S. HRG. 105–638

ADVANCED NUCLEAR TECHNOLOGIES

HEARING

BEFORE A

SUBCOMMITTEE OF THE

COMMITTEE ON APPROPRIATIONS

UNITED STATES SENATE

ONE HUNDRED FIFTH CONGRESS

FIRST SESSION

SPECIAL HEARING

Printed for the use of the Committee on Appropriations

Available via the World Wide Web: http://www.access.gpo.gov/congress/senate

U.S. GOVERNMENT PRINTING OFFICE

50–167 cc WASHINGTON : 1999

For sale by the U.S. Government Printing Office
Superintendent of Documents, Congressional Sales Office, Washington, DC 20402
ISBN 0–16–057550–8

COMMITTEE ON APPROPRIATIONS

TED STEVENS, Alaska, *Chairman*

THAD COCHRAN, Mississippi
ARLEN SPECTER, Pennsylvania
PETE V. DOMENICI, New Mexico
CHRISTOPHER S. BOND, Missouri
SLADE GORTON, Washington
MITCH McCONNELL, Kentucky
CONRAD BURNS, Montana
RICHARD C. SHELBY, Alabama
JUDD GREGG, New Hampshire
ROBERT F. BENNETT, Utah
BEN NIGHTHORSE CAMPBELL, Colorado
LARRY CRAIG, Idaho
LAUCH FAIRCLOTH, North Carolina
KAY BAILEY HUTCHISON, Texas

ROBERT C. BYRD, West Virginia
DANIEL K. INOUYE, Hawaii
ERNEST F. HOLLINGS, South Carolina
PATRICK J. LEAHY, Vermont
DALE BUMPERS, Arkansas
FRANK R. LAUTENBERG, New Jersey
TOM HARKIN, Iowa
BARBARA A. MIKULSKI, Maryland
HARRY REID, Nevada
HERB KOHL, Wisconsin
PATTY MURRAY, Washington
BYRON DORGAN, North Dakota
BARBARA BOXER, California

STEVEN J. CORTESE, *Staff Director*
LISA SUTHERLAND, *Deputy Staff Director*
JAMES H. ENGLISH, *Minority Staff Director*

SUBCOMMITTEE ON ENERGY AND WATER DEVELOPMENT

PETE V. DOMENICI, New Mexico *Chairman*

THAD COCHRAN, Mississippi
SLADE GORTON, Washington
MITCH McCONNELL, Kentucky
ROBERT F. BENNETT, Utah
CONRAD BURNS, Montana
LARRY CRAIG, Idaho
TED STEVENS, Alaska *(ex officio)*

HARRY REID, Nevada
ROBERT C. BYRD, West Virginia
ERNEST F. HOLLINGS, South Carolina
PATTY MURRAY, Washington
HERB KOHL, Wisconsin
BYRON DORGAN, North Dakota

Staff

ALEX W. FLINT
W. DAVID GWALTNEY
LASHAWNDA LEFTWICH
GREG DAINES *(Minority)*

CONTENTS

ADVANCED NUCLEAR TECHNOLOGIES

TUESDAY, MAY 19, 1998

U.S. SENATE,
SUBCOMMITTEE ON ENERGY AND WATER DEVELOPMENT,
COMMITTEE ON APPROPRIATIONS,
Washington, DC.

The subcommittee met at 10:07 a.m., in room SD–124, Dirksen Senate Office Building, Hon. Pete V. Domenici (chairman) presiding.

Present: Senators Domenici, Craig, Stevens, and Reid.

NONDEPARTMENTAL WITNESSES

STATEMENT OF HANK C. JENKINS-SMITH, PH.D., DIRECTOR, INSTITUTE FOR PUBLIC POLICY, DEPARTMENT OF POLITICAL SCIENCE, UNIVERSITY OF NEW MEXICO

OPENING STATEMENT OF SENATOR PETE DOMENICI

Senator DOMENICI. The subcommittee hearing will please come to order.

I thank all the witnesses for being here, and thank you for attending. We do have quite a few witnesses. It will take us a couple of hours this morning, and I think we may go uninterrupted and get the hearing handled in a somewhat appropriate manner.

Good morning, Senator Reid. Thank you for joining us.

Senator REID. Good morning, Mr. Chairman.

Senator DOMENICI. I welcome you as part of this subcommittee. We work together on several things; I hope we can on this issue also.

This morning, the Energy and Water Development Subcommittee will focus on the subject of advanced nuclear technologies; in particular, we are interested in two aspects: The renewal of nuclear power in this country and furthering technologies for the future use of nuclear power.

Electricity from nuclear power plays an essential part of the daily aspects of life that we take for granted in this country. To most of us, electricity is invisible. We do not appreciate that behind that socket in the wall is a huge complex of transmission lines, distribution stations and powerplants. These powerplants can be coal, oil, natural gas, or nuclear.

The renewable technologies so often referred to by the administration cannot replace the power produced by these powerplants now or any time in the imaginable future. Even if the President will not say it because it is not necessarily politically correct, in order to maintain the quality of life for Americans, nuclear power is a necessity for this country. It is not an option.

We need to stop hedging on this issue and acknowledge that 20 percent of the electrically generated power in this country comes from nuclear powerplants, and it is essential to our continued prosperity. Nuclear power is the only source of electrical generation for which we can and do isolate all the waste products and prevent the pollution of air and water.

Coal, oil, and natural gas powerplants cannot make this statement. Nuclear energy generates clean electricity. This environmental value of nuclear power is all too often easily overlooked. We are only beginning to truly appreciate the long-term environmental effects of pollution from coal, oil, and natural gas powerplants. I am uncertain about the existence or extent of global climate change; however, given the uncertainties, we would be prudent to limit the use of energy technologies that release pollutants that accumulate in the atmosphere.

But make no mistake about it, one fact, no matter what pollution goals we set as a Nation, we cannot reach them without the continuation of nuclear power as a major part of our energy production, as well as the world's. The challenge we face is to think anew about nuclear power, and to recognize its environmental values.

The rest of the world has already done so. Even though we were the originators of it, we led in all of its technological aspects for decades on end. The rest of the world is, as I indicated, already have made decisions that they need nuclear power in their future.

Other countries are already committed to nuclear power, because without it they face an uncertain future of increase energy demands and production using fossil fuels, with significant pollution of their air and their water. Nuclear power supplies over 75 percent of the domestic electricity in France, over 60 percent in Belgium, over 30 percent in Germany, and over 27 percent in Japan. And China is planning a significant expansion of nuclear power. These are all countries which do not enjoy the luxury that the United States does in terms of multiple energy supplies.

Further, countries such as France and Japan have not gotten themselves into a quagmire over the disposition of nuclear waste. They have an effective reprocessing program which ensures the continuing of nuclear power as a vital source of energy to their people. The case for nuclear power is a compelling one not only for its environmental value but also for its economic nonproliferation and energy security perspectives that support our national and international goals.

With that, I now yield to Senator Reid, who has an opening statement.

STATEMENT OF SENATOR HARRY REID

Senator REID. Thank you very much, Mr. Chairman. I know this might be surprising to some, but I am really pleased about this hearing and I look forward to the testimony of our witnesses. I think you have set an appropriate tone with this subcommittee in not doing the thing we have done many years past—just accept what has gone on. You are looking at the future, and I think that is important. I think this subcommittee is moving in the right direction.

Mr. Chairman, you have spoken a number of times publicly, questioning the wisdom of the decisions that we made 30-odd years ago. And I think it is important that we analyze—and let me state for the record today that I think it is clear—and I am speaking for myself today—that nuclear energy finds itself in an unusual and, some say, an uncomfortable position. With deregulation going forward and nuclear power being so expensive, some say that nuclear power is on its way out.

The chairman has outlined clearly why we have to give those that are advocated of nuclear power every opportunity to see if there is any way that nuclear power can fit into the new paradigm that is facing this country. I think that the disposition of nuclear waste, a substance that remains highly dangerous for more than human history can be accounted, was not understood when the industry began more than 40 years ago, and it is not understood today. Because of that, there is not a so-called exit strategy if we should conclude that this utility will not be cost effective. Or if it is cost effective, what do we do with nuclear waste?

If nuclear energy is ever to have an assured future, its waste must be managed in an acceptable way. I am not here, though, Mr. Chairman, today to talk only about nuclear waste. I think there has been a fine group of witnesses assembled. I think this will pave the way for more work for us in the future. My record is clear about nuclear waste, and I am not going to dwell on that.

You called this meeting for important reasons, and I am not going to diminish the reasons that you have called this. It was not for purposes of looking at nuclear waste only.

Let me welcome the witnesses, all of whom have made significant contributions in their fields. I will be interested to hear about how we might collaborate to resolve the most vexing problems of this complex industry.

Senator DOMENICI. Thank you very much, Senator.

Now, we will start with the first panel. I think they have you listed there as Dr. Smith. Actually it is Hank Jenkins-Smith. If you come back, we will correct it.

Dr. JENKINS-SMITH. Thank you.

Senator DOMENICI. Dr. Jenkins-Smith is from the Institute for Public Policy, Department of Political Science at the University of New Mexico. It is a very formidable group. It assesses public opinion from various angles and various approaches. Dr. Jenkins-Smith is the director of that.

Then we have Mr. Joe Colvin, Jr., the president and chief executive officer of the Nuclear Energy Institute. Thank you so much for joining us.

And Mr. Corbin A. McNeill, Jr., chairman and chief executive officer of PECO Energy Co. And we are delighted to have you here. You are in the energy business and you have a novel approach to what kind of energy production your company would like to own.

And then we have Dr. Richard Wilson, Mallinckrodt professor of physics at Harvard. And I want to thank you for flying all the way home from England to be here in time for this hearing. I very much appreciate it.

Let us start with Dr. Jenkins-Smith, and move across the table from my left to my right.

STATEMENT OF HANK JENKINS-SMITH

Dr. JENKINS-SMITH. Thank you, Mr. Chairman. And thank you, Senator Reid. I appreciate the opportunity to speak before this committee.

I will be relying today on the expertise of many of my colleagues at the Institute for Public Policy, several of whom are here today—Barry Harrin and Harold Silva—here behind me. I am also going to be drawing on the views of many thousands of American citizens who have participated in focus groups or surveys with us over the last decade, really trying to plumb the issue of nuclear policy and how Americans think about that issue, to try to get past some of the surface conundrums that plaque us, to see what the structure of public opinion looks like on this question.

And I will start with my punch line, which is from the standpoint of American attitudes on nuclear policy, where we need to go now is away from piecemeal nuclear policy to an integrated, open assessment of what our nuclear technology options are for the future. In the past, we have chopped nuclear technology issues into pieces in a way that does enormous damage to how American citizens and our elected representatives can debate these sorts of issues.

When we think the segregation of nuclear energy from the issue of nuclear demilitarization to the issue of nuclear waste transport or storage or disposal, it makes it almost incomprehensible to talk about these policies in a sensible fashion when we cannot put the pieces together in a fashion that allows people to assess benefits, costs, relative risk options. We just cannot under the current system.

Now, much of the problem has to be laid at the feet of an historical legacy that can readily be perceived as high handed, of ignoring the risks to the public, and imposing substantial damage in the interest of national security and other concerns. It has also been the case that historically we have not had much in the way of open, integrated debates about nuclear issues. But I think we are now at a position to put that behind us and look forward. And this hearing is a fine example of how that might take place.

The problem really is this issue of fragmentation. Fragmentation leads us to do a number of things that I think are damaging to the national debate. First off, it leads us to separate benefits from costs. National security benefits, energy production, reduction in CO_2 emissions tend not to get integrated into the discussion, for example, of nuclear waste disposal in the current fragmented policy debate. Also, due to our regulatory processes, we tend not to make comparisons. We do not compare current options against continued temporary disposal. Or we do not compare the options of alternative modes of storage or disposal. We tend to get myopic and look at one option.

It is funny what happens when you do that. Essentially, it forces you into a mode of thinking about absolute risk—the absolute risk of a single repository. We see that with the waste isolation pilot plant, we see that with the Yucca Mountain Repository—in which our Federal program officials are charged with coming up with a number representing the risk associated with a single repository and all of the complicated science associated with that. There is no comparison that takes place in that kind of a setting except against benchmarks set by regulatory policy.

It is very difficult in the public mind to come to reasoned conclusions when you are only thinking about one option. It is a very tricky problem.

It leads to a risk myopia. Look at the public debate on this question. All of the discussion associated particularly with nuclear waste or nuclear materials transport focuses in on waste or on risk. What is the risk? And look at the strangulated language we get into when we talk about this stuff. We talk about risk of 10 to the minus 6, stretched over 10,000 years. These are not reasonable terms for engaging in an open debate in a society like this.

Well, let me just say that this process of fragmentation, risk myopia, failure to engage in comparisons, is acutely damaging to the quality of the public debate in the arena of nuclear waste disposal, nuclear energy, and other issues. As you know, when we separate out these issues, we make nuclear waste acutely exposed to criticism. Essentially the debate is all about risk.

And when you make the debate about risk you, without the integration of benefits and without the benefit of comparisons, we put people in the position essentially of acknowledging that any policy will impose risk on somebody, and that imposition will be unacceptable. Because, again, we cannot integrate it. There is no context for that type of a decision.

This leads to delay, escalation of costs, compounding distrust, unnecessary political antagonism and a number of essentially poisoned fruits of the fragmented policies. It has also led to interesting excursions into stakeholder democracy, which have been attempts to get past blockage by giving special consideration to named stakeholders, through such things as site-specific advisory boards, working groups, stakeholder forums, and things like that, which are sometimes quite valuable mechanisms for dealing with policy issues.

On the other hand, there are some problems with these, in the sense that they can collide with our established institutions of representative democracy. I have had impassioned discussions with locally elected officials who believe that it is simply wrong for representatives of appointed stakeholder groups to represent their constituencies when they are not actually elected. They do not have to go home and be held accountable as their elected officials do.

It also leads to problems with commitment. I believe that when we create these stakeholder groups, in order to entice people to participate, we have to give them some real teeth, something that they gain from this very painful form of participation, which, in fact, leads them to believe that they have made authoritative decisions, which can be overridden by this body and others in a representative republic like the United States.

It is quite difficult to maintain these experiments in stakeholder democracy in the face of the larger political landscape in which we operate. The downside is that we can generate more distrust through creating these sorts of experiments than we can alleviate.

Now, where does this leave us? I think that it is time to look very closely at what the American public do see structurally about nuclear policy in the future. The American public sees substantial benefits in nuclear technologies. Forty-three percent of the public, for example, in a recent national survey said that they wanted to retain existing nuclear energy generating capacity, and another 30 percent said they wanted to increase it. That leaves 27 percent that said they wanted to decrease it or eliminate nuclear energy generating capacity.

Large majorities, 80 percent in the United States, no matter how you put the question, say they would like to at least consider reprocessing as an option for waste management issues. And substantial majorities, while preferring to continue to reduce our nuclear arsenals, do not want to go to zero. They perceive substantial national security benefits from maintaining a nuclear arsenal.

And the point is the U.S. public sees large benefits from nuclear technologies; it does not want to walk away. So where do we go?

PREPARED STATEMENT

And that is where we get back to this integrated debate and the importance of this debate for shaping future policy options. I think all of this has to be on the table for future discussion. And I think that is why this subcommittee is so important and its mission is so important.

Thank you very much, Mr. Chairman.

[The statement follows:]

PREPARED STATEMENT OF HANK C. JENKINS-SMITH

Thank you for inviting me to address this Committee. For my testimony this morning I will be relying on the expertise of my colleagues from the University of New Mexico, two of whom are with me today—Kerry Herron and Carol Silva. I will also be drawing on the insights, concerns and preferences of many thousands of American citizens who have participated in our focus groups and surveys on nuclear issues over the past decade.

I will focus my remarks on the nuclear materials problem facing the United States. The nuclear problem has several critical dimensions. These include:

Nuclear energy—where we are faced with an aging fleet of reactors which currently produce over 20 percent of our domestic electricity. At present, there are no apparent replacements for these reactors in sight. Should conventional fuels be used to fill the energy gap, U.S. dependency on foreign fuel supplies will grow. And CO_2 emissions from U.S. energy consumption are likely to rise significantly, playing havoc with U.S. efforts to reduce greenhouse gas emissions.

Nuclear weapons demilitarization—which has resulted in the stockpiling of plutonium both at home and abroad, poses critical long-term security issues. The handling of the dismantled plutonium pits—and the determination of whether they are to be treated as a waste or a resource—is a pressing matter yet to be resolved.

Nuclear waste disposal—in which national efforts to develop interim and permanent repositories have met with passionate opposition, and about which members of the public express deep concerns about risks to their families and local economies. Conflict over waste disposal programs has led to enormous costs, program delays, and unnecessary political antagonism.

Nuclear energy, demilitarization, and waste disposal are intertwined problems, and I believe that reaching appropriate technical and policy solutions will depend on addressing them openly as an integrated national policy problem.

On many fronts, nuclear materials policy in the U.S. appears to be hamstrung. Government and industry officials charged with developing and implementing U.S. policies are frustrated. From the perspective of many of these officials, a vocal opposition to all things nuclear has stymied efforts to site facilities or to transport, store and dispose of nuclear materials in a safe, efficient and timely fashion. Many opponents of current policies are equally frustrated, arguing that current policies are merely stop-gap solutions, and that the risks of these policies are too large and are unfairly imposed.

What are the sources of these frustrations? In part, the problem is historical in nature. Critics can point to a legacy of high-handed policies, a failure to engage in an open and meaningful national dialogue on the risks and benefits of nuclear technologies, and to what in 20–20 hindsight appears to be a callused disregard for public safety. But difficult steps have already been taken to move beyond the historical record and to deal with problems we face today. Our research leads me to conclude that most Americans are ready to look ahead, rather than behind, on these issues.

Other sources of policy frustration remain to be faced, however. The most important is the fragmentation of nuclear policy in the United States. For reasons that may have been important at the time, we have for all practical purposes segmented nuclear policy into the areas of nuclear energy, transportation, waste disposal, and nuclear weapons demilitarization. This kind of fragmentation has separated consideration of energy production from nuclear waste disposal, and has isolated nuclear weapons demilitarization from both. Fragmentation of nuclear policy seriously hampers meaningful national dialogue on the benefits and costs of any of these critical policy areas. Nuclear critics have long complained that U.S. nuclear energy policy ignored the waste issue—and they were right. We considered the benefits of nuclear energy without adequately addressing the costs. Now the tables are turned: we are considering the waste issue in absence of the energy and demilitarization dimensions of the problem. In any open dialogue on nuclear waste, we now face what are widely perceived to be the costs of managing radioactive waste detached from any identifiable benefits. I think it is time to take the nuclear critics at their word, and reintegrate the cost and benefit sides in an open nuclear policy debate.

One of the key implications of the fragmentation of nuclear policy is that it fosters a "risk myopia". By segregating the issue of nuclear waste we have created a policy context in which the central and salient issue is risk. To see this, you only need look at the debates over the proposed waste repositories at the WIPP and at Yucca Mountain. The debate is fixated on risk, with proponents arguing that risks are small and manageable and opponents arguing that risks are large and unimaginable. "Risk" permeates the public debate. We make matters even worse when the discussion of risk is not comparative. Rather than compare the risks posed by alternative disposal strategies, our regulatory process leads us to focus on the absolute risk posed by a given facility. In the process we talk in strange languages, about risks of "ten-to-the-minus-six" spread over ten-thousand year periods. But by talking about absolute risk, without comparisons to the risks of other options, and without reference to associated national benefits, we put ourselves in a situation where any risk can readily be seen as an unacceptable imposition of harm on somebody. To put it simply, when risk is without context, any risk can appear to be unacceptable. We have created a policy debate which, in the eyes of the public, is about the imposition of risk without context. Should we be surprised when those who might bear the risk become enraged and ask "why me?"

The isolation of nuclear waste issues has made efforts to site nuclear waste facilities and routes easy targets for opponents. Our political system offers many opportunities to block policy initiatives, and these have been employed with great success. Because nuclear waste management policies are so easily blocked, and because of the urgency of moving forward in waste management efforts, we have witnessed the proliferation of very creative efforts to gain "stakeholder" acceptance of radioactive waste clean-up and disposal programs. Included are such entities as Site Specific Advisory Boards (SSAB's), stakeholder forums, various working groups, and many others. These efforts have in fact constituted an experiment in how citizens are to be represented in American politics. Let's call it an experiment in "stakeholder democracy". The nature of the experiment is to have direct—and sometimes authoritative—involvement by those deemed "stakeholders" in the development and implementation of the affected program. The implication is that representative democracy, with the traditional institutions of elections at federal, state and local levels, has proved unsuited to the task. While some of these experiments in stakeholder democracy have been notable successes, I do not believe resorting to stakeholder democracy is a prudent way to deal with the problems created by our fragmented nuclear policies.

First, stakeholder democracy can—and in some cases does—collide with representative politics. Elected officials, who are accountable to their voters, may object to having their constituents "represented" by an un-elected stakeholder representative. From a political standpoint, such a step may undermine the elected official, and reduce the incentive to raise urgent local issues in political election campaigns. If we do that, we undermine the whole point of electoral political processes.

Second, stakeholder democracy can create serious problems of commitment. In the creation of stakeholder groups, gaining the necessary commitment of time and energy from participants usually requires offering them meaningful policy influence. Thus, when stakeholder groups make decisions, they may rightly believe that they have acted with some authority. But when national policies change—as they do when the public elects new leaders—new national priorities may override the stakeholder decisions. When that happens, those involved are likely to be even less trusting of the government. In essence, attempts to gain trust in the short run may actually erode it over the longer haul.

Third, the implications of nuclear policy are so large and far-reaching that all Americans are stakeholders. Resolution of the nuclear problem will require that we bring all Americans, through their elected representatives, into the discussion.

Experiments in stakeholder democracy have value in many public issues, but they will not resolve the problems created by the policy fragmentation and risk myopia that plague nuclear policy in the United States.

Where do we go from here? Part of the answer comes from listening to Americans' views on nuclear technologies and materials in a broader context. Generally speaking, most Americans do not want to walk away from our nuclear options. Let me illustrate this by three findings from surveys conducted by the University of New Mexico over the past several years.

First, Americans do not want to abandon nuclear energy. When a nationwide sample of Americans were asked whether the current utilization of nuclear energy in the United States should be decreased, kept the same, or increased, about 43 percent wanted to keep it the same and around 30 percent wanted to increase it. Approximately 27 percent wanted to decrease reliance on nuclear energy.

Second, most Americans would like the government to investigate prospects for reusing spent nuclear fuel rods, even when apprised of the possible proliferation risks associated with reprocessing. In fact, whether it is called "reusing" or "recycling" spent nuclear fuel, about 4 out of 5 respondents to a random sample of Americans were in favor of making use of spent fuel to produce more energy.

Third, Americans are increasingly in favor of investing now to maintain the infrastructure for possible future research and development in the area of nuclear weapons. Americans believe that, in today's world, there is an important place for our own nuclear arsenal. Americans would like to continue to reduce the number of nuclear weapons we and others hold, but four out of five of our respondents nationwide do not want to reduce our nuclear arsenal to zero.

The point behind these examples is that Americans do see substantial benefits in the use of nuclear technologies, whether they be for energy or national security. But these benefits are not addressed in our fragmented nuclear policy discussion concerning nuclear waste management. When it comes to waste, regardless of who asks, most Americans are opposed to having nuclear waste shipped through their communities or disposed of in facilities in their states. Why is that?

A lot of our research has been focused on why people react as they do to the prospect of nuclear waste transport and storage. In a nutshell, when faced with a controversial problem like nuclear waste, Americans want to hear good and robust reasons for a policy. They want to see that the solution offered is a long term one. And they want to be able to identify tangible national benefits from the policy.

How well does the prospect of conventional deep geologic disposal stand up? Based on repeated tests in our focus groups, not very well. First, because we have disengaged nuclear waste disposal from energy generation or national security, we have isolated the perceived threats, the negatives, and the nightmares from any associated local or national benefits. Second, participants in our focus group discussions have generally concluded that, if the repository can't accommodate all of the current and expected waste, then it is merely a temporary stop-gap solution. Other repositories will be needed. Most are reluctant to accept a deep-geologic repository option unless it holds promise of resolving the long-term problems posed by managing radioactive wastes. Third, our focus group participants are appalled by the prospect that we'll have to make a wrenching political decision about the location of a first repository, only to be faced with having to do it all over again sometime down the road. In sum, the deep geologic repository approach to nuclear waste management is a hard sell with the American public.

