BLUE RIBBON COMMISSION ON AMERICA'S NUCLEAR FUTURE

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REACTOR AND FUEL CYCLE TECHNOLOGY SUBCOMMITTEE

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MEETING

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TUESDAY,
OCTOBER 12, 2010

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The Subcommittee convened at 8:15 a.m. in Salon A of the Marriott Metro Center at 775 Twelfth Street, Northwest, Washington, DC, Pete Domenici and Per Peterson, Co-Chairs, presiding.

MEMBERS PRESENT:

PETE V. DOMENICI, Chair
PER PETERSON, Chair
ALBERT CARNESALE ALLISON MacFARLANE
RICHARD A. MESERVE

ALSO PRESENT:

TIM FRAZIER, Designated Federal Official
KATHRYN McCARTHY, Idaho National Laboratory
CATHRYN CARSON, University of California Berkeley
MARK ABKOWITZ, Nuclear Waste Technical Review Board

ALSO PRESENT(Cont'd):

ARJUN MAKHIJANI, Institute for Energy and Environmental Research

HUSSEIN KHALIL, Argonne National Laboratory

ERICH SCHNEIDER, University of Texas

EVERETT REDMOND, Nuclear Energy Institute

ANDREW SOWDER, Electric Power Research Institute

CHRISTOPHER PAINE, Natural Resources Defense Council

MUJID KAZIMI, Massachusetts Institute of Technology

JAMES ACTON, Carnegie Endowment for International Peace

ROBERT BARI, Brookhaven National Laboratory

RICHARD GARWIN

EDWIN LYMAN, Union of Concerned Scientists

ROBERT GALLUCCI, John D. and Catherine T. MacArthur Foundation

C-O-N-T-E-N-T-S

C-O-N-T-E-N-T-S

P-R-O-C-E-E-D-I-N-G-S

8:17 a.m.

MR. FRAZIER: All right, if I could, in the interest of staying with some semblance of time -- on time. Welcome to the Reactor and Fuel Cycle Technology Subcommittee meeting, and with that, Dr. Peterson or Senator Domenici, which, Senator? Whenever you're ready, sir.

CHAIR DOMENICI: Let me first -- thank you, Tim, good morning. I hope you can hear me, my voice has been a bit of a problem lately but it will get better, I think.

Thanks to the commissioners who were able to be here today, and on behalf of the Commission, I'd like to welcome all the panelists that are here today, and I'd like to thank the members of the public that are in attendance as well, and those who will be with us, who have already agreed to be with us but aren't here at this moment.

Today marks the start of the third Reactor and Fuel Cycle Technology Subcommittee public hearing. Following up on two successful meetings and an informative tour of the Idaho National Laboratory, our Subcommittee is moving successfully ahead with our work.

The meeting today was designed to discuss the waste-management implications of the nuclear fuel cycle alternatives. The advantages and disadvantages of new fuel cycles and the issues of nuclear proliferation and security risks associated with these technologies.

I believe these issues are important and essential in helping us make our recommendations. Given my history in these areas, I believe we must make real recommendations that our government and policymakers can use to benefit our nation.

Our Commission was appointed to do this, and I remain confident that we will find a way to do it. Our nation has time to get this done and get it done right.

As we know, our existing fuel cycle is not perfect. We can do better and we must, whatever the final fuel cycle and waste streams look like.

We need to think ahead and we certainly must make decisions now and preserve, multiply the technology -- multiple technology options for the future, including reprocessing, interim storage, and deep geological disposal.

We look forward to hearing from our panelists, and I know my fellow Commissioners and I have plenty of questions. With that, I'd like to turn it over to our co-Chairman, Dr. Per Peterson.

CHAIR PETERSON: Thank you, Senator Domenici. I, too, look forward to hearing from our speakers today. We are fortunate to have such a well-respected group of experts, and we look forward to hearing your testimony.

When looking at this meeting's agenda, it's important to note that our Reactor and Fuel Cycle Technology Subcommittee was formed to address the question, quote, "do technical alternatives to today's once-through fuel cycle offer sufficient promise to warrant serious consideration and R&D investment, and do these technologies hold significant potential to influence the way in which used fuel is stored and disposed?"

Well, our first Subcommittee in Idaho specifically focused on understanding major U.S. R&D programs, specifically R&D conducted by the Department of Energy's Office of Nuclear Energy and the industry's Electric Power Research Institute.

And our second meeting focused on major issues associated with bringing new technologies to commercial deployment. This meeting takes a deeper look at our key question, particularly how technologies can influence the way in which used fuel is stored and disposed.

Our first panel will examine the waste management implications of fuel cycle alternatives, particularly waste projections, the effects of various waste characteristics on repository design and capacity, disposal costs and licensing.

Our second panel will be looking at the evaluation of advantages and disadvantages of new fuel cycles, including the performance criteria by which nuclear fuel cycle options should be compared and life cycle assessments of costs and benefits of these options.

Our final panel today will address the issues of nuclear proliferation and security risks. Panelists will discuss the policy and technical tools to reduce proliferation risks, methods for proliferation risk assessment, the resources needed to reduce proliferation risk, and the resolution of potential conflicts between security and safety requirements for our infrastructure.

In closing, I would again like to thank all of our panelists. We look forward to a productive meeting today. Now, I'd like to open the floor to any of our other Commissioners who would like to make a brief statement.

(No response.)

CHAIR PETERSON: Very good. Thank you. Senator?

CHAIR DOMENICI: Thank you very much -- thank you very much, Mr. Chairman. I'm going to address the, introduce the panel number one. Before we begin, for the sake of keeping to our schedule, let me remind our panelists to keep their presentations to ten minutes.

Also, in order to help keep us on schedule today, we are introducing our panelists with abbreviated bios. This is difficult given the quality of our panelists.

We are grateful to have the participation of such an accomplished group of experts, but you will have to bear with us and accept that skinnied-down bios. We put formal ones in the record so everyone will know of your great accomplishments.

Our first panel is entitled "Waste Management Implications of Fuel Cycle Alternatives", and our first speaker is Dr. Kathryn McCarthy. Dr. McCarthy is a Deputy Associate Laboratory Director of Nuclear Science and Technology at the Idaho National Laboratory. Thank you very much, Doctor, for being here.

Our second speaker is Dr. Cathryn Carson. Dr. Carson is the Associate Dean of the Division of Social Sciences at the University of California, Berkeley. Thank you very much, Dr. Carson.

Our second speaker is Dr. Mark -- say it for me?

