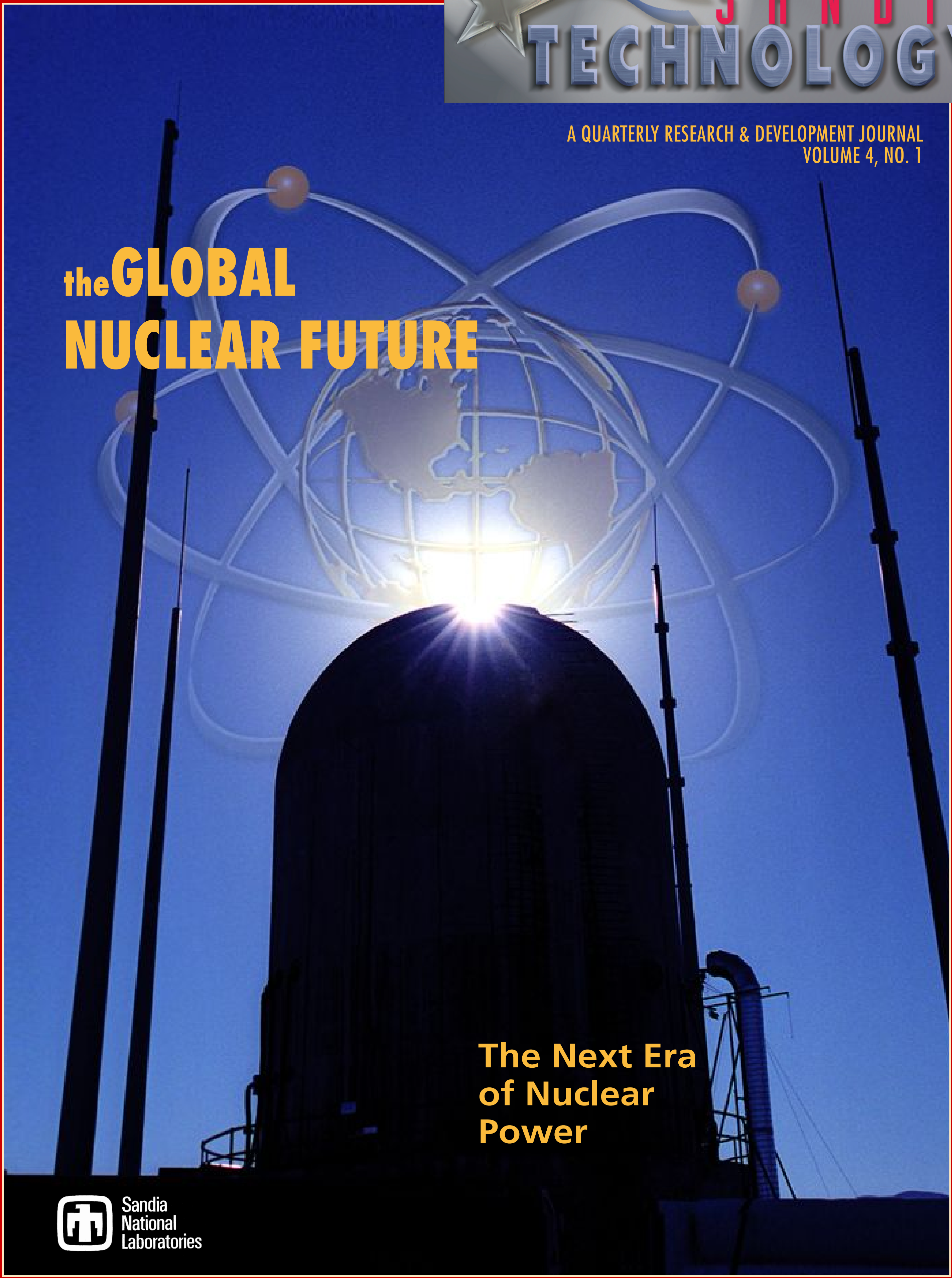
SPRING • 2002

SANDIA TECHNOLOGY

A QUARTERLY RESEARCH & DEVELOPMENT JOURNAL
VOLUME 4, NO. 1



the GLOBAL NUCLEAR FUTURE

The Next Era of Nuclear Power

Sandia National Laboratories

Frank Bouchier, of Sandia's Entry Control and Contraband Detection deparment, tests a version of an airport portal device for sniffing explosives on airline passengers, which is now being commercialized. Sensors — in devices like this — and many other applications are becoming commonplace. The next issue of SANDIA TECHNOLOGY examines the challenges of turning data from these sensors into streams of valuable information for many applications. *Sandia Photo by Randy J. Montoya*

ON THE COVER:
This one-quarter scale-model concrete containment vessel was tested to failure in 2001 to gather experimental data. This experiment marks one of the many pieces Sandia is contributing to making a better Global Nuclear Future.
Photo: Randy J. Montoya
Design: Doug Prout

Sandia Technology is a quarterly journal published by Sandia National Laboratories. Sandia is a multiprogram engineering and science laboratory operated by Sandia Corporation, a Lockheed Martin company, for the Department of Energy. With main facilities in Albuquerque, New Mexico, and Livermore, California, Sandia has broad-based research and development responsibilities for nuclear weapons, arms control, energy, the environment, economic competitiveness, and other areas of importance to the needs of the nation. The Laboratories' principal mission is to support national defense policies, by ensuring that the nuclear weapon stockpile meets the highest standards of safety, reliability, security, use control, and military performance. For more information on Sandia, see our Web site at *http://www.sandia.gov.*

To request additional copies or to subscribe, contact:
Michelle Fleming
Media Relations Communications Dept.
MS 0165
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0165
Voice: (505) 844-4902
Fax: (505) 844-1392
e-mail: meflemi@sandia.gov

Sandia Technology Staff:
Laboratory Directed Research & Development Program Manager: Chuck Meyers, Sandia National Laboratories
Editor: Will Keener, Sandia National Laboratories
Writing: Chris Burroughs, John German, Howard Kercheval, Bill Murphy, Neal Singer
Photography: Randy J. Montoya and John Heald, Sandia National Laboratories
Design: Douglas Prout, Technically Write

FROM THE *Editor*

Dear Readers:

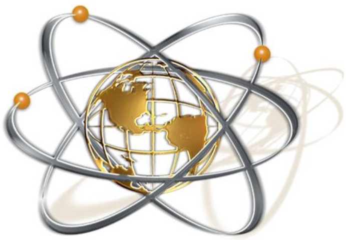
A nuclear power renaissance in the US is at hand. After decades of mistrust surrounding environmental, safety and cost concerns, the New York Times observes that the energy sector is "bubbling with new hopes and plans." The trick is to turn the hopes and plans into reality.

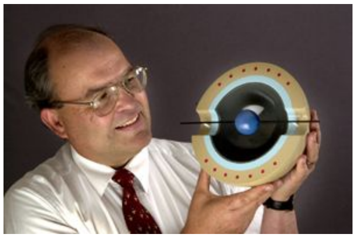
This issue of Sandia Technology outlines some of the issues connected with such an effort, provides a vision of how the renaissance can be achieved, and reviews some of the critical research now under way at Sandia.

Sandia researchers are at work providing the nation and the world with the technical capabilities to respond to the needs of the nuclear renaissance. Together with industry, universities and other governmental agencies, this work can lead decision-makers to a better understanding of issues, opportunities and options for a beneficial Global Nuclear Future.

Will Keener
Editor

TABLE OF *Contents*



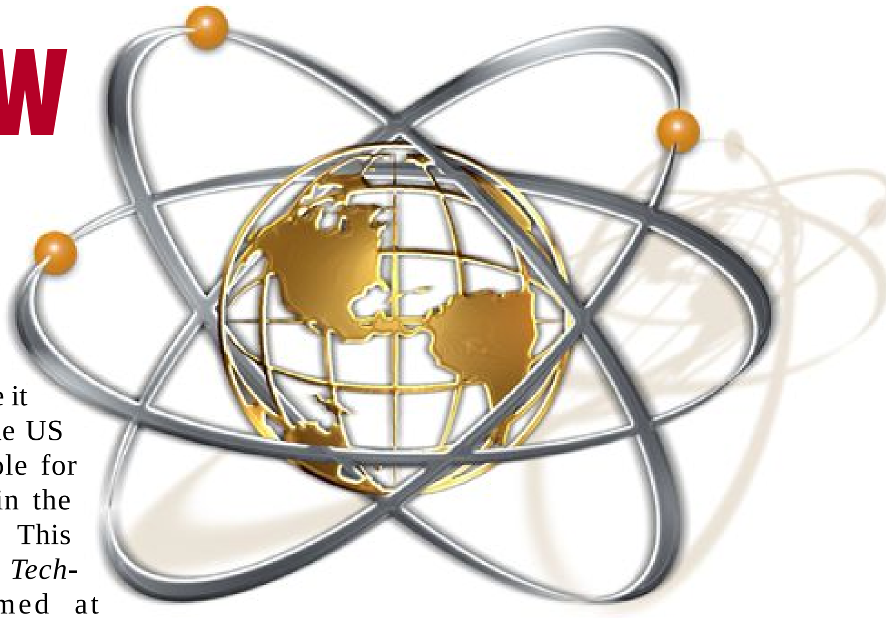


INSIGHTS

by U.S. Senator Pete V. Domenici

the Global Nuclear Future: An Overview

By Thomas Sanders



Question:

What do the collapse of the Berlin wall, the increasing number of Chinese-made goods at your local discount store, global warming, the attacks on the World Trade Center, and your four-year-old, fuel-efficient automobile have in common?

Answer:

While it's certainly not clear they have anything in common, each one impacts America's 21st Century role in a new nuclear era.

Researchers at Sandia National Laboratories and elsewhere believe it is critical that the US define a new role for nuclear power in the coming months. This issue of *Sandia Technology* is aimed at exploring aspects of America's role in the future of nuclear power around the globe. It's a role that started in the Dwight Eisenhower administration of the early 1950s, with his "Atoms for Peace" strategy. The globe is a much more tangled web of interests and issues a half century later, but the need for an international strategy — with the US as a key player — is more critical than ever.

Recently scientists at Sandia began talking to their Russian counterparts via an international video conferencing network about a global model for the next nuclear era that they will provide in coming months to US and Soviet policy-makers. One of the first things needed, experts from both countries agreed, was an understanding of the energy past and present. How did we get to where we are today? That brings us back to the question we began with.

How does nuclear power fit into considerations about the new global political structure, the industrialization of China and the third world, and increasing concern about terrorism? Why did we mention those indispensable gasoline-burning autos? Let's take them one at a time.

Decline of US Leadership

Twenty-five years ago, the US supplied 50 percent of the world trade in nuclear materials, hardware and services. Currently, we actually import most of the enriched uranium used in this country ironically, through an arms control agreement with Russia. Government policies – aimed at successfully controlling the spread of nuclear technologies – have forced civilian nuclear energy suppliers in the US to compete in a new, unfamiliar marketplace. The result is that other nations are now independently developing supplier capabilities to provide nuclear energy services throughout the world. US influence has waned.

This decline is tied to US policy in the first nuclear era, which has seen three major changes over the last fifty-plus years. These changes are marked by the initial Atomic Energy Act, Eisenhower's "Atoms for Peace" initiative and a convergence of events during the 1970s. With the end of the Cold War, a new global nuclear infrastructure is evolving, presenting different challenges to safe, secure nuclear power commerce and operations.

The growing appeal of nuclear power as an environmentally safe, secure, and affordable alternative has set the stage for a new nuclear era. If present trends continue, the US may not be in a position to set foot on this stage, however.

The Atomic Energy Act of 1946 was designed to control the spread of nuclear weapons know-how by maintaining a US monopoly and discouraging peaceful uses of nuclear energy. By the early 1950s, Eisenhower and his advisors realized that secrecy – the main component of the early approach – could not contain interest in peaceful uses of nuclear energy. His “Atoms for Peace” proposal (see page 7) resulted in active international collaboration for peaceful uses of nuclear energy over the next twenty years.

The turbulent 1970s started with positive collaborations, many fueled by the so-called “energy crisis,” and ended with the Three Mile Island incident. Perceived rapid expansions of demand for nuclear power, India’s explosion of a “peaceful” nuclear device and European plans to reprocess fuel, provoked severe restrictions on nuclear trade and cooperation in the US.

US decisions on nuclear power made in the 1970s called for:

- Cutting back uranium enrichment capacities,
- Stopping civilian reprocessing of nuclear fuel, (and by default, research on advanced breeder reactors)
- Reducing research on advanced fuel-cycle reactors, and
- Limiting US interactions globally (because of the Nuclear Nonproliferation Act of 1978)

One impact of these policy decisions is that several nations weaned themselves from the need for US support during the 1980s and 90s. By 1996, fifteen nations had developed some nuclear fuel cycle capabilities without any US involvement. We expect that countries like Japan, Russia, China, South Korea, Argentina, India, and Brazil could become very competitive suppliers in the future. (In fact, the next US-built reactor may be a South African design.) Many nations have established networks for future nuclear cooperation. Some nations in these networks have not signed the non-proliferation treaty.

The end of the Cold War has set the stage for the next nuclear era. Other nations – among them some of those formed in the Soviet Union breakup – now stand to reap the economic benefits of supplying nuclear power to support industrialization in developing nations as energy demand climbs globally. The growing appeal of nuclear power as an environmentally safe, secure, and affordable alternative has set the stage for a new nuclear era. If present trends continue, the US may not be in a position to set foot on this stage, however.

But promising developments have begun. A new energy policy recognizing nuclear energy’s potential contribution and the announcement of Nuclear Power 2010 initiative (see page 12) by the Bush administration show renewed interest in the peaceful possibilities of a new nuclear era. At research institutions like Sandia, there are seeds of ideas that could revolutionize the nuclear

fuel cycle of the future to achieve better efficiencies, minimize nuclear wastes and generate electricity and transportation fuels for a cleaner environment.

