- mobile power conversion with >50% efficiency using liquid fuel
- light sources 50% more efficient as fluorescents
- refrigeration/heat pumps twice as efficient as today's chillers
- electric storage for 10-1 to 107 kwh
- photovoltaic modules at less than $2 per watt
- windows with tunable optical properties (reflectivity and emissivity)
- just in time production of complex chemicals and self assembling structures mimicking biological processes
- safe, energy efficient building shells
- efficient conversion of all parts of a plant (cellulose, hemicelluloses, lignin) to fuels and other chemicals

Graphics, and Cisco Systems – which began with DARPA-developed packet switching and internet gateways.

Letting the DARPA system work requires unusual forbearance on the part of both the Congress and administration officials. Over the years, it's been sustained only because some extremely senior person in the Administration or Congress stepped in to protect it from continuous pressure to cut long-term investment to pay for immediate needs.

An effective energy ARPA can play an essential role in finding new energy technologies that can look for fresh new approaches and bring new players to the table. Like DARPA in its heyday, the organization can be lean, respond quickly to new opportunities, bold in dumping failed projects, and flexible in connecting the best people in industry and in academia.

Congress must take great care in the details of designing an effective DARPA-like research program. The experiment in establishing an ARPA for the Department of Homeland Security has gone badly wrong, and the organization may never be able to escape the confusion of this ungainly new agency. It is critical that the new energy organization be protected so that it can focus on the most important future challenges, take risks, and track down talent.

2. Emphasize energy productivity and conservation and integrate these goals into the missions of critical federal agencies

We have only begun to understand that higher living standards do not automatically demand greater consumption of energy and materials. A fair review of energy investments shows that reducing the need for energy almost always is more cost effective than investments in new energy supplies. Recent advances in three key technology areas provide some insights:

- *Information technology:* New computational and communication technology has been responsible for a major share of US and world economic growth but these businesses manipulate and move bits and bytes, not people and materials. These tools in turn can greatly improve business processes, encourage efficient design and production, and eliminate wasteful process steps.
- *Materials:* Composites, designer alloys, and other innovations increase strength and durability while reducing the mass of materials used. Fabrication at the atomic scale can provide products exquisitely tailored to function with little waste in production.
- *Bioengineering:* Biological systems at every level should give us inspiration about what is possible. Living cells can manufacture thousands of complex structures and chemicals on demand providing only what is needed when it is needed and where it is needed. And many of these materials can be disassembled when they are no longer needed and the pieces reused within the same cell. The energy production and use is similar. Energy is stored and transported to where it is needed and applied to production in precisely the amounts needed. Nothing is set on fire and the small amount of waste is biodegradable.

Three familiar areas deserve priority concern: vehicles, which account for 70% of US petroleum consumption (if asphalt for highways and transmission oils are included), and buildings, which consume 70% of US electricity including space conditioning and lighting for industrial facilities. Agriculture is important because of the huge energy demands from chemical fertilizers, the volume of material transported, and its potential to become a net producer of energy.

The economies of construction, transportation, and agriculture face an antique and extraordinarily inefficient tangled mixture of federal, state, and local rules that frustrate innovation. The power of incumbent institutions profiting from this state of affairs means that the political forces arrayed against change are extraordinary. But unless a dramatic change is made in the way these institutions manage change and innovation, we will frustrate discovery that can rewrite the rules of energy use and generate attractive new jobs and business opportunities. Repeated studies show that real productivity growth depends more on institutional adaptability to change than on raw inputs of capital, labor, and technical know how.

Specifically:

- *The Department of Housing and Urban Development* (HUD) should move beyond its New Deal mission and focus on building safe, efficient, affordable, livable communities. This means shifting from an an ancient system of formula driven grants and subsidies to programs that ask communities to compete in proposing housing standards and creative investments in urban design that meet ambitious energy, environmental, and safety designs. It should also move beyond simply subsidizing the energy bills of inefficient homes occupied by low income families to investments in efficiency that could make these families more comfortable at a lower cost. HUD should also undertake a major research mission of its own to support these goals. HUD is almost alone among federal agencies in having no major research program to support agency goals. Standards for buildings and building components should encourage innovative approaches to energy efficiency and safety. The current patchwork of federal, state, and local standards often discourage precisely the new approaches needed. Standards are not published online since many are set by private organizations that support themselves by charging fees for the information. HUD should be charged with fixing this.
- *The Department of Transportation* (DoT) should also shift its priorities from a pork-ridden allocation of highway funding to competitive grants based on regional transtortation systems that meet high standards for efficiency and safety. DoT administers the automobile and truck fuel economy standards that are absurdly out of synch with current needs. The on-road fuel economy of personal vehicles should double in the next 15 years—beware of accounting

tricks that prevent this. Incentives for creative transportation design must be developed in close collaboration with the "urban development" mission of HUD. Transportation systems meeting efficiency and safety goals depend critically on minimizing the need for transport as well as on the means of transport. DoT should also rebuild its research capabilities to focus on key efficiency and safety problems largely buried in the stampede to support homeland security. Key research objectives are being ignored. Air traffic management is critical to energy efficiency of the rapidly growing airline industry. Innovative aircraft designs can improve efficiency. More than 43,000 Americans are killed and nearly 3 million injured in highway accidents each year. Increases in automobile efficiency should be coupled with greater safety.

- *The Department of Agriculture* is paralyzed by anachronistic incentives that waste resources and undermine innovations that could stimulate rural economic development. A careful review of programs and missions could build new industries around cellulose production from waste and stover, energy rich crops, and wind energy. Sensible incentives could produce higher quality food products with greatly reduced energy use.

Promote Innovation and Discovery

America has an enviable record not just in inventing new technologies but in having firms with the flexibility and creativity needed to take full advantage of these inventions. This has depended on a strong program of public support for basic and applied research and a comparatively flexible, performance-based regulatory program. But success cannot lead to complaisance in the face of pressing research needs and the growth of sophisticated innovation centers worldwide.

1. Major increases in research funding at NSF, NIST, and NIH

The coming decade promises to deliver a spectacular set of discoveries in basic science but federal funding must rise sharply to take advantage of the opportunities. The benefits of this research are enormous but they are also very broad. Corporate research managers can never guarantee capturing financial returns on basic research, which makes federal investment essential. But a large fraction of highly rated research proposals are going unfunded. This means that the benefits of this work will be delayed or that the research will be conducted elsewhere.