DR. ABKOWITZ: Abkowitz.

CHAIR DOMENICI: Abkowitz. Thank you very much. He is currently a Board member of the U.S. Nuclear Waste Technical Review Board, appointed by President Bush in 2002. Thank you very much, Doctor, for being here.

Our next speaker is Dr. Arjun Makhijani. Close? Thank you. Doctor is currently the President of the Institute for Energy and Environmental Research. Thank you very much, Doctor.

Our next speaker is Dr. Hussain Khalil. Doctor is the Division Director of the Nuclear Engineering Division at Argonne National Laboratory.

Thank you to you, very much, Doctor, and we'll note that attached to my remarks are detailed biogs and they're in the record. Let us proceed. Proceed in the order that I introduced you.

DR. MCCARTHY: Is -- should I do it from here, or should I do it from there? What's the process here?

MR. FRAZIER: It's up to you, Kathy.

DR. MCCARTHY: In the five to ten minutes that I have, I'm going to give you a brief overview of some of the systems analysis activities that are, have been done and are underway under the fuel cycle R&D program, the Department of Energy Office of Nuclear Energy Program. Next slide, please.

Just briefly, and I know that you have already heard from Dr. Miller, who has given you an overview of the program, but I wanted to just take a minute to put into perspective what the program is looking at now.

Under the Advance Fuel Cycle Initiative, the GNEP program, the Global Nuclear Energy Partnership, there were, the focus was on incremental improvement of existing technologies, and one of the drivers was better or more efficient utilization of a Yucca Mountain type repository.

And, really, it was focused on near-term technology deployment. Now, what I want to emphasize is that the program has changed, and now the fuel cycle R&D program is looking for transformational breakthroughs.

Now, whether they exist or not is still under question, but it's something that we're looking for, what can we do that can make very large differences.

Unconstrained range of storage and disposal options. We're no longer tied to a Yucca Mountain-type repository, so the potential geological repository could be any type.

The focus is really on long term, goal oriented, science based approach, really trying to take what we know, what we can do in terms of science, and improve the technologies that could potentially be deployed in the future. Next slide, please.

I wanted to first go over a brief summary of the characteristics of radioactive waste that are important when considering ultimate disposal. Both decay heat and radiotoxicity are important factors in radioactive waste handling, storage, and disposal.

Decay heat can damage or impair the ability of the waste form to protect the source term. Radiotoxicity is really the source term of the waste.

And, the decay heat can also affect the ability of the storage and disposal site to effectively isolate the waste form from the environment, so it's an important consideration in looking at the long-term behavior of waste.

Now, I want to emphasize that

radiotoxicity represents the hazard contained in the waste form that must be isolated. It is the source term. What you really need to look at in the end is the dose.

But in order to calculate the dose, we need to have the specific information on the waste form, the packaging, and the disposal site, because it's the job of the waste form and the site to isolate that hazard from the environment.

Radiation requires shielding during radioactive waste handling and storage, and it can also damage and impair the ability of the waste form and packaging to contain the waste, so radiation is also an important consideration in looking at the long-term behavior of the waste.

Radioactive contaminated waste that result from operating and maintaining nuclear facilities are generated in all phases of a nuclear cycle. Now, I'm going to focus on the waste that needs to be contained for long periods of time.

But it's important to keep in mind that there is, for example, low-level waste and greater than class-C waste that can be generated in other parts of the fuel cycle and all of those things need to be looked at ultimately when considering waste disposal.

The importance of each of these factors depends on the choice of repository, so I can't tell you which one is more important. It depends ultimately on the type of the repository and, of course, the waste packaging that is associated with the waste.

Volume can also be an important indicator, but it needs to be considered together with radiotoxicity and decay heat. Next slide, please. What I wanted to do first is just put into perspective what we're talking about in terms of constituents.

For example, a typical Light Water Reactor fuel assembly after irradiation. This is a typical burnup, so this is where the current Light Water Reactor's fifty-one gigawatt-days per ton is the current burnup in our existing Light Water Reactors.

So, when you look at a fuel assembly, what you can see is the hulls and the hardware are about 141 kilograms, so a significant portion of the overall assembly. Uranium is the largest piece, at about 430 kilograms.

And what you see down at the bottom are the smaller constituents, smaller but very important -- fission products, iodine, technetium, other gases, cesium, strontium, and other fission products, and then the actinides, which is about 5.94 kilograms.

So, what's important in this is that although, for example, the actinides and the fission products are a relatively small percentage in terms of mass, that's where you get the majority of your radioactivity --radiotoxicity and decay heat. Next slide, please.

So, this slide shows the radiotoxicity of waste as a function of time after reactor discharge. And again I want to emphasize that this is the source term, this information is important in calculating the dose, but it's not equivalent to the dose.

Now, what you can see here are several different potential fuel cycles and what is the ingestion radiotoxicity of that material as a function of time after the fuel is removed from the reactor. In the grouping where you can see circled once-through and single recycle.

That includes once-through fuel cycles such as our traditional uranium oxide, current Light Water Reactors, gas reactors, and also single recycle concepts such as deep burn, for example, where the actinides are put into a gas reactor for one pass with the purpose of burning as many of the actinides as possible.

And also, a single recycle burner fast reactor but what's important in all these is once-through or single recycle. And so what you see is, they're not -- there's not a significant difference amongst them, and as a -- in terms of long-term radiotoxicity, they're approximately equal.

Now, we look at the family of full recycle options, and this is where the only material that's going into a repository are fission projects and process losses.

Process losses are an important part of this, and in this particular analysis we've assumed they're .1% per recycle. So, changing that will have an impact on where that bottom line lies.

So, what you can see, that, with the full recycle, we do start to burn down the transuranics. The transuranics are what's dominating the radiotoxicity and decay heat in the long term.

Fission products in the short term. And then, when you move out to the right, the difference between the lines, the grouping of the three, the two, out of the three, is the burner reactors. The bottom is the breeder reactors.

The difference between them is the breeder reactors are utilizing all of the recovered uranium, and so the contribution from the uranium isotopes is decreasing, that's the difference between the burners and the breeders. Next slide, please.

Now, you can see on this slide a similar behavior in terms of the long-term decay heat, and again, I've highlighted what the groupings are. Fission products dominate the decay heat for the first couple of hundred of years.

And then the middle section is where the transuranics dominate. Lower right hand is where the, especially for the fast reactor cases, the continuous recycle cases, the uranium isotopes will dominate.