Demand for Power

Another dynamic component of the world energy situation is growing demand for power. As the century turned, conventional wisdom offered a rosy view of available supply for the future. As is often the case, that view failed to consider a number of complex, but interrelated issues. Californians caught a first glimpse of the dire possibilities brought by electrical shortages last summer. Russian experts, faced with aging or non-existent infrastructure for petroleum supplies believe they face a similar type shortage as their nation's economy begins to grow.

China is aiming to be self-sufficient in design, construction, and fuel supply and production. Chinese scientists are also exploring advanced reactor concepts.

Current tensions in the Middle East serve as a reminder that nearly 50 percent of the world's supply of oil comes from one of the most unstable regions in the world. Among the real costs of our over-reliance on imported oil is a significant share of the US $300 billion defense budget. Keeping a US naval fleet near the Strait of Hormuz – where some 14 million barrels of oil pass daily – is a part of the cost of a fossil-fuel economy. This and other energy security issues will grow in importance as the world industrializes during the next fifty years.

In countries like China – a major trade partner with a 6 to 7 percent annual growth rate – energy demand is rising on a steeply increasing slope. By 2020, the International Energy Outlook projects that demand will increase by 160 percent in the Asian nations and by 60 percent in other developing countries. In the most populous nation in the world, China's rapidly increasing economy is causing ripples in the energy currents of the world. To deal with this demand, China has embarked upon a number of approaches. Among them is the construction of eight new nuclear power reactors in addition to three now in operation. China is aiming to be self-sufficient in design, construction, fuel supply and production. Chinese scientists are also exploring advanced reactor concepts.

In both the areas of transportation, where petroleum fuels are still predominant, and electricity, the thirst of the developing nations is growing dramatically. Electricity is an essential component of industrialization and has come to be seen as integral to modern life. Expanding electrical supplies to those who lack access is linked to raising living standards and has become a high priority throughout the world.

Terrorism and Eroding Controls

Despite the end of the Cold War, nuclear weapons continue to pose a security threat to Americans and the world. The powerful role of terrorism and the potential for mass destruction all too clear here and abroad. "We will work closely with our coalition to deny terrorists and their state sponsors the materials, technology and expertise to make and deliver weapons of mass destruction," President George W. Bush promised in his January State of the Union address.

With the collapse of the Soviet Union, control over nuclear materials has grown as an issue of importance. Russia, for example, has reduced its available weapons through Cooperative Threat Reduction initiatives. The US has worked with Russia and other Soviet-bloc nations to prevent the diversion of these materials to terrorists or nations intent on establishing nuclear weapon programs. Early this year, US Energy Secretary Spencer Abraham and Russian Energy Minister Alexander Rumyantsev

agreed to expand joint efforts to protect nuclear materials.

These efforts at bilateral materials protection, control and accountability have been successful. The Russians have also realized that within their old defense complex lies a huge source of talent, technology and infrastructure, which – if properly used – could transition to civilian goods and services, reducing the worldwide cost of energy. Some other former Soviet republics are following this lead. But the transition of a "secret" infrastructure to a commercial enterprise raises issues of safety, security, and proliferation prevention. Transparency is the key so both technologies and partnerships will have a critical role.

The two major uses of energy throughout the world are for electrical generation and for transportation. Striking increases are expected in both of these areas – on the order of 60 percent – within the next 20 years.

The Center for Strategic and International Studies (CSIS) recently identified two key areas were action is needed to even better achieve better materials control:

- Continued improvement in the security of materials management in the former Soviet Union to decrease the level of stress in the world community (an area which the US is now addressing), and
- Bolstering a foundation for US leadership.

US nuclear infrastructure, research and development, and its core of experienced personnel have been in decline for the past two decades, the CSIS report noted. "The US can no longer credibly claim a leadership role in nuclear technology or is seen as having no interest in the future of nuclear energy," the report concluded.

Global Climate Change

The science of global warming took a major step forward early last year with the publication of a United Nations and World Meteorological Organization report, Climate Change 2001. The report concluded that there is new and stronger evidence that most of the warming in the past 50 years is attributable to human activities and that these influences will continue to change the atmosphere in the new century. The United Nations panel suggested that nuclear power, hydropower and low-carbon energy supply systems, such as renewable energies, should be put forward to address these problems.

The two major uses of energy throughout the world are for electrical generation and for transportation. Striking increases are expected in both of these areas – on the order of 60 percent – within the next 20 years.

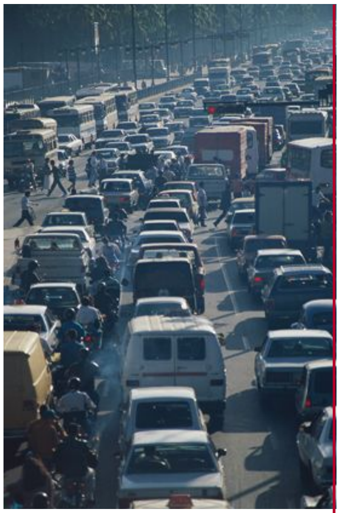
Current surplus nuclear materials in the world can supply 100 million kilowatts of electricity for 20 years. That's enough to power 100 cities the size of Boston for two decades. If the surplus materials were used in high-efficiency advanced plants, two million kilowatts of electricity could be generated for 20 years.

If these materials were recycled they could:

- Avoid the generation of billions of tons of air emissions that contribute to global warming,
- Generate hydrogen efficiently to reduce the amount of petroleum needed for transportation,
- Avoid the import of billions of barrels of oil, and
- Pave the way to provide valuable diagnostic and treatment technologies for those in need on a worldwide basis.

According to the World Nuclear Association, new nuclear power plants coming on line in 2001 avoided 2.4 billion tons of carbon dioxide emissions from electrical generation. While coal-fired generation plants and other fossil-fuel plants contribute to the greenhouse gas problem – leading to global warming concerns – nuclear and hydro-powered plants do not directly contribute any emissions.

Emissions from fossil-fuel generation of electricity and transportation are already creating health problems in many places, the World Health Organization (WHO) notes.



Hydrogen is catching on as the clean combustion fuel of the future. All we need to do is liberate it from our most abundant resources —coal and eventually water. It turns out that nuclear power may be the best way to do that efficiently.

Tom Sanders manages Sandia's Nuclear Initiatives Department. He has been involved in studying energy systems, resources and issues for most of his 18-year career at the Labs. He may be reached at 505/845-8542,or tlsande@sandia.gov

China, the world's most populous country, experiences serious air pollution problems. These include greenhouse gases, acid rain, and particulates, tied to its overwhelming dependence on coal. Seven of the ten most polluted cities are in China, WHO reports. Lung cancer, associated with the breathing of coal particulates, has increased.

Concerns about internal combustion engines have caused the world's major automobile manufacturers to devote significant research resources.

Uncertain about long-term supply, several oil companies have joined in these ventures. While alternative technologies will not be available in any meaningful role before about 2020, some market shift to lower emission vehicles can be expected in the next ten years. Hydrogen is catching on as the clean combustion fuel of the future. All we need to do is liberate it from our most abundant resources—coal and eventually water. It turns out that nuclear power may be the best way to do that efficiently.

Until recently, environmental concerns in providing energy had begun to displace concerns about energy security in policy decisions. Now we see these concerns as inter-related and equally important to our vision of a safe and healthy future.

Atoms for Peace and Prosperity

Given this background, the balance of this issue of Sandia Technology presents a look at what is possible for the future, and where science and technology is taking us. We've taken some steps backward, but it's time to go forward again.

The end of the Cold War, and the support of much of the world in a common front against terrorism have created a new, but perishable opportunity for the next nuclear era. By sharing internationally the management of the stresses caused by proliferation, excess nuclear materials, damage to the environment, and terrorism, a new future is possible. It is a future characterized by energy security, non-proliferation, deterrence to terrorism and a healthier environment.

A half-century after President Eisenhower posed his vision of "Atoms for Peace," the US may at last be in a position to help launch a new, "Atoms for Peace and Prosperity" program in partnership with other nations around the world. It a vision of the future that could lead to realistic, inexpensive, long-lived energy supplies to eradicate the underlying seeds of terrorism, covert "swords into plowshares," and provide a basis for lasting peace with prosperity.

Global Goals

- **Provide a basis for world peace and prosperity**
- **Reduce tension over access to finite resources**
- **Improve developing world health and well being**
- **International participation in converting "swords to plowshares"**
- **Proliferation resistance through partnerships and transparency**

Atoms for Peace

"The United States knows that peaceful power from atomic energy is no dream of the future. That capability, already proved, is here now – today."

Imagine the President of the United States announcing an important new initiative to exploit the vast potential of nuclear power. Imagine a speech to an influential group, such as the United Nations.

The President might couch this vision in terms of achieving world peace by preventing the spread of nuclear weapons and providing commercial opportunities for industry:

- "The United States knows that if the fearful trend of atomic military build-up can be reversed, this greatest of destructive forces can be developed into a great boon for the benefit of all mankind."
- "The United States knows that peaceful power from atomic energy is no dream of the future. That capability, already proved, is here now – today."

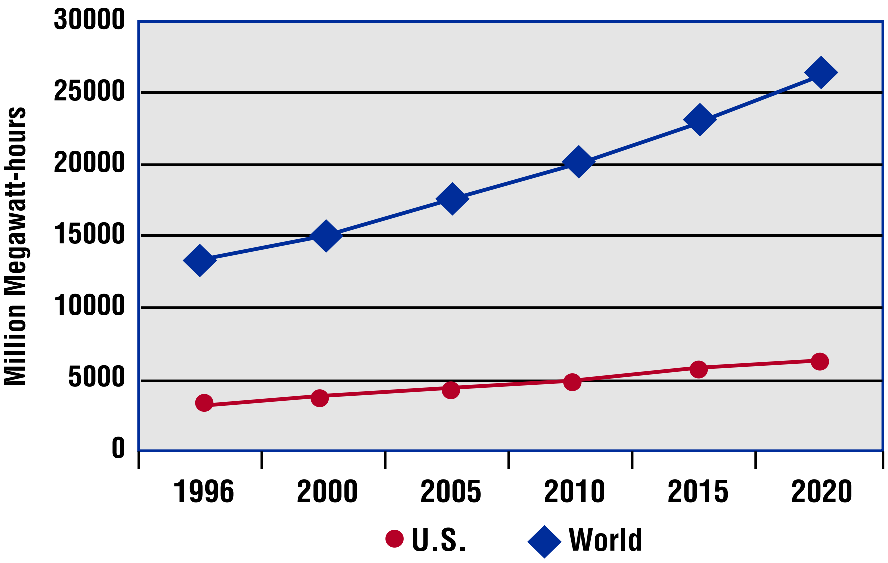
While helping to provide cheap, safe power to the world, the effort would also help continue US influence over nuclear programs around the globe.

In reality, we need not imagine any of these words: President Dwight D. Eisenhower spoke them before the United Nations General Assembly on December 8, 1953, in his now-famous "Atoms for Peace" speech.

Although much has happened in the intervening 49 years, the words still ring true. A "new era" of nuclear power is approaching. As a nation, Americans have gained a better understanding of the issues involved in making peaceful nuclear power a reality. Now, new policies are needed to make Eisenhower's vision a reality.

Potential Demand

U.S./World Electricity Demand



Source: World Energy Council and EIA projections

Although electrical production can vary widely with the type of reactor and operations, on average, a ton of natural uranium will generate 45 million kilowatt-hours.

Another way to think about the enormous potential of nuclear power is to consider that one cubic inch of uranium has the same energy content as 250,000 gallons of gasoline, or 3,000 tons of coal.

Faced with the possibility of sharp increases in demand, shown in the graph, the potential of nuclear power becomes critical. Even with conservation and improved efficiencies electrical generation and transportation demands will expand in much of the world. Use of alternative energy forms can meet some of the demand. Increased reliance on fossil fuels can have a harmful impact on the environment.

Vision

As the world finds itself on the verge of a nuclear renaissance, the US struggles with its role in this global movement. As a national security laboratory, with a long history of integrated systems experience in energy, weapons and environment, Sandia National Laboratories is prepared to play a role. Anticipating this opportunity, its top leaders have sketched out a concept of the nuclear future and the part the US can play.

Bob Eagan, Roger Hagengruber, and Tom Hunter

Three Sandia executives — Senior Vice President for Nonproliferation Programs Roger Hagengruber, Senior Vice President for Nuclear Weapons Tom Hunter, and Vice President for Energy Programs Bob Eagan – have been especially active in this effort. They believe it is time for the US to return to the field as a key player, after more than two decades on the sideline.

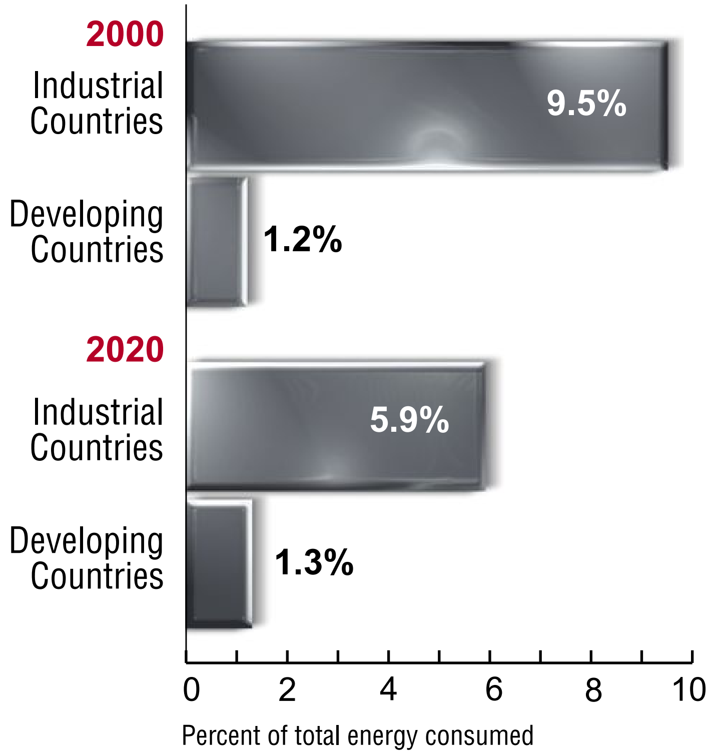
The three call their vision the "Global Nuclear Future." It's a concept they have developed over the past three years. It takes into account nuclear weapons, nuclear energy and issues of nuclear proliferation, deterrence, and nuclear waste management. More than a "solution," Global Nuclear Future is an "approach" to the issues and opportunities the world now faces.