It is important to ensure that the nation provide a balanced investment that supports good work across disciplines. Growth in the physical sciences must be in addition to, not instead of, increases in biological research. Some of the most promising research in biology lies at the intersection of physics, mathematics, engineering, and biology and it is time that the biology budgets include investments in facilities like large computational grids to support biological research. We should:

- Double research spending in the physical sciences over a five year period
- Increase research funding for biological research at least 3 percent over inflation each year
- Ensure secure and growing funding for economics and other social sciences research.

It's extremely difficult to argue for major increases for science on the basis of abstract arguments that science investments pay enormous returns. Grand challenges such as the war on cancer, or going to the moon have stimulated great excitement followed by investments. Since these challenges can also distort priorities and drain resources from other worthy research, the dangerous bargain that must be struck is finding a challenge that is large enough and clear enough to muster national support but also where funding growth would be driven in many key areas. A short list might include:

- *Finding 95% of the universe:* A combination of physics and cosmology has revealed evidence for phenomena and particles beyond the scope of the standard theory. The measurements and theory that could explain dark energy and dark matter will be a great adventure
- *Predicting cell behavior:* A wealth of insights into gene expression, cell signaling, and other features of cell control are approaching the point where we can predict the response of cells, tissues, and organs to attacks and to therapies. This can be a defining goal for future biological research.
- *Explaining climate change:* Much remains unknown about the dynamics of the way astronomical cycles, and temperature and chemical changes in the oceans and atmosphere affect global and regional climates. The steady decline in recent years in investment in climate analysis and in measurements using satellite and other data gathering tools must be reversed.

Good research, of course, depends on good management. Given the shortage of new funds it is increasingly apparent that we must end programs that may have been important a generation ago but are difficult to justify given today's priorities. Concrete steps should include:

- Design new models for establishing research priorities and selecting among competitive ideas that are most likely to put money where innovation will be greatest. DARPA models should be considered closely but the fate of the Homeland Security ARPA provides a cautionary tale about the care that must be taken to ensure that such groups have the needed independence from political masters and legacy institutions.
- Eliminate pork and entitlements. It's essential to have research institutions that can operate national research facilities and allow skilled teams to work on critical domestic and security research topics for extended periods of time. But much of the National Laboratory system created during the cold war is no longer suited to a world where access to dynamic industrial research and university groups is essential and where many of the researchers are not US citizens. Legacy institutions should be able to compete for their funding for new research centers but should not have an entitlement.
- Manned space flight should have to compete on equal footing with other priorities for research in physics and astronomy. It should be forced to demonstrate that it has higher intellectual returns on investment than competing demands for research.

2. Innovation in education

Educational technique must be an integral part of any national innovation program. The US spends about a trillion dollars a year on education and training, making it one of the largest parts of the US service economy. And the demand is growing. People in virtually every job find themselves dealing with constant change, new technologies, and new team members. Employers are looking both for traditional skills including competence in science and math and communications and for "21st century skills" including decision-making under uncertainty, and an ability to gather information from ambiguous sources and learn new fields quickly. The challenge is made greater by the enormous diversity of the backgrounds, experiences, and interests of people who need education and training in the US. New tools for conveying and measuring expertise and tailoring learning to individuals are essential for meeting this challenge. Much of this capability has already been demonstrated in tools developed for entertainment and business but private firms cannot justify the research needed to put these tools to effective use in learning.

It is time to take a fresh look at the unique role of federal funding in education. Core functions can include:

- Research on how to make education more productive and more responsive to the needs of a diverse population. Indeed, federal failure to mount a major, sustained, and well managed research program in this field may be the largest single gap in the current national R&D portfolio.
- Support for the development of curricula materials including integrated performance measurements that make full use of new technology – including the ability to include continuous reviews, updates, and improvements based on nationwide experience. Education institutions would be free to use, modify, or ignore these materials. But they could provide a systematic way to evaluate authentic expertise including the new kinds of skills needed by Americans today. Simulation-based assignments can determine whether students have practical grasp of the information that transfers into an ability to meet real challenges. Well designed, these are challenges that students will tackle enthusiastically.
- A new kind of public media. Public radio and TV are already moving to embrace web-based distribution of their materials but this is clearly just the beginning. It is time to consider whether a new kind of public media should be built, one that embraces emerging techniques for mixing communication and computational resources to create persistent, collaborative, on-line worlds.

Reform Government management of S&T

Undertaking an effective new program in Science and Technology requires management reforms in the federal government itself. This includes:

1. Reestablishing OTA or an equivalent

Congress can not operate successfully as an independent branch of government without its own source of science and technology advice. To be an effective replacement for the late Office of Technology Assessment (OTA), an organization should have adequate resources (at least half of the old OTA budget or $20 million/year) and independence. The organization could be given a formal role in helping organize annual hearings on the entire S&T budget – something that would require the collaboration of several committees.

2. Strengthening OSTP through statute

The White House's Office of Science and Technology Policy should be given the authority now available to the NSC to assess key S&T issues and bring them to the president for decision. It should have a central role in designing the overall national R&D budget and presenting it to the Congress. Doing this requires a significant permanent staff and funds to charter research at the National Academies of Science or other institutions.

3. Ensuring maximum openness and transparency:

Democracy depends on citizens able to understand what their government is doing and critics who propose alternatives. Much information needed to review government decisions, identify potential problems or opportunities in areas ranging from security to health care require information only available from government sources. It is essential that government information be available and easy to access. There are obvious exceptions – such as the need to protect information that could compromise national security or that could reveal personal or proprietary information. Clear and transparent rules should govern the areas where these protections apply and there should be straightforward ways to challenge decisions. A host of vague and dangerous new restrictions on government information have emerged in the past few years. Congress should move quickly to restore secrecy policy that builds secure walls around information that should be protected while ensuring maximum possible transparency in public affairs.

The US scientific community has an obligation both to help the new Congress define an agenda in these critical areas and build a national consensus for action. It's clear that none of the critical challenges facing the federal government can be resolved unless creative, dedicated people are willing to take the time to engage in the debate and encouraged to take key administrative positions in the federal government. **FAS**

Learning Science and Technology Research Challenges

- Knowing how and when to use open, discovery based learning
- Systems for collaborative construction and review of simulations
- Multimedia systems to answer questions reflecting context, who is asking, and a learning strategy
- Methods for assessing mastery of complex expertise
- Effective combination of artificial and real intelligence

[1] *http://www.globescan.com/news_archives/bbcusop/*

An Evening With Richard Garwin -- Plutonium Recycle in the U.S. Nuclear Power System?