And so what you can see is, in order to make a significant impact in the long-term on the decay heat similar to the radiotoxicity you need to destroy the transuranics. And so the fuel cycles where you can do that again are the continuous recycle fuel cycles. Next slide, please.

Now, one of the questions that the panel had asked is what projections exist for waste. There are lots and lots of them out there.

And so what I've done is I've chosen one scenario to go through, this is an example scenario, it doesn't represent, necessarily, a real case. Well, if it were a real case and my projections were that good, then I wouldn't be working, I'd be playing the stock market.

But, what I want to show with this is that there are ways to have an impact on the waste. Now, one of the things that's really important in looking at any of these scenarios is that the assumptions need to be considered, because we can drive lots of different results, depending on the assumptions that we use.

Now, I have a relatively short list of assumptions but behind us there are actually several more pages of assumptions. And if you're interested in those, I can talk about those further.

But these are the major assumptions. In this particular analysis, first new Light Water Reactor is built in 2020. Nuclear grows, about doubles, in terms of installed capacity, by the middle of the century, and then from 2050 to 2100 the nuclear share of total electricity is kept constant from that point.

The first separations plant is operational in 2050, the size is 800 metric tons of LWR fuel per year. Then, every ten years, an additional 1,600 metric tons is added, through 2090.

And, basically, at 2090, you've almost matched the discharge from the Light Water Reactors with the capacity of the separations plants. It's not quite, but close.

In this particular scenario, we're looking at continuous recycle, so fast reactors are built when separated material is available for startup. The remainder of nuclear energy demand is met by the Light Water Reactors.

Now, I could have chosen different technologies, I could have chosen different dates, and all of that would have an impact in the next slide that I'm going to show you. But for this particular example, this is what it would look like.

The fast reactors are what we would call a burner reactor. The discharged fuel has half as many transuranics as the charge fuel, okay, so we're actually burning down the transuranics in this particular analysis.

After removal from the reactor, and this is from the Light Water Reactor, the used Light Water Reactor fuel is kept in wet storage for ten years and then it's moved to dry storage until it's recycled. Next slide, please.

Okay. In this particular example scenario, the used fuel in storage is decreased by almost 50% by 2100. That's driven entirely by the buildup of the separations plant.

If I had said they would be built slower, you would see less of a decrease. If we built them more quickly, then you would see a larger impact, earlier.

So what you see on the left is

for a once-through fuel cycle. By the end of the century, about 450,000 tons of used fuel have been discharged from Light Water Reactors and in that scenario there's no recycling.

In the scenario where we have a continuous recycle in fast reactors, starting after the middle of the century, what you see in green is the reduction versus once-through.

And so, the blue in both of them is the fuel that's in wet storage. The yellow is the fuel that's been moved into dry storage. It's cool enough in this particular scenario to recycle.

And so what you see in the right hand graph is that we've started to turn that line around so that we have -- we're using more of the fuel in the dry storage than we are putting into it.

And if we continue that beyond the century, you would eventually see the two lines meet if we built our capacity appropriately. Next slide, please.

So, in summary, the choice of fuel cycle affects the waste characteristics, reducing the long-term radiation and decay heat can reduce the uncertainty associated with disposing of the waste.

Humans -- there are examples of human engineering that have lasted for on the order of a few thousand years, not tens of thousands or millions.

We can reduce the challenges associated with waste form development. Reducing volume can be important but we need to consider it together with radiotoxicity and decay heat.

And the fuel cycle R&D program is examining a broad range of technology options, I've only shown you a scenario from one. Thank you.

CHAIR DOMENICI: Our next witness,

please? Dr. Carson.

DR. CARSON: Thank you, Senator. I'm --

CHAIR DOMENICI: Would you like to stay there?

DR. CARSON: I would.

CHAIR DOMENICI: All right.

DR. CARSON: I'm glad to be here this morning. I am a historian of science. Before I switched over to history, my background was in physics. And recently, I've been working on the history of nuclear waste R&D. And it seems to me that there are insights that that history can offer you as you think about designing for the future.

I'll be centering what I say around fuel cycle alternatives, but I think the challenges there are a lot like those facing the Commission at large. I might begin my presentation by saying how things look to a historian who's followed the waste story and who's been following your discussions, since this Commission is creating the history I work on.

What's going on in this Commission's meetings is like nothing I've seen in the historical record. It's, I think, unique. It's been stated openly that Yucca Mountain has taught us a lesson, that the system around nuclear waste policy is broken, that lots of excellent work and good intentions and thoughtful consideration has still left us entirely stuck.

Now, historians are interested in these kinds of moments, moments when old ways of doing business get rethought and revisited. The present moment has that kind of potential.

The closest thing I as a historian can find to it in the record is the remarkable openness of the mid 1950s. I'll come back to the fifties.

For the moment, let me say that I am watching to see what you'll do with this historical moment that you've been handed. Now, from a historian's perspective, there are two distinct sets of questions you're facing now, coming out of two different time periods.

I can lay them out this way. The first comes out of the late 1970s and eighties. It's a challenge, essentially, of legislative and organizational design.

In short form, fix the Nuclear Waste Policy Act, seemed like a good idea at the time, and devise a new institutional structure to house waste management, because the one put in place among the DOE, EPA and NRC -- all of these really finding their footing in the late seventies and eighties -- has had problems.

That's one set of challenges, around legislative and organizational design. The other set of challenges has its origins farther back. They're challenges around designing policies and an R&D program in support of them that respond to public input and public concerns.

Whatever else you think about Yucca Mountain, it's a good example of a project that suffered on this score. This challenge of public responsiveness is not one that's historically gotten much attention in the R&D phase of nuclear projects in this country.

That pattern really goes back to the DOE's predecessor, the Atomic Energy Commission, the AEC. The basic strategy was put in place not too long after the Second World War. I think the formative decade was really the 1950s, when the AEC began to take on the job of projecting a civil nuclear industry alongside the weapons program it was created to run.

So, today is not actually the first time that the United States has asked how alternative fuel cycles, waste characteristics and disposal options go together. Back at the very beginning of R&D on disposal, back in the 1950s, this was actually an active and quite troublesome issue.

This was at a time when massive expansion was being forecast for nuclear power, when the options on the table went well beyond Light Water Reactors, when even PUREX reprocessing was just a half-decade old.

Scientists in the National Labs were asking about alternative fuel cycles and waste characteristics, trying to figure out what choices to lead with.

This was the 1950s, so much was open, open in part because scientists and engineers at Oak Ridge and Hanford and elsewhere had very little experience with waste and with fuel cycles beyond what was sitting in their backyards. They were facing a future of almost unlimited alternatives.