The effort began with a proposal for global nuclear materials management, championed by Hunter and Hagengruber. The concept was to manage weapons-grade nuclear materials, both fuels and dismantled weapon materials, in an environmentally sound and proliferation-resistant way. Recognizing that the role of deterrence – the need to maintain some level of nuclear weapon capability – is not likely to go away, Hunter's concept was expanded. It includes nuclear power as a key in the future energy mix and nonproliferation as a long-term national security goal.

To do this, an approach to nuclear power is needed that will wring every possible bit of energy from the uranium fuels used. In place of the "once through" fuel cycle approach, used in the US, a "holistic", or integrated approach is being called for. Such an approach involves the open, or transparent, use and reuse of fuel in a way that can be tracked and managed throughout the life cycle of the materials. The transparent aspect of the fuel management helps alleviate proliferation concerns. Tracking or managing throughout the life cycle makes maximum use of every atom of these valuable materials.

The Department of Energy (DOE) is beginning to address these issues and made a significant step forward with Secretary Spencer Abraham's announcement of new nuclear initiatives (see page 12) to foster a process that will encourage private investment in nuclear power, improve reactor designs to make better use of fuel, and

Predicted Changes in Use of Nuclear Power, 2000 and 2020



Projections from the International Energy Outlook show a pessimistic future for nuclear power, as its use declines in the industrial nations and levels remain flat in developing countries. New approaches are needed to encourage use of nuclear power.

Other nations must also be recognized in looking to the future. "Many emerging economies, such as China and India, are going to have very substantial needs for energy. They face the problem that the world faces, which is that they have abundant supplies of coal, but it produces a lot of carbon and pollution," Hagengruber says. "Nuclear energy will be attractive for them. We can't simply walk away from that fact."

ultimately return the US to a key role in the nuclear future.

As nuclear investment dried up during the 1980s and 1990s, so did US influence over non-weapons nuclear activities. Observes Hagengruber, "It leads you to ask if the national reprocessing policy produced the desired benefit in controlling proliferation? The argument we're making is that an alternative policy about nuclear energy and reprocessing would be more beneficial. The additional problems of potential energy shortages, global warming and energy security only add greater urgency."

The core thesis of the Global Nuclear Future concept is that "the US must engage all the elements, including a proactive policy for nuclear energy to achieve peace and prosperity in the world," Hagengruber explains. A big piece of the success is the full engagement of Russia, as well, he adds.

"I don't think you can think about a Global Nuclear Future without recognizing the Russian situation. They are still advocates for a broad spectrum of nuclear activities, including power generation," Hunter agrees. Russia has the desire and the capability to promote nuclear power generation for its own uses and to serve the developing nations of the world. They continue to be a major weapons state, as well. "It's clear that we need to have some cooperation with them in a way that they are significant contributors to how our plan shapes up." Hunter cites the recent Sandia-Kurchatov agreement to develop a joint paper on the global future of nuclear energy (see page 14) as an "important step."

"It's interesting that in Russia plutonium is viewed as an extremely valuable national asset," Eagan notes. "In this country many view it as intolerably bad. We actually think the Russians have it right."

Other nations must also be recognized in looking to the future. "Many emerging economies, such as China and India, are going to have very substantial needs for energy. They face the problem that the world faces, which is that they have abundant supplies of coal, but it produces a lot of carbon and pollution," Hagengruber says. "Nuclear energy will be attractive for them. We can't simply walk away from that fact."

"The time is right for America to revisit nuclear energy – only now with a new expanded sense of what it means in light of September 11 and looming economic and environmental developments in the world," Eagan says. Eagan notes that President Bush and Vice President Cheney have expressed support for pragmatic approaches to solving these problems. "I think there's a high probability we'll get a favorable hearing on the Global Nuclear Future concept from the

"The opportunity is now and it is perishable."

environmental community, also, as we look at the issue of balancing greenhouse gas emissions with using nuclear power."

All three vice presidents have stressed the role that government must play, leading to a new generation of nuclear energy. "I think we in the national laboratories should be seen as willing to engage in the dialogue, support policy makers and provide factual objective information," Hunter says.

"The challenge is to realize that proliferation prevention and secure disposition are well within the capabilities of research, development and application in the foreseeable future," said Eagan. "Addressing the issues of public trust and capital costs remain significant challenges, but ones that can and must be addressed."

"The nuclear community has a unique opportunity today to work for global management of nuclear deterrents, nuclear materials, and nuclear power," Hagengruber believes. "It is the scientists and engineers responsible for the stewardship of the world's nuclear stockpiles, who are responsible for helping to control the spread of nuclear arms and weapons-grade materials, and for finding ways to dispose of nuclear waste safely and in a way protective of our environment," he concludes.

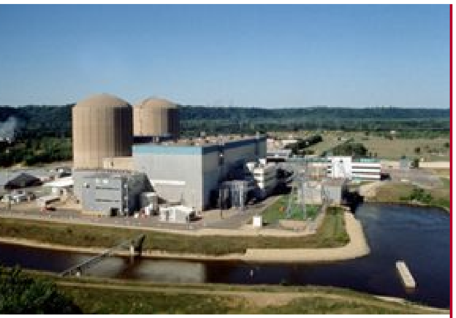
A Recipe for the Nuclear Future

Based on the vision outlined in the accompanying story, here are some of the possible ingredients for a Global Nuclear Future that includes the US in a meaningful way:

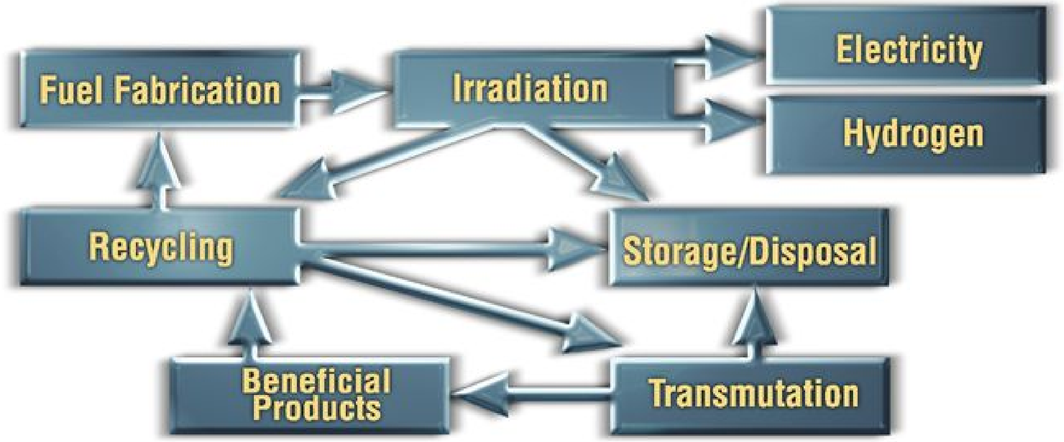
- Creation of economic and regulatory climates that will (1) recognize growing US energy demands and (2) support a 50 percent share of US electric demand supplied from nuclear power sources by 2050.
- Assisting Russia with development of a safe exportable reactor in partnership with Western industry. At the same time, partner with other weapon states to export nuclear reactors and materials for energy production and public health applications.
- Including cradle-to-grave accountability for fuel supply as a part of the reactor-export arrangement. This means providing nuclear power to developing countries while supplier nations maintain responsibility for nuclear materials.
- Recognizing that civilian reprocessing of uranium and military weapons reductions create surplus plutonium. Move the focus from reducing the supply of this critical element to increasing and encouraging its use in energy production.

By joining with other nations to develop a more efficient material and fuel cycle, nuclear power can be shared with the developing world through the use of reactor lease agreements and cradle-to-grave fuel supply contracts. Such agreements enable non-nuclear nations to have access to inexpensive power and share in the consumption of nuclear warheads and byproduct materials left over from the Cold War.

the Nuclear Fuel Cycle



The nuclear fuel cycle is a series of processes involved in the production of electricity from uranium in nuclear power reactors.



This diagram illustrates key parts of the nuclear fuel cycle. Arrows represent another key aspect - transportation.

Uranium, which is relatively plentiful in the world, is mined and milled to extract its elemental form from uranium ores. Processing — called enrichment — is needed to concentrate the uranium. Fuel is made from ceramic pellets of uranium oxide, baked a high temperature. The pellets are encased in metal tubes as fuel rods and arranged into assemblies, or bundles, for use in a reactor.

In light-water reactors — prevalent today for commercial electrical power – the fuel generates heat inside the reactor to produce steam and drive a turbine. An isotope of uranium, U-238, in the fuel is turned into plutonium during this operation. Plutonium and other fission fragments, formed within the fuel , increase over a year or two of use. Then the fuel is described as "spent."

Recycling separates spent fuel into uranium, plutonium, and other useful products. The uranium can be reused as fuel. Although the process is more costly, the plutonium can be mixed with uranium to create a mixed oxide (MOX) fuel for reactors designed to use it.

The use of recycling and MOX technologies describes "closed" fuel cycles. If the fuel rods go directly to storage and disposal, the cycle is called "open" or "once through."

Transmutation is the altering of long-lived isotopes to short-lived ones. This creates other useful products (see page 13) or reduces toxicity of wastes.

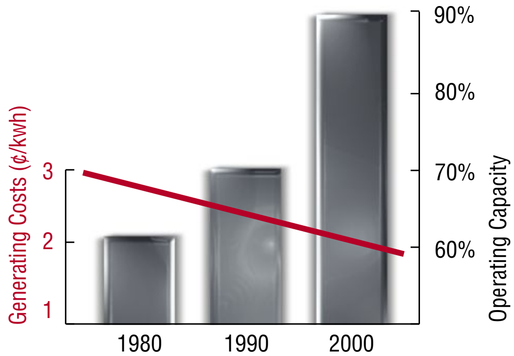
At the present, there are no approved disposal facilities for spent fuel in the US. The Waste Isolation Pilot Project in New Mexico accepts some processing wastes. Most spent fuel is stored at or near reactor sites in cooling ponds or in special containers. Efforts are under way to establish the DOE's Yucca Mountain Project in Nevada as a permanent US repository. Permanent geologic disposal is preferred by a number of other nuclear nations.

The events of September 11, 2001, created a call for spent fuel to be moved to a safe permanent location away from population centers. Until a decision can be made on a permanent storage site, however, the fuel cycle can't be completed.

Nuclear Power 2010

Secretary of Energy Spencer Abraham has announced major Department of Energy initiatives aimed at fostering an expanded role for nuclear energy and strengthening America's energy security. The initiatives support the National Energy Plan unveiled in May 2001 by President George W. Bush.

The view of nuclear power as too expensive, too risky and too unreliable is being overturned, the secretary told members of the Global Nuclear Energy Summit meeting in Washington, D.C. Power plant efficiencies have increased to 90 percent of capacity – up dramatically from the 1970s and 1980s.



Improved US Nuclear Plant Efficiencies

Source: Nuclear Energy Institute

A key to these efficiencies has been better management of the plants, which have sharply rebounded in value as these improving records of uptime have brought down generation costs, making them look like bargain power sources. Reactor refueling, once an operation requiring months, now can be done safely in about three weeks, Abraham noted. An industry that looked nearly moribund a few years ago is now anticipating some applications for getting Nuclear Regulatory Commission (NRC) approval to build new plants.

At the same time, safety records have improved. Public trust has risen to the point that one recent public opinion poll revealed that 65 percent of the American public believes in the use of nuclear power as a part of a power mix for the future, Abraham said. This safety record has been tempered by "the realities of life since September 11", the Secretary noted. Concerns that power plants could become terrorist targets are legitimate. "Both NRC and the International Atomic Energy Agency are working hard to address these new challenges."

The Secretary called for a number of actions to further the role of nuclear power as a safe, environmentally friendly fuel:

- Extend the Price Anderson Act. This act is a promise made by the government to ensure any victim of an accident involving nuclear power is justly compensated. "Only in such an environment can we expect investors to risk the capital for an expansion of nuclear power."
- Establish a permanent geologic repository at Yucca Mountain in Nevada – "a scientifically sound and suitable location" for the nation's nuclear wastes. This will provide a secure and environmentally suitable solution for relocation of spent fuel assemblies, now in storage near reactors around the country.
- Remove barriers to locating new plants, licensing them, and advancing nuclear power technologies available for use in the US. To tackle these issues, Secretary Abraham announced a public-private partnership to enable "a new US nuclear power plant to be built and brought on-line by the end of this decade."

Nuclear Power 2010 is an initiative that will explore sites that could host new nuclear plants, demonstrate NRC processes to make licensing of new plants more efficient, and conduct research to make the safest and most advanced plant technologies available. In addition to a proposed $38 million budget, Abraham called for strong international cooperation to leverage the US funding.

"Together we can establish a clear vision of the future and carry out the work needed to realize that vision," he said.

■

the Peaceful ATOM

Often unannounced, and usually unappreciated, the atom has quietly become a part of our lives during the past 50 years. In addition to the generation of electrical power and its use in weaponry, the uses of radiation have impacted a variety of human activities.

The so-called "peaceful atom" is used to better control applications of fertilizer and to cut harvest losses caused by insects. Spoilage of harvested foods has been sharply reduced by food irradiation technologies. Radioactivity also has uses in measuring the extent of underground water resources.

In medicine, isotopes are used in both diagnosis and treatment. Doctors also sterilize medical equipment, bandages, ointments, powders, and other preparations using gamma radiation.