By Richard L. Garwin, PhD, IBM Fellow Emeritus at the Thomas J. Watson Research Center

Today some 103 nuclear power plants in the United States produce about one million kilowatts each of electrical power, supplying some 20% of US electrical needs. They do this by the use of the neutron chain reaction in uranium-oxide ceramic pellets, sustained by the regeneration of neutrons through the fission process.

Each fission in the light isotope of uranium—U-235 that constitutes 0.7% of natural uranium and is enriched to about 5% concentration in the 25 tons of fuel loaded into the reactor each year, where it produces heat for about 85% of its 4-year sojourn—liberates about 2.5 neutrons on the average, and 30 billion fissions contribute about 1 joule of heat. If your personal computer runs at 3GHz or 3 billion operations per second and consumes about 50W or 50J/s, it is fed by about 150J/s of reactor heat or 4,500 billion fissions per second—about 30 fissions per arithmetic operation, or about 8 fission per bit.

Of the 25 tons of fuel--heavy metal--loaded each year into the reactor as essentially non-radioactive fuel rods and fuel elements, about one ton is fissioned during its 4-yr stay in the reactor— that is, the U-235 is split into a light and a heavy fission product largely retained in the solid fuel pellets in their tubular metal sheaths. The accompanying heat is transferred to water in the high-pressure reactor vessel, and the water boils to steam in the upper portion of the vessel (for a boiling water reactor—BWR) or after a heat exchanger in the case of a pressurized water reactor—PWR.

Because these reactors use ordinary water both to transfer heat from the reactor fuel to the steam turbine, they are called light-water reactors—LWRs. The plentiful U-238 does not fission to a significant extent in LWR, but it does have an appetite for the slow neutrons; instead of fission U-238 undergoes capture of a neutron to form U-239, which in short order decays in the reactor to Np-239 and then to plutonium—Pu-239.

Pu-239 is even more readily fissile than is U-235 and is quite suitable for making nuclear explosives, as is highly enriched U-235 in the range of 80% U-235 or more.

The spent fuel elements removed from the reactor in the refueling operation are highly radioactive. Even after 100 years they are regarded as self protecting in that a single fuel element would irradiate a person at one meter distance with more than a dose of 1 sievert (1 Sv) in 1 hour. Delivered in an instant, a lethal dose of 4Sv would raise the body temperature only about 0.001ºC.

Within the operating reactor, each kg of fuel generates about 30kW of heat. A week after reactor shutdown, fuel elements transferred to the spent-fuel pond still generate about 100W/kg, from the decay of the radioactive fission products. If the water were lost, the spent fuel would heat within hours to the melting temperature of the fuel-rod sheath; the zirconium alloy would burn in air. After 10 years, spent fuel still creates 2W/kg, little enough that the fuel can be stored in massive casks to protect people from the gamma radiation of the fission products; the casks are cooled by natural air convection.

All US power reactors are fueled with low-enriched uranium—LEU—ceramic fuel, and almost all spent fuel thus far has been held in at-reactor water pools that provide cooling of the fuel elements and shielding of plant and public personnel against nuclear radiation. It has long been planned that after 10 years or so of pool storage and cooling, fuel elements would be transferred to long-term storage casks that would then be shipped to the Yucca Mountain, Nevada, mined geologic repository; a recent National Academies study provides an independent assessment of the safety of such shipment3. Following the long-delayed opening of YM, fuel elements in storage casks would be loaded into the underground horizontal tunnels—drifts—with about 1.1 metric tons of initial heavy metal per meter length of drift—MTIHM/m. The US industry in this way has been practicing the open fuel cycle or the once-through or direct disposal fuel cycle—at least up to final disposal in a mined geologic repository.

In contrast, for decades France has been reprocessing spent fuel from its 58 LWRs, using the PUREX process to separate about 16 tons per year of plutonium from about 1600 tons of spent fuel. Much of the spent fuel was of German or Japanese origin, and the separated Pu and vitrified fission products were by law and contract to be returned to the country of origin. France has used its own Pu to fabricate mixed-oxide—MOX—ceramic fuel pellets that displace LEU fuel elements—UOX— and thus reduce the uranium demand by about 20%.

PUREX was used by the US and other states to separate plutonium for nuclear weapons from lightly irradiated fuel from Pu-production reactors; less than one ten-millionth of the radioactive fission products remains with the separated Pu. The civil plutonium is stored and shipped in small welded stainless-steel cans containing 2 kg of plutonium oxide. In contrast to the fierce gamma radiation of the spent fuel, so little radiation emerges from the pure plutonium oxide that the cans can be carried without harm in one's bare hands, and the MOX fuel elements can be fabricated without the use of heavy shielding. However, plutonium is an intense emitter of alpha particles and must therefore be handled in a glove box to prevent ingestion or inhalation. Per gram, weapon plutonium emits about 60,000 times less alpha radiation as does the polonium-210 that killed Alexander Litvinenko in 2006; this is a consequence of the 24,000-yr half life of Pu-239 compared with the 140-day half life of Po-210.

The French approach to the closed fuel cycle has been demonstrated by French government analyses to be more costly than the open fuel cycle.

Despite persistent claims that this approach to plutonium recycle has substantial benefits in reducing the burden on the repository, there has been recent awareness that the capacity of the repository is not limited by the bulk of the spent fuel but by the continuing heat evolution from the fission products and the transuranics—that is, plutonium, americium, neptunium, curium. This is clear from two highly authoritative books by Robert Dautray, former high commissioner of the French Commisariat à l'Energie Atomique—CEA. More accessible is the recent presentation showing that "Limited Recycle" with the disposal of the spent MOX fuel into the repository requires 90% as much repository capacity as does direct disposal without reprocessing. Dr. Finck, who worked in the French program and is now a key technical person in the US Global Nuclear Energy Partnership—GNEP— stresses that major gains in repository capacity can be achieved only with a suite of fast-neutron reactors that can actually fission the transuranics—the minor actinides. This has never been made clear by the French nuclear-power entities.

GNEP was announced by President George W. Bush in February, 20066. Testimony by the Department of Energy at the April 6, 2006 session of the Energy Subcommittee of the House of Science Committee highlighted the fact that of the proposed first-year GNEP budget of $250 M, some $155 M was toward the building of a demonstration reprocessing plant, dubbed UREX+. The intent was to demonstrate at perhaps 10% full-scale the reprocessing of all the fuel emerging from the 103 operating US LWRs, in order to begin to provide fuel for a generation of fast-neutron Advanced Burner Reactors—ABRs. A key element of GNEP was to have a reprocessing approach more "proliferation resistant" supposedly by leaving enough fission products with penetrating gamma radiation— lanthanides—especially europium-154 with a half-life of 8.8 years.