How can nuclear materials policy respond to public concerns? First and foremost, gaining acceptance of nuclear materials management strategies will require reintegrating the way we address nuclear issues. The future of nuclear energy in the United States—with the associated implications for our economy, security and environment—must be put on the table along with nuclear weapons demilitarization and nuclear waste management. Only in the context of the full array of implications do the costs of nuclear waste disposal make sense. Such a step may seem risky to those fearful that Americans may reject nuclear power as the price for tolerating nuclear waste disposal. Our surveys show that to be very unlikely. Recall that most Americans would prefer to retain or increase our reliance on nuclear energy. And, when asked whether their support for a deep geologic disposal facility would change if production of nuclear energy ceased in the United States, almost as many said abandoning nuclear energy would decrease support for a repository as said it would increase support. Furthermore, in an open and integrated debate the implications of nuclear energy for greenhouse gas emissions would, in all probability, receive substantial attention. Such attention is badly needed: in a recent nationwide survey, 43 percent of our respondents thought the generation of nuclear energy was a cause of greenhouse gas emissions. A more open and integrated debate would be very likely to change that, which in turn would be likely to increase support for retaining the nuclear energy option. More generally, a full and open debate on nuclear policy would be unlikely to result in the rejection of nuclear energy. All of us can afford to take the high road on this one.

Opening up the nuclear policy debate would permit changes in current policy designs that have the potential to substantially increase public support for nuclear waste management programs. We have explored how support for a nuclear waste repository would change if the policy were modified in a variety of ways. In one experiment we asked how support for a disposal facility would change if, in addition to storing and monitoring the waste, the facility would be used as a laboratory to study the material to increase safety. Under this option, support increases dramatically, even among those who strongly oppose the facility in the first place. More broadly, "permanent storage" in a monitored facility evokes less fear and opposition than does the idea of "disposal". Benefits are evident as well as risks. In short, Americans prefer to generate and retain options for dealing with nuclear waste in the future, rather than foreclosing them now. Thus even small steps to increase the benefits side of the equation can generate significant increases in support for nuclear waste policies.

Let me conclude by pointing to some very hopeful signs for the future of nuclear policy in the United States. One is that the design for the proposed Yucca Mountain high level nuclear waste repository now includes the capability to remain open for up to 300 years, permitting future generations to pursue options other than entombment. Another is that, after 20 years of often acrimonious debate in New Mexico, a near majority or respondents in a recent University of New Mexico survey said they would vote to open WIPP if a referendum on the issue were held today. Among those who ventured a preference, 52 percent were in favor of opening the facility. My hope is that, with an open and full debate on nuclear policy, we can build on these hopeful signs.

I would be happy to answer any questions you may have.

STATEMENT OF JOE F. COLVIN, PRESIDENT AND CHIEF EXECUTIVE OFFICER, NUCLEAR ENERGY INSTITUTE

Senator DOMENICI. Thank you very much. And we will have some questions later.

Mr. Colvin.

Mr. COLVIN. Mr. Chairman, Mr. Reid, thank you very much for the opportunity to talk about these important issues.

I think it is important, as we look to the needs of our Nation, moving into the 21st century, and that of the world, to look at the strategic elements of these issues and how they come together to ensure that we can address the concerns related to energy demand, energy security and ensuring that we have needs that meet the environmental issues that we are concerned about.

So, as we move forward, we need to take advantage of the lessons learned that we have had in the past, and ensure that we do not focus on the short term but rather on the strategic issues. And as a result, there is a tremendous benefit and importance of the policy debate on these issues moving forward. And I would say, Mr. Chairman, your leadership and that of the committee in this activity is particularly important, and encouraging certainly for our industry.

I think as we see these issues, we see a convergence of the policy issues on nuclear energy coming together from many different forums. And just last week, in San Francisco, Mr. Chairman, we issued a strategic direction for the 21st century, which is a shared vision that the industry has on what we need to do to move forward to ensure that the benefits of this technology continue to inure to our Nation.

You have a copy of that in front of you, and I might just point out the scope and dimension of that. The issues, in fact, we have pointed out—which are just inside the front cover—really are talking about eight compass points which tend to set that direction. I will just mention those briefly.

First, an actual energy policy that ensures diversity and reliability of energy supply. Second, excellence in safe and reliable nuclear power and powerplant operations worldwide. Third, an effective safety-focused regulatory framework. Fourth, an integrated used fuel management system, and effective low-level waste disposal system. Fifth, the recognition of the intrinsic economic value of emission-free nuclear energy. Sixth, business conditions and policies that position nuclear plants for a competitive electricity market. Seventh, increased recognition of the strong public policymakers' support for nuclear energy and, last, really the next generation of nuclear powerplants.

I would like to talk about two of those issues, the first issue being really how we take advantage of the tremendous value and the intrinsic value of emission-free electricity in the United States. And in that arena, I really want to talk about clean air—nuclear's role in meeting not only clean air requirements, but those of the carbon dioxide debate that is going on in the global climate change arena.

The map that is up here really illustrates nuclear's tremendous contribution in the Clean Air Act compliance base. And just on that map, the nuclear powerplants are shown in pink. The blue and yellow sections represent those areas in the United States that do not meet ozone attainment under the Clean Air Act, or will be out of attainment. As you can see, those are also areas that have dense population and many other activities that generate pollution.

Those particular regions of the country are really required to take actions to reduce their emission levels. And those actions may entail and have entailed reducing industrial expansion or even in adding increased emission controls for automobiles. Nuclear energy's role in those areas is particularly important as we move forward and to how we meet clean air requirements.

Nuclear energy in the United States has—really, the powerplants, since 1973—have added 40 percent to our Nation's energy supply, and have done that without any pollutants to the environment. CO_2 emissions have been reduced by over 147 million metric tons, sulfur dioxide by about 80 million metric tons, and nitrous oxides by about a corresponding 30 million metric tons from this energy source. And it is ironic that with this tremendous contribution our administration has not recognized nuclear's important role in any of its discussions on clean air attainment or in this context of global climate change.

Senator DOMENICI. Mr. Colvin, those numbers you just cited are quantities that would have been emitted and contributed to polluted air if the nuclear powerplants that you are describing were coal burning; is that correct?

Mr. COLVIN. Yes, sir; those are the emissions that were avoided through the use of nonemitting technologies. In this particular case, that is nuclear, yes, sir.

Senator DOMENICI. That would be interesting for somebody to see how far off attainment we would be or where those pollutants would get us.

Mr. COLVIN. Yes, sir; in fact, we are doing some analyses. We have done some emission avoidance studies for the United States and for the world. And we are also doing some studies related to ozone nonattainment that follows up on this particular graph. We would be happy to share that with the subcommittee, sir.

Senator DOMENICI. We would be happy to receive that.

Mr. COLVIN. The second issue I would like to talk about, Mr. Chairman, is the issue of public safety. Dr. Jenkins-Smith has raised the issue, and I support the comments that he has made. I would say that in our view and in our analysis, there is tremendously strong public support for nuclear energy. It is ironic when you look at this issue—and this is probably the most disturbing fiction about our industry, and it is a misconception that has gone unchallenged for a long time, and in particular I would like to just point out a couple of facts.

We have done, and continue over the years to do, a number of polls. And two-thirds of the public over these number of years personally support nuclear energy in the United States. As this chart shows, a recent national survey conducted earlier this year determined that 76 percent of the public agreed we should keep our existing plants, 87 percent support renewing the operating licenses of these plants that meet continued safety standards; and, in fact, 73 percent agreed that we should build new nuclear plants in the future.

Interestingly, on this particular poll, when asked what sources of energy would be most used in the United States 15 years in the future, they picked nuclear over solar. I think that is clear that these polls certainly burst the myth of the public. But the reality is that there is a perception gap. And I would say, Mr. Chairman, that perception gap exists within the public and exists within the policy infrastructure in our country.

In this case, in this particular poll, you can see the dramatic difference. When you ask people what they believe, they believe—in this case, 65 percent—we should support nuclear energy. But when you asked them what their neighbors think, they think that number drops to 21 percent.

There are a couple of basic reasons for that. And the first reason, sir, is that the issue is somewhat controversial. The second issue is they really are not educated well on the issue. And they would like more information to be able to support that and debate that.

PREPARED STATEMENT

This perception gap must be closed. And I think this committee and the leadership that this committee is exercising in this area, along with the efforts of the industry, Mr. Chairman, would make a great effort in moving this perception gap closer to the reality that we see in the public.

Thank you, sir.

Senator DOMENICI. Thank you very much.

[The statement follows:]

PREPARED STATEMENT OF JOE F. COLVIN

Mr. Chairman and members of the subcommittee, my name is Joe F. Colvin. I am pleased to be here this morning on behalf of the Nuclear Energy Institute, where I am president and chief executive officer. The Institute is a policy organization for more than 275 companies that operate U.S. nuclear power plants, along with suppliers, engineering and design firms, universities, laboratories, radiopharmaceutical companies, consulting firms, law firms and labor unions.

First, let me thank you, Mr. Chairman, Ranking Member Reid and other distinguished members of this subcommittee for inviting me here to speak about the strategic direction for nuclear energy for the coming years.

As we draw near the 21st Century, the United States and the world face a series of interrelated challenges concerning energy, the environment and population growth. But as we know, long-range strategic issues like these can be easily deferred, and important energy lessons learned in past decades can be easily forgotten. We cannot allow that to happen.

Inaction is no longer an option. The days of dormant energy and environmental policy are a thing of the past. For the coming century, the energy industry must adapt to a new set of pressures and concerns. And policymakers will have to adopt a new course of action to successfully forge solutions on many related issues, such as a competitive energy market, new air quality controls, and a growing need to reach global populations without electricity.

A BETTER DIRECTION

These key policy issues are converging in a way that is positive for society as a whole—and for our industry. Just last week, the industry unveiled a blueprint for the future at the industry's annual meeting in San Francisco. This guiding strategy is called "Nuclear Energy: 2000 and Beyond, A Strategic Direction for Nuclear Energy in the 21st Century."

The strategic direction is an important document for industry, for policymakers and for electricity consumers. It is designed to inform and to guide a thoughtful dialogue about deriving the greatest benefits from nuclear energy. This document was provided to the subcommittee as part of my testimony, and is also in front of you.

This shared vision for a bright future requires resolution on key policy issues that this subcommittee can shape. The document has eight sections, each representing a specific policy area in which we need to pursue a course of action.

Please turn to the opening page as I describe the eight essential compass points to a better future for nuclear energy:

1. A national energy policy that ensures diversity and reliability of energy supply.
2. Excellence in safe and reliable nuclear power plant operations worldwide.
3. An effective safety-focused regulatory framework.
4. An integrated used fuel management system and effective low-level waste disposal system.
5. Recognition of the intrinsic economic value of emission-free nuclear energy.
6. Business conditions and policies that position nuclear plants for a competitive electricity industry.
7. Increased recognition of the strong public and policymaker support for nuclear energy, and
8. The next generation of U.S. nuclear power plants.

Today, I would like to emphasize two of those key points. The first point is the need to recognize how absolutely essential the emission-free value of nuclear energy is to achieving domestic and international environmental controls on clean air.

Today, nuclear energy provides the largest source of America's electricity without compromising the quality of our air.

In the last 25 years, nuclear power plants have met 40 percent of the new demand for U.S. electricity. At the same time, nuclear energy has prevented emissions of 80 million tons of sulfur dioxide and more than 30 million tons of nitrogen oxide that would have been produced by other energy sources.

Yet the Clinton Administration fails to credit the nuclear energy industry for its clean air benefits. Nuclear energy is excluded in the Administration's industry restructuring principals regarding climate change, and in its discussion of the methods the U.S. will use to reduce emissions—whether to meet new Clean Air Act restrictions or worldwide carbon emissions reductions.

Let me illustrate nuclear energy's important contribution to Clean Air Act compliance. This map to my (right) illustrates the critical role of nuclear power plants on a local level. The green dots represent nuclear plants. The blue and yellow sections represent areas that do not meet ozone attainment under the Clean Air Act or that will be out of attainment when a new standard is implemented—areas that also have a dense population and many activities that generate pollution.

These areas are already required to take actions to reduce their emission levels, such as restricting industrial expansion or increasing emission controls for cars. The job becomes much more difficult if the nuclear energy they depend on is not available.

The estimated cost for clean air compliance at the turn of the century is more than $11 billion. Moreover, these costs do not account for controls on carbon dioxide emissions proposed in the international accords from the Kyoto summit.

As these financial commitments to emissions compliance grow, it has never been more apparent that the United States must maintain its existing nuclear generating capacity, renew plant operating licenses and build advanced nuclear plants to meet new electricity demand.

Congress, however, must do more than simply preserve nuclear energy for its emission-free benefits. There must be broader recognition among your colleagues in the Senate and House, as well as the administration, of nuclear energy's environmental achievements.

PUBLIC ACCEPTANCE

That brings me to my second point. There is established strong public support for nuclear energy.

The idea that the public somehow finds nuclear energy unfavorable is perhaps the most disturbing fiction about our industry. It's a misconception that has gone unchallenged for too long and that is particularly distressing when you consider the following facts.

Industry surveys of opinion leaders and the public consistently show that two-thirds of those polled personally support nuclear energy. For example, a national survey earlier this year determined that 76 percent agreed that we should keep our existing nuclear energy plants. Eighty-seven percent support renewing the operating licenses of nuclear energy plants that meet federal safety standards. In that same poll, responders ranked nuclear energy first among electricity sources most likely to be used in the United States in 15 years—beating out solar energy.

The findings from these polls certainly burst the myth that nuclear isn't publicly supported. Yet when asked about the public perception of nuclear energy, policy-makers think that their constituents aren't supportive.

This perception gap must be closed. I encourage the members of this subcommittee to recognize that strong public support exists for nuclear energy, and to exercise the strong leadership necessary to support key nuclear energy initiatives.

The federal government should clearly and openly articulate a critical role for nuclear power plants in the nation's energy and environmental agenda. The industry is prepared to work with the federal government in a leadership role for nuclear energy.

As we leave the 20th Century, it becomes clear that the premise underpinning the U.S. government's energy policy is that we have enough electricity to see us through the next decade or so. This status quo position, however, does not adequately prepare us for the challenges of maintaining our energy diversity, economic security and environmental compliance that lay ahead. Recognizing nuclear energy's valuable contribution in these policy areas is absolutely key as we continue to meet important environmental goals and move toward a competitive electricity market.

Foremost for the remainder of this session, Congress and the Administration must work together when it comes to nuclear waste disposal. There is legislation pending to remedy that stalemate. The Nuclear Waste Policy Act would speed the disposal of used nuclear fuel and defense high-level waste by providing above ground, temporary storage until a long-term, underground repository is ready to accept used fuel. I urge this subcommittee to join the majority of Congress in supporting this legislation. And to do all you can to move this bill to the Senate floor now. Enacting this legislation is a critical step to ensure that nuclear power remains a viable and competitive energy source.

Here to provide a more personal and in-depth view of nuclear energy's promise in a restructured electric industry is Corbin McNeill, whom I have the pleasure of introducing. Mr. McNeill is chairman and chief executive officer of PECO Energy Company. No doubt you all have read about PECO's recent decision to join British Energy in acquiring nuclear power plants around the country. I'll let him tell you why that's a strong position for his and other utilities as we enter a competitive marketplace.

STATEMENT OF CORBIN A. McNEILL, JR., CHAIRMAN AND CHIEF EXECUTIVE OFFICER, PECO ENERGY CO.

Senator DOMENICI. Mr. McNeill.

Mr. MCNEILL. Senator Domenici, Senator Reid, my name is Corbin McNeill. I am chairman and chief executive officer of PECO Energy Co., an investor-owned utility with headquarters in Philadelphia. And I thank you for the opportunity to appear before you today to discuss the very important subject of nuclear energy. PECO Energy operates two nuclear powerplants in Pennsylvania, and we are part owners of a third powerplant in New Jersey.

In the interest of time, I will summarize my testimony, which has been submitted in full for the committee's review.

Pennsylvania, and indeed the entire Nation, is moving toward competition in electric generation. These changes are forcing utilities to make critical decisions about their futures. I and my company believe that nuclear energy must continue to be an important part of our Nation's generation capacity. And PECO Energy is committed to nuclear energy. We formed a joint venture, called Amergen, with British Energy, the nuclear generating company in Great Britain, to acquire and operate nuclear plants in North America.

We are doing this because we strongly believe in nuclear power and that it can, in fact, be competitive when operators take the following action. First, they must develop a strong safety culture. Second, they must make investment in plant reliability in order to sustain high-capacity operation. Third, operating costs must be reduced to competitive levels. Fourth, operators must aggressively self-assess for declining performance and make timely corrective actions as necessary. And, fifth, units must be consolidated to reduce overhead and increase the efficiency and economies of scale.

These steps will make existing plants competitive in the new electric generation marketplace. The entire it, as well as regulators, must learn that low-cost operation and safety are not mutually exclusive. Consolidation, process standardization and a strong performance ethic are keys to success. Consolidation will reduce overhead and allow expertise and best practices to be shared among a number of plants. Commonality of operations will help focus on the processes of operation.

And as noted in the industry's plan for the 21st century, the NRC has a strong role in sustaining a competitive industry, by providing an effective, safety-focused regulatory framework. Currently, nuclear powerplants are regulated to the lowest common denominator. Plants are evaluated against a scale based not on public safety but on average industry performance. And as the industry performance improves, the bar keeps getting raised higher and higher.

While poor performance should be identified and performance improved, above-average performers should not be restrained by inappropriate regulatory standards. What type of regulatory process is needed?

Well, we believe that the NRC should establish performance expectations that are directly linked to public health and safety, and that can be effectively measured. The agency should also establish a firm safety-based threshold for measuring plant performance. The Commission should also take guidance from Vice President Gore's initiative in "Reinventing Government."

For example, during the next decade, a number of nuclear plants will apply for relicense. And it is estimated that the NRC will take 2 to 3 years to complete this process for each plant. I believe that the Nuclear Regulatory Commission should work to put into place processes that, after the first several plants are relicensed, would permit the completion of relicensing reviews within 6 months. This would be the equivalent, at the Government level, of what the industry has accomplished in recent years in reducing its outage links from in excess of 100 days to about 30 days.

The energy marketplace is changing very rapidly. All utilities are repositioning to compete in a new environment. And the NRC must keep pace with the industry to ensure that public safety is maintained without jeopardizing the economic operation of nuclear powerplants.

PREPARED STATEMENT

Thank you very much, and at the end of the presentations I will be glad to answer any questions that you might have.

[The statement follows:]

PREPARED STATEMENT OF CORBIN A. MCNEILL

Mr. Chairman and members of the subcommittee, my name is Corbin McNeill. I am chairman and chief executive officer of PECO Energy Company, with headquarters in Philadelphia.

Thank you for the opportunity to appear before you today to discuss the very important subject of nuclear energy and nuclear regulation in the United States. PECO Energy operates two nuclear power plants—both in Pennsylvania.

In the interest of time I will summarize my testimony, which has been submitted in full for the committee's review.

Pennsylvania, and indeed the entire nation, is moving towards competition in electric generation. These changes are forcing utilities to make critical decisions about the future. I believe that nuclear energy must continue to be an important part of our nation's generation capacity.

PECO Energy is committed to nuclear energy, and we've formed a joint venture—AmerGen—with British Energy to purchase and operate nuclear plants.

We are doing this because we strongly believe nuclear power can be competitive if operators take certain actions. (1) There must be a safety culture; (2) Investment must be made in plant reliability to sustain high capacity operations; (3) Operating costs must be reduced as much as possible; (4) Operators must aggressively self-assess for declining performance; and (5) units must be consolidated to reduce overhead.

These steps can make plants competitive in the new electric marketplace. The entire industry—as well as regulators—must learn that low-cost operation and safety can both be achieved. Consolidation, process standardization and a strong performance ethic are key to success. Consolidation will reduce overhead and allow expertise and best practices to be shared. Commonality of operators helps to eliminate reactionary responses and, instead, focuses on processes.

Currently nuclear power plants are regulated to the lowest common denominator. Plants are evaluated against a scale based not on public safety, but on average industry performance. As the industry improves plant performance, the bar keeps getting higher and higher. Poor performers should be identified and performance improved. Above average performers shouldn't be restrained by standards designed to maintain all plants at a minimum level.

What type of regulatory process is needed? The NRC should establish performance expectations that are directly linked to public health and safety and that can be measured effectively.

The agency should also establish a firm, safety-based threshold for measuring plant performance.

The NRC should take guidance from Vice President Gore's initiative on reinventing government. For example, during the next decade a number of nuclear plants will apply for re-licensing. It's estimated that the NRC will take a year or two to complete this process for each plant. I believe the Commission should work to put into place processes that, after the first several plants are re-licensed, would permit the completion of its re-licensing reviews within six months. This would be the equivalent at the government level of what the industry has accomplished in reducing outage lengths to 30 days.

The electricity marketplace is changing rapidly. All utilities are repositioning to compete in this new environment. The NRC must keep pace with the industry to ensure public safety without jeopardizing the economic operation of nuclear power plants.

Thank you and I will gladly answer any questions you may have.

Senator DOMENICI. Mr. McNeill, maybe you are the right one to answer this. If you are not, maybe one of the other panelists would. Japan builds nuclear powerplants. How long did it take for their last one?

Mr. MCNEILL. I believe it was on the order of 4½ years Kashawazaki No. 4, I believe it was.

Senator DOMENICI. How long did it take for the last nuclear powerplant to be built in the United States?

Mr. MCNEILL. The last nuclear plant in this country was Wilkes-Barre, which took 23 years.

Senator DOMENICI. I assume there is a similarity between the plants?

Mr. MCNEILL. The technology is very similar, yes.

Senator DOMENICI. The risks are similar?

Mr. MCNEILL. I think the risks in Japan may be even a little bit higher because of the higher earthquake potential that they have in Japan.

Senator DOMENICI. Professor Wilson. Again, I want to thank you personally for joining us. I understand that is a difficult thing to fly in and come right over here. I did not know I was doing that to you or I might have held you immune from this. But I am glad you are here.

STATEMENT OF RICHARD WILSON, PH.D., MALLINCKRODT PROFESSOR OF PHYSICS, HARVARD UNIVERSITY

Dr. WILSON. Mr. Chairman, Senator Reid, it is certainly an honor to talk to you today. And I apologize; a copy of my testimony was first sent by fax and then e-mailed yesterday, but they got lost somewhere across the Atlantic.

The United States emits 11 percent more carbon dioxide than in 1990. A Kyoto, we promised to reduce it 8 percent below 1990 levels. If we abandon nuclear power, there will be another immediate 8 percent increase, not decrease. Can we meet our international commitments?

Nuclear power, as your chairman has said, is unique in producing no appreciable particulate air pollution, not contributing to global warming, and be able to produce power for 100,000 years at modest cost. But the cost has gone up threefold in the last 25 years. Twenty-five years ago, Connecticut Yankee Nuclear Powerplant was producing energy at 55 cents a kilowatt hour, including some payment of the mortgage. The actual operating cost was probably about 4 cents a kilowatt hour. Now, it has been permanently shut down because it costs 3.7 cents a kilowatt, a ninefold increase in operating costs.

In most technologies, there is a learning curve. In this one we have an unlearning, or a forgetting, curve. In 1980, the question was, why should any utility company go nuclear? Now, the question is, why should any utility company stay nuclear? Not one unless the costs can come down or the environmental costs of coal burning can be internalized to keep the relative costs up.

Why have the costs gone up? What can we do to bring them down?

Many people suggested that a major problem is the regulation is more than needed for adequate safety, and this increases the cost. In particular, regulation is too prescriptive and not based on performance. Often the response to regulation is to increase staff. The staff number at the Dresden Powerplant went from 250 in 1975 to over 1,300 today. This costs money, and I do not think it increases safety.

Senator DOMENICI. Would you repeat that statement, please?

Dr. WILSON. This costs money, but I do not believe it appreciably increases safety.

Senator DOMENICI. The number, too, please.

Dr. WILSON. According to Wally Banke, the numbers at the Dresden Powerplant went from 250 in 1975 to 1,300 today.

Mr. MCNEILL. Those are not unusual.

Dr. WILSON. In 1974, when the AEC was split, the NRC had no mandate to keep nuclear powerplants in operation, unlike the former AEC, but only to ensure that they operate without undue risk to the public. It was left to the Department of Energy to promote nuclear energy and to provide a balance.

It is important to realize the utility companies cannot provide this balance themselves. Every regulator has the ability to keep a powerplant shut down for an extra day, which costs $1 million. This is an extraordinary power, which few utility companies know how to cope with.

If there is no one actively from outside promoting nuclear energy, regulation will inevitably become more strict, and will force unnecessary price increases, until price competition destroys the industry.