Late last year radiation was used to sterilize mail and to kill bio-terrorism agents, such at anthrax.

Other uses include environmental tracers and instruments to gauge thickness and density of materials. One of the most common radioisotopes today is used in smoke detectors. These contain a small amount of americium-241, a decay product of plutonium-241 originating in nuclear reactors.

Some radioactive materials emit sufficient energy as they decay to be considered as power sources. These materials can power navigational aids, satellites, and human heart pacemakers.

Finally, the use of radioactive materials to date the age of rocks and other materials has made a significant contrbution in the sciences of archaeology, anthropology and geology.

Sources: World Nuclear Association, Nuclear Energy Institute

Russia and U.S. Working Together

Scientists at Sandia National Laboratories and at the Kurchatov Institute, in Moscow, are working to prepare a joint paper on the global future of nuclear energy as a point of departure for policy makers in Russia and the United States.

Sandia President C. Paul Robinson and Executive Vice President Joan Woodard with Evgeny Velikhov (center) President of Russia's Kurchatov Institute.

After discussing a variety of nuclear power issues on a video link in mid-February, a group of Sandia executives, including Labs President C. Paul Robinson, fashioned the agreement with their Kurchatov Institute counterparts. Joining Sandia executives in Albuquerque for the occasion was Kurchatov Institute President Evgeny P. Velikhov.

"It is now appropriate that we have a revival that addresses energy, economy, ecology connected with straight thinking in the U.S. and Russia about counter-proliferation and non-proliferation," Velikhov said. He said Sandia and the Kurchatov Institute are well matched, because both have worked historically to move from scientific discovery to solutions useful to society.

The two institutions agreed to develop an "executive summary" as a first step, including proposals for development of nuclear power based on points of agreement. A more detailed effort – making use of the strengths of the two research facilities – would follow.

"I think it's important that we look more holistically at the problem of power generation," Robinson told his Russian counterparts during the video link-up. "Working together, can lead to a solution."

Bob Eagan, Sandia Vice President for Energy and Critical Infrastructure, described a number of areas where cooperation with the Kurchatov Institute can be beneficial. These include economic modeling and fusion research, he said. "We see a lot of similarities between our vision of a global nuclear future and where Dr. Velikhov wants to go,"Eagan said.

Velikhov, who has advised Soviet Premier Mikhail Gorbachev and now Russian President Vladimir Putin, spent two days at Sandia, where he was briefed on a variety of technologies relevant to the future of nuclear energy. On his second day, he spoke for about an hour with a group of high-ranking Sandia executives on issues of nuclear power and the future. The video-link discussion followed his talk.

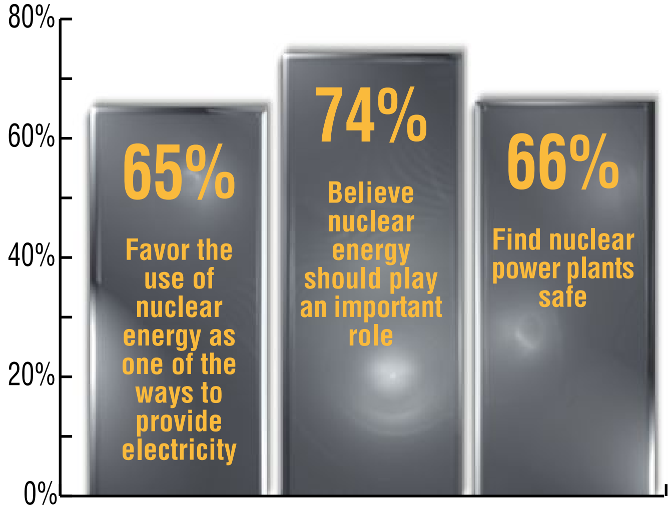
"I think this is an opportune time for us to work in parallel to understand the energy field. We have good agreement in our economic models, although there are some differences," Velikhov said. Russia would like to make use of its materials, manpower and experience to become a leader in developing global nuclear power. Velikhov said his government is taking important steps that will aid joint-nation collaboration.

Sandia National Laboratories
Kurchatov Institute

A Shift in Public Opinion

A nationwide survey in the fall of 2001 shows that record numbers of Americans favor nuclear energy and consider today's nuclear power plants to be safe.

Record Numbers Favor Nuclear Energy



Record Levels of Support in 2001

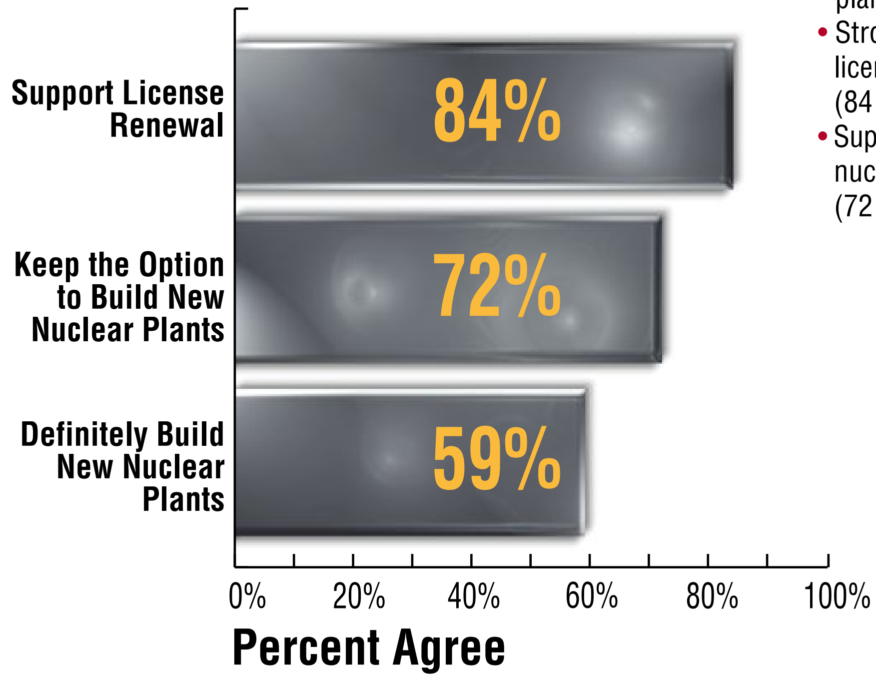
The survey — conducted by Bisconti Research, Inc. — found higher support than ever before for:

- Favoring the use of nuclear power to provide electricity (65 percent),
- Believing nuclear energy should play an important future role (74 percent), and
- Finding nuclear power plants to be safe (66 percent.)

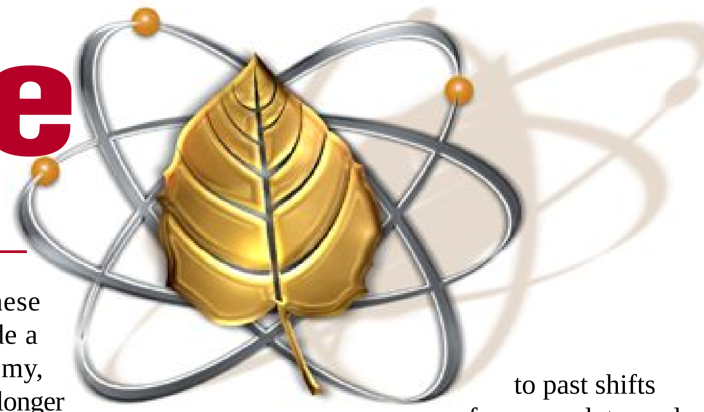
"Support for nuclear energy historically has increased with disruptions in the Middle East and upturns in patriotic sentiment," said Ann Stouffer Bisconti, who conducted the survey for the Nuclear Energy Institute. Although concern about energy shortages and price spikes earlier in 2001 had declined, "the public still believes that more electricity will be needed as our population grows," she said.

Among other trends reported in the survey were:

- Growing agreement (59 percent) that the US should build more nuclear power plants in the future,
- Agreement that it is acceptable to build more nuclear power plants at the nearest existing plant sites (66 percent),
- Strong support for renewing the operating licenses for existing nuclear plants (84 percent), and
- Support for keeping the option to build more nuclear power plants in the future (72 percent.)



Seeds of the Future



From Sandia's strength as a national energy laboratory comes a unique perspective for dealing with tomorrow's issues in nuclear power. The Labs have been involved in the entire spectrum of energy-related work, noted Joan Woodard, Sandia's Executive Vice President. Sandia has been immersed not just in nuclear energy issues, but also in fossil fuel research and in studies of renewable energy alternatives. "We see all of the promises; we see all of the challenges, all of the pitfalls. No one technology is the answer to all of our energy problems, but certainly nuclear has an important role to play."

The following pages outline some of the many areas of research where Sandia is contributing to the vision of a Global Nuclear Future. These are the "seeds," or beginnings, of projects that can contribute to a better energy future.

Energy Future

While many economists these days are being asked to provide a preview of next week's economy, Sandia's Arnie Baker is taking a longer view. Baker, chief economist at Sandia, has led development of two important economic tools to help decision-makers in the future energy and environmental debate.

One tool—the US Energy and Greenhouse Gas model (USEGM)—looks at US energy use by economic sector and fuel, as well as greenhouse gases. It runs possible scenarios 20 years into the future. Another – called the Global Nuclear Future model – looks at commercial nuclear power, fuel cycles, materials in weapons and dismantled weapons, and the economics of five global regions. It projects 50 years into the future.

Baker's work has been praised by energy experts and will be the basis of some near-term cooperation between US and Russian nuclear power researchers. (See page 14.) The international team hopes to use Baker's models to better understand the valuable future role of nuclear power in maintaining global economic growth and the environment.

The USEGM uses laptop computer technologies to calculate carbon emissions from fossil fuels and track oil imports. It uses data from the Department of Energy's Energy Information Administration and offers users the option of changing the energy mix used in the transportation, electricity, industrial, residential and/or commercial sectors. Users can vary economic growth rates, prices for petroleum or other fuel types, and energy efficiency in this model. "The idea is for policy makers, students, or others to plug in data and sit around a conference table with the computer and a projector and discuss alternative impacts," Baker said.

"There is historical evidence to suggest that the world may move to a less carbon intensive energy future," Baker said, referring to past shifts from wood, to coal (about 1900) and then to oil (in the 1970s.) "Perhaps oil will be overtaken by natural gas and in turn by nuclear, renewables and zero carbon energy sources. Sound policy and technology development choices can accelerate these transitions."

The Global Nuclear Futures model adds more detail in the nuclear power supply sector. It allows input as to wastes at the end of the fuel cycle from commercial reactors and weapon conversion to energy. It addresses how economics in the US, other industrialized countries, China, the former Soviet states, and other developing nations may impact the global power, transportation and other energy demand picture. Users can set shares for various power sources and economic growth levels and model carbon emissions, other environmental effluents, and spent nuclear fuels. The model tracks methane, nitrous and sulfur oxides, particulates, volatile organic compounds and mercury, among other environmental effluents.

"Present trends would indicate that the energy intensity of economic growth in the developing world will make those nations and China the largest carbon emitters," Baker said. "This is a tool that will give people a common reference point to focus their discussions."

International Security

Sandia's International Security Programs Center is playing a role in the Global Nuclear Future by reducing the threat of nuclear weapons and bringing technologies to bear that help nations manage their energy futures.

"While others look at safety, environment, and defense aspects of nuclear energy, our focus is on the nonproliferation part of the equation," explained Dori Ellis, center director. The center's activities include cooperative programs and efforts to secure

special nuclear material at weapon production and storage facilities in Russia and other former Soviet Union states.

Through the International Atomic Energy Agency (IAEA), Sandia also supports efforts to safeguard nuclear materials worldwide, by preventing countries from diverting civil nuclear materials to military purposes. These efforts support the provisions of the Nonproliferation Treaty, under which nuclear weapon states have pledged to help others pursue peaceful uses of nuclear energy in return for pledges from the non-nuclear weapons states not to develop nuclear weapons. Through the IAEA, Sandia is providing technologies, such as video cameras at facilities, tags and seals for nuclear materials containers, and other monitoring technologies

In another project Sandia is working with the Russian Federation to provide alternatives for weapon scientists as Russia downsizes its weapons program and spins up commercially viable enterprises. "We are involved in the National Nuclear Security Agency- funded Russian Transition Assistance program," explained Larry Walker, manager for Cooperative International Programs. "We go to their nuclear cities and bring American businessmen who are willing to invest in Russia, and match them with scientists." The program also helps with direct investments in business infrastructures as well. You have to have banking and Internet connections to work in a competitive modern world," said Walker.

Potential attacks on the system have long been recognized to have implications to the economy and national security, he noted. A recent study focused specifically on nuclear plants and the implications of the loss of one or more of these plants from the power grid.

National Power Grid

Question: What has 11,000 generating facilities, 200,000 miles of high-voltage transmission line and thousands of substations?

Answer: a complex, national power grid. It's a grid that is really three regional power areas, each uniquely developed over the years, according to David Robinson, of Sandia's Risk and Reliability Analysis Department. "Each of the three regions is pretty autonomous," Robinson explained. "Each reacts to failure events in unique ways."

With few exceptions, inter-regional power lines "simply don't exist," David explains, but major energy problems in one area will impact others as well. "The movement toward deregulation, with power companies operating closer to acceptable reserve power margins and emphasis on cost-effective generation, has created economic ties between the regions. "The US economy is very energy oriented and problems in one area will cascade quickly into the other regions," Robinson explained.

Sandia lends its systems analyses abilities to this transmission system in a number of ways. Labs' researchers in New Mexico and California study the security of communications between control systems, the distribution of power generating facilities and how it could be improved, and system vulnerabilities.

Studying the vulnerabilities of the massive grid became the predominant focus in the days after September 11, Robinson said. Potential attacks on the system have long been recognized to have implications to the economy and national security, he noted. A recent study focused specifically on nuclear plants and the implications of the loss of one or more of these plants from the power grid.