Few of them were hemmed in by

technical or societal constraints or gauged by what other countries were doing. So they were essentially doing at this point a kind of blank slate analysis.

What kinds of wastes would different fuel cycles produce? How would the consequences play out for storage, for transportation, for disposal?

And central to all of this, how much would it cost? Now their estimates in those days were pretty rough. These were very hard problems to tackle.

And interestingly, most of the research moved on to other, more tractable questions, largely technical problems that seemed decoupled from societal outcomes, political or market outcomes beyond sheer order of magnitude estimates of the scale of the problem.

So, beginning in the 1950s, in the face of this openness, this became how the AEC did research. Questions about the fuel cycle were defined as technical questions.

The deference that the AEC got meant that it had to deal very little with societal acceptance, much less do research on it, until ten or twenty years later on.

When change there did come, it was due to developments around the AEC's handing of potential controversies, such as its ways of dealing with the leaking waste tanks at Hanford and to conflicts between the AEC and the states that were preliminarily being considered for new waste disposal plants.

On a larger scale, the new challenges on the scene went back to bigger societal conflicts arising around nuclear power, and I would stress this just as importantly, to a kind of society-wide displacement away from trust in existing institutions in government, industry, and science.

So, I should say that this loss of trust is partly about nuclear, but it's not solely about nuclear. It shows up in many other domains.

It has a great deal to do with skepticism about inherited organizational and institutional arrangements and about the disinterestedness or truthfulness of experts working for some government agencies or for large corporations.

This is not about anti-nuclear activism alone, dealing with what is sometimes characterized as a kind of stirred up fearful public that mainly needs education on technical facts. A lot changed over the AEC's life cycle, and into DOE's era.

We are now residing on the other side of a kind of historical divide. Historians should not go predicting the future, but I will wager one thing, that there probably will be social and political complications around fuel cycle alternatives, as there have been around waste.

So, whether its disputes over the relative credibility of scenarios for proliferation, or public confidence in assurances that the new technologies are safe, or arguments over the claim that new fuel cycles are needed to help with the waste problem, or substantial government investment in R&D that will help private firms, or facility siting or trust or transparency, or whatever.

The things we've seen before are probably will not go away, and new things will be added, and that's leaving aside the complications if something goes wrong. Now, in the context of waste, DOE as well as the National Academy did start engaging some of these problems.

Social scientists got brought in. Often, they went away feeling unheard.

Still, the challenges exactly around Yucca Mountain and more positively, WIPP, have opened up some new activity around public acceptance. There is a base to build on.

There's been much comparative experience, internationally comparative experience gained by other countries that are also dealing with waste management.

Here is the kind of back door benefit to not being out alone in front, as the U.S. was in the 1950s, even the seventies and eighties.

And comparative experience in other controversial technical domains that have come along in the mean time, such as, for instance, the National Nanotechnology Initiative in this last decade, which has taken on questions of public acceptance in interesting and provocative ways.

So, to wrap up, this Commission has a chance to consolidate that experience. The challenges that are around from the

1970s and eighties around legislative and organizational design, probably do need to be addressed in the short term.

The challenges that are still around from the fifties, though, to design R&D programs that fit better with contemporary social reality, are adaptive, evolving challenges with a time constant of decades.

They can be addressed in the waste disposal program if the present moment is recognized for what it is, and they can be addressed in fuel cycles as well.

They can be addressed if we broaden a lesson from our experience with repositories, which is one thing that, as a historian, I am curious to see if the Commission will do. Thank you.

CHAIR DOMENICI: Give us a second, we were talking. We'll be right with you. Would you please proceed, Doctor?

DR. ABKOWITZ: Thank you, Senator

and members of the Subcommittee. Speaking today on behalf of the Nuclear Waste Technical Review Board, and we are very appreciative of the opportunity to spend some time with you today and we hope to be able to share other information that involves our activities as the deliberations of the Subcommittees and the full Committee continue.

In my brief comments today, I'm going to talk predominantly about our systems analysis capabilities and some of the applications that we're running that relate to understanding various waste streams under various scenarios.

We do intend to submit a more detailed testimony to the BRC Subcommittee and it just requires, as you probably know, some clearances from the full board and we will be meeting in a couple of weeks to cover that ground. Next slide, please.

Most of you are familiar with the

Nuclear Waste Technical Review Board but just as a very quick review, our duty is to conduct an independent and ongoing evaluation of the technical activities that are undertaken by the Secretary.

And that purview includes both high level radioactive waste and various forms of spent nuclear fuel, commercial included.

I think the bullet number three on this slide is perhaps the most important, which is that, although the Yucca Mountain Repository Program has undergone an evolution, it has not changed the responsibilities of our Board.

We were never considered, I don't believe, the Yucca Mountain Waste Review Board, we are the Nuclear Waste Technical Review Board. And therefore, we've had to shift our focus, much as this Commission has been focusing on some of the new questions. Next slide, please.

As Senator Domenici mentioned before, we are appointed by the President of the United States. We serve fixed terms. But we are supported by a full time staff that's located here in Arlington, Virginia. In fact, Nigel Mote, who is our executive Director, is with us today in the audience.

And it is also important, I think, to recognize that the Board is an independent agency, not part of the Department of Energy, and for that reason, we believe that the objectivity and credibility that we bring to these challenges remain intact. Next slide, please.

There's a number of major initiatives that we have underway. They are listed here. You will be hearing from, and have heard from, various members of the Board and its staff on these subjects.

The one I'm actually going to focus on today is the first bullet, which is our capabilities to look at various spent nuclear fuel and high level waste options.

And we have referred to this by the acronym of NUWASTE. As is typical, that acronym kind of came about late at night and on the back of a napkin. The objectives -- next slide, please -- the objectives of NUWASTE, I think, are particular important for this Subcommittee and for the full Committee.

We believe it takes a lot of systems analysis capability to recognize all the different fuel cycle initiatives and what kinds of implications that has on spent nuclear fuel, high level waste, and other wastes.

I think Kathryn pointed out that there's just a number of scenarios that one can concoct and be interested in looking at what the tradeoffs are.

And, consequently, the Board felt that they needed the ability to look at all these different scenarios and understand from a waste-centric standpoint, what's going on.

And I think one of the most important messages for me today is the last bullet on this slide, and that's that we need to recognize there are a lot of different waste management criteria.