Part of the GNEP program is to offer foreign reactor operators a secure fuel cycle at advantageous rates— leasing of fresh fuel and take-back of the spent fuel— and also cartridge reactors that would be delivered loaded with fresh fuel and could operate for 20-30 years without refueling. The cartridge reactor would then be replaced by a fresh one and taken back for de-fueling. I strongly support these aspects of GNEP, observing, however, that the U.S. will be far from the only one to offer cartridge reactors or the secure fuel cycle.

Still, national and international regulations and customs need to be changed in order to permit spent fuel to be transferred from one country to another for ultimate disposition, either by direct entombment in a mined geologic repository or by reprocessing followed by entombment in a repository. The secure fuel cycle makes good sense economically from the point of view of the using country, and for the world from the point of view of limiting facilities capable of providing weapon-usable materials: enrichment plants and reprocessing plants that, respectively, produce enriched uranium (and could produce highly enriched uranium), and the reprocessing plant that produces plutonium, even if it is mixed with 50% uranium in some of the recent proposals. The proposal to lease and take back reactor fuel was published long ago by Harold M. Agnew, then Director of the Los Alamos Scientific Laboratory, in the Bulletin of the Atomic Scientists (May 1976, page 23), as "Atoms for lease: An alternative to assured nuclear proliferation."

States that express concern about the reliability of future fuel supply under potentially tense international conditions could well buy a stockpile of LEU fuel for 10 years of operation of their reactors; fortunately, LEU fuel is safe and cheap to store and cheap to buy, in comparison with fossil fuels.

Beyond the provision for the US to join other supplier states in a secure fuel cycle without commitment to reprocessing, I believe that GNEP has its priorities all wrong. GNEP as formulated and presented at the hearing of April 6, 2006 is not necessary to achieve the stated goals of nonproliferation and is more likely to hinder the achievement of those goals.

According to DOE announcements of August, 2006, the DOE is planning to replace the proposed engineering-scale demonstration—ESD—plant with a purchased conventional reprocessing plant very much like the one that has just begun operation at Rokkasho-mura, Japan. Except that the DOE plant would be the largest in the world. Although it would not separate "pure plutonium" if it operates like Rokkasho, the extracted pure plutonium oxide would be mixed with about an equal amount of uranium oxide. This would add little to the cost or time required for a state or terrorist to convert a stock of this COEX product into plutonium metal for a nuclear weapon.

As for terrorist acquisition of nuclear weapons, to acquire plutonium from spent fuel elements is a daunting task because of their intense radioactivity and the fact that to obtain the 10kg of reactor-grade Pu for a nuclear weapon a terrorist would need to steal and reprocess a ton of intensely radioactive spent fuel. In a reprocessing world, the task is to acquire 10kg of separated Pu (from the PUREX process) or 20kg of COEX product, either of which can be carried off without additional shielding. Despite the fact that the GNEP reprocessing product is less proliferation resistant than the direct-disposal approach, in GNEP-speak the claim of proliferation resistance features importantly in the arguments for GNEP.

France and Japan have often supported their activity in reprocessing and recycle of plutonium by pleading that they lack native energy resources and need reprocessing in order provide some degree of energy independence. This argument does not hold water, since the recycle of Pu in LWRs (or the use of the ideal ABR—one that consumes every plutonium atom without producing another—to burn up the actinides) reduces uranium needs by only about 20%, at best. I must say, however, that I have been notably unsuccessful in dissuading either country over the decades by the argument that far more energy independence would be obtained by buying ahead an 8 or 10-year stock of uranium fuel, and the same degree of energy independence would be achieved by buying ahead 20% of a 10-year stock of fuel.

This saving of uranium comes at a very high price. Assuming a reprocessing cost of $1000/kg of spent fuel, and noting that 5 kg of spent fuel must be reprocessed for each kg of MOX fuel produced (that is, 5 spent fuel elements for each fresh MOX fuel element), it is a simple matter to calculate the cost per kg of uranium saved. Each kg of fresh fuel element (5% U-235) requires 9 kg of natural of uranium, although less NU would be required if the tails concentration from the enrichment plant were reduced, as would naturally follow from the higher price of uranium. Nevertheless, at 9kg of NU per kg of LEU, the break-even cost of uranium as contrasted with reprocessing would be $5000/9 = $555/kg of NU. In reality, the fabrication of a MOX fuel element, given the MOX material is far more expensive (by about $1000/kg) than is the fabrication of a UOX fuel element. So the break-even cost of NU that would make reprocessing and recycle in LWRs a wash is thus about $555 + $1000/9 = $666/kg of natural uranium. For comparison, I show the historical cost of uranium.

Now, it may be that 50 years ago with less knowledge about the availability it might have seemed a good bet to reprocess. But that bet has failed, and it has made no sense for Rokkasho to be built and it makes even less sense from the point of view of saving money and uranium for the U.S. to go into reprocessing.

Reprocessing has other problems. I have visited both THORP at Sellafield, England, and the COGEMA plant at La Hague, France. During the reprocessing (and for decades after in the case of Sellafield) much of the radioactivity instead of being locked in spent fuel elements has been made freely available in enormous tanks of concentrated CS-137, that must be actively cooled (via a triply redundant cooling system) if it is not to evaporate and spread its radioactivity over the countryside. GNEP proposes not only to separate the minor actinides and to burn them in the ABR fast-neutron reactors, but to separate out the 30-year half-life strontium-90 and cesium-137 (each has a 30-year half-life) and to store them for hundreds of years above ground (one hopes not in the form of liquid) until they decay and can be entombed in the repository. But these radionuclides have the preponderance of the decay heat, and they must either be actively cooled or contained in passively cooled shielding casks essentially identical with those that would be required for the spent fuel from which the Cs and Sr were obtained.

The rather complicated considerations of benefit of minor-actinide removal and Cs-Sr removal on repository capacity, to remain below the boiling point of water in the "dry environment" of Yucca Mountain, are shown in the figure.

The reprocessing world adds additional potential hazards. The THORP plant at Sellafield was shut down in April 2005 with the discovery that 25 tons of spent fuel (a full reactor-year's worth) dissolved in 83 cubic meters of acid had leaked over a period of months into a stainless-steel-lined concrete enclosure. THORP will have been closed for at least two years, sacrificing an income stream that at 750 tons per year of spent fuel and an estimated $1000/kg reprocessing fee would amount to some $1.5 billion

A current EPRI-INL paper provides a sobering assessment both of the prospects for the reprocessing approach and of its necessity:

"In addition, reprocessing plants are expensive and not attractive to commercial financing in the context of the U.S. economy. Thus, the cost increment for reprocessing (i.e., the incremental cost above the cost of repository disposal) will be subsidized initially by the federal government. Although the estimate above does not include repository costs, it is expected that reprocessing will remain more expensive than storage (centralized above-ground plus geologic repository) for the foreseeable future.