New Regulatory Approaches

Sandia's decades-long experience in risk assessment studies for the Nuclear Regulatory Commission (NRC) is now leading to a new role for the Labs -- suggesting new approaches for regulating reactors. This work applies to modifying existing regulations as well as shaping regulations that will be needed for new reactors now in design.

"The NRC has the job of preparing for and licensing new nuclear power plants," said Allen Camp, Deputy Director of the Nuclear and Risk Technologies Center. "We are helping with what we call 'risk-informed regulation,' which is a way to focus on the most important aspects of design and operations in terms of public safety."

The potential for savings using risk-informed approaches are even greater in advanced reactor designs, where improvements can be made during design. Sandia is supporting the Department of Energy's Nuclear Energy Research Initiative as part of a team to develop risk-informed approaches for advanced designs.

Risk-informed regulation combines the results from risk assessments with sound engineering practices to develop regulations that ensure a cost-effective approach. "After 20 years of research, we've gained a clearer understanding of how accidents begin and progress. We know which requirements make a plant safe and which one's don't. A risk-informed approach allows the NRC to relax requirements that aren't important and focus on those that are," Camp explained.

Sandia began conducting risk assessment work for the NRC in the mid-1970s. These risk assessments provide evidence to the NRC that power plants are meeting the goal of not exposing the public to significant additional risk. The evidence shows that nuclear energy continues to be a very safe method for generating electricity. Risk assessments have shown plant workers areas where improvement was needed and it has shown areas where regulations may be overly conservative.

Following the Three Mile Island incident in 1979, NRC regulations became extremely burdensome, building many safety layers into plant designs. In some cases, this caused plant personnel to spend time training for extremely unlikely accidents instead of events that posed more of a threat to the public. Following two decades of visits by Sandia researchers to power plants, testing, and risk assessment study, the Labs now provide a unique perspective to NRC on nuclear power safety.

Earlier this year, Sandia presented technical documentation to the NRC on alternative regulations for emergency core cooling. These cooling systems provide water in light water reactor designs in the even of a loss of normal coolants. Jeff LaChance, one of the researchers involved in the study, estimates consumers could save as much as $1 billion with improved regulations, which would allow plants to run at higher power levels, while reducing operations costs.

The potential for savings using risk-informed approaches are even greater in advanced reactor designs, where improvements can be made during design. Sandia is supporting the Department of Energy's Nuclear Energy Research Initiative as part of a team to develop risk-informed approaches for advanced designs. The team involves national laboratory, university and industry players, Camp said, and has suggested some general approaches. The next step will be to work with NRC on a regulatory approach for the advanced designs. That work is just getting under way, as researchers look at the options of re-writing the existing regulations or adapting them to better fit the advanced designs.

Sandia continues to shine in the venue of risk assessment work as well. Risk studies on the pebble bed modular and advanced gas turbine reactor designs are under way at the Labs. (See page 26)

Nuclear Waste Management

The Yucca Mountain site in Nevada is scientifically sound and suitable for development as the nation's long-term geological repository for nuclear waste. That is the recommendation made in January by Secretary of Energy Spencer Abraham to President George W. Bush.

Although the state of Nevada is challenging the recommendation, the move signals the next step in a process that has already taken several decades. Congress will ultimately decide the fate of the Yucca Mountain project.

"Because of widespread public concern about nuclear waste, there have been no easy solutions to the tasks of packaging, transporting, and ultimately disposing of the nuclear waste and spent nuclear fuel now temporarily stored in literally hundreds of locations throughout the United States," explained Dennis Berry, director for Sandia's Nuclear Waste Management program. His organization brings to bear the capabilities of the Labs on nuclear waste disposal problems, often deemed the Achilles' heel of nuclear power.

Sandia has participated in scientific research to validate the effectiveness of geologic waste storage at Yucca Mountain and at the Waste Isolation Pilot Plant, near Carlsbad, New Mexico. Sandia has taken the view that waste disposal must be safe and based on scientifically sound principles that withstand the scrutiny of both regulators and the public, Berry said. The Labs have a history of successful work in cleaning up environmental sites and of working with regulatory agencies, citizen groups, scientific oversight groups and

The Yucca Mountain site in Nevada

Richard Simpson, of Sandia's Applied Nuclear Technologies department, measures a weld in a 1/5 scale model pressure vessel lower head assembly.

other stakeholders on waste issues.

Lessons learned from these efforts have given Sandia stature in the areas of geological analyses, contaminant transport, barrier effectiveness, and risk assessment in the US and around the world. As part of this, Sandia is actively engaged with scientists and government officials from Japan, Taiwan, and other countries to share technical knowledge about the best ways to dispose of nuclear waste.

The data from the work will help improve modeling of failures. This, in turn, will help operators at nuclear plants to better understand what actions they can take to allay an accident. It will help improve designs of newer reactor parts, as well.

Test to Failure

Although much of Sandia's nuclear power research is in the form of analyses and modeling, the Labs also offer the capabilities for real world testing of plant components and systems. Researchers are presently polishing a final report to an organization representing eight nations on series of nuclear plant tests. The tests subjected scale model pressure vessels – the heart of a nuclear reactor – to high pressures and temperatures anticipated in severe accident conditions.

The result: a better understanding of the materials properties and structural factors at work in a severe reactor accident.

The pressure vessel is designed to withstand extremely high internal pressures and temperatures. Between June 2000 and July 2001, Sandia engineers completed a series of four tests to provide data to computer modelers. In the fall of 2001, an international team reviewed the first test and assessed the ability of several programs and modeling techniques to predict the vessel's response to conditions.

In a 1/5th-scale test conducted in October 2000, a lower-head assembly was heated to 1880°F, began to deform, stretching like a balloon, and finally failed with a loud bang at a temperature of 2780°F. "These tests are very impressive to watch," said Sandia test engineer Larry Humphries. "The strength of the steel even under these conditions is remarkable."

The data from the work will help improve modeling of failures. This, in turn, will help operators at nuclear plants to better understand what actions they can take to allay an accident. It will help improve designs of newer reactor parts, as well.

The tests were done for the Organization for Economic Cooperation and Development (OECD), representing Germany, France, the Czech Republic, Belgium, Spain, Sweden, Finland, and the US. The Nuclear Regulatory Commission (NRC), which had funded eight earlier tests of this type and the Department of Energy provided US funding.

In another example of international cooperation, Japan has partnered with Sandia and the NRC on a number of nuclear power plant safety projects in the past 20 years. A 10-year program with the Nuclear Power Corporation of Japan to study the response of nuclear plant containment structures to pressures beyond design ranges was recently culminated with the failure test of a one-quarter-scale model. Previous programs have included a spectacular F-4 Phantom rocket sled crash test.

Weapons to Energy

Sandia is playing a key security role in two major efforts to reduce weapons materials in Russia. These programs are converting weapons materials – plutonium and highly enriched uranium – to use as fuel for the generation of electricity. Researchers in Sandia's International Security Center are developing plans to assure the US that the plutonium and uranium being disposed of is from Russian weapons and is being handled appropriately, explained Larry Walker, manager for Cooperative International Programs.

The two programs:

- In 2001, the Department of Energy (DOE) announced an agreement with the Russian federation, to dispose of 34 tons of surplus US plutonium by making it into commercial reactor fuel. The Russian government agreed to do the same.
- Earlier the US agreed to purchase 500 tons of highly enriched uranium from the Russians. As part of this agreement, the Russians will "down-blend" the weapons-grade uranium to produce material suitable

To achieve energy independence and meet America's goals for a cleaner environment, renewal of licenses at many of the nation's existing nuclear power plants becomes a critical issue.

for reactors, but not for weapons. A US company will buy the down-blended fuel.

In the case of both agreements, Sandia has developed monitoring plans to assess compliance. Although some controversy has surrounded the plans, the work is important to efforts to reduce proliferation and bring some economic stability to Russia, government project managers maintain.

The DOE announced early this year that it would dispose of the US plutonium by converting it into a mixed oxide (MOX) form. The oxide can be used in commercial reactors, although some of the plutonium will have to be further refined to meet MOX standards for purity. Even with the oxide conversion and purification costs, the MOX plan will save an estimated $2 billion over earlier plans, which called for immobilization of some of the plutonium in glass. It will also put the plutonium to work providing electricity to Americans instead of keeping it in storage.

Controversy has surrounded the MOX approach to plutonium disposal and the proposed down-blending of the Russian uranium. Some groups fear these measures could serve to legitimize reprocessing and re-use of plutonium, which in the long run could make weapons grade materials more readily available to terrorists or other nations wanting to start weapons programs.

Another key part of the Sandia job has been to design a monitoring approach that will assure the US that the amounts of Russian uranium and plutonium processed are accurate.

Proliferation Scorecard

Researchers from Sandia's non-proliferation and nuclear energy organizations are working to identify how different technologies in the fuel cycle impact the potential for the spread of weapons.

If technologies have the impact of making weapon's grade nuclear materials more available — thus making the creation of new weapons more likely — the team will assign a higher number to that impact. If the technology or activity has the impact of making it less likely that additional nuclear weapons can be built, it will be judged more proliferation resistant and assigned a relatively lower number.

"We are looking at the fuel cycle from mining through reprocessing, through what gets buried in a once-through fuel cycle as compared to one where there is recycling and reuse," explained Gary Rochau, manager of Sandia's Modeling and Analysis department and team leader. Using laboratory funding the team will look at nuclear energy processes used around the world. "We want to look at the Japanese breeder and French mixed oxide process and the Russian high temperature gas technologies as well as our own," he said.

The team will use a process called risk informed proliferation analysis. This involves a detailed knowledge of the various processes and the risks associated with them. It then makes use of this knowledge to calculate "proliferation scores" for the various activities.

License Renewal

To achieve energy independence and meet America's goals for a cleaner environment, renewal of licenses at many of the nation's existing nuclear power plants becomes a critical issue.

Presently nuclear plants are licensed for 40 years, with the option for a 20-year extension. The first US license renewal application was filed in 1998 and approved by the Nuclear Regulatory Commission (NRC) in 2000. A half-dozen other applications for renewal have followed. Experts expect something like a third of the nation's 103 power plant operators to file for renewal by next year, with more to follow.

The NRC, recognizing likely problems that come with an aging group of reactors, is moving cautiously in this arena. Sandia is helping the NRC address these issues with research in several areas. (See page 17.) One example is a project under way to evaluate concerns about plant pressure vessels. Robert Waters, manager for Risk and Reliability Analysis Department at Sandia, explained that pressure vessels could be subjected to severe stresses in the case of certain operational disruptions. An example would be the inadequate or inappropriate use of emergency

Randy Cole (left) and Randy Gauntt, of Sandia's Modeling and Analysis department, with copies of MELCOR 1.8.5. One-quarter scale model containment vessel (background) was tested to failure in 2001 to gather experimental data.

Sandia is in the process of taking an established software product used by the nuclear power industry to a new level.

cooling procedures, which provide cool water in the place of lost hot water or steam within a pressure vessel.

Because the vessels are operated at high pressures and temperatures, the potential for cracks or damage are of concern and could limit the life of a plant, Waters said. "We are now studying this problem from a risk point of view." The study, expected to be complete by late summer, will help the NRC and plant operators to better communicate on this issue. "Human operators at the plants have a key role in these situations," Waters said. By looking at what can happen, how it is likely to happen, and consequences, in a risk assessment process, Sandia can assist NRC in proposing effective training at the sites to prevent the scenarios where pressure vessel damage might occur.

A key to the Labs' success in risk assessment is Sandia's real-world experiments and the subsequent data developed from them, explained Waters. "When you do a risk assessment, you need good data for the scenarios you are considering," he explained. "When good data aren't available, experiments often offer the best way to obtain the needed data. Sandia has done these kinds of experiments for years - most recently the quarter-scale containment vessel tests conducted through the (DOE- and NRC-sponsored) International Nuclear Safety department."

MELCOR

To accomplish this, researchers are updating special computer software that models the complex physical phenomena that occur in a nuclear power plant accident. Distributed to domestic and foreign power plant operators on a compact disk, the software — named MELCOR — incorporates 20 years of nuclear safety research. The effort to expand analysis capabilities to advanced designs is expected to take about two years.

"Our goal is to look at advanced reactor designs from a safety viewpoint before we build them," explains Gary Rochau, manager of Sandia's Modeling and Analysis Department. "We also want to look at mixed oxide issues to help better utilize the plutonium and other spent fuel products from reactors. This is a huge step for the NRC in working to know what to expect with the advanced reactors."

Sandia issued its most recent version of MELCOR late last year. Using the latest experimental data, the software is designed to help regulators and utilities define operational margins of safety. "It will allow them to revisit some of the perhaps overly conservative regulations…and refocus on areas where greater safety precautions might make a difference," said Randy Gauntt, Sandia project leader.

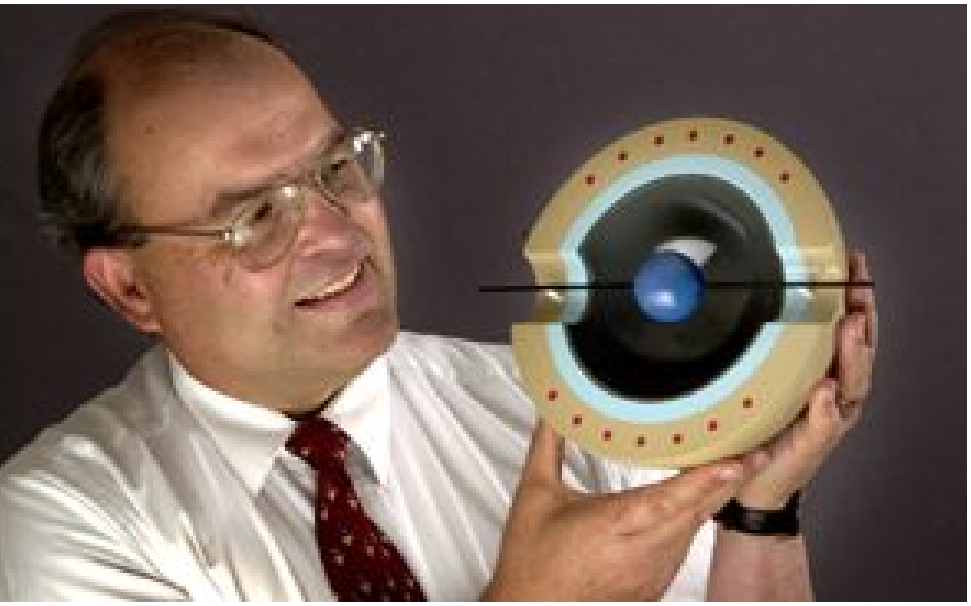
MELCOR models the whole power plant from cooling systems and control wiring to physical interactions between the nuclear fuel rods and their pressure vessels. A user defines details of a plant's design and equipment and specifies an initiating event – such as a break in a cooling system pipe or power outage. MELCOR calculates a play-by-play summary of the accident, based on experimental data, past experiences and probabilities.