I think two steps are necessary. The first is to find more efficient regulation; and the second, to find a group which will play the active promotional role that is so necessary in the U.S. system. The first step was already begun by the first Commission under the astronaut, Bill Anders, 14 years ago. After 2 years of public hearings, the NRC set radiation safety goals. The radiation exposure should be reduced if it costs less than $1,000 per man-REM, now increased to $2,000 per man-REM. A corollary to this, which was implied but not stated, is if a proposed dose-reducing action would cost more than this, it should not be done.

In the 1980's, the Commission promulgated a set of safety goals. These were calculated and based on keeping it lower than the risks of other technologies. A subsidiary safety goal which I will address here was to keep the frequency of core melt to less than 1 in 10,000 years per reactor. Safety improvements must be made to keep the core melt below that amount. Presumably, steps to reduce the frequency still further were unwarranted unless particularly cheap.

Studies can be made retrospectively to see whether the regulations are such that these goals are met. An independent study at Harvard School of Public Health suggests the rad waste regulations cost $1 million per man-REM, which is a thousand times the goal. That seems a waste of money.

A PRA can be used to discuss retrospectively whether the safety of the reactions, designed and operated under existing regulations, are safer or less safe. If they do not meet the goal, they should be tightened. If they do meet the goal, with a large margin, regulations can be relaxed.

For example, 8 years ago, the NRC had a study of four typical reactors in new regulation 1150. It was found that core melt was always less than this amount. Nonetheless, they were proposing safety improvements. And when I am on a committee I propose that either the goals were wrong, the calculation was wrong, or they were being made to save money. Unfortunately, in a somewhat isolated case, they decided not to push the movements.

If you have gone too far and you have a structure and you have deliberate violations then, of course, it is much more difficult. But even here, I would suggest a graded response. A powerplant must be shut down, as it was at Millstone in Connecticut 2 years ago, but only until the NRC could determine whether the safety goals were exceeded.

Now, several successive administrations have felt it desirable to tighten up regulations in order to convince the public they are no pushover. I think it is wrong. Far better it would be to study, know, understand, and explain to the public what the problems do to safety.

Now, the NRC recent record in the above respects is, I think, abominable. Over 2 years ago, I asked the chairman of the Commission, by fax, what the technical problems at Millstone Point were, and what effect they had on safety. I still have not had a reply from the chairman. But after 2 months, I got a reply from the director of regulation, who gave me a two-page comment on procedural violations, but nothing on safety.

No one, within or without the Commission, has challenged my contention, repeated many times since then, the effect of the procedural violation that caused the shutdown was a change of about 1 in 100,000 in core melt frequency—less than 10 percent of the safety goals. Yet, why do they make such a big thing of it?

Twenty-five years ago, when I started my interest, I sent a two-page letter to the chairman of the AEC, with about one or two dozen criticisms. Three days later, I got a personal phone call from Dr. Glenn Seborg, and I spent 3 days with him and his staff down at the AEC. He introduced me to all his staff and answered the questions. These were the secrecy and coverup of the bad old days. I personally prefer them.

Senator DOMENICI. Were you more renowned when you were young?

Dr. WILSON. No. [Laughter.]

But I was probably more competent. [Laughter.]

Senator DOMENICI. I doubt that, too.

Dr. WILSON. So, it was calculated that the cost of the overregulation at Millstone was huge. It is about $3 million a day, or $2 billion so far. The effect on public health is important to realize. It is absolutely enormous. Because energy has been produced largely by coal-burning powerplants, there have been particulants emitted. I calculate, using the numbers in this book—of which we sent you a copy last year—there have been 400 deaths so far due to that particular action.

Now, other utility companies have got the message of what happened at Millstone: Get out of nuclear power as fast as you can.

It was calculations such as those I have just done here for you that led the late Senator Tsongas to say that he did not understand how anyone who preferred coal to nuclear power could call himself an environmentalist. I urge NRC once again to act in the public interest and according to their own safety goals to change regulations in either direction to match those goals. When there is a procedural violation that has safety consequences which are within those goals to give a slap on the wrist rather than an execution.

PREPARED STATEMENT

I think I would prefer them to be like W.S. Gilbert's Mikado, who made it an object oh sublime to make the punishment fit the crime. And let us hope that it will be achieved in time, before the nuclear industry is destroyed.

Thank you.

Senator DOMENICI. Thank you very much.

[The statement follows:]

PREPARED STATEMENT OF RICHARD WILSON

Mr Chairman, Senator Reid, ladies and gentlemen. It is an honor to be invited to talk to you today.

In the USA we now emit 11 percent more CO_2 than in 1990; and at Kyoto we promised to reduce CO_2 emissions to 8 percent below 1990 levels in 10 years for a decrease of 19 percent below today's levels. If all the electricity now generated by nuclear power were to be generated by coal that would increase CO_2 another 8 percent making it more difficult if we abandon nuclear power. As we ponder whether the U.S. will meet the commitment made at Kyoto, one fact stands out. That of all the alternate fuels nuclear power is alone in producing no appreciable particulate air pollution, not contributing to global warming and, if we develop a breeder reactor being able to produce power for 100,000 years at modest cost. The present problem is that both the construction cost and the operating cost has risen between two and threefold in the last considerably in the last 25 years. It is more expensive than fossil fuels and begins to approach the costs of some of the solar energy alternatives.

25 years ago, Maine Yankee nuclear power plant had just been completed for $180 million, or $200 per day installed capacity. Connecticut Yankee nuclear power plant was producing electricity at 0.55 cents per kWh busbar cost, some part of which was paying off the mortgage. The operating cost was perhaps only 0.4 cents per kWh. Now, 25 years later, the most recently completed nuclear power plants cost at least $2,000 per installed kWe of capacity, 10 times the 1972 cost, and Connecticut Yankee is being permanently shut down because it costs 3.7 c/kwh, 9 times the 1972 cost even though the mortgage is fully paid. Yet inflation can only account for a part—perhaps a factor of 2.5 to 3—of this.

In most technologies there is a learning curve and are cheaper as time goes on. In this technology we have an unlearning or forgetting curve. Numbers that I have seen from France give an average cost of nuclear electricity including all costs, of 2.9 cents/kwh, whereas a similar number in the U.S. averaged over all plants operating in 1995 was 5 cents/kwh (this ignores costs of plants, like Shoreham, which were abandoned for political or other reasons). More generally, the operating costs of the best operated nuclear power plants in the USA are now about 1.8 cents per kwh compared to a coal cost of about 1.6 cents a kwh. Construction costs are much more. In 1980 the question was “Why should any utility company go nuclear?” In 1998 the question is “why should any utility company stay nuclear?”

Not one unless the costs can come down or unless the environmental costs of coal burning can be internalized to increase the coal price. I have pointed out this problem before (Wilson 1994, 1996) and note that if the present trend continues half our nuclear power plants will be gone in 10 years and we will have no nuclear power plants at all in the USA by 2017. Yet if Parkinson (1957) is right the regulatory authority will still be expanding many years later!

Why has the cost gone up? What must we do to bring it down again? Various ideas include the following:

—In 1970 manufacturers built turnkey plants or otherwise sold cheap reactors as loss leaders. But this can only account for a small proportion of the capital cost.

—Construction costs generally have risen in this time.

—It may be that in 1972 we had good management and good technical people. But why has management got worse when that has not been true for other technologies?

—It is probable that nuclear power plants are safer today than they were in 1972. But it would be hard to argue that the actual safety improvements have cost that much money. Most are a result of more careful thought using such approaches as event tree analysis, but without excessive hardware expense.

—Many people have suggested that the problem is that the regulation is more than needed for adequate safety and this increases the cost (Towers-Perrin 1995). In particular that it is too prescriptive and not based upon performance.

—The response to many regulations is to increase staff. The staff numbers at the Dresden power plant went from 250 in 1975 to over 1,300 today (Benhke 1997).

—The problem is not unique to the USA. In the UK the Atomic Energy Authority had to spend a lot of money making the plant as earthquake proof as an operating reactor—yet the inventory of dangerous material is far less and the danger of recriticality remote (Hill 1997).

I want to address here the problem of regulation and the intricate and complex relationship between regulator and licensee. Although not an expert, I claim one advantage: I look on the problem from outside and I keep the three fundamental societal aims in mind.

THE FUNDAMENTAL NEED FOR BALANCE IN REGULATION

When the U.S. NRC was separated in 1974–5 from the old Atomic Energy Commission it was insisted that the promotional role of nuclear energy be separated from the regulatory role. It was already geographically separated by putting the promotional arm in Germantown and the regulatory arm of AEC in Bethesda. But unlike the mandate given to the AEC by the Atomic Energy Act of 1945, the NRC has no mandate to keep power plants in operation—only to ensure that the power plants operate without undue risk to the public. It was left to ERDA and now the Department of Energy to promote nuclear energy and to provide the balance. It is important to realize that the utility companies cannot and will not by themselves perform this function of balance. The utility companies are under close local or regional control, and historically have shown extreme reluctance to challenge any regulatory body. There is a great unbalance in power. A regulator often has the ability to keep a power plant shut down for an extra day—an action which costs the utility company $1,000,000 per day. There is no counterbalance to ensure that this power is used wisely and well. The Nuclear Regulatory Commission has been sued in the courts, (in what seems to be the preferred procedure in the USA for obtaining balance) by one or another group opposed to nuclear power, but to the best of my knowledge has not been sued by utility companies. Any regulator will automatically adjust his strategy to minimize lawsuits—and probably that is easiest done by ensuring that the number of lawsuits from each side is equal. If there is no one actively promoting nuclear energy, therefore, the regulation will inevitably become more strict and will force unnecessary price rises until price competition destroys the industry.

How can we regain the balance in regulation? I submit that two steps are necessary. The first is a procedure to decide to regulate nuclear power in a more efficient way (including deciding upon how much regulation is necessary) and the second to find a group which will play the active promotional role that is so necessary in the U.S. system and those patterned after it.

The first step was already begun by the first Commission to take office some 14 years ago when astronaut Bill Anders was chairman. After 2 years of public hearings started by the AEC the NRC set some radiation and safety guidelines. (NRC 1975). The Commission proposed that expenditure on radiation exposure reduction should be made if it costs less than $1,000 per ManRem, now doubled to $2,000 (Kress 1994)—a number higher than anyone in the hearing had proposed. A corollary was implied but not explicitly stated. If a proposed dose-reducing action would cost more than this, it should NOT be done.

In the 1980's the Advisory Committee on Reactor Safeguards (ACRS) made a study that led to the promulgation by the Commission of a set of SAFETY GOALS. These were appropriately related to the safety of individuals living near a power plant. The risk must be appreciably less (10 percent or so) of that of another electricity generating facility. But it was recognized that such safety goals were difficult to implement and a subsidiary safety goal was promulgated that the frequency of core melt must be kept to less than 1 in 10,000 years per reactor. Safety improvements must be made to keep the core melt frequency below that amount. Although not stated, it was implied that steps to decrease core melt frequency still further were unwarranted and it was not worth the expense to undertake them. For simplicity I will address this "intermediate" safety goal here but the same argument can be applied to the more fundamental safety goal.

There is a fundamental problem in implementing GOALS as opposed to issuing or following regulations. There is no definitive way of proceeding. But studies can be made retrospectively to see whether they are met. Clearly the $2,000 per Man Rem is a safety goal. An independent study (Tengs et al. 1995) suggests expenditures in the nuclear industry for RADWASTE have been 1,000 times this amount. It seems that either the regulations (in this case probably the Technical specifications) are stricter than needed, that the industry is spending more than the regulations call for, or the total amount of money is so small it is not worth worrying about. The procedure does not, however suggest how they be relaxed or whether the cost decrease is large enough to be worth the bother. I suggest that the nuclear plant operators and the NRC, perhaps aided by IAEA since it is an international problem, should study the matter with some urgency.

Similarly the ACRS has repeatedly stated that it is not sensible to regulate on the basis of a Probabilistic Risk Assessment (PRA). But a PRA CAN be used to discuss retrospectively whether reactors that were designed and operate under existing regulations meet the goals. If they meet them, fine. If they do not regulations must be tightened. On the other hand if the safety goals are met with a large margin maybe the regulations can be relaxed. Indeed the important parts of a PRA can now be put on a small PC or laptop so that the effect of any small change in procedures can be quickly calculated.

An example of how the use of this concept can prevent unnecessary regulation occurred some 8 years ago. A very careful PRA was done by the Nuclear Regulatory Commission (NRC 1987) for a number of "typical" nuclear power plants including an early Boiling Water Reactor (BWR). In all cases it was found that the core melt probability was LESS than one in ten thousand per year. There are uncertainties about this calculation, and there has been some discussion about whether one should take the median, the mean or the mode of the probability distribution. I have argued elsewhere that one should take the mean, and do so in what follows. An immediate use of this argument was discussed at an NRC research advisory group meeting. The NRC staff was suggesting addition of safety devices to BWR Mark I reactors to improve safety. I, as a member of that advisory committee, pointed out that these reactors met the safety goal with flying colors. Either the safety goals were wrong, or the NRC's research program that produced NRC 1150 was useless, or the staff suggestion was excessive. The committee agreed with me and so did the director of regulation. In this case the staff suggestion was dropped. Unfortunately this was an isolated instance. It was also an instance in which regulation was not increased rather than an instance in which it was actually decreased. Reducing regulatory requirements is FAR more difficult. However, I urge that NRC have a formal and MUCH more rapid procedure for examining regulations.

Shortly thereafter I was asked to be Chairman of a task force reviewing the safety of the nuclear power plants in Taiwan on behalf of the Minister of Foreign Affairs. The director of regulation in Taiwan told us that he accepted the idea of guidelines but wanted to have the core melt frequency to be less than 1 in 100,000. I asked why he wanted it to be so low when the careful studies by NRC thought that 1 in 10,000 was low enough. The reply was that "industry can meet it". Maybe so. In the event, I believe that Taiwan did NOT change the safety goal. Since the power plants, which were U.S. designed and very well run meet the 1 in 10,000 goal easily that leaves wiggle room for the utility company (TAIPOWER) to cope with occasional lapses of their staff and an occasional overzealous regulator. The ROC AEC can, by using PRA can easily justify their goal to the public and TAIPOWER can proudly tell the public that they are doing even better.

Hard though it is to reduce the severity of a regulation, it is harder to forgive a deliberate violation of regulations even when that violation does not result in any safety goal being exceeded. But again I urge immediate and rapid effort in this direction. If there has been a procedural violation the NRC must of course act in some way because such violations can escalate. But I suggest a graded response. The power plant might be shut down, as were the four power plants at Millstone and Connecticut 2 years ago, but only until NRC can determine whether or not the violation led to exceeding the safety goals. With fast computers a PRA can be set up to do such an analysis within a week or two at most. If a safety goal was NOT violated, it seems a clear indication that the regulation or technical specification was too strict and it could be modified and the reactor allowed to restart with no further "punishment".

Of course utility company staffs and in particular utility company managements are often the most to blame. We have seen in the late 1970's how TVA went in a few years from one of the best utility companies to one of the worst. In the early 1990's Ontario Hydro went from having the highest plant availability of any reactors in the world to being among the lowest. Many observers attribute each of these to a change in top management. There is less agreement on whether the management was malevolent (antinuclear) or merely incompetent. The Ontario hydro board used to have one person who understood nuclear technology—now it has none. (But the management incorrectly in my view insist that the only problem is on the shop floor). But the regulatory structure should be able to cope with this. If it is necessary (and I do not believe it is) to always have perfect regulators and perfect management to run nuclear power, there is no hope that costs can be reduced. Fortunately the PRA confirms for us that light water reactors are a forgiving technology. Northeast Utilities had clear management problems. The costs were one of the highest and in an effort to reduce costs there was, and is a temptation to cut corners. In addition there are cases of inadequate regulation. That usually comes from inadequate alertness. There are also occasional "whistle blowers" who for whatever reason raise issues that they feel have been neglected. In such situations there is a temptation for a regulatory authority to tighten up all round in the hope of reassuring the public. Indeed several successive Chairmen of NRC recently seem to have felt it politically desirable to do something dramatic to tighten up regulations in an attempt to convince the public that they are no pushover for industry. I do not believe that it does reassure the public. I believe it makes matters worse, by implying that the regulatory action had been too lax. Far better would be to study, know, understand and explain to the public the effect that such problems have on safety. As noted above, we now have the techniques of PRA available to ensure the completeness which is otherwise so difficult. I suggest a joint approach by utility companies—perhaps through the Institute of Nuclear Power Operations (INPO)—the NRC and academia (hopefully with funding from DOE) to study the critical interaction between regulator and licensee—always with a background of the risks of other energy technologies as discussed in Comparative Risk Assessment (CRA). Even though regulatory procedures vary between countries IAEA could also play an important role.

The above would NOT be promotion of nuclear power. It is less clear to me how to achieve my second step and who should play the active role of promoter of nuclear power. Who should constantly call the regulator to task when he takes actions that exceed his own goals. In the USA that would have to involve lawsuits because that is where the action finally occurs in any subject. I suspect that is not politically possible for the Department of Energy (DOE) and to that extent the political concept of 1973 when the AEC was broken up was fatally flawed. Other mechanisms must be found.

In 1987 six Long Island residents started a lawsuit nominally against Long Island Lighting Company but really against New York State, (with a supporting brief by a Department of Energy more friendly to nuclear power than the present department) in an effort to prevent them dismantling the Shoreham nuclear power plant without filing an environmental impact statement—and in that statement would have inevitably had to contradict the comments of Governor Cuomo's staff in the previous EIS that nuclear power is environmentally advantageous. This suggests to me that a publicly minded group of scientists, who are concerned about the three environmental issues with which I began this paper should form a group to be watchdogs and file suit to enforce fair regulation when appropriate. Unless something is done, I do not think that nuclear power in the short term will survive.

The NRC's recent record in the above respects is abominable. I mentioned above that the radwaste regulations cost 1,000 times too much. The actions at Millstone point were vastly exaggerated also. Over 2 years ago I asked the Chairman of the Commission by FAX what the technical problems were and what effect they had on safety. I have had no reply but after 2 months I did get a reply from the Director of Regulation, since resigned, who gave me a 2 page comment on procedural violations. NO ONE within or without the commission has challenged my contention, repeated many times since then that the effect of the procedural violation that caused the shut down was a change of perhaps 1 in 100,000 per year in core melt probability. The NRC should have been able to realize within 2 weeks that this is one-tenth of their safety goal and that the draconian action was unnecessary.

Although many people, in Congress and in the press talk about the evils of the old AEC it is noteworthy than in those "bad old days" response to criticism was much faster and more substantive. 25 years ago when I started my interest in energy and environmental matters I wrote to the Chairman of the AEC a 2 page letter with a dozen or more criticisms. 3 days later Dr. Glenn Seaborg, not a secretary, telephoned me and invited me to spend 3 days with him and his staff going over detailed responses. During the first 3 hours in Dr. Seaborg's office I was introduced to each of the appropriate Assistant Secretaries who answered my queries to the best of my ability and directed me to further sources. That was the secrecy and cover up in the "bad old days" about which we repeatedly hear complaints.

The cost of the over regulation at Millstone is huge and seems to have been deliberately understated in many reports so far. I take it here to be the busbar cost of replacement electricity of about $3,000,000 a day or 2 billion dollars so far. The effect on public health is also huge. Supposing the replacement electricity to come from a mixture of fossil fuels and hydro power in the average proportions, each power plant replacement costs over 50 premature deaths a year from air pollution, (Wilson and Spengler 1996) or over 400 deaths so far. Other utility companies have got the message: "Get out of nuclear power as fast as you can".

Indeed it is calculations such as this that led former Senator Tsongas to declare "I do not see how anyone who prefers burning coal to nuclear power can call himself an environmentalist".

I urge NRC to begin once again to act in the public interest and according to their own safety goals. To change regulations too, in either direction, to match these goals. When there is a procedural violation that has safety consequences that are within these goals to give a slap on the wrist rather than an execution. I urge each commissioner to take the approach of W.S. Gilbert's Mikado who made it "an object all sublime * * * to make the punishment fit the crime". Let us hope that it will be achieved in time—before the nuclear industry is destroyed.

REFERENCES

Benkhe W. (1997) Communication from W. Benkhe, former C.E.O. of Commonwealth Edison Co. owner and operator of Dresden II and Dresden III.

CMP (1972) Report from Central Maine Power, Majority Owner of Maine Yankee. This cost does not include a (later) cost of $20 million to remove a causeway and improve tidal flow in the coolant estuary (which many experts thought was unnecessary and certainly would NOT and have been, and was not demanded of a fossil fuel plant).

Hill, J. (1997) communication to the author by Sir John Hill, Chairman of the UK Atomic Energy Authority at the time.

Kress, T. (1994) Report to Nuclear Regulatory Commission from the Advisory Committee on Reactor Safeguards NRC (1975) Rule making RM–30–2.

NRC (1987) Nuclear Regulatory Commission report NUREG 1150.

NYT (1996) Figures reported in the New York Times.

Parkinson, C.N. (1957) "Parkinson's Law" page 12, Heighten Mifflin, Boston.

Tengs, T., et al (1995) "Five hundred life saving interventions and their cost effectiveness" Risk Analysis 15:369.

Towers and Perrin (1995) report to Nuclear Energy Institute.

Webster W. (1972) Letter from William Webster, President of NE Electric System to Richard Wilson.

Wilson R. (1994) "The Potential for Nuclear Power" in Global Energy Strategies: Living with Restricted Greenhouse Gas Emissions, edited by J.C. White, Plenum Press, NY, pp. 27–45.

Wilson, R. and Spengler, J.D. Eds. (1996) "Particles in Our Air: Concentrations and Health Effects" Harvard University Press, Cambridge, MA 02138.

Wilson R. (1999) "Overregulation and other Problems of Nuclear Power" Presented at the Global Foundation Conference, Washington, DC, October 1998.

Senator DOMENICI. Could I ask any of you who feel most expert, I am going to go during the Fourth of July recess—since I have decided that this cause—not just nuclear power, but the whole issue of nuclear activities—needs to be looked at, I intend to vote some of my time to that—in fact, formidable time to it—I am going to go to France, and then I am going to go to Russia.

In France, we are going to see how they do their system and what happens to their waste. And then, in Russia, we are going to talk about their notion of how valuable plutonium, in terms of reuse, and see if we cannot generate some exciting conversation between Russia and America on some way to accelerate the disposition of their plutonium from dismantling nuclear arms—and ours—through using MOX facilities around the world. That is just a new concept, but anyway it has gathered a bit of excitement.

But, essentially, I built my premise that I wanted to ask Congress, and ultimately the people, to take another look at things on essentially the proposal and the idea that President Jimmy Carter came up with, that we would not have any MOX, that we would not use reprocessing of the MOX kind. We are now going to have to do some of that in the dismantling process, but we are going very, very slowly at it.

Could any of you tell me what is essentially the difference in the way we are treating our nuclear waste from civilian reactors versus France? My friend from Nevada comes from a State that the United States has already spent $6.5 billion exploring the idea of putting a tunnel in a mountain so that we can put the spent fuel from civilian reactors, high-level waste, so we can put it in there and feel safe for, what are we thinking, 200,000 years. And we are asking the computers and the technology people to be able to give us simulation and other things to prove it can be done.

Not only have we not started building it, we still have not proved it to be viable under the conditions imposed for the safekeeping. Maybe those conditions are too extreme, but, nonetheless, here we sit. We have a policy, since President Carter's time, that says we will not reprocess using the MOX approach because it may produce plutonium and spread it around the world so that it could be used for nuclear weapons.

The interesting thing is that we did that based on the proposition that nobody would do it, and that if we set the standard nobody would do that. But it was a good decision, it was almost entirely based on that. Other countries have not seen fit to follow suit and, in fact, are doing that.

So, with that background, what distinguishes what France is doing wastewise to what America is doing wastewise, in terms of the cycle?

Mr. COLVIN. Mr. Chairman, let me give that a shot. I think it is important to say by way of background that you have to remember that the United States pioneered this technology. And when you compare the United States against a country such as France, you have to remember that, in fact, the technology that we pioneered was transferred to the French, and, in fact, they have operated that exceptionally well. And with that, they have learned the tremendous lessons of what to do and perhaps what not to do in the operation of this technology and, in particular, as it relates to the waste stream.

Basically, the French program takes the waste byproducts from spent fuel, reprocesses that once, twice, three times; uses the materials out of the reprocessing and puts that back into new fuel. In essence, they are reprocessing their fuel. That leaves you with a smaller waste stream that has a long-lived activity and that needs disposal.