Projections of major savings in Yucca Mountain repository costs as a result of reprocessing are highly speculative at best. On the other hand, the increased revenues to the Nuclear Waste Fund from an expanding fleet of new reactors will eventually help defray the costs of operating closed fuel cycle facilities.

I add here also material from the EPRI report: of May 2006, "Program on Technology Innovation: Room at the Mountain – Analysis of the Maximum Disposal Capacity for Commercial Spent Nuclear Fuel in a Yucca Mountain Repository. EPRI, Palo Alto, CA: 2006. 1013523." There we read, "EPRI is confident that at least four times this legislative limit (~260,000 MTU) can be emplaced in the Yucca Mountain system..." And EPRI believes that with additional site characterization this minimum factor of 4 could well be a factor 9.

"It is important to note that despite the extended timetable for introducing reprocessing in the U.S. (due to R&D prerequisites to satisfy cost and nonproliferation objectives, policy considerations, etc.), that a single expanded-capacity spent fuel repository at Yucca Mountain is adequate to meet U.S. needs, and that construction of a second repository is not required under this timetable.

"If, however, reprocessing is implemented on an accelerated schedule before it is economic to do so based on fuel costs, then the federal government will need to bear a much larger cost. As discussed in Appendices B and D, the optimum scenarios for transitioning nuclear energy to a closed fuel cycle in the U.S. context requires us to focus the R&D on those technologies that would enable a transition to cost-effective and proliferation resistant "full actinide recycle" mode with fast reactors that would eventually replace light water reactors. This path is preferred over one that maintains for decades a "thermal recycle" mode using MOX fuel in light water reactors, because the high costs and extra waste streams associated with this latter path do not provide commensurate benefits in terms of either non-proliferation or spent fuel management costs."

In what world does the drive for reprocessing make sense? In the long-sought world of fast-neutron breeder reactors which differ from the fast-neutron ABRs in that the breeders produce at least one plutonium atom for each transuranic atom destroyed—a conversion ratio—CR—of 1.0 or more; in contrast, that ABR is desired that has a CR of 0.0, which could only be achieved with fuel containing no uranium. The CR goal for ABR is 0.25, although previous analyses for a very comprehensive 1996 National Academy study12 quotes a General Electric judgment that a CR of 0.65 is the minimum practical. The difference is that the number of million-kWe ABRs to burn up the plutonium from 100 LWRs is proportional to (1/(1-CR)), which is more than doubled with the reactor of CR=0.65. Since the fast-neutron reactor is expected to be more costly than the LWR, this has serious cost implications for the GNEP approach.

It is clear that some GNEP supporters have mixed feelings about the central pillar of GNEP—the ABR fleet. For instance, at an October 17, 2006 meeting, in presenting his very detailed technical paper, "Technologies for Advanced Fuel Cycles," Finck commented that he did not favor the Compact Core sodium-cooled fast reactor (pp.17-18) 39.7 mills/kwh (a mill is 0.1 cent) over a "highleakage" reactor with the same CR and a Total Levelized Cost of 47.7 mills/kwh. Finck's reason is that the compact-core fast reactor could not be readily converted to a breeder reactor by replacing the inert (steel) "blanket" by depleted-uranium fuel elements.

Given that the cost paid by US reactor operators for waste disposal is 1mill/kwh, to accept one fast reactor design over another at 10 times the non-reprocessing waste disposal cost is a phenomenal penalty to be paid for a contingency never discussed in the GNEP literature—that we should deploy sodium-cooled fast reactors that can readily be converted into breeder reactors under the guise of reactors that burn up as much plutonium as possible rather then regenerating it.

Credit -- DOE Photo

Yucca Mountain is the site Congress designated for suitability as the nation's first repository for spent nuclear fuel and commercial high-level radioactive waste. It is 100 miles northwest of Las Vegas in an isolated part of NYE County. The long narrow ridge is in an arid transition zone between the lower Mojave Desert and the rugged basin and range regions. It is one of the most arid and most sparsely populated regions in the U.S.

Could GNEP be a wolf in sheep's clothing?

Ironically, I favor the deployment of breeder reactors and their mandatory reprocessing and recycle of plutonium, but only when the cost and safety of the fast reactor system is demonstrably better than that of reactors with the once-through cycle. In the future, once-through is not limited to LWRs but could include the micro-encapsulated fuel pioneered by General Atomics and now under development in a joint program with Russia as a modular high-temperature gas turbine reactor, and in South Africa as a pebble-bed reactor. In 1982 I testified against the Clinch-River breeder reactor program because it had no chance of demonstrating anything other than that the concept was a high-cost approach.

Similarly I testified in 1970 against the US Government-funded commercial supersonic transport program—SST—and was vilified by program supporters, including the US airlines which had had their arms twisted to provide moral support for the SST program. The USG had testified that if the US did not develop the Mach-3 SST to compete with the British-French Concorde Mach-2 SST, US airlines would end up buying 500 Concorde aircraft. In fact, only 16 Concorde aircraft were built and transferred to the national airlines, of which only 9 ever flew in commercial service. Ten years later, the SST contractors, Boeing and General Electric, thanked me for helping to terminate the program in its early stages.

The DOE process for obtaining approval for GNEP is defective; DOE does not have the systems analysis tools to design and judge such a program, despite its commitment to the Congress to develop them. Nor does it freely provide information for independent analysis. I have long urged my DOE colleagues, including Vic Reis, a moving spirit of the program, to create a DOE website where government-financed papers would be posted, as I and Frank von Hippel post our own analyses. The response has been that the existing technical website operated by Sandia National Laboratories and available only to government and selected contractors cannot be influenced by DOE headquarters.

Einstein's words,"The right to search for truth implies also a duty; one must not conceal any part of what one has recognized to be true" are engraved in stone on the Keck Center of The National Academies in Washington, DC. It would be helpful if the DOE took them to heart. Failing to do so is likely to inflict serious damage on the US nuclear industry.