Sandia began work on MELCOR in 1982 and made its first release in 1989. Four updated versions have been released through the NRC.

Modeling Many Factors

The cooling tower for a nuclear power plant has become a symbol to many Americans of that form of energy. To researchers, trying to determine how plants can be constructed on schedule and on budget, the abandoned plant may be an even more powerful symbol. "I have visited abandoned, unfinished plants, where utility companies have just walked away from huge investments, in the billions of dollars," said Gary Rochau, manager of Sandia's Modeling and Analysis department. "Unless we can show that nuclear is profitable to investors, nuclear power won't happen."

Rochau is involved in a multi-organization, multi-disciplinary approach to try to overcome some of the obstacles faced in building new nuclear power plants. "We have looked at all



Gary Rochau holds a cutaway model of magnetically insulated fission electric cell.

A fission battery? Gary Rochau, manager of the Labs' Modeling and Analysis Department, and his research staff are planning a "proof of principle" experiment to demonstrate that electricity can be provided directly from fission, without boiling water.

the reactor plants built to date and watched how the time from start to operations increased dramatically with the creation of environmental and other regulations in the 1970s. Three to five years is a reasonable period for investors, but when the period of construction is lengthened, it is no longer cost effective." New laws created regulatory obstacles that slowed construction, but they also opened avenues allowing nuclear power opponents to file litigation. New regulatory processes are now in place, but they have never been used.

Now a Sandia team is working with researchers from Stanford and Texas A&M universities and architectural engineers from Stone and Webster, to study the process of locating and constructing new power plants. The team includes environmental engineers, regulators, social and political scientists and nuclear engineers. The goal is to visualize impacts and address them in advance. Part of the effort will involve a charette approach, Rochau said. A charette is a meeting where interested stakeholders meet well ahead of construction to discuss how all of the various interests in a project can be addressed.

"There are ways you can reduce plant costs through smart construction, but if you can't assure a process that can be completed in a reasonable amount of time and at reasonable cost, nuclear power is likely to fail to be competitive with other power generation technologies like natural gas," said Rochau. The team's objective will be to create a model incorporating environmental, social and regulatory impacts of building a new plant. The model should be available within the next three years to assist in the deployment of the Department of Energy's Nuclear Power 2010 initiative (see page 12) to construct and operate a new US power plant in the next decade.

Fission Battery

The fission battery is a marked departure from traditional reactor concepts, where water is converted to steam to drive a turbine. Instead, positively charged heavy atoms and negatively charged electrons — released during fission reactions in fuel — are separated and collected at electrodes. This can create a usable voltage.

Achieving the separation is part of the current challenge. Designs call for the use of magnetic fields to stop electrons from bridging the gap. After looking at several concepts, researchers are now pushing ahead with what they view as the best path.

The DOE-funded project will take about three years to reach the critical experiment stage, Rochau estimated. "We want to demonstrate that the basic physics that works on the nanosecond level in the Z machine (Sandia's fusion research facility) can also work in a continuous time frame." If successful, the effort could lead to a dramatic new source of power "A baseball-sized device could generate four million volts," said Rochau.

The concept isn't just for high-intensity power levels, either. "We are also looking at americium and strontium 90, essentially nuclear waste materials, to build batteries the size of resistors to put in MicroElectroMechanical Systems (MEMS), or micro-machines."

Micro-machines are so small that they are imperceptible to the human eye, with working gears no larger than a grain of pollen. They can be batch-fabricated – tens of thousands at a time – at a cost of only pennies each. "We have a research project to see how small we can build power sources for these devices and how much power we can generate," Rochau said. Radioactivity levels are tiny on such a scale and could easily be shielded to protect humans.

"We know we can use radiolytic processes to scrub pollutants out of flue gases," Powers said. "So we asked the question, could we find a way to use radiolysis to strip out CO and CO2 in a process designed to make hydrogen?" Radiolysis is use of radiation to break chemical bonds and re-arrange molecules. It has been used in decontamination of mail – to kill anthrax – and is also used to help preserve some foods.

"We could have lady-bug-sized probes. This opens up new vistas for self-powered devices."

Hydrogen Fuels

Hydrogen, a promising fuel of the future, faces some difficult technical hurdles. Although it's plentiful – it's right there in our water after all – getting it can be very energy intensive. The question of finding an inexpensive, clean way to generate hydrogen may tie directly to the development of new generation nuclear reactors.

As a part of a Nuclear Energy Research Initiative funded by the Department of Energy, Sandia is partnering with the University of Kentucky and General Atomics Corporation on a new chemical method to generate hydrogen. The work also has implications for the National Climate Change Technology Initiative (NCCTI), announced recently by the Bush administration.

The NCCTI is aimed at research, development, and deployment initiatives for renewable energy projects; hydrogen production and storage; life extension of nuclear power plants; more efficient coal and natural gas generation; the capture and storage of carbon dioxide; and other projects with potential for improving climate.

Sandia and partners are experimenting with a thermal-chemical cycle for creating hydrogen from sulfuric acid and hydrogen iodine, using high temperatures. "There are a lot of aggressive chemicals needed to make hydrogen in the current process," explained Paul Pickard, manager for Sandia's Advanced Nuclear Concepts department. But simple electrolysis – taking the hydrogen from water – is not as efficient as the thermal-chemical techniques.

Interest in hydrogen as a fuel grew during the energy crises of the 1970s, when it was believed that fossil fuel prices would continue to climb. The prospect of using new low-cost nuclear energy to produce hydrogen for mobile and stationary applications looked promising under those circumstances.

"Those conditions didn't materialize," said Pickard. But new generation reactors with higher running temperatures – in the 700 to 800 degree Celsius range – and better energy conversion rates, may make the hydrogen-nuclear link work in the future.

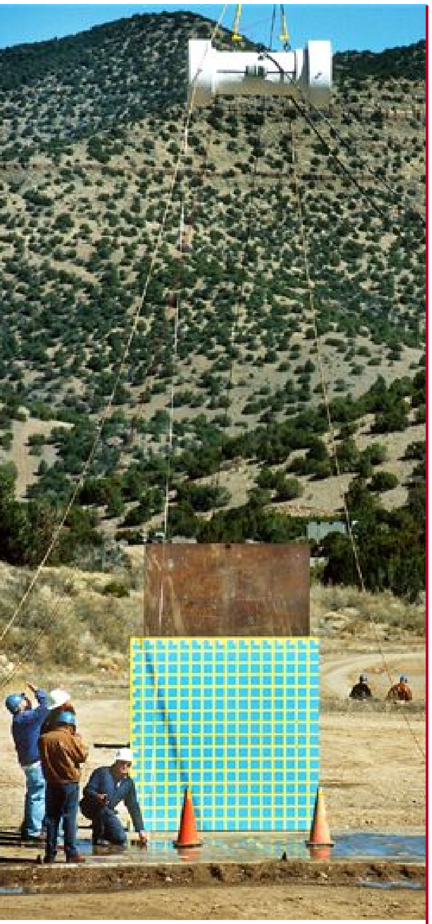
Currently most hydrogen used in industrial processes is produced from natural gas through a steam reforming process. Hydrogen produced by this process results in greenhouse gas production, another concern. Another classic approach to hydrogen production is to run steam over coal, explains Dana Powers, senior scientist in Sandia's Nuclear and Risk Technologies center. Again greenhouse gases are an issue.

Economic hurdles also exist for hydrogen storage systems – they are too expensive and do not meet the performance requirements of the various applications. This is especially true for hydrogen's potential use as a transportation fuel, where there is a need for high energy density. Hydrogen has a very low energy density at normal conditions. Mobile fuel tanks must operate at very high pressure and be light in weight. Researchers at Sandia California are now testing new materials, called hydrides to address this problem.

"Our concept is to create a solid state material that a lot of hydrogen can soak into reversibly," explained Jim Wang, manager of Sandia's Analytic Materials Science department. "Hydrogen gas is very flammable and as it is compressed this becomes more of a problem. Our goal is to develop materials where hydrogen is stored near ambient pressures and temperatures in solid form."

New hydrides that are different from those used for cell phones and laptop batteries offer hope to store hydrogen on-board for transportation applications. One of the goals of the recently announced FreedomCAR initiative, a collaboration among national laboratories, industry, universities and government, is to develop solid state materials for storing 7.5 percent and higher hydrogen by weight. Presently, Wang's California group successfully synthesized complex aluminum hydrides that are capable of storing hydrogen up to 5 weight percent reversibly at temperatures below 100^0 C. Research efforts are underway to develop other hydrides by studying the mechanisms of the current complex hydrides.

In the long run, hydrogen could be an important source of energy in the US. Sandia's research is helping to support that effort.



An NRC study conducted at Sandia and released in March 2000 used even newer technologies to analyze the ability of containers to withstand severe accidents. This study concluded that the risks are even smaller than estimated by the 1987 study.

Transparency Frameworks

A Sandia-developed technique, called Transparency Frameworks, is being used to create a way for countries to observe one another and assure themselves that nuclear energy activities are not fostering the spread of weapons.

This new tool draws heavily on an old idea, called "transparency."

"Transparency is the ensuring of confidence by the public of nuclear facilities, said Kent Biringer, a researcher at Sandia's Cooperative Monitoring Center (CMC.) The CMC has been busy since the mid-1990s demonstrating how activities at remote sites can be monitored using video systems, seals, tags, sensors, tracking devices, and data authentication. Sometimes simple, sometimes sophisticated, transparency methods help nations earn trust from one another.

With researchers from Sandia's information systems, nuclear energy, and non-proliferation organizations, the team is ready to kick off an effort to extend the CMC experience and create new transparency software. British Nuclear Fuels is also a partner in the effort.

"The industry is pushing more and more toward automation of its nuclear energy processes. It is proving cost efficient, but it also provides a dearth of information," explains Gary Rochau, manager of Sandia's Modeling and Analysis department. "If you can provide information with the automation, you can analyze it with risk informed proliferation assessment methods. You can constantly calculate the probability that something important is being stolen."

Sandia envisions a multi-disciplinary approach to a transparent and proliferation resistant future. This approach that involves a variety of technologies, including advanced controls, cyber security, sensors, information and computational developments, and information sharing. Sandia also hopes to apply its experience in radiation effects testing and radiation hardening to develop new sensors that can be placed in very radioactive environments like a reactor core. These technologies will be woven together into a Transparency Framework to provide continuous real-time monitoring of global nuclear fuel cycle activities.

The CMC started working toward transparency with Internet observation methods and the current project would propose to build upon that. "The idea is observation without interference," explained Rochau. "With transparency, people can look at all kinds of fuel cycles. We have a philosophy that with control, there are far more possibilities for the future. Without control, there is fear of the unknown. Through transparency, Sandia can make a strong contribution."

Transport Testing

Containers used to move spent fuel by rail or by highway are designed to withstand accidents. United States and international regulations require that these containers be able to pass a series of tests that simulate severe accidents. The NRC reviews and certifies that spent fuel container designs meet these regulations. The containers must be able to survive a sequence of four accident tests involving impact, puncture, fire, and submersion. During and after the tests, the casks must maintain a leak-tight seal that would prevent escape of any of the contents.

Working closely with Sandia, the Nuclear Regulatory Commission (NRC) completed its first comprehensive study on the risks of transporting radioactive materials including spent nuclear fuel in 1977. This has become the "baseline" study, used to compare new information and studies completed since. In 1987, improved research methods were used to study the ability of spent fuel shipping containers to withstand severe accidents and to estimate the risks to the public of possible releases of radioactive materials during severe accidents. This study added assurances about the ability of spent fuel shipping casks to withstand an accident and confirmed that risk estimates in the 1977 study were conservative.

An NRC study conducted at Sandia and released in March 2000 used even newer technologies to analyze the ability of containers to withstand severe accidents. This study concluded that the risks are even smaller than estimated by the 1987 study.

Through the Center for Strategic and International Studies (CSIS), Sandia leaders have participated in task forces on nuclear materials and arms control, a revisiting of the "Atoms for Peace"concept, domestic energy policy, education, and a variety of other subjects.

"We felt that to really create and take advantage of new opportunities, the entire management team had to be engaged. We needed a 'shared vision' that both tied us to the rest of the Labs and challenged us to develop an exciting future."

The NRC is continuing to follow developments in spent fuel shipping to assure that risks remain within safe limits. Following the most recent study, NRC initiated a four-year project at Sandia, which will conduct a high-speed impact test and a long-duration fire test of a rail cask, said Ken Sorenson, manager of Sandia's Transportation Risk and Packaging department.

Sandia made history in the nuclear materials transport field by conducting the first full-scale crash tests in the late 1970s. One of these tests involved crashing a tractor-trailer rig carrying a shipping cask into a concrete target, using the Labs' 2000-foot rocket sled track. Another test crashed a 120-ton diesel locomotive traveling at more than 80 miles per hour into a cask and trailer at a simulated rail crossing. Videos of these tests are still being shown today to demonstrate the robustness of the transportation casks. Other experiments have followed using Sandia facilities to conduct drop, burn and puncture tests of the casks.