And they are currently storing that waste stream, that byproduct, which is significantly less in volume and, in some cases perhaps less in longer-lived activities because of that—they are currently, like we are evaluating Yucca Mountain, the French have, as I understand, two laboratories that they have established to evaluate the long-term geologic disposal of their waste stream.

I must say that in this discussion you have to remember that the volumes of that waste stream ultimately, in a reprocessing cycle, will be significantly less than a once-through fuel cycle that we are using currently in the United States.

Senator DOMENICI. Yes; Dr. Jenkins-Smith.

Dr. JENKINS-SMITH. Senator Domenici, the other aspect of it, again, from the public perception side and the public acceptance side, that distinguishes the French and the American systems is that in the United States we have approached nuclear waste as a disposal process. We are taking spent fuel and we are planning to poke it in a hole and cork it, as it is crudely often put.

The French approach has been to designate these as laboratories. In fact, the siting of the repository process focused on the creation of facilities to explore future enhancements in safety, reductions in volume and alternative utilization. So, it was not simply creating a repository or, as it is often colloquially known in the United States, as a dump, but it was the creation of a high-tech facility that would generate benefit streams in the future.

People view that very, very differently. And in experiments we have done, looking at the public reaction to policy modifications for repositories and even transport programs, when people believe that the waste is actually going to be used for these kinds of beneficial future activities support for the programs goes up substantially.

Senator DOMENICI. Yes; please, Dr. Wilson.

Dr. WILSON. Senator Domenici, in response to the question, I would say that it is important to realize that there is a different fundamental concept started in much of Europe than here. Here we had the idea, which I think was an erroneous one, that you put the waste in the ground in such a way that you can now forget about it forever. And there they have the idea that you can do something with it and look after it in a modest way.

There is no doubt in my mind that the waste from a powerplant is much safer than operating a powerplant. And you can put it next to a powerplant, as we are doing sometimes, without appreciably increasing any risk to anybody. So, when you are monitoring it and keeping it all the time under your eye, there is, it seems to me, no technical problem whatsoever.

Added to that, of course, as you pointed out earlier, we do not compare things. There was a waste product of a lot of activities called arsenic. It comes naturally. Once you dig something in the ground you dig arsenic up, particularly in the West and in California. And that arsenic is carcinogenic. It is very nasty stuff. And in comparison with nuclear waste, it has one major disadvantage: nuclear waste lasts maybe 30 years for most of it, a few thousand years for some of it; arsenic lasts forever.

Senator DOMENICI. I have two more quick questions here, and then I will yield to Senator Reid.

I note the presence of the chairman of the full Appropriations Committee, Senator Ted Stevens. Senator, thank you very much for joining us. And whenever you would like to inquire or be heard, it will be your turn.

Let me just ask, what is the comparable risk of the French and the United States fuel cycle? Is one more dangerous than the other, more risky than the other? Is one safer than the other? Can somebody answer that?

Mr. COLVIN. Yes; Mr. Chairman, off the top of my head, I do not know the specific answer. I think that I could say pretty realistically that when you look at it from a public health and safety perspective, as Dr. Wilson has indicated, the risk levels that we are talking about in the disposal and storage or the reprocessing of nuclear waste are significantly below the levels that we typically look at from a public health and safety risk standpoint.

I mean, whether we are talking about automobile or airline travel or we are talking about other types of public risk, we are operating at much lower levels. And I do not think if we did that comparison that there would be a significant difference. It would probably be in the range, as Dr. Jenkins-Smith said, of 10 to the minus 6, 10 to the minus 7 types of numbers. It probably would not be significant from a public health and safety standpoint.

Mr. MCNEILL. MOX fuel is used in many locations in Europe, not just in France.

Senator DOMENICI. Right.

Mr. MCNEILL. And MOX fuel is a well-established fuel regime that, to my knowledge, has no perceptible risk difference between normal uranium fuel and MOX.

Dr. WILSON. I think it is important that of 35 reactors licensed in Europe to handle MOX fuel, and I think 22 of them have MOX fuel in them at the present moment.

Senator DOMENICI. Have what?

Dr. WILSON. Have MOX fuel at the present moment. And if you took all the likely reactors now licensed to handle MOX fuel, you could dispose of all the military plutonium we want to dispose of within about 18 months. And all you have to do is to decide to do it.

Senator DOMENICI. You understand what the purpose of the trip to Russia is now?

Dr. WILSON. Yes, indeed.

Senator DOMENICI. Now, let me ask, do the United States or French nuclear workers, in any of your opinion, and the public receive higher doses of radiation?

Mr. MCNEILL. Not to my knowledge.

Senator DOMENICI. Anybody else?

Mr. COLVIN. No, sir.

Dr. WILSON. Approximately the same.

Senator DOMENICI. Approximately the same?

Dr. WILSON. That is right. It depends on exactly what years you are comparing.

Senator DOMENICI. Mr. McNeill, we recognize the tremendous commitment by a utility to decide to build and operate a nuclear powerplant in today's climate in the United States. What would it take to get an advanced reactor designed in this country built with industry support?

Mr. MCNEILL. Well, our interest currently is more in acquiring the operating plants and continuing to operate those. Because we think that they have a cost basis that is competitive. I believe that for a new plant in the United States, in the short term, we would undoubtedly need some form of governmental support for that. Because the first-of-a-kind construction of one of the new plants has high upfront costs in the cycle, and may not be competitive with other forms of generation right now.

But as those forms of generation—the cost of fuel for gas plants or the construction costs rise for other forms of generation, there will be a time in the not too distant future when the economics of a new nuclear plant will make them competitive.

Senator DOMENICI. Senator Reid, I am going to yield to you now. I just wanted to make the point with reference to an issue that has been part of your responsibility in behalf of your State that what we are talking about when we speak of MOX fuel, we are talking about a mixed oxide [MOX] reprocessing that takes the spent fuel that we are contemplating moving to your State by the truckloads and putting in the mountain, we are talking about reprocessing that. And not all of the residue, but substantial portions of the residue are then used in nuclear reactors to produce more energy.

Now, that is typical of what people think when they speak of reprocessing. But in the United States, we have a policy of ancient origins, 30 years ago or 40 years ago, that says we cannot do that. I understand why you would be very interested in reprocessing in that context, not only because you have begun to pay close attention to the energy needs of America, but you have a very real problem that is demonstrable changed if, in fact, we went in a different direction.

I yield to you.

Senator REID. Mr. Chairman, that is why I appreciate your holding these hearings.

No matter how we do the poll numbers, I think realistically, Mr. McNeill, to get Federal Government support to build a new nuclear powerplant any place in this country is farfetched at this stage.

Mr. MCNEILL. And I did not call for that.

Senator REID. I know that. And I understand that you were not advocating it. You were just saying that the industry, to build a nuclear powerplant, is going to have to get some help.

Mr. MCNEILL. In the short term, yes.

Senator REID. That is right.

And I think the way the mindset of the American public is, as articulated by the Congress, it is not going to happen now. And that is why I commend Senator Domenici for holding these hearings. We have to look at doing some of these things differently.

Dr. Wilson, your statement, I think, said volumes. Professor, you said—and I would like for you to expand on your comments about how safe it is to store waste near the plants. As you know, we have out here at Calvert Hills, in Maryland, and other places, where they are storing not only in the cooling ponds, but they have moved it one step further and they have dry cask storage containment on site.

Now, I would like for you to expand on your comments about how safe it is to store nuclear waste on site.

Dr. WILSON. I think it is a very safe procedure. And I know in Europe that was very strongly encouraged, certainly when I first started thinking about this 30 years or 25 years ago. One of the main things you need is already in existence. That is to say a site perimeter where you keep out for their safety reasons. And that is rather important. If you have them off site and on a site remote from a powerplant, you do not have that safety perimeter. So, all you have to do is to keep people away from the waste, and then you are in good shape.

I suppose the one thing I think would be if a meteor hits the nuclear waste cask, I think all bets are off. It would be quite a mess.

Senator REID. If a meteor hit.

Dr. WILSON. It would be quite a mess whether the waste cask was there or not.

Senator REID. It would be kind of a mess, as you have indicated, whether the casks are there or not?

Dr. WILSON. That is right.

But those are the sort of calculations that people are doing when they are trying to prove that Yucca Mountain is safe and trying to imagine what would happen in rather extreme circumstances. And if those extreme circumstances happened, there would be a lot of other troubles, too.

Senator REID. But as you said, Dr. Wilson, these same calculations about the meteor would also apply to onsite storage.

Dr. WILSON. Of course.

Senator REID. Now, Mr. McNeill, what is the average life expectancy of nuclear power in the country today if there is no relicensing?

Mr. MCNEILL. If there is no relicensing, plants were originally licensed for 40 years.

Senator REID. And I have been told the average life expectancy for nuclear power, based upon those calculations, is about 15 years.

Mr. MCNEILL. I guess the average remaining life of all plants is in the 15- to 20-year range, yes.

Senator REID. How many nuclear powerplants are there in America today?

Mr. MCNEILL. Slightly over 100.

Senator REID. That is my understanding. For $7 billion which we have spent already at Yucca Mountain, what could we do to build a—it is my understanding it is called a breeder reactor, to start reprocessing some of these plants—how much would it cost to build a breeder reactor facility to start reprocessing some of our spent fuel?

Mr. MCNEILL. I have no knowledge of that. It would be probably be in the single-digit billions of dollars.

Senator REID. It would not be $7 billion?

Mr. MCNEILL. I do not know that. I have a two-unit station that the original cost was $6.7 billion. So, the same comparable number.

Senator REID. Dr. Wilson, would you agree?

Dr. WILSON. Well, I think there is an important distinction here. You do not, in the first instance, need a breeder reactor. You need a reprocessing plant. And we have had, of course, reprocessing plants in this country, certainly in the military sector. In fact, the first use of nuclear fission was to reprocess the material and make plutonium for military purposes.

But a reprocessing plant for civilian purposes will be in the billions, I think, but probably not $8 billion. But I must say, the Japanese, on the other hand, did spend a lot of money on their reprocessing plant—close to $20 billion. And everybody thinks that was much too much.

Senator DOMENICI. Senator, England spent $3 billion for their MOX reprocessing.

Dr. WILSON. That is right.

Senator DOMENICI. And the difference between the breeding and MOX is breeding is used to produce more plutonium. MOX is used to make plutonium such that it can be burnt in the kind of reactors that produce electricity around the world.

Senator, did you have any more questions?

Senator REID. Not at this time.

Senator DOMENICI. Senator Stevens.

Senator STEVENS. I have no questions.

Senator DOMENICI. Senator Craig.

STATEMENT OF SENATOR LARRY E. CRAIG

Senator CRAIG. I came late, Mr. Chairman, and I do not have questions. I will make a very brief comment, and ask unanimous consent that my statement become a part of the record.

I thank you for pushing the envelope on the knowledge that this Senate has to gain as it relates to our nuclear generation industry in this country. For those who are frustrated by it, I would only ask them that in areas where we are in search of reaching attainment in clean air, we are going to build some more new nuclear plants to get there, plain and simple. We have got to.

And the environmental community is beginning to awaken to that simple fact: that our country runs on energy, abundant energy, and that to clean up our congested urban areas, a lot of things need to get done. And to get there, we have got to, whether it is short term, 50 to 100 years, or long term, longer than that, we are going to need some more nuclear generating plants, powered by nuclear energy.

Now, having said that, bringing permanency to the issue of spent fuel is critical, along with all the other advancements we have to make. Their willingness to push the budget envelope in this area is critical. This country ought to get smart and it ought to wake up. It cannot deny its facts. And even 2 weeks ago, when I journeyed out on the front over here, to look at all these marvelous new electric car prototypes, I was reminded by one thing that is inside the battery of those cars. It is electric energy generated by somebody.

So, even that process is going to require us to have an abundance of electrical energy. And there seems to be only one way to get there and still achieve our clean air and climate change concerns. And I do believe that the country is awakening to that.

Thank you.

Senator DOMENICI. Thank you very much.

I have one last question for you, Dr. Wilson. The Nuclear Regulatory Commission has clearly, as you have indicated in your brief remarks, a very important role in safety and oversight and regulation of the nuclear power and related nuclear licenses. The Louisiana Enrichment Corp. decided, after 11 years of attempting to obtain a license for an enrichment facility, to quit this effort. How can the Nuclear Regulatory Commission commit to such an excessive licensing process to occur? And what can Congress do to ensure such delays do not occur?

Dr. WILSON. Well, I heard about that particular item last week, when I was in Vienna. And I thought it was only 7 years that they had been trying for the license, but that is bad enough. Because this enrichment facility is much safer than a reactor. It is one of the more benign things one can have. And to spend 7 years on licensing it, it seems utterly absurd. And I do not quite know what one can do about it. I would just urge the NRC to go at every one of the regulatory actions with much more speed than they are now doing.

Senator DOMENICI. Mr. Colvin, do you have some suggestions in that regard?

Mr. COLVIN. Well, Mr. Chairman, that is a tragic example from our national perspective in two elements. And that is, first, that the Congress, with the passage of the Energy Policy Act in 1992, in fact, set up a one-step licensing program to license this enrichment facility, which I agree with Dr. Wilson, at those levels, is safer than most other facilities, certainly chemical plants or other plants that would be built in that part of the country.

The recommendations that I have for the Nuclear Regulatory Commission are really to expedite the changes in their licensing process and their atomic safety and licensing and board processes that have been, in my view, the problems that have caused these delays with respect to not only the scope of those hearings, the depth of those hearings in areas not related specifically to the safety of the operation of those facilities, and also in the incentives, in establishing incentives for those licensing boards to bring those issues to conclusion within a reasonable period of time.

In order for our Nation to go forth and relicense or transfer the licenses of any issue, they need to deal with that in a very expeditious process.

Mr. MCNEILL. Senator, if I could comment.

Senator DOMENICI. Mr. McNeill, you look like you wanted to comment.

Mr. MCNEILL. I do. Because this will be an important issue as we move forward to acquire plants, because it will be a license transfer process. And I think I will be very specific on this. I think that the Nuclear Regulatory Commission itself needs to make sure that the issues that are allowed to be heard are relevant to the license transfer process and that they provide very strong guidance for their administrative law judges as to the timeframes in which they reach decisions. Those two things are going to be very critical in moving forward on this issue.

Senator REID. Senator Domenici.

Senator DOMENICI. Yes; Senator Reid.

Senator REID. I am going to go to my office for a few minutes and then come back, but I would like Dr. Jenkins-Smith, sometime in the next few days, to call me so we can go into some detail about your work. If you will do that, I will not take up the time of the committee.

Senator DOMENICI. Very good.

Senator REID. Thank you.

Dr. JENKINS-SMITH. Yes, Senator.

Dr. WILSON. Mr. Chairman, can I make one comment?

Senator DOMENICI. Sure.

Dr. WILSON. This is partially on the waste question. You asked about temporary waste storage. Everybody says no one wants waste in their own backyard. But an Indian tribe in Utah wants waste in their own backyard. And there are one or two people who do not want them to have it. The Nuclear Regulatory Commission are estimating the licensing here would last at least 4 years, when, in fact, it is not a particularly unsafe business.

I have got together a group called the Scientists for Secure Waste Storage, which has six Nobel laureates, three former chairmen of the NRC, two former Ambassadors, a former astronaut, and an Indian, with some overlap between these, and we are trying to intervene in support of this licensing hearing. I believe actions such as this may, in fact, if people are galvanized into doing these things, public citizens, we may get somewhere. But unfortunately, so far, the Licensing Board has voted 2 to 1 not to allow us to do it, and we are appealing to the Commission.

Senator DOMENICI. How long did the Southern Nuclear license transfer take? Who knows the answer to that?

Mr. COLVIN. It took about 5 years, Mr. Chairman. That was to transfer the license for Plant Vogel and Plant Hatch in Georgia, which is part of the same Southern Co. system, to the Southern Nuclear Operating Co., one of its subsidiaries.

Mr. MCNEILL. If I might make a point here. The operators were no different. These were legal entities, and the people at the plants were no different before or after the license transfer.

Mr. COLVIN. Exactly.

Senator DOMENICI. You have probably answered this, but were there any difficult issues involved in that?

Mr. COLVIN. There were allegations that were provided to the Nuclear Regulatory Commission in a number of different areas. But, in my opinion, none were germane to the issue of license transfer between the entities, as Mr. McNeill points out.

Senator DOMENICI. Did you want to say something, Dr. Jenkins-Smith?

Dr. JENKINS-SMITH. Yes, Senator, just one point on the issue of obtaining licenses and public support. And that is, first off, when we get into these debates, what the public hears are discussions of risk. Is it big or is it small? They never hear it is zero, of course. And because they have detached the idea of risk from the national benefits that are associated with it, any risk that is being imposed upon people from the outside is going to be seen as unacceptable.

If we do not change the tenor of this debate and integrate some notion of benefits and what the national gains are, we are not going to make much headway.

Senator DOMENICI. That is a very good point.

In closing, I just wanted to share with the four of you, and as part of this public record, there have been a lot of complaints and concerns about the Kyoto accords, with reference to their impact on the United States and how urgent are the reductions that are contemplated. Professor Wilson, as Professor Jenkins-Smith alluded to, I wanted to share with you that I made a major proposal with reference to a whole scheme of nuclear activities, and delivered it at Harvard University, and then I circulated it to a number of people.

First, let me say to all of you that our office has been absolutely amazed at the hundreds and hundreds of Americans who are knowledgeable in the fields of energy and physics and the like who have responded, essentially with long letters, but essentially saying it is about time for America to debate this issue. We are not on the right wavelength. We are talking about something that is not real.

But getting back to Kyoto, as a result of that text, I held a meeting in a number of cities—one in Los Alamos, where some of the great, great physicists that America has had, and some Nobel people came. And one of them said, I read with interest the Kyoto accord, from page 1, all the way through. And I must conclude that they were a fraud. And that is a pretty tough word. And so I said, why? He said, because how could you write in depth on the status of pollution in the atmosphere that comes from generating electricity and not mention nuclear power one time in the entire report?

Now, if I had not had such great respect for this particular gentleman, who I first met 25 years ago and had just marvelous opportunities to talk to him about what was going on in Russia when he used to go visit—he was an early on predictor that they were not as powerful as we thought. I will tell you one thing, professor, that you will appreciate, he said, I went to the laboratory of one of their great nuclear physicists, and I noted that he was the only one around who had a way to sip tea. And he had produced his own little teapot as part of a bunsen burner that is used in a laboratory, and that they did not even supply that—tea, coffee, or anything—to any of their major scientists in this laboratory. And he started thinking back from that, that things were kind of different than we might have expected.

But we have to raise the issue with the people of this country, that if we are worried about pollution and we are worried about what is going to happen if, in fact, we have some big climate changes because of ozone, you know some leadership is going to be blamed if we do not consider a dramatic way to avoid that over the next 50 to 100 years by a source of energy that contributes absolutely nothing to the water and air pollution of our country and the world. And that is essentially the big picture idea that is behind what we are talking about.

Thank you, all four of you. And let us have the next witnesses, please.

Senator CRAIG. Mr. Chairman, while the next witnesses are coming up, I am pleased that you noted the relicensing process. In another committee, I am examining hydro relicensing. Now, between nuclear and hydro, nonpolluting energy sources, that represents about 33 to 34 percent of the total electrical output in this country. And those are the two very areas that are most impacted by bureaucracy and uncertainty at this moment.

And, frankly, it is us. It is the Congress of the United States that has not had the statesmanship, if you will—and that is no reflection of anybody on this committee, but we have kowtowed to a myth, and now we are faced with that. And I notice that in the administration's proposal, when we talk about climate change, you notice they did not mention nuclear. And the professor mentioned this. And they did not mention hydro either as a renewable.

So, I think it is reasonable to say that the reports were a hoax, because they did not mention, in this country at least, nearly 35 percent of the electrical output, of the clean output.

Thank you.

Senator DOMENICI. Thank you for the comments.

Can we go through the next four witnesses and identify them right now, and then we will proceed from right to left as we did before. And I would hope you would keep to your time. We have gone over a bit.

We have Alan Smith, master of engineering candidate, Department of Nuclear Engineering, Massachusetts Institute of Technology; Dr. Stan Schriber, deputy division director, Los Alamos National Laboratory; Mr. Linden Blue, vice chairman of General Atomics Corp.; and Dr. Charles Till, senior counselor to the laboratory director at Argonne National Laboratory. I am delighted you all would come.

We will start with you, Mr. Smith. I am going to be excused for just 2 minutes. Harry, would you take over for that 2 minutes?

Senator REID [presiding]. Please proceed.

STATEMENT OF ALAN B. SMITH, GRADUATE STUDENT, NUCLEAR ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. SMITH. Very well, Mr. Chairman, Senators Reid, Stevens, and Craig, my name is Alan Smith. I am a graduate student at MIT. And with me is Dr. Jeffrey Friedberg, the head of the Nuclear Engineering Department at MIT. And I am here representing a group of both graduate and undergraduate students who have spent about the last 6 months investigating advanced nuclear energy technologies that have the potential to be developed to address global climate change on a proliferation-proof worldwide scale. We think we may have an answer.

This morning I would like to report on this nuclear energy design project and what I believe are opportunities to get students interested in pursuing a career in nuclear technology. This nuclear energy plant design project began as a design competition sponsored by the American Nuclear Society, aimed at stimulating interest in nuclear energy at those universities that still teach the subject. The original title of the competition was "The Economic Imperative," which challenged students to think creatively about what could be done to bring down the cost of nuclear powerplants to a level to be competitive with new natural gas fired fossil plants.

At MIT we took a broader view, and renamed our effort the economic and environmental imperative, to incorporate our belief that it will take more than just an economic advantage to bring nuclear into the energy mix. Our desire was to develop a conceptual design of a politically acceptable reactor that was also economically viable. And the recent developments in India, for example, reinforce the need to develop a nuclear energy plant that is more proliferation proof, to take advantage of the enormous environmental benefits that nuclear energy offers.

Our goal is to develop an entire package, not just the technology. Which, you see, in the past we have had wonderful technology in the nuclear industry. We keep wondering why people do not get it. It is safe. It is reliable. We have focused on the technology. We have tried to broaden that, to look at the design, the fuel, the waste, construction schedules, final cost of power, and the financing and public acceptance portions of this.

What we did know is that today's current plants were expensive to build, are expensive to operate, are very difficult to keep in current regulatory compliance, and are perceived by a significant portion of the public as generally unsafe. And it was our belief that an improved version of the same old thing would be insufficient. The time is right to develop something completely new. So, with that framework, we said we have no preconceived ideas of what is available. What would the ideal nuclear plant really look like?

We decided it would be naturally safe, transparently safe, so safe there would be no question. We do not have to talk about 1 times 10 to the minus 5th or 10 to the minus 7th or whatever else. The answer is it cannot have a fuel damaging accident.

We knew that it had to be economically competitive. And we translated that into being able to be assembled in a factory, a production line if you will, to crank out these things. It did have to be politically acceptable, with easy waste handling and storage. And we looked at 20 other different factors, things from operating staff size, whatever. Then we researched all the available plants that are in the world. We looked at advanced lightwater designs. We looked at heavywater designs. We looked at the gas plant.

As a matter of fact, we had a representative from Mr. Blue's General Atomics come and speak to us about the things they were doing.

We picked the best attributes, in our estimation, from each of those different things and combined them into one conceptual idea. And from there we began, this past semester, doing detailed analysis of could it really be done. Could it really be made foolproof? Could it be made operator proof? Could it be made in a factory and shipped by truck, quickly?

And what we found was it can and it can. There is no exotic technology involved. We decided on a gas-cooled small, pebble-bed type fuel nuclear plant with gas turbines. And it allows us a lot of different things. First of all, no meltdown can occur. And Mr. Blue, I know, will speak on that some more. It can be factory assembled and shipped by truck to any particular site.

Our particular design has online refueling, which means that the plant never has to shut down to refuel. Our concept, with a small, 110 megawatt plant, is that you can tailor it to any specific energy size demand you need. Perhaps in the United States, if you want 1,200 megawatts, that is fine; you can build 11 or 12 of those units. But say, if a developing nation is looking for a new, environmentally safe energy source, they do not have the electrical grid to be able to build a 1,300 megawatt plant and distribute the power. But they can build 300 megawatts, 400 megawatts.

We then went and looked beyond just the nuclear technology. And we were able to develop, and are still developing, a concept for an international licensing approach. One of the goals of this particular plan is it is so simple that a country does not need a detailed nuclear infrastructure, with a large number of nuclear laboratories, just to support this. So, an external organization could be more involved in the operations of this.