For a copy of the PowerPoint presentation please visit www.fas.org/RLG

FAS

Plutonium Reprocessing and the Global Nuclear Energ

By Ivan Oelrich, Vice President of FAS Strategic Security Program

Nuclear power is undergoing a reevaluation because it potentially offers electricity generation with much lower carbon dioxide emissions than fossil fuels and could mitigate future global warming. Among several uncertainties clouding the future of new reactors is the ultimate fate of the highly radioactive waste that is inevitably produced.

As a solution, or at least contributor, to the global warming challenge and the waste problem, the Department of Energy is promoting the Global Nuclear Energy Partnership (GNEP), a program to restart plutonium reprocessing and recycling in the United States after a three decade hiatus. The administration is asking for $405M for GNEP for Fiscal Year 2008 with costs expected to exceed a billion dollars a year within a few years. GNEP includes plans to extract plutonium and other actinides from the spent fuel from light water reactors, fabricate the material into new fuel, and develop and build new fast neutron reactors that can burn the actinides as fuel. The "Global" part of the name refers to plans to provide fuel for, and take spent fuel back from, foreign light water reactors for reprocessing in the United States.

The GNEP has the potential to revolutionize nuclear power if it works and the potential for being the greatest technological fiasco in the history of the country if it does not. Because of the technical and scientific importance of this question, the Federation of American Scientists organized a special session on the GNEP at the annual meeting of the American Association for the Advancement of Science held in San Francisco in February 2007. (In the interests of full disclosure, I have written on the GNEP on the FAS website and in the trade press and have briefed many Congressional offices on the program, strongly opposing the program by arguing that even if it eventually proves useful, it is decades premature.)

The first speaker was Phillip Finck, now at Idaho National Laboratory, having recently moved from Argonne. Dr. Finck set out the case for GNEP. There are several major technical hurtles to implementation and they all have to work together for any of them to work at all. Dr. Finck makes this point and added that some of the technical approaches that are now part of the GNEP proposal provide "proof of existence" of some solution but further evaluation is required to optimize technical choices.

The vision laid out by Dr. Finck is more ambitious than the limited recycling now underway in France. GNEP will require development of new reprocessing techniques, new fuel fabrication techniques, and the commercialization of a fast neutron reactor, something that has not been done successfully thus far.

If successful, the fuel from light water reactors would be separated into various waste streams. The great majority of the fuel by weight and volume is uranium-238, which, with a five billion year half life, is not particularly radioactive. It could be disposed of as low level waste or saved to be used in a breeder program later. All nuclear power processes produce fission products and these will be separated as well and will have to be disposed of in a geological repository in any scenario. Because the greatest radioactivity in the fission products comes from strontium-90 and cesium-137, both of which have half lives of about thirty years, it may prove beneficial to separate out those products and store them above ground for a century or two to let the radiation levels die down.

The real benefit to waste disposal comes, however, from separation of the plutonium and other actinides. These dominate the heat contribution for the first few centuries and it is heat, not volume, that limits the amount of waste that a facility like Yucca Mountain can in theory handle. But what to do with the actinides? They are not suitable for a light water, thermal neutron reactor. If they are to be burned, it must be in a reactor with a fast neutron spectrum. The current leading candidate is a liquid sodium cooled reactor. Several such have been demonstrated but none has been commercially successful.

The fuel from the fast reactor will itself be reprocessed and recycled repeatedly until only fission products remain, solving the plutonium/actinide disposal problem. The planned fast reactor will burn up plutonium about three times faster than thermal reactors will produce it so eventually there will have to be one burner/reprocessing complex with three light water reactors feeding it their waste fuel.

Richard Garwin, an IBM Fellow Emeritus at the Thomas J. Watson Research Center, was the second speaker. He agrees with the GNEP goal of breaking the norm that nuclear waste must be disposed of in the country where the reactor operates. And he supports working toward fast reactors that could be used as breeders. But he points out that right now the cheapest approach to nuclear power generation is using fresh enriched fuel in light water reactors with geologic disposal of the used fuel. Much work remains to be done before breeders will be economically competitive.

Whichever fuel reprocessing technology is chosen for GNEP, the plutonium will be much easier to divert or steal than is now the case when fuel is kept in large, intensely radioactive fuel rods. Garwin points out that the temperature stability of fast reactors depends on the Doppler broadened neutron absorption of uranium-238. But this neutron absorption obviously means that the reactor is producing some plutonium while it is burning other plutonium. The overall effect is net consumption of plutonium but at a much slower rate than implied by the GNEP proposals. If the burner fuel contains the minimum concentration of uranium judged necessary to provide inherent thermal stability, then at least one fast reactor will be needed for every two thermal reactors. Since thermal reactors cost more than thermal reactors, the overall cost of nuclear electricity will go up.

Moreover, Garwin reports that choices about preferred fast reactor design reveal the true goals of GNEP: Phillip Finck has expressed a preference for low density, high neutron leakage core design—even though they are more expensive than a high density core design—because they can be later converted to breeders. Garwin argues that breeders might be a good idea in the long term but that GNEP should not be used to find a back door to a breeder reactor program.

Reponses to a Dirty Bomb Attack

By Ivan Oelrich, Vice President of FAS Strategic Security Program

The final speaker was Victor Gilinsky, the former Commissioner of the Nuclear Regulatory Commission and now an independent consultant, working with, among other clients, the State of Nevada on questions related to Yucca Mountain. Gilinsky argues that the primary justification for GNEP is to reduce nuclear waste, specifically to make certain that a second repository in addition to Yucca Mountain is not needed for hundreds of years if ever, and that that justification isn't going to work. The limits to disposal at Yucca Mountain—and any second site—are both technical and political. It is naïve to think that the political opposition to new, expensive fast reactors spread around the country, each with a potentially polluting reprocessing plant next door, is going to be any less than political opposition to a second repository. In any case, key technology for GNEP is untested. The DOE is rushing this development and experience shows that "fast tracking" the first build of any sort of large, complex facility is a recipe for huge schedule and budget overruns. Finally, there is no need to hurry. Dry cask storage is simple and cheap and allows at least a century of safe storage. We have time to pursue a prudent and deliberate technology development program.

There is nothing in the proposal that violates the laws of physics. The problems are in the engineering, the economics, and the timing. Even with an aggressive buildup in nuclear power plants, the world's proven uranium reserves are large enough to insure that the simple once through fuel cycle will remain cheaper than reprocessing for at least seven decades, and probably longer. Reprocessing has potential and might be an excellent idea at the end of the century. The GNEP program will commit us to technical choices literally decades earlier than we need to. If we were to revisit this question in fifty years, we would, given the inevitable advances in materials and computers and simulation, have more than enough development time to prepare for the end of the era of cheap uranium. GNEP can wait. **FAS**

The radiological dispersion device, more commonly called a "dirty bomb," is one of the most frightening and one of the most frequently discussed type of possible terrorist attack. Radiation is silent and invisible, potentially deadly, and poorly understood and much feared by the great majority of the population.