The chance of a radioactive material release in an accident cannot be entirely eliminated. However, based on more than 20 years of shipments without a radioactive release and ongoing testing and simulation work, the NRC has determined that the chance of a release is extremely small and that the existing regulations are still valid.

Engaging the Debate

Since the late 1990s, Sandia has recognized the need for a nuclear renaissance and has pushed for the US to be a participant by engaging in a number of forums. The Sandia – Kurchatov Institute Initiative to provide decision-makers with information about nuclear power (see page 14) is only the latest in this series of efforts by Labs' leadership to engage in the nuclear power debate.

In fact, the nuclear effort grew out of a wider vision, said Joan Woodard, Sandia's Executive Vice President, who led the Labs' energy programs from 1995 to 1999. "We started in the context of trying to bring an active debate about energy strategy as a whole," she said. "We highlighted the idea that no one energy supply was the answer given the world's energy situation. We stressed the need for an integrated energy strategy across a portfolio of energy options, so as not to close the door on any one option, including one like nuclear power that we will need in the future."

Those early efforts led to Sandia's 1997 participation in a seven-lab study, which recommended the inclusion of nuclear power as an element in the US energy mix.

Sandia executives C. Paul Robinson, Roger Hagengruber, Tom Hunter and Bob Eagan have been at the forefront in working with a number of organizations over recent years to further their vision of the role nuclear power can play in the world's energy future.

Through the Center for Strategic and International Studies (CSIS), Sandia leaders have participated in task forces on nuclear materials and arms control, a revisiting of the "Atoms for Peace"concept, domestic energy policy, education, and a variety of other subjects. Under the direction of the Labs' leadership, researchers have performed a number of studies to help advance policy toward the beneficial use of nuclear technology.

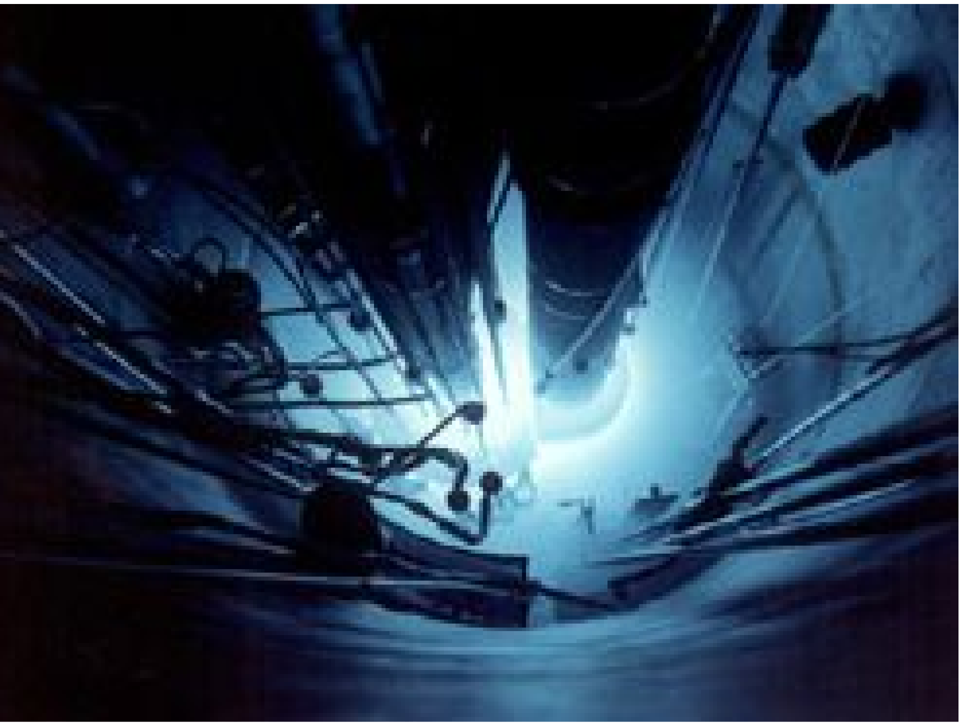
In June 2000, the CSIS initiated a briefing for Senate and House staffers that grew into a "Nuclear Caucus" with growing attendance from lawmakers and staff. Sandia and other national laboratories experts joined the CSIS in sponsoring the caucus. New Mexico's two US Senators, Pete Domenici and Jeff Bingaman, have since urged that the caucus become a bi-partisan base for energy policy action.

Sandia's efforts have paid dividends in the years since. Numerous leaders and decision-makers have picked up on the idea of an integrated national energy strategy and multi-year initiative to create such a strategy has grown.

Sharing the Vision

Imagine a group of independent, motivated managers and their staff, each dedicated to an individual research direction in areas that have steadily declined for many years. Imagine that some managers, at multiple levels, begin to believe that the business environment can change and that Sandia can influence that change in a way that will help the country. Yet, others see this belief as a mirage, not a real opportunity.

This was the challenge faced by Tom Blejwas, director for Sandia's Nuclear and Risk Technologies Center, and his management team.



Sandia's Annular Core Research Reactor can be used in a vareity of experiments.

One of the big challenges in achieving a successful nuclear future will be bringing advanced reactor technology to the marketplace.

A part of the impetus for the change was a new vision statement, crafted by three Sandia vice presidents (see page 8.) At the same time, Blejwas and some of his managers realized that changes in political and social views in the US and elsewhere were making the possibility of reaching the new vision a stronger possibility.

”We felt that to really create and take advantage of new opportunities, the entire management team had to be engaged. We needed a ‘shared vision’ that both tied us to the rest of the Labs and challenged us to develop an exciting future,” said Blejwas.

To address these issues and move from multiple independent visions to a single shared one involved a somewhat different approach to management, explained John Guth, of the center’s program management office. “I told the group when we convened that we weren’t going to start by spending two days to write a one-page mission statement,” he said. Instead, Guth focused on the behaviors that were going to be needed to succeed.

The behavior approach can be a painful process, Guth conceded. It calls for putting all issues and concerns on the table, discussing them and then moving toward a consensus. The first step in the process was not a final mission, but a group of agreed upon ways to communicate and behave to reach the goals, yet to be established. In this case the behavioral plan led to a consensus on where the center fit into Sandia’s larger mission.

“We are a national security laboratory, we had the Global Nuclear Future vision, and we were working on a number of Nuclear Energy initiatives for the Department of Energy, the Nuclear Regulatory Commission, and others,” explained Blejwas. “We believe the Nuclear Energy initiatives are a key part of the Global Nuclear Future vision and that energy independence is a pivotal part of national security.”

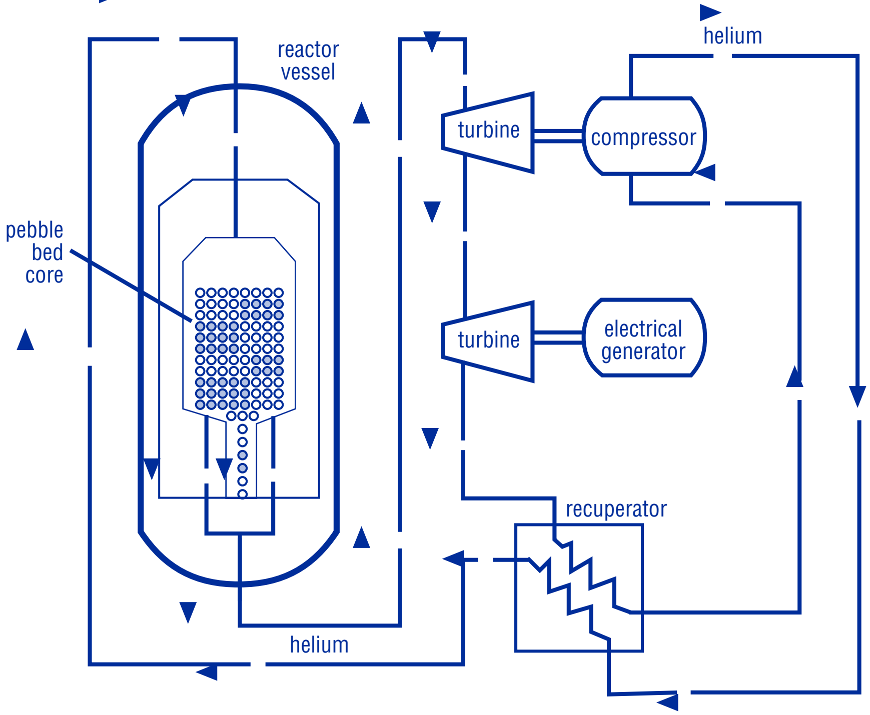
From this realization, the team “down-scoped” to identify thrust areas to focus efforts on in a way that tied them together and to the Labs’ broader missions. Identifying these areas also helped the team to establish linkages between the center and other Sandia organizations. These include international security programs, geosciences and environment, and nuclear waste management organizations.

Advanced Reactors

“Sandia is working on advanced reactor concepts,” Tom Blejwas, Sandia’s Director for Nuclear and Risk Technologies, said. “We are looking at integrated fuel cycles in more detail to see the impact. We think we have to show the policy makers more detail to demonstrate what is needed.” Researchers at Sandia are looking toward an evolutionary suite of reactor designs, each improving on cost effectiveness, safety, and more efficient use of available fuels.

To reach a level where 50 percent of US power is provided from nuclear by 2050 — with an 80 to 90 percent reduction in waste — advanced reactors are a must, Blejwas explained. The nuclear future can expect to see a movement away from the present light-water reactor technologies, which operate at high temperatures to heat water to make steam, to newer gas reactors, which generate power more efficiently. Breeder reactors actually

Schematic of Pebble Bed Modular Reactor



The pebble bed design may not require a large containment building, as do light-water reactors. Some observers have suggested it could even be earth sheltered to protect from the possibility of terrorist attack.

create new fuel while generating power and will further extend uranium resources. The experimental concept of direct energy conversion, which makes use of the heavy ionization of nuclear materials to generate electricity directly from the fuel materials, is further into the future. Finally, beyond these fission efforts lies the promise of fusion.

For the next 10 to 20 years, proposed new nuclear power plants are likely to look like improved versions of today's water-cooled designs, said Paul Pickard, manager of Sandia's Advanced Nuclear Concepts Department. Investors for the next generation of reactors – 30 to 50 years out – will be looking for more. They will want inherently safe, proliferation resistant, highly efficient reactors that minimize waste and offer multiple uses.

"You have to start with the fuel cycle and consider the full picture, including wastes and proliferation concerns, and decide where you want to go," said Pickard. "We could fill Yucca Mountain by 2030, but if we expand nuclear power we're going to either need more repositories like that or develop a more efficient use of the fuel cycle. We have to minimize the load on the repository and look at transportation and proliferation issues. When you look at the integrated fuel cycle issue in the long term, you can see we're going to need a mix of reactors to optimize nuclear power resources and costs."

Pebbles and Gas

Oak Ridge National Laboratory and the Idaho National Engineering and Environmental Laboratory are taking the lead in DOE research for two near-term gas reactors under the Secretary of Energy's Nuclear Power 2010 initiative. These designs should meet some of the demands for optimizing future reactors. The pebble bed modular reactor and the advanced gas turbine helium reactor both are considered real options for future power generation because of the promise they hold for lower costs and inherent safety.

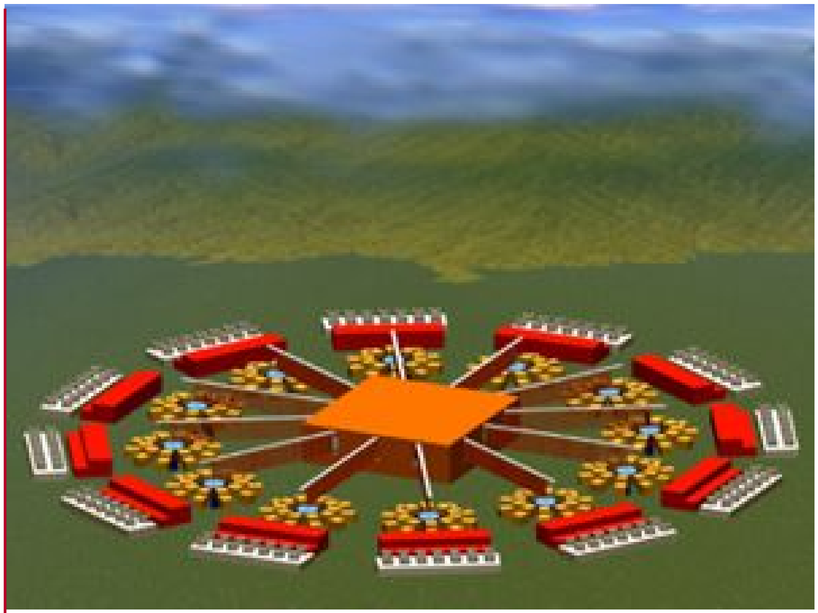
Sandia's likely role in these near-term projects will be in addressing regulatory and safety issues. New reactor types will require regulators to look at different issues than in the past and perform new types of analyses. (See page 17.)

In the pebble bed concept, pipes pump helium to flow around carbon-coated uranium "pebbles." The helium absorbs heat and flows out of the reactor to produce electricity. Higher temperatures and pressures result in the efficient generation of power. Further, the design is seen as safer in that it will conduct heat away from the fuel and is unlikely to melt down.

In the pebble bed approach, modular construction will allow addition of capacity at existing plants in many cases, eliminating the issues of finding a new site with accepting neighbors. The pebble bed design may not require a large containment building, as do light-water reactors. Some observers have suggested it could even be earth sheltered to protect from the possibility of terrorist attack.

Further into the future, advanced very-high temperature gas reactors are also on the drawing board. These so-called "Generation IV" reactors take advantage of higher temperature operation to create better generating efficiencies. They also provide the ability to generate hydrogen from water and

The basic idea is a wheel of a dozen Z-type machines with a distribution center at the hub to provide recyclable cartridges. The cartridges include transmission lines and targets and are manufactured at the hub and connected to each of 12 containment chambers. In the present plan, turbine systems adjacent to each of the containment chambers would generate the actual electricity.