We have developed a rapid construction methodology, and we have a working model now that shows that the first unit could be available in just over 2 years from the time a construction order went in. They would build it in the factory, put it on a truck, and you could get it.

Finally, we are developing some frameworks for creative financing alternatives to make it more attractive for industries to get into this, in some consortium-type ideas, whereas with our current plans, if you put in an order, it would then go out to bid. Well, who is going to build the turbine? Well, let us look at General Electric. Let us look at Westinghouse. And it continues to change the design. Now, the turbine manufacturer is an equity owner in this operation so they can get right into it.

Senator REID. Mr. Chairman, one brief question.

Senator DOMENICI [presiding]. Yes; Senator Reid.

Senator REID. What does being factory manufactured have to do with it? You keep talking about that. What difference does that make?

Mr. SMITH. To address the fact that the current plants we have right now are taking anywhere between 7, 8, 9, 10 years to build. So much can change to project the energy needs for a particular area 7 to 10 years from now, especially with deregulation, there is a very big disincentive. Now we can say 2½ years, or build six of these small units and then, 5 years from now, if you need more capacity, you can add it on relatively quickly.

A great deal of work remains to be done, obviously. The inherent safety of this design means that the current regulatory framework will need to be reshaped. Risk analysis needs to be further evaluated. But as someone who is personally convinced of the importance of nuclear power in our national security, it has been very encouraging to see the amount of enthusiasm that this project has built. One of the things we have not heard as we are looking at the future of the nuclear industry in the United States is who is going to do it.

The people that designed these plants in the sixties and built them in the seventies are retiring. We just had the new, incoming class of freshmen at MIT declare their majors and we only had six say nuclear, which is less than one-half of what we would typically have. So, it is an issue. And in order to keep the interest and ensure enough students continue to pursue this, it is important to support projects of this type with new, innovative designs, to show there are new challenges.

PREPARED STATEMENT

And I would like to close by thanking the committee for your interest and hope that as you are talking about pushing the funding envelope, Senator Craig, that ideas and developmental projects like this will be an important part of the mix.

[The statement follows:]

PREPARED STATEMENT OF ALAN B. SMITH

ADVANCED NUCLEAR ENERGY TECHNOLOGIES

Mr. Chairman, my name is Alan Smith. I am a graduate student in the Department of Nuclear Engineering at the Massachusetts Institute of Technology. With me, is Dr. Jeffrey P. Friedberg, the Chairman of the Nuclear Engineering Department. I am representing a group of both graduate and undergraduate students who have spent about 6 months exploring advanced nuclear energy technologies that could be developed to address global climate change on a proliferation-proof, worldwide scale. We think we might have an answer. This morning I would like to report on our nuclear energy plant design project and what I believe are opportunities to get students interested in pursuing a career in nuclear technology.

This new nuclear energy plant project began as part of the American Nuclear Society's design competition aimed at stimulating interest in nuclear energy at the universities that still teach the subject. The original title of the competition was "The Economic Imperative" which challenged students to think creatively about what it would take to bring the cost of new nuclear power plants down to levels that would be competitive with new natural gas fired fossil plants. Natural gas plants were chosen as the standard because they are the current choice of electric generating companies due to their low capital and present low fuel costs.

At MIT, we took a broad view and renamed our effort as "The Economic and Environmental Imperative" to incorporate the belief that it will take more than economics to bring the benefits of nuclear energy to bear in addressing the problems of air pollution and global climate change. Our desire is to develop a conceptual design of a politically acceptable reactor that is also economically viable. Recent international developments in India should reinforce the need to develop a nuclear energy plant that is more proliferation proof to take advantage of the enormous environmental benefits that nuclear energy offers.

The issues confronting reintroduction of new nuclear power plants into the world energy mix are many. They have to do with public and political perceptions about safety, nuclear waste, proliferation, radiation, regulatory stability and financial viability, given the history of nuclear power to date. We took a broad view to this issue, to the extent that the acceptability of the technology was as much a part of the solution as the economics. Our position is that the acceptability of the technology is as much a part of the solution as the economics. Our objective was a complete package—the technology, the design, the fuel, the waste, construction schedules, the final cost of power, the financing and the public acceptance program.

This project began with a review of the present issues confronting nuclear energy that prevent its widespread use. The nuclear technology currently in use across the country has several shortcomings that limit its desirability as the type of nuclear plant for the future. Most of the shortcomings stem from the size and complexity of the various integrated support systems, which have driven up capital costs, staffing requirements, and regulatory requirements. Today's plants were expensive to build, are expensive to maintain and operate, and difficult to keep in compliance in the current regulatory environment. Due to these factors, extraordinary management attention and skill is required to keep the plants operating. The high demand for management attention, far exceeding that of the alternative sources of electricity, is a serious deterrent to new orders. Prescriptive regulatory constraints imposed by the Nuclear Regulatory Commission stifle innovation, which makes current and even future nuclear plants hostage to old technologies and approaches.

Despite ample scientific evidence to the contrary, the public perceives the current generation of nuclear power stations as generally unsafe. Additionally, existing nuclear stations are faced with an increasingly critical lack of a spent fuel disposal capacity. Falling coal and natural gas prices, when coupled with expensive modifications to nuclear plants following the Three Mile Island accident resulted in the elimination of much of nuclear power's generation cost advantage over fossil fuels. Ultimately, the combination of adverse public opinion, regulatory pressures, and economic challenges that exist today have resulted in two decades of no new orders of nuclear stations.

As you are aware, worldwide concern over greenhouse gas emissions is prompting a reevaluation of the role nuclear power should play in the world's energy generation. Conservation efforts and renewable resources will simply be unable to meet the growing global demand for electricity, let alone reduce current dependence on fossil fuels. Secretary of Energy Frederico Peña recently called nuclear power "an important part of our energy mix" and noted that the Department of Energy's proposed fiscal year 1999 budget contains $44 million in funding for nuclear energy research and development. When pressed, even the most vocal nuclear power opponents are beginning to admit that emission-free nuclear power will continue to play a vital part in meeting the world's growing energy needs without accelerating the greenhouse effect.

In spite of the obvious benefits, the prospect for building future nuclear power plants in the U.S. is questionable. What is not in question, however, is that any future nuclear plant must be perceived as a significant improvement over current designs if it is to warrant serious consideration. Experience gained after thirty years of commercial operation has shown that development of a successful design must address much more than just engineering issues. Political and economic considerations play just as important a role in determining the eventual success or failure of nuclear power.

Perhaps the three largest public (political) hurdles facing the nuclear industry deal with the eventual disposal of spent fuel, the potential for nuclear proliferation, and eventual plant decommissioning. The long delayed nuclear waste disposal facility at Yucca Mountain is becoming a multi-billion dollar monument for why nuclear power is in decline in the U.S. Additionally, political instability and the threat of terrorist use of nuclear material, no matter how remote, make growth of nuclear power unattractive to many governments. Finally, decommissioning of current nuclear stations is costing as much as ten percent of the original construction cost. These issues were not considered during the design and construction of the current generation of nuclear plants. However, future designs must be able to effectively address these issues if they are to receive serious consideration in the future.

Based on the preceding challenges, and even with renewed interest in commercial nuclear generation, it is likely that problems associated with current designs will make them unattractive for consideration for future construction. Public perception, regulatory, and economic factors that have caused existing designs to lose favor are unlikely to change. It is therefore apparent that any future commercial nuclear power plants must be a significant departure from stations built in the past. In other words, to be "revolutionary" rather than "evolutionary". To that end, we feel the following attributes are essential for the new design:

—The plant design must be naturally safe. In other words, even in the worst-case scenario of having the nuclear plant at maximum power and simultaneously stopping all coolant flow, there can be no damage to the plant or any adverse impact on the safety of the public or the environment. The safety of the plant must be obvious to both the public and the regulators. The design must support risk-informed regulation. The safety of the plant must be demonstrable.

—The plant design must support a much shorter construction time. Construction costs should be low and predictable. To facilitate rapid construction, designs should emphasize modular construction. This will not only reduce total assembly time, but also offer the improved quality control and economic advantages of production line fabrication.

—The plant must also be designed with eventual decommissioning in mind. Sizing and design of systems to facilitate rapid disassembly, ease of decontamination, and ease of disposal should be performed so that a decommissioning plan can be developed before construction even begins.

—In order to reduce operating costs, the plant must be designed to minimize lost generation due to refueling or maintenance shutdowns. Accordingly, the design should provide the capability to refuel and perform maintenance on-line. If online refueling is not possible, the design should allow for rapid refueling. Components that are expected to require replacement during the life of the plant should be designed for ease of removal and installation.

—The plant should be simple to operate (amenable to automation), and maintain in order to allow for small staffs that require less technical expertise.

—The design should be able to be used in a country without the extensive nuclear infrastructure through a turnkey type of contract for operations and support.
—The design should provide a plant with lower radiation dose levels and less radioactive contamination than current plants.
—The design should ensure minimal environmental impact. Additionally, it should be capable of operating at high thermal efficiencies and allow for the use of waste heat for other commercial applications if desired.
—The design should use a simple fuel cycle that provides the highest possible resistance to proliferation, does not depend on reprocessing have high fuel burn up, and it should support burning mixed oxide fuels. Additionally, the fuel type used must offer ease of fuel storage and disposal and good fuel integrity.
—The design should be acceptable for the international market in terms of safety and proliferation resistance under a standard international safety authority.
—The plant should be able to be site assembled quickly using prefabricated units shipped by barge or by train to potential sites.

Using these fundamental criteria as to what we thought we would need, we then proceeded to review the options that are currently available for construction and those under development to see how they ranked against our criteria. As you are aware, the nuclear industry has been developing new advanced reactor designs under guidance documents prepared by the Electric Power Research Institute and implemented by major nuclear plant vendors in the United States. Each of these new designs is under review by the Nuclear Regulatory Commission for design certification. Some have already been granted approval and detailed first of a kind engineering is underway.

In addition, the issue of nuclear proliferation was explored to determine what kinds of design features were important to reduce substantially the risk of the spread of nuclear materials to terrorists or terrorist states. Presentations of "new" technologies were also heard which included gas-cooled reactors, lead bismuth reactors and light water reactor breeders. We chose not to consider liquid metal breeder reactors because the political climate for their acceptance was not conducive at the present time (although a great deal of work has been done on them in this country).

Based on these presentations and student research, a matrix of important factors was developed with weighting factors and each plant type was subjectively ranked against these criteria. The primary factor used to judge acceptability was demonstrable safety. Economics was second. The list of criteria numbered over 20 and included such things as short construction time, small operating staff, high efficiency, proliferation resistance, short or on-line refueling, public support, ease of maintenance and repair, and ease of decommissioning.

Upon completion of this review, we selected a small, modular pebble bed fuel, helium gas cooled reactor with gas turbines to generate electricity. We chose a small modular reactor about one tenth the size of today's large nuclear power plants because of the improved safety, ease of operation, and ability to be mass produced, which we expected to yield lower costs. The 110 Megawatt electric size of the plant is naturally safe with no operator or other passive mechanical action required, even for the worst contemplated accident in which all cooling systems are turned off. No meltdown can occur.

Given the small size of the plant, there will not even be any fuel failure, thus no release of harmful radioactivity. The plant is specifically sized and designed such that it will naturally shut itself down with no dependence on active or passive systems. The small size and improved proliferation resistance is also suitable for developing nations as they seek to build their electric grids and developed nations who want to add incremental capacity based on market demands. Modules in increments of 110 megawatts could be added to each plant to make up a plant of 1,100 megawatts or larger depending upon the needed capacity.

The pebble bed fuel design was chosen because it allows for on-line refueling which will increase the generating potential of the plant. The gas turbine electric generating cycle is also very efficient with efficiencies as high as 50 percent possible with less wasted energy. The electric generation side consists of a gas turbine that is similar in many ways to those currently used in natural gas burning fossil plants. Although initial designs would include an intermediate helium to helium heat exchanger, future designs could eliminate this feature as fuel performance data is developed. The "direct" gas cycle compares very well with conventional natural gas plants and far exceeds present nuclear plant efficiencies of 33 percent.

The proliferation concerns are addressed by the fuel type used. The fuel is contained in carbon microspheres, which provide the containment for storage and disposal, and is of a form that makes reprocessing extremely difficult, if not impossible. As all nations attempt to combat global climate change, proliferation resistance is extremely important for worldwide deployment of advanced nuclear energy technologies, especially in developing nations. A key attribute of our design is that the plant is simple enough such that the need for a nuclear infrastructure will not be necessary to allow for safe operation. Our concept calls for an international licensing approach that will have fuel supplied by international authorities and used fuel collected and disposed of by the same international consortium that would have strict fuel accountability.

These plants, because they are so simple in design and naturally safe, would be sold as turnkey modules as standardized units. The consortium in charge of design and construction would also provide training to the operators and maintenance personnel to assure safe and reliable operation. This plant would truly be an international plant suitable for use in all countries without the need for these countries to develop sophisticated research laboratories to support this technology. The plant's safety and performance would be regulated in accordance with an international regulatory authority such as the International Atomic Energy Agency.

The other key factor in the selection of this technology and size of plant is its ability to be factory assembled. This will not only enhance quality which can be better controlled in a factory environment, it will also speed construction time such that we expect to be able to have a 110 MWe module operating within 122 weeks of start of construction—just slightly over two years. The key is the small base units that allow rapid sequential completion of up to 1,100 Mwe or larger. The factory assembling the modules can ship a module to the site as soon as it is complete and the next module is still being assembled.

Our analysis shows that the site preparation to support a ten-unit station will be completed at approximately the same time that the first module is ready to be shipped to the site. It is also estimated that a limited-scope factory assembly operation is capable of assembling a module and preparing it for shipment within three months of receiving all necessary components. Therefore, if modules are shipped to the site as soon as they are assembled and tested, a new module will be arriving and being installed every three months. Because each module is completely autonomous, the unit will be capable of operation as soon as it undergoes fuel loading and final installation testing. This means that power generation can begin well before the completion of the remaining units.

This radically new approach understandably presents new economic conditions and considerations. We believe our design makes it uniquely attractive to a wide variety of investors. In the U.S., for example, the uncertainties associated with deregulation, regulation, and future energy demand have served to discourage construction of nuclear facilities. The small size of our design allows for prompt, incremental addition to existing generation capacity at the lowest possible capital cost. In developing nations or areas that do not have the infrastructure to support the construction of a large plant, a few of these smaller units represent the ideal solution to their energy needs.

This past semester was spent performing much more rigorous engineering analysis to bring our concept to life. Work on the nuclear plant design was performed to analyze the performance of the nuclear fuel over the operating cycle. Nuclear plant operating characteristics were analyzed under various accident conditions to demonstrate that the design is in fact naturally safe (it is). Equipment dimensions were calculated in order to determine if components could be shipped from the factory to the site by truck or rail (they can). Vendors and consultants were contacted to validate the feasibility of the rapid construction potential of this design (it is possible).

In summary, we are very encouraged by the potential of this design to meet some of the world's future energy needs safely, economically, and without harming the environment. Producing electricity by splitting atoms is a technical challenge we were able to meet forty years ago. If we wish to continue to do so, however, many more challenges must be addressed with the same effort. We believe that this design is uniquely able to meet the challenges of proliferation resistance, waste disposal, safe operation, and economic performance that the next generation of nuclear plants will face. And we are not alone. The Germans, Japanese, Chinese, and Russians are all doing research into designs of this type, and the South Africans are moving ahead with plans to construct a gas cooled plant for commercial power generation.

Of course, a great deal of work remains to be done. Additional research is needed to further investigate new techniques for safe handling and storage of waste, improvements in the design of the fuel, and ways to make the fuel even more resistant to proliferation. The natural safety of this design means that the current regulatory framework will need to be reshaped, and risk analysis needs to be further evaluated.

During the course of our work, a large number of students and faculty became very interested in the possibilities this design offers. As someone who is convinced of the importance of nuclear power to our national security, it has been very encouraging to see the amount of enthusiasm this project has generated. The enthusiasm however is not limited to this specific design. Rather, it is generating new discussions about the future of nuclear energy, waste, proliferation, and plant safety that will improve the performance of any nuclear plant design. They are talking about meeting the greenhouse gas emission goals recently established in Kyoto, and talking about new ways to safely meet the world's growing energy needs. In short, Mr. Chairman, there is a spark of optimism about the future of nuclear power that has been absent during recent years.

I would like to close by thanking the committee for your interest and hope that you and your committee approve additional funding for universities to continue this project and others like it.

Senator REID. Mr. Chairman, I would like to be excused. I will say that I have read the testimony of the other three witnesses. It was very impressive, just as with this young man. I am especially interested in the testimony of Linden Blue, about the new technology that we are going to have to look at very closely in this subcommittee.

Senator DOMENICI. Mr. Smith, I continue to be amazed at what the students and graduate students in our great universities can accomplish. And your professor was a very astute fellow when he asked you, as students, to take this project on. And I would venture a big bet that your conclusions are probably fairly close to being correct, without having large resources to accomplish what you have done. And I personally am glad that we found you and brought you here.

And thank you very much for your testimony and for what you are doing. And I hope that we do not let people like you down, who have these great ideas and want to do these kind of things by turning the spigot off and saying that we want to hide from all of this in the United States.

Dr. Schriber.

STATEMENT OF STAN O. SCHRIBER, PH.D., LANSCE DEPUTY DIVISION DIRECTOR, LOS ALAMOS NATIONAL LABORATORY, NEW MEXICO

Dr. SCHRIBER. Mr. Chairman and members of the committee, I am honored to be here to talk to you about an opportunity for this country in one aspect of our generating energy.

Energy is a strategic commodity for our country, and it has and will continue to have an enormous impact on our lifestyle and our ability to remain a great nation. In this context I would like to make four key points today.

First is that a technical solution to the issue of long-lived nuclear waste is feasible. Second, the solution can contribute to nonproliferation goals. Third, the solution can be economically effective, politically attractive, and has international support. And last, the solution builds on developments underway in Department of Energy laboratories with worldwide collaborators.

The issue I am addressing is disposal of spent nuclear fuel from our nuclear power reactors. Accelerator-driven transportation of waste, or ATW as I will call it in this presentation, is a technology option for assisting waste disposal in this country. With ATW, a permanent repository is still necessary, but more efficient use of its capacity is possible. A key concept in ATW is transmuting nuclear waste, actually destroying the long-lived isotopes so that the material to be stored has a lifetime that is short compared to the time scale of geological change.

We have reached the stage in the development where it would be prudent to take the next step in technology development: a 5-year plan. The path of ATW technology development can provide technologies important to future nuclear options and/or strategies as recommended by the President's Committee of Advisors on Science and Technology, even if ATW was not added to the suite of future systems.

ATW design has matured significantly over the years, being based on elements that have evolved within the international, as well. The nuclear burner would use liquid lead bismuth technology based on extensive Russian nuclear reactor work. Research groups in Europe and Asia are also considering similar systems.

Operating the ATW burner in a subcritical mode enables the destruction of actonides and fission products safely without isolation of weapons-grade material, and without extensive separations work, all in a single-purpose device. ATW impacts the need for a second geological repository by increasing storage efficiency and decreasing long-term risk. In addition, the ATW system converts the transuranics that were going to be buried into useful electrical energy. Thus the system could be energetically self-supporting, providing its own energy and providing a net power output to the electrical grid.

I will run through a brief scenario. Over a 65-year period, an ATW system consisting of 20 burners could transmute the spent fuel accumulated to the year 2015, and enhance the efficiency of the repository such that a second one would not be necessary well into the foreseeable future. The 70,000 tons of spent fuel includes 600 tons of transuranics, mostly plutonium, with some neptunium and americium.

Output from the system would be 67,000 tons of uranium that could be considered low-level waste; less than 0.3 tons of transuranics—that is a reduction by more than a factor of 1,000; 3,000 tons of fission products, with minimal technetium and iodine, which are really the bad actors—a reduction by more than a factor of 20 in capacity for the repository. In addition, you get electricity for the grid, you get 5 trillion kilowatt hours of emission-free energy over the 40 years.

And, finally, residual activity and radiotoxicity of waste in the repository after 300 years is less than that of a nonassisted repository after 100,000 years. The seven organizations that are part of this official ATW collaboration are the Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratory, Westinghouse Savannah River Co., Bechtel National, Northrup Grumman, and Westinghouse Electric Corp.

In addition, the University of California, Berkeley, and the University of Illinois are participating. This is a strong collaboration, with expertise in the relevant technologies and large-scale applications. Up to now, all of the funding in support of ATW studies has come from discretionary funds of the institutions participating in this collaboration.

With our industrial colleagues, we have determined that the economics appear favorable for an ATW-assisted waste management system. And, in addition, a technical path for the development of this option has been identified, with no show-stoppers.

With industry, we have developed a viable program plan for ATW and determined rough cost estimates for the above scenarios and for the development program. The 5-year technology development program has been estimated at $150 million.

There are important outcomes or legacies that come from this 5-year program that will have an impact in many other areas. To give you an idea of the outside view of this program, we held a review in January by the Nuclear Engineering Department of the Massachusetts Institute of Technology, a 2-day, in-depth review. Their report was positive, and I would like to just make a couple of excerpts from the report.

One of them was: We see no insurmountable issues or show-stoppers. The second one was: While we do not judge the merits of the ATW as an option and to improve the management of nuclear waste, we acknowledge that it has the potential to provide added flexibility to the design of the high-level waste repository and to reduce the uncertainties about its performance. And last: The R&D program is well designed to address these concerns.

The ATW collaboration has reached the stage where it is prudent to take the next step. We have an opportunity to make significant advances and to enhance the capability of a repository solution. In addition, the United States would continue its leadership role in an important area for the country and for the world.

Finally, I would like to thank you for the opportunity to speak to you today on ATW and its possibilities, and for your kind attention to this important issue.

[The statement follows:]

PREPARED STATEMENT OF DR. STAN O. SCHRIBER

ACCELERATOR-DRIVEN TRANSMUTATION OF WASTE: AN OPPORTUNITY

Introduction

Mr. Chairman, members of the committee, distinguished visitors, I'm honored to be here to talk to you about an opportunity for this country in one aspect of our generating energy. Energy is a strategic commodity for our country, and it has and will continue to have an enormous impact on our lifestyles and our ability to remain a great nation.

In this context, I would like to make four key points today:

—A technical solution to the issue of long-lived nuclear waste is feasible.

—The solution can contribute to nonproliferation goals.

—The solution can be economically effective, politically attractive, and has international support.

—The solution builds on developments underway in the Department of Energy laboratories with worldwide collaborators, but now needs your support.

The Issue—Nuclear Waste

The issue I'm addressing today is the disposal of spent nuclear fuel from our nuclear power reactors. I do not have to lecture you on the political difficulties in finding a home for nuclear waste that has a radioactive half-life of tens of thousands of years.

Accelerator-driven Transmutation of Waste, or ATW as we call it for short, is a technology option for assisting waste disposal in this country and other countires with nuclear power systems. With ATW, a permanent repository is still necessary, but more efficient use of its capacity is possible. The key concept in ATW is transmuting nuclear waste—actually destroying the long-lived isotopes—so that the material to be stored has a lifetime short compared to the time scale of geological change.

A national collaboration led by the Department of Energy laboratories has made significant technical progress in accelerator transmutation technology because of an interest in future energy economies for our country. We have reached a stage in the development where it would be prudent to take the next step in technology development—the 5-year plan which I will describe later. The path of ATW technology development could provide technologies important to future nuclear options and/or strategies (as recommended by the President's Council of Advisors on Science and Technology) even if ATW was not added to the suite of future systems. A suitable program to continue this important activity should be established in the Department of Energy.

What is ATW?

ATW is based on three major building blocks. These are:

1. A nuclear assembly where radioactive waste is transmuted by an intense neutron flux without using or creating a self-sustaining nuclear reaction.
2. A chemical extraction process to separate elements for recycling and eventual disposal, based on work underway at Argonne and Los Alamos to enhance proliferation-resistance and minimize environmental impact.
3. A high-power linear accelerator being developed under other programs within the USA.

ATW design has matured significantly over the years, being based on elements that have evolved within the international community as well. The nuclear burner would use liquid lead/bismuth technology based on extensive Russian nuclear reactor work. Research groups in Europe and Asia are also considering similar systems.

The accelerator provides high energy protons that produce copious neutrons from the lead/bismuth spallation target. These neutrons assist the nuclear burner in transmuting transuranics by fission, and fission products (especially technetium and iodine) by absorption. Operating the burner in a subcritical mode (possible because of the accelerator drive) enables the destruction of actinides and fission products safely, without isolation of weapons grade material, and without extensive separations work: all in a single-purpose device.