And so the eye of the beholder really governs whether one strategy looks more attractive than another. And I think that from the Commission's standpoint, there needs to be the acknowledgment that there are various criteria out there and that one needs to be able to come to terms with how important these criteria are and whether there are certain scenarios that can achieve most of what you want out of the various criteria such as a hybrid or compromise type of approach. Next slide, please.

I'm not going to bore you with details of what's in our tool, but I think that some of the features that you see listed on this slide really bring out how we're organizing ourselves.

First of all, we're looking at the entire U.S. program and for now we're focused on the Light Water Reactor world. And we're doing that initially because that's the world we're dealing with right now, it's the world that we'll be dealing with for at least the next fifty to sixty years by most everyone's account.

There are other features to what we're building into this tool that I'll mention at the end of my presentation, where we'll go and extend beyond this vision.

But for the early stages of the work we're doing, we really believe you've got to start with the here and now and then move forward based on your understanding of what that is.

There's a variety of different spent nuclear fuel management options. The three most popular ones are the ones you hear discussed quite a bit, which are dry surface storage, perhaps for long periods of time, the use of reprocessing and recycling, or just direct repository disposal.

There's a variety of different ways in which nuclear energy generation capacity is being viewed that range from the present nuclear power plants and their extensions, all the way to creating the capability to maintain the current generating capacity that we have into the foreseeable future.

And there's a variety of fuel fabrication options as well. Next slide, please. To add to the mix, we have the facilities that are capable of doing these things that can come on board at any particular time in the future, can operate for any particular time and may have varying capacities.

There's also the issue of burnup

that was introduced by one of the previous speakers, and there's also issues with regard to what fuel is aged at what level and how we pick it out for disposal and reprocessing. And there's the ability to put certain criteria at the forefront of what's important to consider. Next slide, please.

I am not going to try to explain the graph you see on the right, other than to say that this is a full representation of the Light Water Reactor world that we live in today, with the possibilities of recycling and various fuel fabrication options listed as well.

The point of this slide is that it's a very complex process and from a systems perspective, you have to look at all the different combinations of scenarios that represent ways that you can work through this particular graph.

Every arrow is a potential transportation movement. Every trash can --

that's not meant to say that it's necessarily unusable waste, but every trash can and green drums you see are waste streams.

And so you can, you can appreciate, I hope, just how important it is to recognize the pushes and the pulls that go on when you look at these scenarios.

The first bullet on this slide -- I want to bring to your attention primarily because there's a lot of different waste streams that can be generated through this process.

And we need to be mindful of the fact that while we're trying to solve the management of spent nuclear fuel there's the possibility of generating more high level waste and generating a lot of other different waste types as well. Next slide, please.

I'm going to share with you three scenarios today that we consider to be somewhat reasonable in terms of ideas or options that have been discussed by people in, in the industry. And each of them is kind of representative of a different direction that we might go in terms of implementation.

Scenario one is just looking at long-term storage only. That's the idea that between now and 2100, we would have no repository or reprocessing.

Scenario two introduces direct disposal into a repository, starting in 2040, with a capacity of 3,000 metric tons per year, but no reprocessing.

And scenario three involves bringing both a repository and reprocessing on board with the capacities that you see. We're in the process of looking at a variety of one-offs, if you will, relative to these, but I think these are very important points to anchor our discussion around.

I might also point out that the

results I'm going to share with you now are preliminary in nature, but we do believe they're indicative of trends that, that are emerging and that the Board will be speaking more about in short order. Next slide, please.

If you remember the criteria that I showed you before, I'm going to now walk you through four or five of those with respect to these three scenarios. This first one has to do with the number of dry storage casks that would be required over time.

And as you can see from the red and the blue lines, that if we do introduce a repository and even more so if we introduce reprocessing, we will be able to reduce the capacity of dry storage facilities required for spent nuclear fuel.

However, the number of dry storage casks do not drop down to zero, and in fact, if you were to introduce the repository and or reprocessing at a later date or perhaps with lower capacity, everything is going to shift up on this curve, meaning that we'll have that much more dry storage casks that we need to deal with as time goes on. Next slide, please.

Under the criteria for number of waste packaged required, what's kind of interesting when you look at this relationship is even though we are able to cut down, perhaps in the neighborhood of 25% on the number of waste packages that we would need to eventually deal with, the, even under the reprocessing with repository option, we're still going to have a substantial amount of waste that's going to require a permanent home. Next slide, please.

There's been a lot of discussion about how much savings in natural uranium that we might have from reprocessing. And this particular scenario, as you can see that there is a measurable amount of savings, but in the big picture, it only amounts to about 10-to-15% of natural uranium usage.

So, consequently, under a scenario like this, we would still be substantially dependent on using raw uranium for most of our generation. Next slide, please.

I've been concerned a little bit about people who refer to recycling and reprocessing as a closed fuel cycle. Depending upon your interpretation, that may be true.

But one of the byproducts of going through reprocessing is the generation of other waste streams and particularly with regard to the low-level waste.

You can see that there's a fairly large quantity that's generated in that regard, and therefore we need to be cognizant that there are ramifications with trying to solve one problem which may introduce another type of bottleneck or challenge. Next slide, please.

My final slide, just looking at some of these scenarios and comparing and contrasting, is under the proliferation concern about the quality of plutonium separated. Now, the red bars show the amount of plutonium that's generated from recycling and reprocessing in a given year.

The blue line represents the accumulation over time. And the point of this particular slide is that unless we have the ability to use the MOX fuel that we intended to fabricate from the plutonium, we're going to accumulate a stockpile of plutonium that I don't believe anyone is interested in trying to have occur.

And I think the French are a good indication of the types of issues that they have to deal with when you have supply of plutonium around and nowhere to go with it. Let me wrap up with my last two slides, next one, please.

Just some overarching observations. We believe that NUWASTE can help understand the impacts of potential fuel cycle initiatives on the generation and management of spent nuclear fuel, high level waste, and other wastes.

And we believe it's important that when you use these types of tools that you understand the criteria that are driving whether you believe one approach or another is more sensible.

But I think the takeaway points, just based on a preliminary analysis alone, and I think you've heard from others about this, but it's pretty clear that we need a geologic repository one way or another.

It's pretty clear that the longer that we delay in at least opening a repository, the more accumulation of dry storage casks that we'll have.

And in our preliminary

assessment, those casks, absent moving them to a centralized facility, would have them residing in at least thirty-three states. And based on our analyses up to this point in time, and they are ongoing, we don't see a major advantage from reprocessing.