An early concept: Inertial Fusion Energy Power Plant

other hydrogen-containing compounds, such as fossil fuels. Hydrogen (see page 22) may be valuable as a future transportation fuel.

Sandia is involved in conducting research on these concepts from the perspective of associated safety and engineering issues, said Paul Pickard, manager of Sandia's Advanced Nuclear Concepts Department. Achieving a higher output of electricity per plant, reducing wastes and generating clean transportation fuels can help the US move toward its goal of energy independence.

Fusion Power

While uranium is a potent fuel source, fusion power makes use of resources abundant in nature – such as the hydrogen isotope deuterium – to extend available energy to the point where it is essentially limitless. To get to the point of sustainable energy from fusion power, however, many technical issues must be addressed. Sandia is working with a number of groups – national laboratories, universities and international collaborations – to address fusion from multiple approaches, explains Craig Olson, Scientific Advisor for the Labs' Pulsed Power Sciences center. At the same time, the Labs' own focus has been largely on inertial confinement fusion (ICF) and it's unique "Z-pinch" technology.

Researchers at Sandia's Z-machine are working to develop z-pinch driven x-ray sources to drive ICF targets. Their long-range vision is to achieve high fusion yield on a future machine called X-1. Meanwhile, another group of researchers are working on a first concept to harness repetitive pulses of fusion power to produce an inertial fusion energy power plant that would produce electricity.

"We have to scale up the x-ray output energy of the Z-machine by a factor of 10 to 25 per shot and have a shot once every 10 seconds," says Gary Rochau, manager of Sandia's Modeling and Analysis department.

The scaling up of energy may mean a plant that is two or three times the size of the current Z machine, according to projections. Reaching the frequency of one shot every 10 seconds requires pulsed power development. "Right now we have one shot a day and it is very labor intensive," says Rochau. Working with researchers from several Sandia groups, several universities and private industry, the Sandia team is developing an initial Z-pinch power plant concept.

The basic idea is a wheel of a dozen Z-type machines with a distribution center at the hub to provide recyclable cartridges. The cartridges include recyclable transmission lines and targets that are manufactured at the hub and supplied to each of 12 containment chambers. In the present plan, turbine systems adjacent to each of the containment chambers would generate the actual electricity.

In a cycle, the chambers – at the heart of each of the machines – would be fitted with cartridges from the central distribution hub. Then, z-pinch driven intense x-ray energy

In the past, the main energy needs in space – propulsion and station support – have been provided by chemical and solar methods, respectively. Nuclear power fits into the space picture in cases where larger power demands are called for or propulsion is needed over lengthier times and distances.

compresses and heats the target until it ignites. Heat and energy are produced, melting the cartridge and contents of the chamber. Thick liquid walls made of the molten salt mixture called Flibe (containing fluorine, lithium and beryllium) would be used to capture the energy from the explosion, shield the walls of the chamber and breed new tritium fuel. The turbine plant uses the heat to generate electricity. Finally, the molten material in each chamber is recycled into new cartridges and coolant for the next cycle.

"There are physics issues in developing fusion targets, but basically power generation is an engineering problem," says Rochau. "If this worked, it would be clean, there would be no long-lived radioactive products, and it would greatly reduce proliferation-associated issues." Olson agrees. The process is inherently much safer than fission, he notes. "There is a considerable amount of research and development that needs to be done, but we have not found or heard of any fundamental objections that would prevent this concept from working."

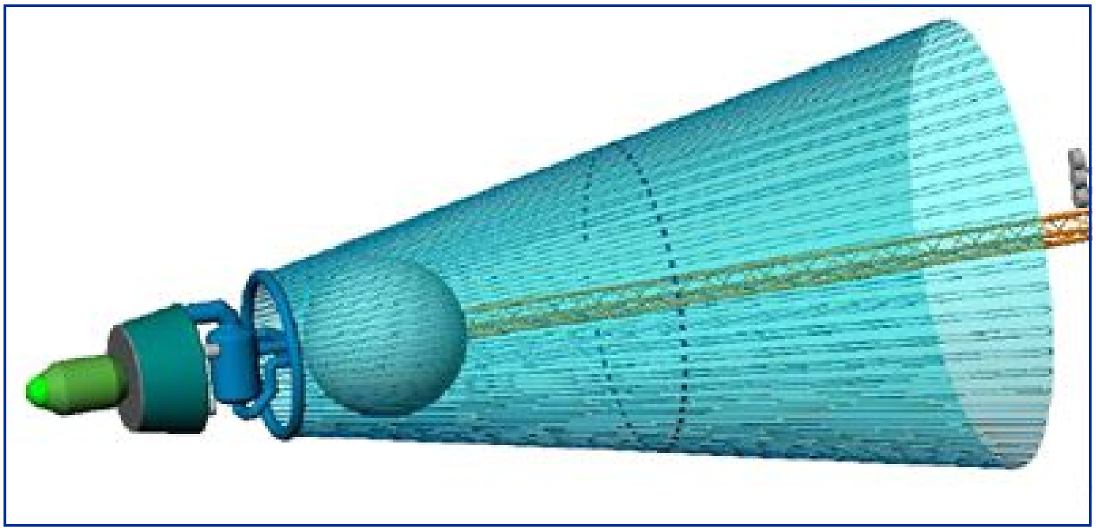
Space Power

Sandia researchers are finding a resurgence of interest in nuclear power and other nuclear applications in space. A small nuclear reactor can provide very large amounts of energy for extended space missions with only a small fraction of the weight of conventional power systems. DOE has been supporting space nuclear research and now the National Aeronautics and Space Administration (NASA) has announced interests in nuclear power for planetary missions and space station support. The Department of Defense (DoD) and several commercial enterprises have also indicated interests in nuclear technology for space applications.

In the past, the main energy needs in space – propulsion and station support – have been provided by chemical and solar methods, respectively. (For extended space missions, where solar may be less effective, RTGs – radioisotope generators – have been used to supply smaller amounts of power.) Nuclear reactor power fits into the space picture in cases where larger power demands are called for, or propulsion is needed over lengthier times and distances. Small, special-purpose reactor systems that provide more power in smaller packages for space could become an important area forSandia, believes Paul Pickard, manager of Sandia's Advanced Nuclear Concepts Department.

Getting a satellite to low earth orbit (LEO) at 400 miles above earth has become relatively routine with chemical rocket technology. However, moving a satellite to geosynchronous earth orbit (GEO) at 22,000 miles above the surface is much more difficult and expensive. One innovative potential application for special purpose reactors currently being discussed is a nuclear powered transport vehicle that could pick up satellites in LEO and move them to GEO. Such a capability could be valuable in a number of ways. It could make orbital corrections, recover damaged satellites and reduce both expense and risk for placement of larger, more capable satellites in the future.

Sandia's history in the design, building, operation and testing of special purpose nuclear reactors can be valuable



An Advanced Electric Propulsion Concept using special purpose reactor technologies

"We look forward to continuing this team approach," says Paul. "We have a combination of nuclear energy and weapons expertise and our integrating systems strengths. We can bring them together on a national level."

in developing power or propulsion units for special cases like the LEO-GEO transport system. NASA-proposed planetary exploration and other deep space activities will also require new propulsion systems. "These are space applications only a nuclear reactor can provide economically. At some point you need to move to a reactor to meet the higher energy demands," Pickard explains. "Current concepts call for small reactors – with dimensions generally less than a meter – to be coupled with electric propulsion systems, called ion thrusters. These nuclear electric propulsion systems are clearly what NASA is thinking about right now to maximize propulsion efficiency."

Sandia has already had some experience with nuclear power in space. "We have worked on safety and thermal aspects of the Space Nuclear Thermal Propulsion Program, the Cassini space probe to Saturn, the Russian Space reactor TOPAZ and other space applications," Paul explains.

Sandia has been involved in the DOE Special Purpose Fission Technology Program (SPFT.) In this program, DOE is looking at how its nuclear technologies can help NASA with manned missions to outer planets. These nuclear-electric propulsion systems can significantly reduce trip times for manned flights to distant targets. Further, these reactors could go up "cold" with their uranium fuel and then start up and head for the outer planets or other targets, minimizing any potential safety problems. For manned flights, shielding can be designed to reduce the radiation levels from the reactor to well below the natural background of space.

NASA's recently announced Nuclear Systems Initiative dedicates one billion dollars and five years to the study of advanced nuclear power for propulsion. "We have already been involved in this technology through the DOE's SPFT program, looking at small systems for propulsion and for terrestrial power. We want to provide technical options for NASA that are achievable in the near term," says Paul. DoD has also recently announced interests in nuclear power in space applications and that they would work with NASA on research into these systems.

"We can hopefully provide support to DOE, NASA and now DoD, plus commercial interests, who are all looking at similar technologies," Paul says. Sandia's charter to provide testing capabilities for the nuclear stockpile has created unique facilities with the Labs' Technical Area V research reactors. These test reactors can be reconfigured for flexible testing and also have applications for space propulsion.

Sandia and Los Alamos National Laboratory have teamed on SPFT and NASA projects on small, special-purpose reactors. "We look forward to continuing this team approach," says Paul. "We have a combination of expertise in nuclear energy technologies and our systems integration strengths. We can bring them together on a national level."

INSIGHTS

By U.S. Senator Pete V. Domenici

"Together, we have much more to accomplish."

In 1997 I presented a speech at Harvard University calling for a new national dialogue on nuclear technologies. I noted that the benefits of nuclear energy can only be realized if we carefully control the proliferation and military issues associated with nuclear technologies.

Progress in nuclear energy since 1997 is nothing short of phenomenal. The industry has performed very well. The Nuclear Regulatory Commission is much more predictable and responsive. There is growing appreciation for the role of nuclear energy in limiting emissions of greenhouse gas emissions.

There's a rebirth of enthusiasm within the industry for new expansion and a growing recognition that nuclear energy is our only expandable source of emission-free baseload power. We aren't alone in this conclusion, Japan and France are well ahead of us.

The Senate has now completed its work on a comprehensive energy bill, which passed with a large margin. I've been very pleased with acceptance of several nuclear energy amendments that I've supported. Extension of the Price-Anderson legislation to cover liabilities associated with all nuclear activities was accepted. A new Office of Spent Nuclear Fuel Research has been created to evaluate the role that advanced fuel cycles, including reprocessing and transmutation, can play in alternative management strategies for spent fuel. The Nuclear Power 2010 initiative was authorized, establishing a goal for new nuclear capacity.

The debate has shown strong support for nuclear energy. Now I'm looking forward to serving on the conference committee to develop the final legislation.

Later this year, the Senate should deal with the veto by the Governor of Nevada of the proposed high-level waste repository at Yucca Mountain. Some Senators may favor parliamentary maneuvers to sustain his veto, but it's too early to predict the final outcome. I'm hopeful we'll proceed with licensing activities at Yucca Mountain.

But independent of that vote, I support research in reprocessing and transmutation. There's an immense role for the national laboratories in this area, along with universities and industry, to study new reprocessing concepts that avoid proliferation concerns and minimize waste generation. Other exciting areas for involvement of the national labs include new reactor designs, fuel cycles, and licensing issues.

A move towards reprocessing would be an immense step in moving nuclear energy towards a sustainable power source. Transmutation – after still more research – could provide sustainable energy for future generations.

Finally, I want to return to my initial comment about the importance of addressing potential security risks caused by nuclear technologies at the same time that we seek to benefit from the opportunities they enable. We must work towards a world where these risks are understood and controlled.

The national labs must provide strong leadership to realize this vision. Their expertise will help determine the fate of nuclear energy. They must develop new approaches for global control of nuclear materials. And they must develop new nonproliferation tools to ensure that nuclear technologies never threaten global stability, but instead remain a vital force in preserving stability.

You know of my interests in these areas from my past work with Sandia and other national laboratories. My interest in these subjects has only increased over these years. Together, we have much more to accomplish.

For Further **Reading....**

Managing the Global Nuclear Materials Threat, January 2000, a Center for Strategic and International Studies panel report, 1800 K Street, NW, Washington, DC, 20006, or http:www.csis.org/

China: Environmental Issues, U.S. Department of Energy, Energy Information Administration (EIA), at http://www.eia.doe.gov/emeu/cabs/chinaenv.html and China Country Analysis, also EIA, at http://www.eia.doe.gov/emeu/cabs/china.html

Fire in the East: the rise of Asian military power and the second nuclear age, Paul J. Bracken, New York: Harper Collins, 1999.

Climate Change 2001, authored by a joint United Nations and World Meteorological Organization Intergovernmental Panel on Climate Change, January 2001.

Global Warming: Focus on the Future, the official website of a traveling exhibition developed by the Environmental Defense Fund as an educational tool, at http://globalwarming.enviroweb.org

The Geopolitics of Energy into the 21st Century, November 2000, a Center for Strategic and International Studies panel report, 1800 K Street, NW, Washington, DC, 20006, or http:www.csis.org/

The Nuclear Fuel Cycle, March 2001, World Nuclear Association, at: http://www.world-nuclear.org/ and Washington Nuclear Corporation site of information and links at : http://www.nuke-energy.com/

America The Powerless, Alan E. Waltar, Cogito Books, Madison, Wisconsin, 1995.

Frontline: Nuclear Reaction, 1997, PBS Video on the question of why Americans fear nuclear power generation. Narrated by Pulitzer Prize winner Richard Rhodes.

"The national labs must provide strong leadership to realize this vision. Their expertise will help determine the fate of nuclear energy. They must develop new approaches for global control of nuclear materials. And they must develop new nonproliferation tools to ensure that nuclear technologies never threaten global stability, but instead remain a vital force in preserving stability. "

US Senator Pete V. Domenici

Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

SAND 2002-1400P

Media Relations & Communications Dept.
MS 0165
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0165

PRSRT STD
U.S. Postage
PAID
Albuquerque, NM
Permit NO. 232