High level waste can be treated using an ATW system, whether that waste is staged to be placed in an operating geological repository or temporarily stored in a monitored retrievable storage facility. A deployed ATW system will likely eliminate the need for a second geologic repository by greatly increasing the high-level waste storage efficiency through transmutation. Transmutation would change the inventory of the types of materials stored, reducing long term risks. In addition the ATW system produces useful electrical energy as a byproduct. Thus the system could be energetically self-supporting, providing its own energy, and providing a net power output to the electrical grid.

ATW System Scenarios

We will have about 70,000 tons of spent reactor fuel accumulated in this country by the year 2015. This fills the repository as presently conceived. If we continue with nuclear power generation in this country after 2015, then a second repository will have to be considered unless some efficiency improvements are instituted within the repository plan. Three scenarios that have been investigated are described in the following:

1. Over a 65 year period, an ATW system consisting of 20 burners could transmute the spent fuel accumulated to the year 2015 and enhance the efficiency of the repository such that a second repository would not be necessary for the foreseeable future. Why was 65 years chosen? It was a reasonable compromise between the number of ATW systems, electrical output, infrastructure and a desire to stay within a logical human time frame up to a quarter filled before ATW starts to have an effect. Again the repository capacity is enhanced significantly and one can decide at that time whether it is appropriate to remove the stored material for treatment within an ATW.

Program and Plans

The seven organizations that are part of the official ATW collaboration are Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories, Westinghouse Savannah River Company, Bechtel National, Northrup-Grumman, and Westinghouse Electric Corporation. In addition, the University of California—Berkeley and the University of Illinois are participating. This is a strong collaboration with expertise in the relevant technologies and large-scale applications. Up to now, all of the funding in support of the ATW studies has come from discretionary funds of the institutions participating in the collaboration.

With our industrial colleagues we have determined that the economics appear favorable for an ATW-assisted waste management system. In addition, a technical path for development of the option has been identified; with no show stoppers. The no show-stopper situation has been verified independently by a MIT review that is mentioned later. A proposed 5-year engineering and development program that addresses key issues provides direction for the program and would provide logical exit criteria for decision makers based on the program developments. If successful, this assisted repository option would have many positive environmental and/or societal impacts.

With industry we have developed a viable program plan for ATW and determined "rough" cost estimates for the above scenarios and for the development program. Part of the five-year plan is to complete a more comprehensive study of costs and benefits. The five-year technology development program plan has been costed at \$115M total assuming funding levels at \$15M, \$20M, \$25M, and \$30M for each successive year. These levels have been determined on the basis of significant deliverables and demonstrations, and would provide adequate information for decision-makers to make an informed (retirement ages and expected human lifetimes). Input to the system would be the 70,000 tons of spent fuel mentioned earlier, which includes 600 tons of transuranics (mostly plutonium with some neptunium and americium). Output from the system would be: 67,000 tons of uranium that could be considered low-level waste (a much smaller quantity than what we have from the mining of uranium) or a resource to be used in reactors again in the future; less than 0.3 tons of transuranics (a reduction by more than a factor of one thousand) that would have to go to the repository; 3,000 tons of fission products with minimal technetium and iodine (the "bad" actors), that would have to go to the repository—for a reduction by more than a factor of 20 in capacity; electricity for the grid (5 trillion kilowatt hours of emissions-free energy over the 40 years); and residual activity and radiotoxicity of waste in the repository after 300 years that is less than that for a non-assisted repository after 100,000 years.

2. Assume that we continue with about 100 power reactors in this country for another 40 years beyond the 2015 time frame. For this scenario another about 70,000 tons of spent fuel would be produced. With an accompanying infrastructure of ATW's, as in the above example also producing electrical energy, the spent fuel material is converted while it is being produced; but with one ATW for every four power reactors on the assumption that they are of the present-day light-water reactor (LWR) type. If improved nuclear reactor concepts are realized then the support ratio could be one ATW for every ten power reactors or even maybe up to one for every twenty. This scenario produces electrical energy from the power reactors with a minimized high-level waste stream going to a geologic repository that has the possibility for a much reduced operation lifetime.

3. Assuming that an ATW demonstration would not occur until about 2015, means that the repository would begin accepting spent fuel for about 5–10 years prior to an ATW being introduced into the overall nuclear system. In this scenario, the repository may be decision on future program direction. These development costs, while substantial, are small on the scale of national electrical energy economics.

The five-year program focuses on essential technology development and evaluation necessary for a technically and economically sound concept for the first implementation. Critical technologies include mass flows, pyrochemistry, materials verification, technology transfer and integration, liquid lead/bismuth cooled cores with integral target, system studies, costing studies, solid fuel development and preliminary tests, repository interfaces and nuclear data experiments for improving computer modeling. Much of the technology development has broader applications.

Spin-offs

There are important outcomes or legacies from the five-year program. These include liquid lead/bismuth for future advanced nuclear systems, nuclear data and code improvements for basic science advances, high power neutron production targets for basic science research, waste disposition processes for environmental management, and system studies providing advanced fuel cycle information and a basis for future decisions and/or directions.

ATW Board

As mentioned above, we have a national collaboration involved in the ATW studies. We have formed an ATW advisory board from the members of this collaboration, a board to provide Los Alamos with advice on program's activities.

MIT Review in January

The Nuclear Engineering Department of the Massachusetts Institute of Technology held a two day in-depth review of the ATW technology in January. Their report was positive for the ATW program in general. Excerpts from their report include the following comments:

—“* * * we see no insurmountable issues or show stoppers. While the proposed technologies are in several instances extrapolations of existing experience to untested conditions, they represent reasonable targets for development over the next 5 to 10 years.”
—“While we do not judge the merits of the ATW as an option to improve the management of nuclear wastes, we acknowledge that it has the potential to provide added flexibility to the design of the high level waste repository and to reduce the uncertainties about its performance.”
—“* * * the main technologies to be developed * * * are all worthwhile technologies for other applications beside the transmutation of wastes. We see the spin-offs from the development efforts as equally important reasons for the undertaking of the proposed development program in the next few years.”
—“As detailed in the following sections there are several commendable attributes but also questions and caveats to be addressed. * * * The R&D program is well designed to address these concerns.”

Megascience Forum

The Nuclear Physics subgroup of the Megascience Forum for the OECD (Organization for Economic Cooperation and Development) included ATW as one of the applications for investigation. I believe that this spring they will state that the nuclear physics community could assist the ATW program with useful nuclear data experiments and with improvements to the models and codes that are used in studies of nuclear systems. These advances would be useful in many areas other than ATW.

Summary

The ATW collaboration has reached a stage where it is prudent to take the next step in technology development—the 5-year plan. We have an opportunity to make significant advances and to enhance the capability of our repository solution. At the same time, ATW holds the promise of making nuclear power more acceptable to the general populace by minimizing the amount of material that has to be stored in a repository and by reducing the length of time over which a geologic repository must be licensed. In addition, the USA will continue its leadership role in an important area for the country and for the world.

Finally, I'd like to thank you for the opportunity to speak to you today on ATW and its possibilities, and for your kind attention to an important issue.

Separately we have provided copies of an October 1997 presentation to the Swedish Royal Academy of Engineers at their request in order to assist them in discussions they were going to have with the Swedish Government relative to policies in effect for nuclear power within Sweden.

Accelerator-Driven Destruction of Long-Lived Radioactive Waste and Energy Production

Abstract.—Nuclear waste management involves many issues. ATW is an option that can assist a repository by enhancing its capability and thereby assist nuclear waste management. Technology advances and the recent release of liquid metal coolant information from Russia has had an enormous impact on the viability of an ATW system. It now appears economic with many repository enhancing attributes. In time, an ATW option added to present repository activities will provide the public with a nuclear fuel cycle that is acceptable from economic and environmental points of view.

INTRODUCTION

The nuclear waste disposal issue for spent fuel from nuclear reactors is one that has a large impact on public acceptance of nuclear power generation and of long-term storage options. To a lesser degree, this issue has an impact on the costs of generating electricity, and the shipping, handling and transport of highly radioactive materials. Various options for long-term storage are being considered by different countries, but most schemes result in a geologic repository that has to be licensed and certified for a lifetime in excess of 100,000 years. Much investment has been made in repositories and their capabilities, with significant progress and rational solutions. Many individuals state that a geologic repository is a good solution and one that can work well. Others express concern over the time needed to protect such facilities from overt or covert actions, either from natural effects or by planned intrusions. Some express concerns about passing a serious legacy to future generations and about the loss of an energy generating resource from the heavy elements in the stored spent fuel. These are all difficult issues to consider and require well thought-out solutions to effect a win-win outcome for a country, its leaders, industry and the populace.

The Accelerator Transmutation of Waste (ATW) system is a repository enhancing option that should be considered because of the benefits it provides; no matter where the repository is located and no matter its status. The ATW option can be employed whether the spent fuel is fully buried, monitored and retrievable, or in interim storage ponds at nuclear installations. ATW supports the premise that a repository is a very good solution and assists this solution by making more efficient use of the capacity. A comparison can be made of flying across the Atlantic Ocean from North America to Europe in a propeller driven plane versus a modern jet aircraft. A traveler spends less time getting across, the higher flight path is usually less impacted by the weather and the turbulence, and the economics are better because of improvements in technology; even though the propeller driven aircraft is safe and gets to the destination. Both are acceptable solutions, but the jet aircraft is preferred by most individuals because of economics, technology enhancements, time spent and other associated benefits. Successful development work on jet engines and associated technologies allowed the introduction of this option into air travel.

Estimated benefits to be accrued for an ATW assisted repository include the following:

—Radiotoxicity and radioactivity are significantly reduced. An ATW assisted repository has a lower toxicity (and activity) after 300 years than an unassisted repository after 100,000 years.

—Because of the above improvement, it may be possible to license a repository for 300 years rather than the present anticipated 100,000 years plus.

—The amount of transuranic material introduced into a repository is reduced by more than three orders of magnitude. In the USA this means that the 600 tons of transuranics, contained within the 70,000 tons of spent fuel estimated to be handled by 2015, is reduced to less than 0.3 tons.

—At the same time that the transuranic material is being transmuted in the ATW system, it is generating useful energy that can be coupled to the electrical grids.

—At no time during the operation of the ATW cycle are weapons materials separated or made available in the processing streams. In that sense, the processes are proliferation resistant.

—Two of the most worrisome fission products, Tc and I, are transmuted and minimized to the point that they are no longer major concerns for repository licensing.

Over the past decade many technology alternatives for an ATW system were studied. It is intriguing and interesting that the international community has evolved to the same three basic components for an ATW system. These three components are pyrochemistry for the chemical processing, the liquid lead bismuth eutectic (LBE) used for both the target and the coolant, and the high-power linear accelerator that provides the protons for the spallation process in the target. Other common features used in the design of an ATW include solid fuel, fast neutron spectrum and a sub-critical assembly. Previously studied elements that are no longer considered include molten salt, thermal neutron spectrum, liquid fuels and centrifuge separations.

We have reached the stage in the development for an ATW system where it makes sense to take the next step—to start significant funding over the next five years to develop and test the concepts to the point such that an informed decision could be made by policy makers on whether this technology should be taken to the next stage, a demonstration ATW plant of the 1,000 MWt class.

An outcome of the five year development program would not only be the concepts and the feasibility of an ATW system, but would include the technology that could be used in other applications. The pyrochemistry, the LBE target, a LBE-cooled fast reactor concept and the accelerator technology could all be of benefit to programs which have as part of their infrastructure items such as spallation neutron sources and targets, future nuclear stations, and high-power proton accelerator applications including radio-isotope production, muon colliders and neutron scattering. Some have even suggested that the technology developments in LBE and pyrochemistry could be the bridge to future nuclear systems that may have the following advantages: simplified operation, minimal waste streams, more efficient use of heavy element resources and reduced costs.

SYSTEM DESCRIPTION

As mentioned above, an ATW system consists of three major building blocks. These are the high-power proton accelerator, a liquid LBE target and cooling system, and pyrochemistry processing. Our studies and those of our international colleagues indicate that economics for an ATW-assisted repository appear to be favorable. This economic indication has been verified by industrial partners who have completed simple systems studies; not detailed economic analysis based on item-by-item component lists, scheduled deliveries and supplier quotes. We have not reached the state in our studies to be able to provide such detailed information. Information of this nature would be part of the outcome from the five year technology development program planned for the future.

Choices for the three major building blocks are based on the following information. The subcritical burner uses liquid LBE and is based on solid fuels and extensive Russian nuclear reactor work with liquid LBE. The pyrochemical processes are based on significant work at ANL and LANL on efficient processes that have the potential for proliferation resistance and low environmental impact. The linear accelerator is based on work underway within the USA for an Accelerator Production of Tritium (APT) accelerator (170 MW of continuous beam power), and the innovations and developments achieved earlier under the Strategic Defense Initiative (SDI) ion beam programs. These three recent developments have revolutionized the ATW capabilities and have made it possible to consider significant advantages for an ATW-assisted repository.

ATW assists waste disposal options by transmuting waste. The process starts by accelerating protons to about 1 GeV in an efficient linear accelerator. Accelerator economic studies using real hardware costs have shown that 1 GeV is an optimum energy for this application, within a rather large minimum cost band. These energetic protons produce copious neutrons from the spallation process when they impinge on a high atomic number spallation target. At the proton beam energies and LBE target of interest, each proton produces about 30 neutrons. Having this source of neutrons allows an ATW system to operate sub-critical and thereby assist the nuclear system in transmuting transuranics by causing them to fission, and transmuting fission products (mainly Tc and I) by neutron absorption to other isotopes. Subcriticality and pyrochemistry enable the destruction of actinides and fission products safely, without isolation of weapons-grade material, without extensive separations and in a single-purpose device. Aspects of handling and transportation are minimized by having most of the activities completed at the ATW site. The proton beam impinges on a liquid LBE target that is also the coolant for the nuclear system consisting of transmutation solid fuel assemblies. The choice of liquid LBE for the target and coolant is based on the more than 75 reactor years of experience in Russia for liquid LBE-based nuclear reactors that were mainly used for their "Alpha-class" submarines. The solid fuel assemblies are made from first decladding spent fuel and then performing several stages of pyrochemistry involving direct oxide reduction, electrorefining and electrowinning of the materials. Fuel assemblies are then fabricated from the material coming from the electrowinning process and from the Zr that was declad from the spent fuel.

Transmutation assemblies spend about a year within the transmutation burner core, being shuffled between the three zones of the core during this period. After this shuffling cycle is completed, the rods are allowed to "cool" and then go through a similar process as for the spent fuel to provide separations and material streams that eventually lead to a reduction of three orders of magnitude in the transuranics that would be put into a repository.

Operational parameters for the liquid LBE coolant (340 °C inlet and 540 °C outlet with 400 °C to the steam generator) permit efficient conversion of heat to electrical power. About 10 percent of the power generated would be fed back to the accelerator to provide the necessary power to operate it and its ancillaries.

REPOSITORY ENHANCING SCENARIO

A scenario has been developed using information available at this time for the performance of the ATW system described in this paper. This scenario is based on the 70,000 tons of reactor spent fuel expected to be accumulated within the USA by the year 2015. Assuming that this material should be transmuted within a reasonable time-frame and that the number of ATW systems shouldn't be too complex or costly, the following attributes are possible. No optimization of the transmutation complex has been completed, nor has any inference been made about continuing ATW-type systems after the campaign—this scenario is provided only to give an indication of possibilities that can be accrued. Over a 65 year period it is possible to convert the 70,000 tons of reactor spent fuel (with 600 tons of transuranics) to:

—67,000 tons of uranium (could be considered as LLW (Low Level Waste)—radioactivity of natural U) which would be a small addition to the present LLW uranium.
—Less than 0.3 tons of transuranics.
—3,000 tons of fission products (with minimal Tc and I).
—560 GWe-year of electricity generation assuming an overall 35 percent plant efficiency (including thermal conversion). Even at 20 mils per kW/hr this represents a sizable return on the investment—about $100 Billion over the 65 years.
—No significant Pu or Np.

Because of this conversion only about 3,000 tons of material needs to be transferred to the repository (a reduction of a factor of 20 from the initial 70,000 tons), a situation that seriously impacts the needs for additional repositories in the future. This impact is realized because the repository storage efficiency is improved by the transmutation process, by the types of materials to be stored, and by the changes in the heat load and radiotoxicity—all leading to decreased long-term risks.

The 65 year scenario involves the commissioning and installation of twenty 2,000 MWt transmutation burners, staggered over a 25-year period and each with a 40-year lifetime, such that the transmutation campaign ends after 65 years. This scenario could be realized by utilizing three locations with seven transmutation burners at each of the locations, with only one location functional for the last ten years of the campaign. A very rough investment cost of this three location scenario for the 25 years is in the "ball park" of $60 B with average operating costs "guesstimated" at $2 B per year. Much work needs to be done to refine these "ball park" numbers and their implications.

TECHNOLOGY CHOICES

As stated above, the three major choices for the accelerator, subcritical assembly and the chemical processing were made on the basis of recent technology developments and information releases, all of which make the ATW system a very interesting option to be considered for assisting repositories in the future. Development work is still needed to bring this technological application to a state of maturity such that reasonable decisions could be made on whether this option should be pursued further.

Chemistry And Fuels

Based on significant work at ANL and at LANL in pyrochemical processing and because of difficulties encountered with waste streams from aqueous processing, pyrochemistry was chosen as the appropriate method for processing reactor spent fuel and the transmutation assemblies. Some of the pyrochemical processes are interpolations of systems that have been demonstrated, whereas the majority involve extrapolations which appear to be within reasonable bounds. Although within reasonable bounds, they still need to be demonstrated on a larger scale than at present. This is part of the five year development program planned for the future. We are using process models and simulations that have been verified with data from systems that have operated at ANL and LANL.

The pyrochemical process is considered to be proliferation resistant because the transuranics are separated as a group to be transmuted within an ATW burner. At no time are weapons-grade materials made available during the processing. Obviously, international controls will have to be employed to ensure that chemical processes are not altered in a significant manner.

Figure 1 shows a chemical processing flow chart for reactor spent fuel on the left and transmutation assemblies on the right. Within the processes, secondary wastes are minimized and waste materials destined for the repository are segregated in a manner that assists preparations necessary prior to repository transport.

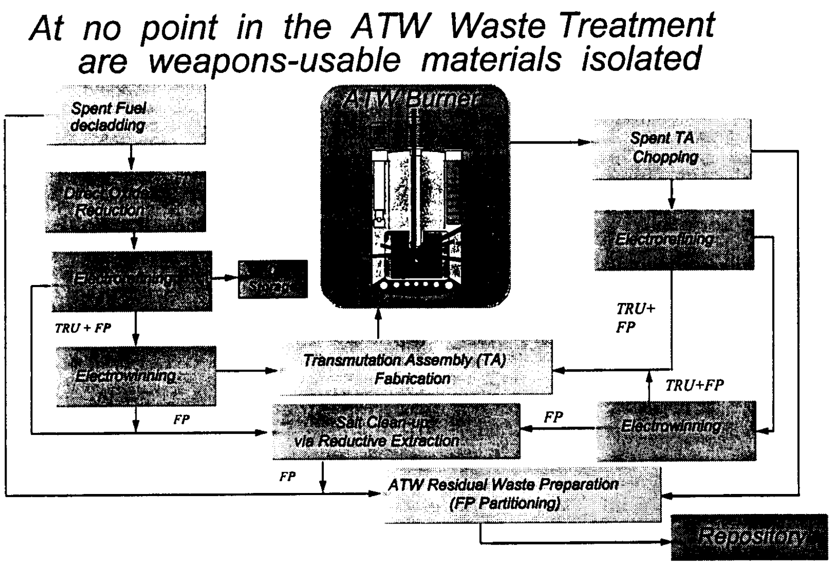

Figure 1 ATW Process Chemistry Flow Chart

The spent fuel decladding process provides the feed material for the direct oxide reduction process. Zr from the cladding is used as feed material for fabrication of transmutation assemblies. Within the oxide reduction process, Sr and Cs are left in the molten salt, oxide fuel is converted to a metal for further treatment and offgasses are collected as in the decladding process. Electrorefining accomplishes uranium separation in a manner to ensure no other actinides are transferred with it. Electrowinning provides the feed material for fabrication of the transmutation assemblies. A reductive extraction process is used to remove the rare earths from the molten salt. At most, three plants would be required to accommodate the 65 year transmutation scenario described above and each of these could fit within a 5,000 square foot building.

In a similar manner, the spent transmutation assembly chopping provides the feed material for the electrorefining process. Here the electrorefining process separates the U, transuranics and the fission products. These processes could fit within the building mentioned above.

The high melting point transmutation assemblies consist of non-fertile actinides (15 percent) and Zr (85 percent) with 316 SS cladding, and are compatible with the pyrochemical processes mentioned above. There are many issues that need to be addressed for the assemblies including swelling, bonding compatibility, and other irradiation effects.

Liquid Metal Coolant

Using the same fluid for the spallation target as well as the core coolant results in many improvements including elimination of a target cooling system and associated mechanical assemblies. Liquid LBE is an excellent spallation source because of the high atomic number, very "hard" neutron spectrum generated and very low neutron absorption.

Russian advances in the use of liquid LBE for nuclear reactor cooling showed the importance of oxygen control, and the instrumentation for monitoring oxygen to the levels required has been developed by them. Liquid LBE is an excellent coolant for this application, as well as for future fast reactors, because liquid LBE has the following properties: Maintains the "hard" neutron spectrum; has a very low neutron absorption, which can lead to core design improvements; is a very effective radiation shield for the outer walls; has the potential to enhance natural convection; has no violent reactions with water or air; has low melting and high boiling temperatures; and has a potential for self-plugging leaks.

Accelerator

Using a high power proton accelerator to drive a subcritical assembly enables effective nuclear waste disposal. The accelerator-produced spallation neutrons allow much flexibility for a system that needs to handle many types of nuclear waste forms. This frees the designer to concentrate on advantages for the transmutation core without invoking constraints that could lead to specific designs for specific spent fuel assemblies or severely constrain end-of-life inventory burn down. Advantages for a subcritical system include the following:

—Power control is linked to accelerator drive, not to control rods, reactivity feedback and delayed neutrons.
—Fertile materials are not needed for the core. Pure transuranic cores ensure a minimum of further transuranic production.
—The burner operates independent of fuel composition to first order.
—End-of-life inventory is not limited by criticality criteria.
—Neutronics and thermohydraulics are effectively decoupled.

Design for the ATW accelerator driver invokes a number of design constraints including high conversion efficiency of electrical power to beam power, current variable by a factor of two, extremely low beam loss, minimal length, minimal operating and capital costs, and high availability and reliability. Maximum proton beam power required for each 2,000 MWt burner is 40 MW at 1 GeV.

The accelerator design constraints have led to selection of a modest linac, 355 m in length, which employs superconducting structures to accelerate the proton beam from 21 to 1,000 MeV. The "front-end" employs conventional room-temperature structures and injectors for which all of the necessary performance characteristics will have been demonstrated when the "front-end" Low Energy Demonstration Accelerator (LEDA) operates with proton beam before CY 1999 as part of the APT program. Work on the "spoke" cavities employed for acceleration from 21 to 100 MeV will be required as part of the five year development program. Table 1 lists the parameters for the linear accelerator. Combining benefits of room-temperature and superconducting technology exploits the advantages of both systems for the maximum benefit of the "driver". Room-temperature technology is employed to 21 MeV in order to provide excellent emittance control and minimize halo generation. After this, superconducting technology is employed to minimize rf cavity losses, provide large beam apertures, reduce accelerator length, and provide flexibility for rf phasing, error tolerances and beam current variations.

TABLE 1.—*Accelerator Parameters for 1 GEV ATW Proton Linac*

Parameter	*Value*
Injector	0.075 MeV
RFQ	0.075 MeV–6.7 MeV
CCDTL	6.7 MeV–21.2 MeV
S/C Spoke Cavities	21.2 MeV–100 MeV
S/C Elliptical Cavities	100 MeV–1,000 MeV
Maximum Gradient	4.4 MV/m
S/C Cryomodules	5/26
Cryoplant Load	15 kW
Maximum Beam Power	40 MW
Total RF Power	42.3 MW
Linac AC Power	95 MW
Peak Coupler Power	200 kW
1 MW Klystrons	3–350 MHz/53–700 MHz
Aperture Radius	1/4/7.5 cm
Focusing Lattice	FODO
Room Temperature Quadrupoles	210
Superconducting (S/C) Quadrupoles	165

Nuclear System

A schematic for a 2,000 MWt nuclear transmutation burner is shown in Figure 2. The proton beam impinges on the liquid LBE (44.5 percent Pb/55.5 percent Bi) from the top with the transmutation area consisting of transmutation assemblies surrounding this target area. Liquid LBE cools the burner with pumps and heat exchangers co-located in the nuclear system. LMR experience is used in the design of the nuclear system incorporating hexagonal canned assemblies. The core is about 3 m in diameter and 2 m in height fitting into a nuclear system with an overall diameter of 10 m and an overall height of about 17 m. Maximum keff is 0.967 and maximum power density is 0.34 MW/1. A three zone concept is envisioned with fuel assemblies being moved from the outer zone to the center and then to the inner zone during burnup fuel cycle changes.