Let me complete my presentation by just mentioning where we are in our process and where we're going. Clearly, being in forums such as this one gives us an opportunity to share the information that we're accumulating on the subject and we intend to continue to do that.

We are right now adding the capability to look at relative costs, because the economic aspects associated with these things are also very important, as are the risks in terms of relative dose to the public. So those capabilities are in the process of getting put into place and once we do that, we'll pretty much have all those criteria represented.

We continue to be interested in looking at additional scenarios and would certainly invite the Blue Ribbon Commission to identify some things that they might be interested in having us try to evaluate and we would certainly take those under consideration.

And then, finally, there's a number of different capabilities that we're adding to the tool, in addition to the ones I just mentioned about functionality with criteria. We don't want to forget about the stranded DOE spent nuclear fuel and high level waste.

We want to look at transportation logistics more carefully, interim storage facilities away from the reactor, and some of the more advanced reactor designs.

I tried to do a quick job of that, I apologize for going over my time. Thank you.

CHAIR DOMENICI: Thank you very

much.

DR. MAKHIJANI: I mixed up my schedule, so my slides are still in drop form, I'll submit them for the record later on.

CHAIR DOMENICI: That's fine.

DR. MAKHIJANI: Just to give you an overview, you know, last time I suggested when I made a presentation to the full Commission, that the problem of existing spent fuel from the current fleet should be separated from new reactor initiatives.

If you're going to develop breeders, what happens with the fuel that goes into it. The uranium that you use -- and I suggest, you know, although I don't think breeder reactors are a very good shot for, for putting public money into their development, that even if you went there, the uranium and existing spent fuel is, is not the right uranium to be using there.

Depleted uranium, we have plenty,

it's a waste, it's free, be reducing the waste burden if you targeted that uranium for breeder reactor development. So I do think that you're hearing, at least the sessions I've attended, a pretty consistent message that reprocessing of existing reactor spent fuel doesn't make sense.

And to remind you of the numbers that I gave you last time, to use up the uranium in existing reactor spent fuel would take 100,000 reactor years in breeder reactors, which we haven't developed yet. That's 500 reactors operating for 200 years, some, whatever combination you want.

And at a penny a kilowatt-hour extra, that amounts to about eight trillion dollars. That makes, you know, current deficit ideas, I don't think industry would be willing to pay for that. It's a more than the worth of the electricity that's being produced from the existing reactors.

So I really think an early

indication that -- you've heard this, that we ought to think about managing the spent fuel from existing LWRS as settled once-through to a repository would be very useful. You know, the waste volume issues, the MOX fuel cycle issues, so on.

So, the short of it is, the new reactors will produce new issues and so I want to go over some of the transmutation issues that are involved, so. You have breeder reactors, you have repeated recycle. The first thing to know is that you're going to have to have repeated reprocessing and repeated separations in order to be able to deal with the troublesome radionuclides that are not plutonium.

Plutonium in principle, you could say, well, you're going to use it in breeder reactors, and you're going to improve the isotopic composition, and if you do repeated recycle and produce very high purity plutonium in the blanket, then somehow you can deal with the plutonium.

But the other -- the minor actinides, the neptuniums, the americiums, and so on, as well as the technitium-99, the iodine-129, you're going to have to have repeated recycles to deal with it. Let me just go over the list of problem radionuclides, and there are quite a few.

Tin-126, about 100,000 years. Long lived fission product. Very, very difficult to conceive of transportation. Selenium-79, the same. Cesium-135, very difficult. You've got to separate from cesium-137, doesn't look like a sensible idea. So cesium-135, 2.3 million year half life. You've go to live with that, and the more fission you have, the more cesium-135 you're going to have, guaranteed.

Zirconium-93, no transportation option available at present. And I have to say, we looked at this a few years ago, so there's not completely fresh research.

Carbon-14, also no potential. Chlorine-36, none. Technitium-99, repeated recycle, you could make a dent into it. Iodine-129, also.

Uranium, I've already told you, it's a real problem. If you pay a penny a kilowatt-hour extra in any type of reactor, you're already into trillions. So the idea that you can use breeder reactors to create a closed fuel cycle, probably from the Nuclear Waste Technical Review Board, is that the idea of a closed fuel cycle is a physicist's idea.

This is the magical thing of Alvin Weinberg, the magical energy source. But when you translate physics into engineering and cost, this becomes an essentially impossible thing. To leave aside all the proliferation implications.

So, unless breeder reactors are somehow magically reduced in cost and physicists somehow don't seem -- I guess, you know, you could, you can get as much money to study the universe as you like, and so you don't have to worry about cost or results or -- you know, with all due respect to physics. I love physics. It's my first discipline, love.

But it's not very efficient in terms of practical, everyday considerations and this has got to be taken out of the magical idea of physics giving us some great energy source. You got strontium-90 and cesium-137, they are your major, medium term heat sources.

And I can't imagine storing these things for hundreds of years on surface. I think its not a very good idea, so. So your main heat load is going to be there in the repository anyway.

I want to make some comments on small modular reactors, because there's been a lot of talk of those and we're hurtling into this public funding of small modular reactors as if they're going to solve the nuclear reactor renaissance problem.

Now, so far as waste is concerned, the Light Water Reactor evolutionary small modular reactors are not going to change the waste picture. They have the same type of fuel, so it's going to be a quantity problem not a quality problem.

But we haven't begun to talk, at least I'm not aware that there's been any serious considerations of the new waste problems you're going to have from some of these graphite moderated reactors, pebble bed reactors.

You're going to have massive amounts of carbon-14. Can you put unoxidized carbon-14 in a repository and how is it going to complicate? Now you remember before the new rules for Yucca Mountain, Yucca Mountain had standards problems because it could not meet the carbon-14 standard of the EPA.

I was on that EPA Subcommittee

that looked at that problem, so all graphite moderated reactors are going to give you severe headaches for thinking about repositories, in my opinion. The idea that you can bury a sodium cooled reactor for thirty years is, in itself, kind of far fetched, you know, in some Alaskan village out there and it would work perfectly for thirty years.

But once you take it out and take it away from the Alaskan village, it's completely unthinkable to me, technically, that you're going to bury a reactor with liquid sodium in it. And we haven't even begun to discuss what you do with a sealed reactor that has liquid sodium in it, as a waste management problem.

If we have difficult technical problems with repositories now, I think we're going to have headaches that we haven't even begun to imagine. Because in principle, a ceramic fuel form, waste form, is a pretty good waste form. It's hard to do, make a fuel that will in itself have some resistance to leeching out into the groundwater and so on. Then, the existing ceramic waste form, it does have that virtue.