A dirty bomb is intended to spread contaminating radioactive material. Strictly speaking, there does not even have to be a "bomb" part of a dirty bomb but explosives are particularly effective at dispersing some materials. The explosive itself does little to spread material very far; yet the heat and shock of the explosive can efficiently convert solid material into fine particles, and the heat and blast of the explosion then loft the particulates some distance into the air where they can be carried long distances by the wind.

With small amounts of explosive, the immediate damage might be quite limited. Only the largest radiation sources would cause rapid, acute radiation sickness. In the more plausible dirty bomb attacks, most people exposed to radiation could easily walk out of the contaminated area before receiving seriously threatening doses of radiation. In fact, it is easy to imagine a dirty bomb attack that results in no immediate casualties at all; the problem is that lingering radiation may make long-term exposure in the contaminated area intolerable, resulting in the abandonment or razing of huge tracks of a major city. Dirty bombs are, therefore, sometimes called "weapons of mass disruption." Total economic damage from a large bomb attack could soar into the hundreds of millions of dollars.

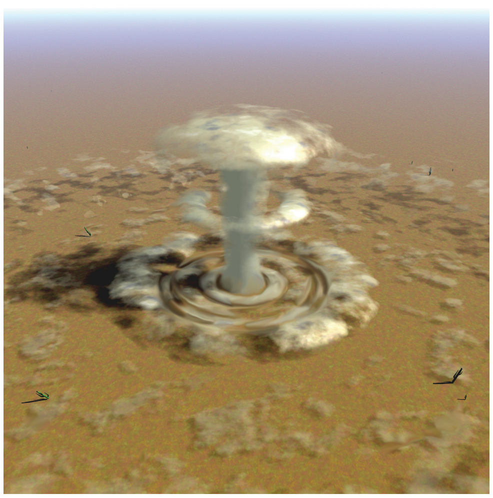
Clearly, the first line of defense should be to prevent a dirty bomb attack in the first place through a combination of global radiation source security, international cooperation in policing, and radiation monitoring to detect illicit diversions but are there measures we could take now to reduce the *consequences* of a dirty bomb attack? We might work to reduce the costs of a dirty bomb attack because of simple economics: small investments in research or planning now could save huge amounts later in the event of an attack. In addition, though, because the goal of a dirty bomb attack is to inflict economic costs, if we could reduce those costs, we could reduce a terrorist's motivation for carrying out the attack in the first place. This is deterrence through preparedness.

While emergency response to a dirty bomb attack gets a lot of visibility, including television dramatizations, surprisingly little research goes into reducing the consequences of an attack, should it occur. The Federation of American Scientists wanted to highlight some of the excellent work that is going on and to draw attention to gaps in efforts to deal with the aftermath of a dirty bomb attack. With this in mind, we organized a special session on the topic at the annual meeting of the American Association for the Advancement of Science held last February in San Francisco.

Four presentations gave a broad overview of the problem and a summary of some of the specific work being done. The presenters were Fredrick Harper at Sandia National Laboratory, who reported on his work on how explosives dispersed radioactive materials; Stephen Musolino at Brookhaven National Laboratory, who talked about practical rules that first responders could apply when dealing with a dirty bomb; Michael Kaminski from Argonne National Laboratory, who described both his and other's work on how to decontaminate buildings; and Daniel Hirsch from the University of California at Santa Cruz, who discussed the Department of Homeland Security's cleanup guidelines.

In a subject that includes a great deal of assertion and paper analyses, Fredrick Harper does real experiments which he described in his presentation "Radiological Dispersal Devices: Physically Based Dispersal Characteristics and Limitations." The fact that cobalt-60, strontium-90, or some other dirty bomb material is radioactive does not affect its chemical and physical properties in any appreciable way. Harper can prepare non-radioactive surrogate dirty bombs, explode them, and measure the results. He uses explosive charges from ounces to pounds. Some are conducted outdoors but he has also developed a thousand cubic meter igloo-like tent in which he can detonate simulated dirty bombs, keep all the particles contained within the tent, and get good measurements on the distribution of particle size. Particle size is critical as input to wind dispersion models: small particles will be carried much more easily and further than larger particles. In fact, extremely fine particles can even be carried so far away from the bomb site—presumably a high population density city center—that they are carried away from the city to where the population density would be less. The type of health threat also varies with the particle size: larger particles, over 100 μm, will fall to the ground and cause harm primarily by emitting radiation from outside the body while fine particles, 10 μm or less, present a much greater inhalation threat.

Stephen Musolino's presentation, "Emergency Response Guidance for the First 48 Hours After the Outdoors Detonation of an Explosive Radiological Dispersal Device," picks up where Harper's leaves off (and they pair have been long-time collaborators). Particle size distribution is the first input to dispersion models. Musolino reviewed different approaches to calculating wind-borne dispersion. Simple diffusion models, which result in the familiar cigar-shaped distributions of radioactive fallout and which FAS used in some of the very early dirty bomb analyses, have severe limitations in an urban environment. The interaction of tall buildings and wind patterns makes prediction of particle fallout difficult but it is safe to say the pattern will be complex with hot spots and cold spots. Sometimes higher radiation intensities will be found further rather than closer to the detonation site. Some streets could be strongly contaminated while a block away could be virtually free of contamination.



Given the challenge of assessing such a complicated situation quickly, Musolino has developed a set of rules that responders could use after a dirty bomb attack. For example, if nothing is known at all about the bomb, responders should ignore the wind direction and set up a control boundary 500m from the site of the explosion, then use measurements to gradually move the boundary in closer. Cobalt-60, strontium-90, and cesium-137 are the only isotopes that could plausibly be available in thousand Curie sources so just knowing what the radioactive material is gives some information about the possible intensity. Authorities should not try to decontaminate victims, should allow them to return home with instructions to shower carefully and dispose of their clothing properly. Authorities at the site should only try to direct people to help them avoid moving into areas of even greater radiation intensity.

Beyond the first forty eight hours, we have to start to worry about how to clean up the contamination from a dirty bomb, the subject of Michael Kaminski's presentation, "How do we decontaminate areas following a dirty bomb?" Kaminski's research has examined how different particles bond to different common building materials, including stone, concrete, metal, glass, and asphalt. Particles can become tightly bound, and more so with the passage of time; there is some premium to acting quickly. Several technologies are available, including ablation of the surface layer and a gel that can be applied to the exterior of a contaminated building and allowed to harden, entrapping contaminating particles, and then pealed off, taking the contamination with it. Each approach has pros and cons and must be evaluated in terms of worker exposure to radiation, cost of materials, and the volume of contaminated material that must be disposed of.