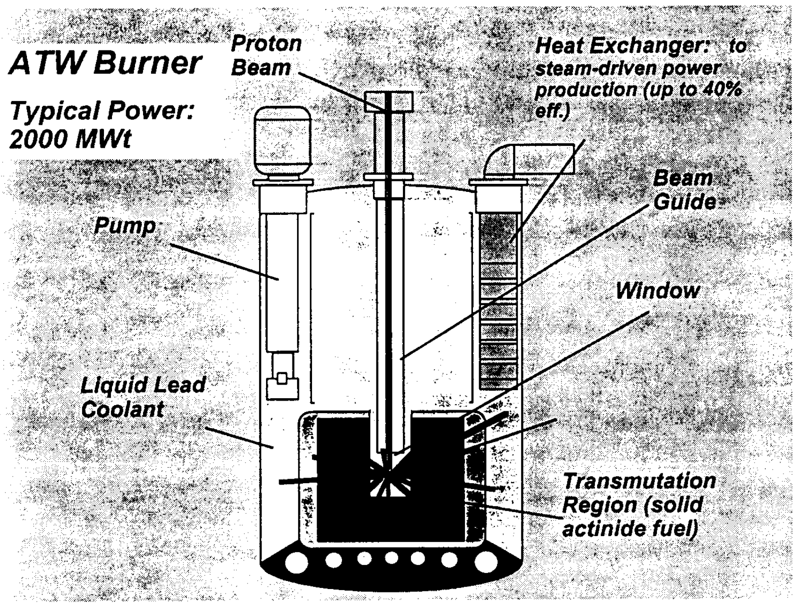

Figure 2 Schematic of 2000 MWt ATW Burner

ATW Development Program

With industrial input, a five year development plan has been determined that will provide the technical support for large-scale integration and deployment of ATW technologies. This $115 M program over five years focuses on issues of importance to enable a logical decision to be made at the end of the five year development program as to whether a further five year program should be pursued. This second five year program would focus on construction and operation of a 5 MW Subcritical Test Facility to be driven by a 1 MW proton beam, design of an ATW Processing Facility geared toward full scale pyrochemical processing and design of a 1,000 MWt Demonstration Plant that could be located at some strategic location.

The first five year program plan focuses on materials verification studies and experiments, liquid LBE performance verification including spallation product measurements, nuclear design, chemical database, chemical processes at up to 10 kg scale, mass flows, accelerator design, system studies and some design work to determine characteristics necessary for a future Demonstration Facility.

COLLABORATIONS

Considerable interest in ATW has developed within laboratories, institutions and industries around the world, not only because of ATW but because of technologies spinning-off from this program which have many other applications. Within the USA we have formed a team consisting of LANL, LLNL, Sandia, Savannah River, Bechtel, Northrup-Grumman, Westinghouse-STC, UC-Berkeley and U. Illinois. Funds to this point have been forthcoming from each institution participating, with LANL recently investing $1.7 M for each of the three years ending in 1999.

A common technical approach has emerged within the international community and this common approach has assisted collaborations in a significant manner. Europe and Asia are investing considerable amounts of manpower and money in order to put ATW technology on a firmer foundation than at present. Within Europe, countries including the Czech Republic, France, Italy, Spain and Sweden have shown considerable interest and within Asia, S. Korea and Japan have started investigations. Collaborations exist between Russia, CERN, CEA, KAERI, Sweden and the USA team.

CONCLUSIONS AND SUMMARY

An ATW system could assist a repository by enhancing its capability. An ATW-assisted repository has many other worthwhile features that need to be investigated in more detail. Work on repository solutions should not be stopped. However, options that could make a repository even better in the future should be investigated to the point that logical decisions based on complete information can be made. For this reason it is suggested that a five year development program should be vigorously pursued. Enough information is available at this time to indicate that there are no known "show-stoppers". Some development work will lead to further technology selections, but this does not appear to indicate that ATW is not possible, nor that it isn't within the economic "ball park".

The major components of an ATW system are based on proven technology or on those that will be demonstrated very soon by other programs. Performance drivers that have been used in determining the present ATW system are safety, proliferation resistance, low environmental impact, fast burn rates and low inventories. All of these goals are met in the system described above.

A logical path has been shown for developing an ATW system with opportunities to make future decisions for continuing or stopping.

ACKNOWLEDGMENTS

Many people have been working in the ATW area for the past ten years and they have made significant contributions to the needed technology base and understanding. Their legacy will allow others in the future to build on this strong base—one that is well documented with many international connections. This program is truly an international effort and one that requires international collaborations to succeed. Resources from the many laboratories, institutions, universities and industries around the world have played an important role in advancing the technology to the point that it makes sense to take the next steps requiring modest government funding. It is difficult to acknowledge everyone who has had an impact on making this ATW option more visible within the world community. However I'd like to express my grateful appreciation to Carlo Rubbia, Massimo Salvatores, Yuri Orlov, Waclow Gudowski, Curt Miliekowski, Vladimir Kazaritsky, and Edward Arthur for their foresight and willingness to push hard against what appeared to be "closed" doors. We have come a long way on this ATW journey and many new individuals have joined the throng. Although we are of differing opinions, Charlie Bowman needs to be singled out because he has had a significant influence on the program and the understanding of the technology choices.

Within the USA, I am particularly indebted to the ATW team led very ably by Francesco Venneri. This team has put together the promising technology and a system that has many exciting attributes. I am grateful for contributions from members of that team: Mark Williamson (chemistry), Ning Li (LBE), Mario Carelli (nuclear system), Mike Houts (nuclear design), George Lawrence (accelerator), Tim Myers, Tom Wangler, Keith Woloshun, Valentina Tscharnotskaia, Michael Bjomberg, Joey Donahue, Steve Wender and Ann Schake. Others that I would like to thank are Sam Harkness, Bob Taussig, Mike Kreisler, Arthur Kermin, Pete Lyons, Nestor Ortiz, Pete Miller, Tony Favale, Reed Jensen, Rulon Linford, John Ireland, Mike Cappiello, Edward Heighway, Bill Bishop, Greg VanTuyle, Paul Lisowski and John Browne for recognizing the many implications of this program.

Senator DOMENICI. Thank you very much.

Senator Stevens, I might say that one of the reasons this now appears feasible, whereas it was not so feasible in prior years, is that the idea of the accelerator is an American one, but we always had trouble with what kind of a reactor would you use. And the Russians have submitted a subcritical lead bismuth reactor. Subcritical, if you understand what that means, it is very important.

And it is around those concepts that they are building this possibility, which 5 or 6 years ago they could not have done.

Dr. SCHRIBER. That is right.

Senator DOMENICI. Let us proceed now.

Mr. Blue.

STATEMENT OF LINDEN BLUE, VICE CHAIRMAN, GENERAL ATOMICS

Mr. BLUE. Mr. Chairman, Senator Stevens, just a little over 12 years ago my brother and I bought General Atomics. And we did it voluntarily. You can say that the last 12 years have not been great years for nuclear energy. But I have to say that in spite of the fact that that decision was made 12 years ago, we would do it again today, and, in fact, we would do it much more adamantly than we did then for two basic reasons.

First of all, we believe strongly in the importance of nuclear energy for abundant energy without environmental effects. We still do. And as this hearing has bore out, you almost cannot get to the future with a proper environment without nuclear energy. The second reason was that we believe strongly that nuclear energy could be done better; that science was making advances that would make it even better than it has been in the past 40 years or so.

And, very interestingly, 40 years ago, when General Atomics was founded, the likes of Freeman Dyson and Edward Teller were gathered around very similarly to probably the conferences they have had at MIT, and they sort of took an empirical look at it, and they said, well, how should nuclear energy be done properly? And they had many of the criterion that Mr. Smith suggested. And they said, and then, sometime far in the future, we will be able to hook it to a gas turbine and then get the ultimate in efficiency. And essentially that is what Mr. Smith and the people at MIT are concluding now, that the time is right.

Well, we at General Atomics saw a fundamental capacity in the gas reactor for changing the safety equation. And by so doing, you also can change the economics equation, because you can save the efficiency. And when you drive up efficiency, you dramatically reduce waste and proliferation.

And I would like to just show you how basically and fundamentally we think that the safety equation can be changed.

Mark, if you would just turn that one around. [Chart.]

In order to get the kind of safety that Mr. Smith was describing, you really should have no possibility of a meltdown. And it is simple. You have to have a low-power density. It has to be combined with proper geometry. And you must have fuel that is tolerant of high temperatures. And that is ceramic fuel.

And if you put those three things together you are not going to have enough decay heat to have a meltdown. And that is what MIT is after, and I believe what they should be after. It is very basic; it is very simple. And people are going to say, well, why hasn't it been done before? The short answer is that because the reactors that have served the world so well these past 4 years, most of it came out of submarine technology, where space was at an absolute premium and power density was terribly important.

Well, as good as those reactors have been, it is time to move on, time to have low-power density cores that are tolerant of the high temperatures and with fuel that can increase the efficiency.

Now, on the efficiency side it is fundamental that you must increase temperatures. And ceramic fuel is tolerant and makes an increase of temperatures possible. And when you combine the increase of temperatures with a gas turbine, you come up with much higher efficiency.

And, Mark, would you show the next one, please. [Chart.]

The first generation water reactors have been up in the 33 percent thermal efficiency range, and we are clearly going to get above 47. And that assumes operating temperatures of 850 degrees centigrade. And the Japanese will next month go critical on their test reactor that will move up to 950. When you get to 950, efficiencies up in the mid-50's are clearly indicated.

Senator DOMENICI. What does the efficiency mean in this context?

Mr. BLUE. Thermal efficiency essentially drives everything else. The amount of energy you get from a given number of fissions in the amount of heat generated. And when you drive up that efficiency, all good things happen, particularly in the waste arena.

So, again, MIT is on the right track here. You want the higher temperatures, and you want the gas turbines. [Chart.]

And this graph shows it pretty basically. If you start with 24 megawatt hours of electricity in both cases, both for a lightwater reactor on the top and a gas reactor on the bottom, you essentially need 3 grams of fissionable material in the lightwater and 2 in the gas reactor. And you get the result, out to the right, where you have twice as much reject heat with the lightwater reactor, you have 50 percent more high-level waste and you have four times as much plutonium 239, which was the bad weapon stuff.

So, to summarize, may I have the next one? [Chart.]

As Dyson and Teller, and now MIT, have concluded, if you start with the right basis, if you start with helium as a coolant, you get away from stress corrosion, the Achilles heel, if you will, of first-generation nuclear. If you use ceramics, you can have the higher temperatures and, therefore, the higher efficiencies and a much better waste picture. You can get to the ultimate in safety, which is no meltdown. And, finally, with the modularity that Mr. Smith is talking about and the simplicity, you get to the lowest possible capital costs. And that means low-cost electricity. And that is where I think we ought to be going.

[The statement follows:]

PREPARED STATEMENT OF LINDEN BLUE

Mr. Chairman and Members of the Subcommittee, thank you for allowing me this opportunity to discuss the Gas Turbine-Modular Helium Reactor (GT–MHR). The GT–MHR represents a major technical breakthrough in power production that addresses several important issues affecting nuclear power: it is almost 50 percent more efficient than first generation reactors, produces about 50 percent less waste and essentially eliminates the potential for melt down. In addition, it has some distinct advantages for destroying WPu.

During the last few years, development of the GT–MHR has been sponsored under a joint venture between General Atomics (GA) of San Diego and the Ministry of Atomic Energy (MINATOM) of Russia. Framatome and Fuji Electric are also participants. Prior to this, the U.S. Government invested about $1 billion in the technology over a period of many years.

The GT–MHR, the only second generation nuclear reactor currently under active development, takes advantage of four recent, and very significant, technical advancements. We are also positioned to take advantage of the historic opportunity to complete this technology in Russia at a very low cost. Cost for completion of the detailed design will run about $240 million—about one quarter the cost of completing the design in the U.S. Russia has agreed to match all design funds coming to Russia. The first operating unit would have the additional benefit of destroying Russian weapons grade plutonium (WPu) by using it as its fuel. Indeed, at the Vancouver summit, President Yeltsin requested that the U.S. share this energy technology to enhance Russia's conversion from weapons production.

GA and Russian scientists and engineers have been working together in this project for three years. This partnership is a natural extension of nearly forty years of joint GA and Russian cooperation on nuclear fusion research and development.

Mr. Chairman, I will briefly describe some of the characteristics of the GT–MHR and some related issues.

Market.—Electricity is the fastest growing segment of the energy market: it is portable, flexible, low cost and environmentally benign. However, when it is generated by burning hydrocarbons, it has adverse environmental effects. Nuclear power has the potential for eliminating adverse environmental effects if reactors are meltdown proof and waste is reduced and properly handled. The world market for electricity generating plants is estimated at $100 billion per year. GT–MHR represents an excellent new technology for fulfilling world energy requirements at low cost, without environmental degradation.

Technology.—The GA developed GT–MHR is the culmination of 40 years and $6 billion of R&D world wide. The four enabling technologies combined in the GT–MHR are the modular helium reactor, high performance gas turbines, highly effective recuperators and magnetic bearings. All of these technologies are state of the art now in other applications. They were not available a few years ago.

Safety.—GT–MHR is the only reactor design that is melt down proof. It is melt down proof because its power density is 20 times less than current reactors. The reactor power density and geometry mean that there is simply not enough energy density to raise reactor temperatures to the point which would melt its high temperature ceramic fuel.

Efficiency.—High temperature helium gas goes directly from the reactor to a gas turbine which directly drives an electric generator. The laws of physics mandate that higher gas temperatures mean more efficient energy conversion. Helium direct drive is also more efficient, allows utilization of higher temperatures and eliminates costly equipment. The result is thermal efficiency of 47 percent which is about 50 percent greater than other reactors. Future GT–MHR's will allow efficiencies of close to 60 percent. The GT–MHR opens the door to quantum efficiency improvements for nuclear energy.

Environment.—Higher efficiencies mean less thermal discharge to the environment, less high level waste. The GT–MHR will produce 50 percent more electricity for a given amount of thermal discharge and waste creation.

Proliferation.—The GT–MHR is the most proliferation resistant reactor design. It's fuel is engineered to achieve high burn up in a once through fuel cycle. This means no reprocessing. Because of the high burn up, its waste fuel is extremely low in plutonium 239 (4 times lower than other reactors). It would be virtually unusable for weapons production.

Cost.—50 percent greater efficiency assures substantially lower costs of electricity. After learning curve effects, a plant should cost less than $1,000 per KWe and produce electricity for 2.1 cents/KWh. Also, GT–MHR is intended to be factory built in modules with factory cost and quality control. Electricity capacity can be added in digestible bites of about 285 MWe as electricity demand increases.

Modularity.—The ability to add electricity generation capacity in modules of 285 MWe allows more conservative capacity planning, reduces developmental carrying costs, allows more flexibility in maintenance schedules, reduces backup power requirements, is adaptable to areas where power grids have low capacities, allows better distribution of generation capacity, and reduces transmission losses in low demand power markets.

WPu destruction.—GT–MHR uses 100 percent Pu fuel compared to 5 percent Pu in MOX fuel. This means MOX fuel requires something like twenty times more fuel manufacturing throughput to dispose of an equal amount of WPu. Starting with the same amount of WPu, the residual Pu–239 in once-through MOX spent fuel would be five times greater than in GT–MHR spent fuel. A plant suitable for production of Pu particle fuel has been estimated to cost $50 million. This is about one-tenth the cost of a MOX plant processing the same amount of WPu. It would be possible to convert WPu to GT–MHR particle fuel on whatever schedule was expedient. Once converted to particle fuel, it would be substantially proliferation resistant and can be stored for later use in GT–MHR's.

Technical Challenges.—Further fuel tests must be run to prove the fuel for the GT–MHR has characteristics similar to fuels used successfully at the Peach Bottom, Fort St. Vrain, AVR, and THTR reactors rather than the fuel proposed for the NPR which had an inherent design flaw. Design confirmation testing must be done on recuperators, seals, and magnetic bearings. The power conversion module is large and complex and will experience substantial thermal growth during its heat up. All of the systems must be proven to work together.

Balance of Payments and International Ramifications.—The U.S. currently burns about $1 billion per week in imported oil. This is by far our largest import and accounts for about half of our entire balance of payments deficit. Installed in the U.S., GT–MHR will reduce U.S. reliance on foreign oil. Installed in Russia, it will free up natural gas supplies to earn foreign currency and create a new export industry.

Attached are some additional details on the issues discussed above.

GT–MHR: TECHNOLOGY BACKGROUND AND OVERVIEW

The GT–MHR plant design has evolved from the experience of operating more than 50 gas cooled nuclear reactors worldwide and recent technological advances in fossil-fired Brayton (gas turbine) cycle systems.

Five helium cooled reactors, which operated in the 1960's, 1970's, and 1980's demonstrated the inherent characteristics of helium cooled reactors. In the 1980's, modular helium reactor (MHR) designs were developed, both in Germany and in the U.S. in response to the general public's safety concerns. These designs had inherent passive characteristics for meeting stringent safety goals without relying on active safety systems or operator action. The major drawback of these passively safe designs, which employed the Rankine power conversion cycle, was they were evaluated to be non-competitive economically.

By the early 1990's, because of advances in industrial gas turbine technology, highly effective recuperators and related equipment, the potential emerged for coupling the unique high temperature capability of an MHR with a gas turbine in a closed Brayton cycle for the achievement of high efficiency and competitive economics.

The GT–MHR couples an MHR, contained in one vessel, with a high efficiency gas turbine energy conversion system contained in an adjacent vessel. The reactor and power conversion vessels are interconnected with a short cross-vessel and are located below grade in a cylindrical silo.

The MHR employs a graphite moderator and TRISO-coated particle fuel. TRISO fuel contains a spherical kernel of fissile or fertile material, as appropriate for the application, encapsulated in multiple coating layers. A low-density carbon (buffer) layer surrounds the kernel to attenuate fission recoil atoms and provide void volume to accommodate fission gases. Surrounding the buffer is an inner pyrocarbon coating (IPyC), a silicon carbide (SiC) layer, and an outer pyrocarbon coating (OPyC). The IPyC, SiC, and OPyC layers together form a miniature, highly corrosion resistant pressure vessel and an essentially impermeable barrier to the release of gaseous and metallic fission products. Extensive tests in the U.S., Europe, and Japan have proven the excellent performance characteristics of this fuel.

The overall diameter of standard TRISO-coated particles varies from about 650 microns to about 850 microns. For the MHR, TRISO-coated particles are bonded with a graphitic matrix to form cylindrical fuel compacts approximately 13 mm in diameter and 51 mm long. Approximately 3,000 fuel compacts are loaded into a hexagonal graphite fuel element, 793 mm long by 360 mm across flats. This is the same type of fuel element which showed excellent performance at Fort St. Vrain. One hundred and two columns of the hexagonal fuel elements are stacked 10 elements high to form an annular core. Reflector graphite blocks are provided inside and outside of the core.

TRISO-coated particle fuel remains stable to very high temperatures. The coatings do not start to thermally degrade until temperatures approaching 2000 °C are reached. Normal operating temperatures do not exceed about 1250 °C and worst case accident temperatures are maintained below 1600 °C.

Helium, heated in the reactor, expands through a gas turbine to generate electricity. From the turbine exhaust, the helium flows through the hot side of a recuperator transferring residual heat energy to helium on the recuperator cold side which is returning to the reactor. From the recuperator, the helium flows through a precooler where it is further cooled. The cooled helium then passes through low and high-pressure compressors with intercooling. From the compressor outlet, the helium flows through the cold, high-pressure side of the recuperator where it is heated for return to the reactor.

The gas turbine power conversion system has been made possible by four key technology developments during the past decade in: large aircraft and industrial gas turbines; large active magnetic bearings; compact, highly effective plate-fin heat exchangers; and high strength, high temperature steel alloy vessels. Demonstrated gas turbine technology is available for turbines with power ratings that match the requirements of the passively safe modular helium reactor. Indeed, the high pressure (and density) helium working fluid actually provides higher output (i.e., the GT–MHR gas turbine is actually smaller) than an equivalently rated fossil fired gas turbine. The gas turbine system eliminates extensive and expensive equipment required for the century-old Rankine steam cycle technology used by other nuclear power plants for conversion of thermal energy to electrical power.

Not only does the elimination of steam plant equipment reduce capital and operating costs, but also the plant efficiency is markedly increased. The GT–MHR achieves a net thermal conversion efficiency of approximately 47 percent as compared to current nuclear plants that have efficiencies of about 33 percent.

GT–MHR advantages include:

Unique Reactor Safety.—The GT–MHR is meltdown-proof and passively safe. The overall level of plant safety is unique among nuclear reactor technologies. This is achieved through a combination of inherent safety characteristics and design selections that take maximum advantage of these characteristics. These design selections and features include: (1) helium coolant, which is single phase, inert, and has no reactivity effects; (2) graphite core, which provides high heat capacity and slow thermal response, and structural stability at very high temperatures; (3) refractory coated particle fuel, which allows extremely high burnup and retains fission products at temperatures much higher than normal operation; (4) negative temperature coefficient of reactivity, which inherently shuts down the core above normal operating temperatures; and (5) an annular, 600 MWt low power density core in an uninsulated steel reactor vessel surrounded by a reactor cavity cooling system. Power level and geometry together enable passive heat transfer from the core to the ultimate heat sink while maintaining fuel temperatures below damage limits. These safety design features result in a reactor that can withstand loss of coolant circulation or even loss of coolant inventory and maintain fuel temperatures below damage limits (i.e., the system is meltdown proof).

High Plant Efficiency.—Use of the Brayton Cycle helium gas turbine in the GT–MHR provides electric generating capacity at a net plant efficiency of about 47 percent, a level that can be obtained by no other nuclear reactor technology. This high plant efficiency results in low power generation costs. The high efficiency also results in significantly less thermal discharge to the environment, than other reactor technologies, and significantly lower waste generation per unit electricity produced.

GT–MHR Fuel Cycle.—Per GWe-Yr, the GT–MHR requires more U3O8 but achieves 2.5 times the burnup of the comparable PWR. The GT–MHR thermal discharge is about 50 percent less and the actinide production is about 60 percent less per unit electricity produced.

Superior High Level Waste Form.—Coated particle fuel provides a superior spent fuel waste form for both long-term interim storage and permanent geologic disposal. The refractory coatings retain their integrity in a repository environment for hundreds of thousands of years. As such, they provide defense-in-depth to ensure that the spent fuel radionuclides are contained for geologic time frames and do not migrate to the biosphere.

Effective Plutonium Destruction.—For the disposition of weapons grade plutonium (WPu), the GT–MHR provides the capability to consume more than 90 percent of the initially charged plutonium-239 and more than 65 percent of the initially charged total plutonium in a single pass through the reactor. The performance of plutonium coated particles to burnup levels of 750,000 MWd/MT has been demonstrated by irradiation tests in the Dragon and Peach Bottom 1 gas cooled reactors. The level of plutonium destruction is well beyond that achieved by other WPu disposition alternatives. By achieving this high level of plutonium destruction, the GT–MHR extracts a substantially higher portion of the useful energy content from the material than other reactor options without reprocessing and recycle. Because the plutonium fueled GT–MHR uses no fertile fuel material, all fissions in the core are plutonium fissions, and no new plutonium is produced by the operation of the reactor. Comparable results would apply to the utilization of reactor grade plutonium.

Diversion/Proliferation Resistance.—The GT–MHR is particularly well suited for international deployment for plutonium disposition. Both the fresh fuel and the spent fuel discharged from the GT–MHR have higher resistance to diversion and proliferation than other reactor options for plutonium disposition. The plutonium content of the fresh fuel is very diluted within the fuel element graphite. In addition to having the self-protecting characteristics of other spent fuel (high radiation fields and spent fuel mass and volume), the amount of plutonium per GT–MHR spent fuel element is very low and there is neither a developed process nor capability anywhere in the world for separating the residual plutonium from GT–MHR spent fuel. Furthermore, the discharged plutonium isotopic mixture is severely degraded (well beyond light water reactor spent fuel) making it particularly unattractive for use in weapons.