Reprocessing involves waste that you really need to consider. Repeated reprocessing is going to create repeatedly increased volumes of aqueous wastes, even if you have an initial electrolytic cycle, you're going to have large volumes of side wastes.

While I agree with some of Dr. McCarthy's presentations, I cannot agree that a 0.1 residual from repeated reprocessing and a completely closed fuel cycle is realistic based on past experience. The main past experience we have with repeated reuse of transuranic materials is in the weapons program.

And in the weapons program --

first of all, we haven't been able to keep track of it. Los Alamos has two sets of books on plutonium, one in the waste streams and one in the security stream, and they have a 300 kilogram discrepancy in the waste statistics.

If you look at the official memorandum with the fifty year plutonium report and look at the waste totals estimated by the waste management people in the U.S. nuclear weapons complex, it's more than five tons. That's about 5%.

So, that's fifty times the estimate that you've just received for the radionuclides we're most familiar with and can control best and whose chemistry we understand best, among the transuranics, let alone the americiums and the neptuniums and the more headachy kind of things that are difficult to transmute.

I think .1% from repeated reuse is, you know, hope against technical reality. Maybe we'll improve the technology by nearly two orders of magnitude, I don't know. But I know that the Japanese had a 200 kilogram tussle for many years with the IAEA just from the simple reprocessing.

To summarize, I think we really should put an end to the notion that existing spent fuel reprocessing can solve anything, and it will complicate every single problem and introduce new problems. You should separate the new reactor development.

In the new reactor development, I think you've got two streams. You've got these small, modular reactors that are going to create new waste headaches that, I don't know that you've begun to consider, but I've seen almost no public debate.

The third thing, is industry going to pay for this wonderful new system that we're talking about, the reprocessing and repeated recycle? I think the cost issues are very big public policy issues. My suggestion for repositories, fairly independently of what you see for the future of nuclear power, is we're going to need a high level waste repository that's pretty big.

Most everything's going to be occupied by existing spent fuel. I also think that you ought to recommend a separate repository possibly, or at least a repository for all the other waste that we're going to have. We have a lot of depleted uranium, we have a lot of transuranic waste.

There's a lot of defense wastes that really need to go to a repository that isn't a high heat load, and we ought not to be burdening the high heat load repository with large volumes of long lived materials that don't need to meet the standards.

So we've got a successful example before us in this country of WIPP. I think a

WIPP-like repository is really, needs to be put on the table of public debate separately from the issue that the utilities are concerned with, which is spent fuel.

I think if we have these three streams of thinking, we'll at least have the right technical bins in which to consider the problem of nuclear waste. Thank you.

CHAIR DOMENICI: Thank you. Our last speaker for this panel is Dr. Hussein Khalil. Thank you, Hussein.

DR. KHALIL: Well, thanks for the opportunity to contribute a very different perspective from the one that you just heard, and I hope there will be an opportunity to have some discussion of some of the sweeping assertions that were made.

I will provide some perspectives on reactor and fuel cycle technology options that can impact waste management. Next slide, please. Regarding the question of used fuel and waste generation and the interest in estimating these, as you've already heard, there have been many scenario studies that have been done by DOE and other institutions that have looked at different scenarios and have made estimates of used fuel and waste discharge rates.

The situation with used fuel is very simple. The annual discharge of used fuel is simply equal to the average thermal power generated by the reactors, divided by the burnup of the fuel. So, the quantity of discharged fuel is inversely proportional to burnup and one way of reducing used fuel is do increase the burnup from reactors.

The benefit from that is limited, however, because with increasing burnup, there is generation of plutonium and higher actinides of course in the used fuel which have to be disposed of.

So, the burnup of used fuel of course determines its composition and its emission characteristics, its radiotoxicity, its decay heat emission. And of course, other than extending burnup, there's the possibility of recycling the spent fuel.

And the main, the main goal with recycling is to make use of the actinides that are discharged from the used fuel. And there are many different possibilities in terms of what fraction or what types of fuel that reprocessing and recycle are applied to, as well as which elements are targeted for recycle and reuse in the reactors.

So, the recycle can be partial recycle or it can be full recycle. The reference to repeated recycle simply means that you recycle the fuel that's discharged, simply recycle all the discharged fuel. That is the basically what is done when you are doing repeated recycle.

There's been recently a very extensive compilation of used fuel generation and waste quantities that DOE has developed. It provides used fuel quantity and composition as a function of burnup and cooling time, looking at different alternatives, different energy use scenarios, different recycle processes.

And also looking, of course, at generation of low-level waste. It's very likely that recycle will increase the generation of low-level waste, though we think this problem will be much easier to manage than the very long isolation that's required for high-level waste.

The main point in this chart though is that in all the scenarios that we've looked at, we will need both temporary storage of used fuel and long term isolation of the hazardous constituents of used nuclear fuel. Next slide, please.

The design and licensing of waste isolation sites is a very challenging undertaking that requires consideration and accommodation of many different physical phenomenon. And among the characteristics of the waste, there are many of them that Dr. McCarthy mentioned in her presentation.

The quantity of waste, the radiotoxicity, the heat emission. Among these, I'd like to focus on the heat emission from the waste as a particularly important factor that affects the capacity of a disposal system and also its operation.

This is to meet thermal limits that are defined to preclude the degradation of the, of the waste forms and the perturbation of the engineered or natural barriers in the disposal site. Heat generation effects the capacity, the waste emplacement capacity in that configuration.

And also, operationally, cooler wastes are much easier to handle. They could be placed in a repository sooner, and would require less active cooling. Additionally, to the design and operation and construction challenges for waste isolation sites that come from heat generation, heat generation also greatly increases the complexity of modeling the performance of disposal sites.

And in particular, the ability of a disposal system to mitigate the dose release. The dose release is the criterion typically by which a disposal site is evaluated. Radiotoxicity is the source of the dose, but the criterion for licensing a repository is typically the dose released to the biosphere.

And heat generation perturbs the disposal environment, it effects the geochemistry in the near field, the degradation rate of engineered materials, the hydrologic flow and mechanical processes in the disposal system, in ways that aren't necessarily easy to represent.

So we expect reduction of heat generation to provide a benefit not only for design of a repository but also for the licensing phase. Next, please.

So, in considering how to deal

with heat generation, we first look at its sources. This chart shows the total heat generation from used fuels starting at ten years post discharge of standard Light Water Reactor fuel through 10,000 years. The total heat decays by a couple of orders of magnitude in this period.