Finally, Daniel Hirsch's presentation, "Dept. of Homeland Security 'Dirty Bomb' Guidance: Allowing High Long-term Radiation Doses to the Public without Cleanup," criticized the Dept of Homeland Security's (DHS) cleanup guidelines released in January of 2006. The guidelines state that above 10 rem/yr radiation intensity, an area must be cleaned up or avoided and intensities less than 10 rem/yr will be treated on a case by case basis. Hirsch calculates that 10 rem/yr results in about a one in three lifetime risk of cancer from radiation, orders of magnitude greater than what is considered tolerable for, say, radiation workers.

During the question and answer period, there was a sharp disagreement between Drs. Hirsch and Musolino. They did not disagree on the numbers or analysis, nor on what the DHS report says but on how it would be interpreted. Hirsch felt that the report language could be used by local authorities to too easily set cleanup standards too loosely, even up to 10 rem/yr exposure. Musolino thought this was not a reasonable worry, that above 10 rem/yr action was demanded but the report would not mislead anyone into believing intensities below 10 rem/yr could be ignored.

While we should make every effort to avoid a dirty bomb attack, much work also remains to be done on how to respond.
Better understanding of radiation diffusion is needed, technologies could be tested more realistically, and cleanup standards should be clearer and better justified. Economic analysis is needed to understand whether specialized cleanup equipment and material should be stockpiled near major urban centers. With events of uncertain likelihood, but probably rare, how prepared we ought to be is not obvious but given the horrendous consequences of a dirty bomb attack, some preparation should be weighed seriously.
FAS

Using Advanced Learning Technologies to Revolutionize Education

By Monica Amarelo

On Saturday, 17 February 2007, FAS organized a session on the promise of information technologies in learning. Henry Kelly, president of the Federation of American Scientists; Lorne Lanning, CEO of OddWorld, Inc.; and Anne Murphy, executive director of The Digital Promise Project, addressed a crowded room filled with people who wanted to learn how to integrate digital technology and education.

Digital technology is an integral component of our daily activities, from surfing the world wide web and instant messaging with multi-media mobile phones to sending e-mail and sharing calendars with personal digital assistants.

Unfortunately the U.S. education system has not joined this digital age. The traditional "tell and test" model of instruction is still in use by a system that is slow to change and still operates on an agrarian calendar. Recent reports warn about declining U.S. competitiveness and point to an urgent need to improve work-force skills and the American education system. Powerful tools for teaching and learning need to be placed in the hands of educators. Today's students are often frustrated by the digital disconnect they experience at school.

Last year, FAS joined the Entertainment Software Association (ESA) to release a plan of action to advance the use of modern video games to strengthen U.S. education and training. The plan set forth specific steps that the federal government, industry, and the education community need to take to develop, commercialize, and deploy educational games that will help students and workers attain globally competitive skills in demand by employers. The action plan was based on deliberations from the Summit on Educational Games held on October 25, 2005 in Washington, D.C. The Summit brought together more than 100 experts to examine how to harness the power of video games for learning.

There is near universal agreement that the competitiveness of American companies, national security, and our ability to meet critical needs in health care, energy, and the environment, depend on advances in technology that can only be achieved with a world-class workforce. Holding students and school systems to high standards is necessary (the goal of No Child Left Behind) but there is widespread concern that this alone is simply not sufficient.

Henry Kelly reported that advanced information technologies have already improved our lives in unexpected ways such as through sophisticated software that helps personalize online shopping, efficient systems for answering consumer questions, and eye-popping simulations on inexpensive computer game consoles. These tools have the potential to reshape learning through interactive simulations, question management, and powerful continuous assessments.

In spite of huge investments in communications and computer hardware made by universities, schools, and training institutions, most formal teaching and learning still uses methods familiar in the 19th century: reading texts, listening to lectures, and participating in infrequent - and highly stylized - laboratory experiences. Games offer an exploratory environment in which students can engage in active, problem-based learning, receive immediate feedback, and create their own pathways to knowledge.

Speakers will address the digital disconnect, why investments haven't bridged the divide, legislation being considered by Congress, and the corporate perspective regarding a solution.

Anne Murphy, executive director of the Digital Promise Project, lobbies Congress to create the Digital Opportunity Investment Trust (DO IT) to transform America's education and workplace training through the development and use of advanced information technologies comparable to those that have already transformed the nation's economy, its communications system, and the media. Digital Promise was started by former FCC Chairman. Newton Minow and former PBS President Lawrence Grossman to get Congress to create a trust fund to finance education and public broadcasting from spectrum auction proceeds. The trust fund would finance educational and public broadcasting for the nation's schools, universities, libraries, museums, and public broadcasters to reach out to millions of people in inner cities and remote regional areas.

DOIT would support the research and development of new models and prototypes of educational content, taking full advantage of the Internet and other new digital distribution technologies. DO IT is designed to do for education, workforce training, and lifelong learning in the 21st century what NSF has done for science, NIH for health, and DARPA for the military

Lorne Lanning, founder and CEO of Odd-World Inc., provided a different perspective on why games aren't more widely used in classrooms today. Lanning is a game developer and animated film director. He is best known for creating the Oddworld series that includes *Oddworld: Abe's Oddysee ,Oddworld: Munch's Oddysee , Oddworld: Abe's Exoddus and Oddworld: Stranger's Wrath.*

Video game companies are focused on developing new products for the entertainment market. While the gaming industry has the technology and game designers have skills that could be applied to develop educational games, a poor market discourages the private sector from making R&D investments.

For example, the gaming industry uses sophisticated game engines that could be adapted for education applications. The game industry technologies also features intelligent avatars, computer-generated characters that can simulate dialogue and conversation, and detailed virtual physical environments.

Lanning emphasized that one of the beauties of learning on a computer simulation or with a video game is the student's ability to try and try again. After 100 attempts, the computer program doesn't say, "maybe math's just not for you" but instead conveys the message that "it's okay, you can do it again."

Game designers understand how to deliver critical information while keeping the player engaged. Millions of dollars are invested to develop game engines. Lanning believes the secondary market potential for these powerful pieces of software is enormous and could probably be adapted to applications that would teach people how to lead, read, how to do physics, how to learn math, and other subjects. FAS

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