CONCLUSIONS

The GT–MHR represents a second-generation, meltdown proof, nuclear power solution.

—The GT–MHR is the best nuclear energy source for the next century. The design addresses many of the current concerns with nuclear power with regard to safety, economics, proliferation resistance, and high level waste disposal.
—The GT–MHR is highly attractive for the disposition of weapons plutonium. High levels of plutonium destruction are achieved, a high portion of the useful energy content from the material is obtained without reprocessing and recycle, and the fuel is highly diversion and proliferation resistant.
—The GT–MHR small modular size coupled with its safety, economic, environmental, and proliferation resistant characteristics make the GT–MHR an ideal system for responsibly meeting the burgeoning electricity demand in developing countries. The GT–MHR's passive safety characteristics reduce the need for a developing country to have an elaborate nuclear infrastructure.
—An international team is actively working on the design to (1) complete the deployment of a prototype in Russia, with an initial mission of plutonium disposition, and (2) marketing uranium fueled GT–MHR plants to the world for electricity generation.
—Technical issues are solvable.
—Support of the U.S. Government will accelerate completion of the project and early destruction of Wpu.

STATEMENT OF CHARLES E. TILL, PH.D., ASSOCIATE LABORATORY DIRECTOR (RETIRED), ARGONNE NATIONAL LABORATORY

Senator DOMENICI. Thank you very much.

Dr. Till.

Dr. TILL. Thank you, Mr. Chairman, Senator Stevens, for having me here today. I am Charles Till.

For 17 years, until January 1 of this year, I directed the reactor development program at Argonne. And, with my colleagues—in particular, my successor, Dr. Chang—I was the initiator of the IFR concept at Argonne and was responsible for its development. So, when I was asked by your very competent staff to talk about the IFR today, it should not be expected, although I will try to be as neutral as I can, it should not be expected I will say unkind things about it. Where opinion slips in, it is my own.

The what, where, why of the IFR: First, the what. What was the IFR? The IFR is the integral fast reactor. It is a type of reactor, an advanced reactor concept is actually a whole reactor system—the reactor, the fuel, the new reprocessing scheme, and the new waste form, the whole entity, for a complete reactor system—that has a range of unusual and valuable characteristics. It was invented at Argonne in 1983.

It saw intensive development from 1984 through 1994. It was a program funded at about $100 million a year, including the operation of the necessary facilities. And it was terminated, incomplete, in 1994, following the President's 1993 State of the Union Address, where he stated no further need for advanced reactor development.

Now, the why. Why was it undertaken at all in the 1980's, not a favorable environment for nuclear any more then, than it is today? Simply, by the early eighties, several things were clear. The path to long-term sustainable nuclear power was blocked, and increasingly so. In part, it was because the reactors in place at the time do not have the characteristics necessary to change that. The characteristics that are necessary are pretty easily identifiable. They are not the ones that were the basis of the choice for the present reactors. And, finally, the new reactors that do have these characteristics were now possible.

The when: It was first put together as a complete in 1983. The idea was a new reactor type that had inherently safe operational characteristics, a new fuel which allowed a radically different reprocessing scheme, and new short-lived waste form. It was not out of the blue. It was based on the discoveries mainly at Argonne, going back 40 years.

As to where: It was carried out at Argonne, IL, the analytical work, but largely Argonne in Idaho, where the necessary facilities were, the reactor, the safety facilities, the chemical hot cell facilities and so on.

And where did it stand when it was terminated? It was largely proven as a concept, some parts more than others. It was sufficiently promising that the Japanese had either invested or promised $100 million, part of which was cancelled then when the administration cancelled the program. And two large American utilities had also put money in it.

Mr. Chairman, in the moments I have, I think it is important to describe the characteristics of this. It is not so important—it is in my testimony—the technical reasons why these characteristics are possible. But the principle characteristics are inherent safety, proliferation resistance, reduced waste, and fuel resource efficiency. Those four things. That is what this reactor was aimed at.

Now, in inherent safety, fundamentally—you can define it a number of ways—but, fundamentally, what you are trying to do is protect against overheating. Every reactor accident involves overheating. And a reactor that will regulate its own temperature naturally is an inherently safe reactor. The IFR would do that.

In proliferation resistance, any proliferation threat from a commercial reactor simply means, can you get pure 235 or weapons plutonium from it in an easier way than you could get it by some other path. Weapons plutonium is normally the focus of this, and it is not a radioactive material. As you know, it is adequately shielded with a piece of paper. But if you have fission products and it remains highly radioactive even after processing, that product is self-protecting and it does not add in any material way to proliferation threats.

Reduced waste—what do I mean by that? I mean the goal in reducing nuclear waste is twofold. One is the volume. The IFR did that by a factor of about three. The other is the longevity and the importance of the longevity of the radioactivity associated with the waste. The important radioactivity as far as groundwater and so forth is concerned comes with the actonide elements. The IFR removed the actonide elements. That reprocessing scheme did that. The present reprocessing schemes do not. And that is a difference.

In uranium resource efficiencies—and that is the most important point for future reactor development in my view—is that you have got to use the U_{238}. Only one-half percent of the uranium mined is used today. You can do a simple calculation, and that limits the life of nuclear power. You have got to use the 238. The IFR did that.

So, in summary, all of those things have to be done. The IFR had all four of those characteristics. But they have to be done without increases in cost. They have to be a natural part of the system. The IFR did that, too.

So, it is important that advanced technology, if it is to be developed, be the right technology. And, Mr. Chairman, I think those are the characteristics that are required. The IFR had those. And I think it is useful to have another look.

Thank you.

[The statement follows:]

PREPARED STATEMENT OF CHARLES E. TILL

Mr. Chairman, members of the Committee, I thank you for the opportunity to speak to you today on the possibilities for reactors of the future.

I am Charles Till. For seventeen years, until my retirement on January 1st this year, I was in charge of reactor development at Argonne National Laboratory, the principal laboratory in the DOE system for civilian nuclear reactor development.

With my colleagues, and, in particular with my successor, Dr. Yoon Chang, I was the initiator of the Integral Fast Reactor, or IFR, concept at Argonne National Laboratory. In the early 1980's, it became very clear that nuclear reactors could and should be designed which would have significant improvements over today's nuclear plants. It was also clear that the time was right to include the full fuel cycle in the new plant design—for to not do so would mean a continuation of intractable problems with nuclear waste and resource efficiencies which could eventually preclude any further use of nuclear power.

Nuclear reactor systems, and the problems associated with them, are best thought of in terms of the whole of the fuel cycle—everything from mining the uranium ore to producing the waste products. The IFR is a reactor which incorporates each step of the nuclear power fuel cycle into one complete system treated as a whole. We knew that the IFR must be an efficient system, that it must utilize the uranium resource properly and completely—if not, it would not be a long-term energy option, and probably not worth spending tax dollars for it's development.

Begun in 1984, the IFR was a $100m per year development program at Argonne in which the entire system—a reactor, a new fuel cycle and new waste process were all being developed and optimized as a single nuclear plant system, each part complementing the other. Its rationale was based on resource use, ultimate safety, and waste content, improved proliferation resistance, with revolutionary improvements to be expected in each of four areas. These are:

—It is self-protecting against overheating, and therefore is passively safe;

—It's fuel is self-protecting against diversion, and therefore is proliferation resistant;

—It both burns more of its fuel and includes a simple recycle procedure, and therefore is nearly 100 percent fuel efficient; and

—It burns material that would be waste in other reactors, and therefore produces far less waste.

Reactor system characteristics are established fundamentally by the choice of basic materials used for coolant and for fuel, primarily, and somewhat so for structural materials. Water, oxide fuel and zircaloy cladding, for example, define the current generation Light Water Reactor used in the United States and throughout the world for commercial power production. Helium and graphite define the High Temperature Gas Reactor; sodium, oxide fuel and stainless steel define the traditional Liquid Metal Fast Breeder Reactor.

Reactor material choices made 40 years ago did not recognize the importance of characteristics that are now seen as vitally important to a reactor system. The materials must be chosen and exploited specifically to achieve the characteristics being sought. The IFR is defined by liquid sodium metal as coolant and metallic uranium/plutonium alloy as fuel. It is the fundamental, natural properties of these materials which give the IFR the ability to achieve the four characteristics I outlined above.

Mr. Chairman, allow me please to give you and the committee an overview of how these characteristics are achieved.

INHERENT SAFETY

Every reactor accident has to do with overheating. To achieve inherent safety, the reactor must be able to regulate its own temperature. To be inherently safe, this must be done without depending on any engineered system or operator intervention because both engineering and operation can fail. The IFR regulates its own temperature through the natural physical phenomena of thermal expansion and convection flow.

Like most metals, the metallic fuel is quite responsive to changes in temperature. It stores very little excess heat. When a disruption in cooling occurs, even at full power, there is ample margin in the sodium coolant to safely remove the heat and protect the fuel from melting. The reactor simply shuts down.

This phenomenon is supported by the liquid metal sodium coolant and its natural properties. Sodium has a boiling point in excess of 1600 degrees Fahrenheit. The reactor operates between 700 and 900 degrees Fahrenheit. This means the coolant does not have to be pressurized. Which in turn means you can have a large pool of coolant. A current generation water cooled reactor, by comparison, has to be pressurized to about 2,200 pounds per square inch to avoid boiling off the water. The high boiling point of liquid sodium allows the IFR to have large pools of coolant which run at low pressure and are easy to build and maintain. Currents naturally develop in this large pool just as they do in an ocean or lake. These currents, produced by a natural phenomenon called convection flow, serve to further cool the reactor core as the metal fuel properties shut down the reactor in any off-normal event.

I wish to note that what I describe is neither conjecture nor a computer model. It has been demonstrated and proven. In 1986 we produced accident conditions more severe than both Three Mile Island and Chernobyl. In all cases, the IFR prototype reactor regulated its own heat and shut itself down with no damage to the reactor or its fuel. The IFR is passively safe. It has an unprecedented degree of inherent safety.

PROLIFERATION

The need remains to assure that the nuclear material used for the peaceful purpose of generating electricity is never diverted to a military purpose. This concern was at the forefront in the conception and design of the IFR.

The IFR addresses this in two ways. First, as I will discuss in more detail in a moment, the IFR is extremely efficient in its fuel use. What this means for proliferation and diversion concerns is that the IFR burns as fuel the plutonium used to make weapons. And it does so with great efficiency. Further, it can burn as fuel, with great efficiency, the material taken from dismantled warheads. It is the ultimate swords-to-plowshares machine.

The second way the IFR is proliferation resistant is in how it protects against the improper diversion of its fuel material. As the fuel comes out of the reactor to enter the recycling process I will describe shortly, the fuel is highly radioactive. So much so that exposure to it for even a few seconds would be lethal. This requires special remote handling techniques performed behind walls and windows that are five feet thick in special rooms called hot cells. The recycling process is chemically incapable of separating pure plutonium from the fission products that are emitting this lethal radioactivity. Weapons plutonium in its pure form, as I know you know, Mr. Chairman, is not highly radioactive at all. In fact, this piece of paper in my hand provides enough shielding to keep me safe if some were on this table now. But the plutonium in the IFR process in always, and I repeat, always, mixed with fission products which render it immediately deadly to anyone who would try to remove it from the hot cell. Any attempt to use fuel from an IFR for weapons purposes would require applying other, separate, well known and established chemical processes to extract the pure material.

The IFR therefore, does nothing to add to any proliferation risk. In fact, it has the ability to reduce proliferation risk by tying up existing stores of plutonium with highly radioactive fission products, and by burning the plutonium.

EFFICIENCY

The efficiency of the IFR comes from the nature of the reactor physics—which is driven by the choice of fuel and coolant. I'll not go into detail here except to say that the sodium coolant and metal alloy fuel allow much higher energies in the nuclear reactions with the result that the IFR system could utilize uranium fuel 100 percent—instead of the 1 percent or so that today's reactors can do. But that isn't the whole story—the IFR could fully use weapons plutonium, the reactor waste plutonium and other, similar elements found in spent fuel.

Let me give you a rough feel for the economics of burning nuclear fuel—and this includes waste and weapons materials. One ton of material fissioned in a reactor will result in a revenue stream of about $350 million if the electricity generated is sold for 4 cents per kilowatt/hour. Economics really does matter. Burning waste and selling power is better than burying waste and collecting taxes. By the way, the example is about what a large IFR plant would consume in a year—to produce power at the rate of 1,000 Megawatts for a year.

WASTE

As with all the major goals for the IFR, waste reduction is integrated together with all the other goals. To reduce the amount of waste per unit of energy produced, you must recycle fuel until all the usable fuel is fissioned. To further improve the waste stream, the majority of materials in waste which have long radioactive lives must be removed. In the IFR, both goals were met by recycling the fuel and the long-lived materials like plutonium, americium, and related materials with very long radioactive lives are simply used as reactor fuel.

The bottom line for waste for the IFR is that the quantity is small compared to the amount of power produced, and compared to what is produced by today's reactors. In addition, the waste that is produced has a shorter lived radioactivity. It decays to less than the original uranium ore in about 300 years. That means that the toxicity rapidly becomes less than if the uranium were not removed from the ground in the first place.

The purpose, then, in initiating IFR development was precisely that implied by today's hearing—to define the best advanced nuclear reactor options for the nation. The Integral Fast Reactor program began with a reexamination of the aims of advanced reactor development, to redefine the characteristics of a successful reactor system according to today's knowledge. In the IFR we sought to develop a new reactor, a new fuel, a new fuel cycle, and a new waste process—all building on the old. But for the first time, really integrating our knowledge into a coherent system—something which had not been done before. No single characteristic promised by the IFR makes the IFR unique, but taken together, the characteristics constitute a revolutionary improvement in reactor technology.

The reason was simple. The old path that the nation had taken in nuclear development, the Light Water Reactor; or LWR, could even then be seen to be blocked. LWR orders had stalled, the Clinch River Breeder Reactor project had been canceled, reprocessing was blocked, and progress on the repository was difficult. But it was equally obvious that a viable long-term system to replace fossil fuels would still be needed.

The basic purpose of advanced reactor R&D should be the same today as it was then. Such R&D must provide the means for substitution of uranium-based fuel for carbon-based fuels on a massive scale in the next century. Simple arithmetic shows the need to use all the uranium resource. Today's reactors just use one-half of one percent of the total uranium resource.

In addition to resource utilization, tomorrow's reactors need improvements in other characteristics as well. Although there is temptation to call nuclear's problems "institutional," technical improvements that address the public concerns are essential. Safety, safeguards, transportation and waste; all these are now critically important reactor system characteristics. And, in the long term, it will be increasingly clear that uranium is a scarce resource too, so resource efficiency for the next-generation system is important to long-term success.

During its decade of development, IFR progress was rapid. The status in the key areas of fuels, safety, and fuel and waste processing can be summarized as follows: The fuel is largely proven. Remarkable safety characteristics have been demonstrated, most dramatically by demonstrations of passive safety from full power in EBR–II. In the experiments, the IFR prototype easily survived both TMI and Chernobyl-type accidents. The highest priority remaining in the program when it was canceled was the demonstration of the entire fuel-cycle in EBR–II.

In summary, the improvements that were promised by the IFR included passive, simple safety, proliferation resistance, much more efficient use of resources, and a decrease in the amount of waste produced, as well as it's long-term toxicity.

The IFR program was an R&D program that was aimed at making feasible a huge new energy source for the next century, and well beyond. It was based on, and related to, present nuclear power but differed in significant ways so as to eliminate, or at least ameliorate, present problems with nuclear power. In the magnitudes of energy possible, it is comparable in importance to the 19th century exploitation of oil for our century. The development—undertaken on every element of the nuclear reactor system—reactor, processing, and waste product was pushed far along before being terminated in 1994, for stated lack of need.

Mr. Chairman, I can supply any further information you might want on any aspect of this subject, and I wish to thank you and your staff for giving me this opportunity to discuss this with you.

Thank you.

Senator DOMENICI. Well, you can tell what we are trying to do here today. And obviously this chairman is interested in taking another look at some technologies that we might have passed over or even defunded. We are going to have to do them in a way that is practical and acceptable around here and out there in the countryside. And I am very much appreciative of what I have heard. Obviously our staff people have to do a little more work with you all, in terms of what we might recommend. And I thank you very much for that.

Let me talk a minute with you, whomever feels comfortable, Mr. Smith or Mr. Blue. Incidentally, Mr. Smith, how far away are you from a Ph.D.?

Mr. SMITH. I have just finished my master's degree, sir; and that is enough for now. [Laughter.]

Senator DOMENICI. Enough for now. Well, just keep on this work and somebody will give you one for free. You will not have to do any more. They will call you Doctor. [Laughter.]

The MHR, which you spoke of, and you, Mr. Blue, consumes more than 90 percent of the initial plutonium 239, the weapons material. That is a lot more than a conventional reactor. And that is a big plus. I understand that the MHR effectively burns or uses weapons plutonium fuel far more completely than a MOX approach and conventional reactors.

Can you provide some specific examples of this increased destruction of plutonium? And can you discuss the proliferation potential of spent fuels in an MHR fueled with plutonium versus a reactor fueled with MOX? How much weapons plutonium can each module of MHR destroy in a period of time, a year, say?

Mr. BLUE. Well, I imagine Mr. Smith has been more oriented toward the pure commercial reactor, so I will go with that.

First of all, there is an inherent advantage that we have with the gas reactor. It does burn down the 239 to a five times greater degree than the MOX does. But it also, because it burns 100 percent of plutonium as compared to 5 percent of plutonium which is in a MOX system, it effectively allows us to produce plutonium fuel for destruction at a much more rapid rate—like 20 times.

So, one of the things that is very interesting to the Russians—and I should mention that we have a very significant, ongoing program with the Russians. We completed the conceptual design of the reactor last October and we are continuing with it. One of the primary reasons the Russians are interested in this is because of its ability to destroy their weapons plutonium. And I think we should be very, very pleased about that prospect.

The first thing you do is convert the weapons plutonium to fuel. And then you can feed it into reactors at whatever rate you want. The difference being that you are dealing with 100 percent plutonium instead of 5 percent plutonium. And that is good if the objective is destroying plutonium.

Senator DOMENICI. Did you want to comment, Mr. Smith?

Mr. SMITH. Sir, although the fuel we are going to use is a slight variation of that ceramic fuels in the way that it is fabricated, we looked at that from a proliferation standpoint. And the studies that the Germans have done particularly shows that it is much, much more difficult, if you had one of these reactors, to try to extract any kind of weapons-grade material. So, it is a very complicated process, and we could not see it happening.

Senator DOMENICI. Dr. Schriber, I did not ask you, nor did you mention, the dollar figure that you think would be necessary now for this 5-year plan to be carried out with the players that are involved.

Dr. SCHRIBER. The 5-year to carry out the program would be $150 million total. And that is on the basis of a 5-year program, and for each subsequent year, of 15, 20, 25, 30.

Senator DOMENICI. So, in 1999, 15 would get the program going, in this 5-year plan?

Dr. SCHRIBER. Yes, sir.

Senator DOMENICI. Mr. Blue, did you summarize the extent of the international interest in the MHR and the kind of agreements that are in place?

Mr. BLUE. Well, I would like to amplify. We have a 50/50 joint venture going with the Russians now. It has been operational now for about 3 years. Progress has been excellent. The Russian physicists and engineers, we have the highest respect for. We have been working with them in the fusion program for nearly 40 years. They are extremely competent. Their product is excellent. I have a model of the reactor that I brought with me, which you might like to see.

The work has been superb. They have done more work for less money, faster than the program called for.

In addition to the Russians, the French and the Japanese, Framatome and Fuji Electric, have joined our consortium. The French are looking at it. They see a limited time for the first generation technology. With 75 percent of their electricity coming from nuclear, it is terribly important. They have gone further than anybody else. They want to continue that into the future, because they do not have options. So, that is why they are interested in it.

The Japanese also look far ahead. And as I said, the Japanese are going active with their test reactor just next month. They will be loading fuel and going critical soon after that.

Senator DOMENICI. Did you want to comment, Mr. Smith?

Mr. SMITH. Well, just one more thing, sir. Also, the South Africans are taking a real lead in the gas-cooled reactor design. As a matter of fact, SCOM, which is the major utility in South Africa, has got plans underway to construct a full-size commercial nuclear powerplant using ceramic, pebble-type fuel, and gas turbines. And they are estimating completion in 2001 or 2002. And in talking with them, they are estimating their generating costs, total, of 1.2 cents per kilowatt.

If you look at long-term natural gas futures in today's Washington Post or the Wall Street Journal, just to buy the gas would be 3.4 cents. So, the high efficiencies, the high operability of these plants really have a big economic potential.

Mr. BLUE. If I might add something.

Senator DOMENICI. Please.

Mr. BLUE. The fact that the Russians have agreed to match whatever funds we bring to Russia in the design effort, and the French and the Japanese are involved, it is a great opportunity for the United States to keep its costs at an absolute minimum.

Senator DOMENICI. Yes; and we do not put anything in now.

Mr. BLUE. No; the U.S. Government does not; General Atomics does.

Senator DOMENICI. Right. Of course.

Dr. Till, let me raise one issue with you. First, I want to congratulate you and the laboratory for all the work you have done, not only in the IFR, but the many exciting things that you do as part of the laboratory system. And I must confess that I have visited more and more of the laboratories as I undertake this job. Some people think that I do not do right by them all because I have two of them in New Mexico, the big ones, but I am trying to get around and I am trying to understand what is going on.

I just wanted to ask you a question. This IFR would be sodium cooled.

Dr. TILL. That is correct.

Senator DOMENICI. And sodium can be very difficult to work with. Are you certain you have resolved that issue?

Dr. TILL. Yes; I believe so. First of all, let me say you would be most welcome at our laboratory, particularly in Idaho, where the sodium facilities are.

We had, of course, operated the sodium-cooled reactor, EBR–II, that we operated from 1964 to 1994. We had occasional spills. We had occasional small fires. What happens? You put them out.

Much has been made of the dangers of sodium. Much more should be made of what a wonderful reactor coolant it actually is. It is better than water in thermal ways, and it allows a room pressure system. Too much can be made with its interaction with air.

Senator DOMENICI. Do you think those incidents that you have referred to could be tolerated in commercial plants?

Dr. TILL. No; I think if it happened in a commercial plant, they would deal with it perfectly sensibly, as happens. You know, what happens, Senator, I mean, if you get a small leak, you do not have water rushing out at 2,200 psi. What you have is a small coil of smoke which announces the fact that you have got a leak. And in a commercial plant it would be fixed, the same as in the experimental plant, EBR–II.

My point in EBR–II was it was one of a handful of first-of-a-kind, and a lot of the things were done experimentally there that would allow such spills. You would not have those things happening commercially.

Senator DOMENICI. I was telling my staff—they were discussing the characteristics of sodium—and I said that I vividly remember my one-half year of getting ready to teach in junior high and high school and science—was to go to a high school and run a chemistry class, which included a laboratory. And one of the most prominent young kids in that school, in that laboratory session, left sodium without any liquid around for just a little while, and all of a sudden we had smoke and a little bit of flames. And that was the last time I ever taught kids in a laboratory. [Laughter.]

I am not sure if I would have done it again. But I ended up teaching algebra and then going to law school. So, I do not remember much about it.

I note the presence of Sam Gibbons, a former Member of the House, a longtime Member, and former chairman of Ways and

Means. I welcome you. I was not aware of your interest, but I am delighted to have you here.

Mr. GIBBONS. I am deeply interested in what you are doing, and we will talk later.

Senator DOMENICI. Thank you very much.

It is 12 o'clock, and we have had a lot of testimony in our 2 hours. And there have been no obstructions, which is very good. I want to thank all of you. Our staff may be back in touch with you. We are going to do something in some of these areas—I do not know what yet—in this year's appropriations bill. And then we will have to defend it with some of the exciting testimony you have given it, and maybe some more that we will have to get.

I look forward to the debate. And I hope we can find some issues where the debate is properly framed. And I believe our pollster and public opinion director that testified first today has it right. I do not know that we can do it, but you cannot let the debate center around a problem with risks. You have got to have it in a broader arena of what is the overall situation versus America's future and energy in its totality, including all the others that we might have to use. I do not know that we can get that done, but I am learning. And I am hoping that people like you will give us good examples of how minimal the risks really are, even as we have to discuss risks, which we will have to.

CONCLUSION OF HEARING

Does staff have anything further to put in the record?

[No response.]

We stand recessed. Thank you.

[Whereupon, at 12:01 p.m., Tuesday, May 19, the hearing was concluded, and the subcommittee was recessed, to reconvene subject to the call of the Chair.]

○