Initially, it's dominated by fission products, and almost strictly by the cesium and strontium and their decay daughters. Their heat emission decays to where it's comparable to that from the actinides, the heavy elements that are fissioned and produce energy, in about sixty years. So at sixty years, the heat source comes from the actinides, to a greater extent than the fission products.

And in less than 300 years, the heat emission from the fission products is essentially negligible. Now, the thing that's very important to keep in mind is that the dose released from a repository is typically governed by the long lived fission products: technitium 99, iodine 129, isotopes of cesium and chlorine.

So they are the dominant source of dose release. However, it's the short lived fission products that contribute the heating to the repository. This decays away quickly and much more slowly decaying is the heat source from the actinides.

And the integrated heat source from the actinides is much greater than that from the fission products. So the heating from the fission products can be handled through interim storage, through active cooling in the initial waste isolation period. But the long term heating from the actinides is much more difficult to manage, and it contributes the vast majority of the long term heating. Next, please.

So, I already mentioned then that for the storage period, the fission products, the short-lived fission products dominate the heat emission. For long term disposal, the actinides dominate heat emission.

And so it's very natural to look at fuel cycle options that don't discharge these long-lived and slowly decaying actinides to the repository. It turns out that these are precisely the same constituents of spent fuel that are reusable for making energy, they're the actinides.

And in particular, americium and plutonium are, govern the long-term heat emission. So, fuel cycle options that fission and recycle these elements, keep them out of the high-level waste repository and this is a very compelling argument for recycle is that it's exactly the problematic constituents that are reusable for energy generation.

Fuel recycle converts the actinides to fission products. That's true, however, fission product generation is only dependent on the amount of nuclear power generation. So their production is completely unaffected by recycle. It's strictly proportional to the amount of nuclear power generation.

So, by keeping the actinides out of the waste stream, we greatly reduce the long term decay heating. Also, we avoid the discharge of very long-lived radiotoxic elements. This is the radiotoxicity aspect of the problem, as Dr. McCarthy pointed out.

And keeping the actinides and especially their heat emission out of the waste stream should greatly facilitate the design, licensing, and operation of a disposal site.

And one of the most effective approaches to keep the actinides out of the waste stream is to enhance their fission probability in a reactor, to employ efficient recycle of actinides that are discharged, minimize the losses of the elements that are being recycled and, of course, durable waste forms are also important as part of the isolation strategy, additionally to engineer barriers and the natural isolation that's provided by the repository environment.

The first bullet is why we're interested in fast neutron reactors. Fundamentally, fast neutron reactors, as this chart shows, are much more efficient in fissioning the even isotopes of plutonium and the minor actinides.

Both fast and thermal reactors fission the fissile isotopes like uranium 235, plutonium 239, but only fast spectrum reactors efficiently fission plutonium 240, plutonium 242, and this is of very fundamental importance because it avoids the capture to heavier elements, which are problematic in, during the reactor irradiation. Next slide, please.

So, then to summarize, fast

reactors and recycle have tremendous potential to reduce the cost and improve the performance of waste disposal systems. This is true whether they are implemented to help manage the back end of the Light Water Reactor fuel cycles or they're implemented for energy generation in a break even or even a breeding fuel cycle.

But they can also contribute to the management of the back end of the Light Water Reactor fuel cycle. And, again, primarily through the reduction of heat generation from the waste.

Now, people may argue about whether this waste management benefit is the primary incentive for pursuing fast reactors that recycle, but at least it's a benefit. Other benefits are vastly improved utilization of uranium resources, and ability to use up vast quantities of depleted uranium that have, have been produced as a result of enrichment operations, as well as used uranium that's discharged from reactors.

There's also a benefit of reducing enrichment by recycle. It's true, you are separating plutonium and minor actinides, and this has to be, has to be safeguarded in the fuel cycle, but it has a compensating benefit of reducing the fuel enrichment, which is probably one of the most proliferation-sensitive aspects of the fuel cycle.

I don't mean to imply that there aren't significant challenges for fast reactor recycle. There are and I've listed them here.

They are: chief competitive cost and they're to assure safety and reliability of operation, and to assure efficient implementation of safeguards and physical protection, and these are exactly the goals of the DOE R&D program on fast reactor and recycle technologies.

And then, most fundamentally though, is that irrespective of the fuel management option that is pursued, a full used fuel management infrastructure will be required even where we are today.

This includes storage of used fuel, transport of fuel to either processing or disposal locations, and of course, final disposal of high-level waste in a repository.

That concludes my presentation.

CHAIR DOMENICI: Thank you very much. I think we have finished the witnesses. Mr. Co-Chairman and in the rest of our time, I think we'll follow the agenda, is that correct? Do you have questions? Let's start with anyone. Al, do you want to proceed?

MEMBER CARNESALE: Before I get to specific questions, most of what we've heard when it comes to reprocessing and whether its fast reactors or other form, whatever benefits arise, arise in the long-term. Those are the benefits.

And yet we've also heard not just today but elsewhere that the principle, among the principle things we need to address is the societal implications and the political obstacles and the like. The U.S. Government, to a first approximation, and the people, have a very high discount rate.

The idea that the benefits are going to come more than 100 years from now is inconsistent with the way we think about climate change, Medicare, social security, the debt, everything else, where the discount rate is roughly one, or perhaps eight years at the outside.

So, can you help me out. It appears that among these, whether you reprocess or not, there aren't many differences for 100 years except if you reprocess, you have to build reprocessing plants, you need more transportation, you need more low-level waste, or I should say, lower-level waste. Because it really isn't, it's not the same as what comes out of the hospital.

So, it sounds like the disadvantages come up front, and the advantages come after not only when nobody's any longer in elected Office, but they're all dead. So, help me to understand how I put these two things together. I have a nuclear waste technical, but I don't have a political Board.

And yet, we all realize that that's a big part of the problem. So could you tell me a little bit about, what are the disadvantages in the near term, by which I mean fifty years, of moving away from once-through? What are the advantages, what are the disadvantages, moving away from once-through fuel cycle and saying goodbye to that spent fuel and putting it in a repository someplace?

CHAIR DOMENICI: Who do you want the question of, Al? Who do you direct the question to?

MEMBER CARNESALE: Well, they've all sort of --

CHAIR DOMENICI: They were all put up to manage answers --

MEMBER CARNESALE: I'd like it from the technical people, perhaps, first, I think the, but whoever --

CHAIR DOMENICI: Why don't you put up your hand if you'd like to answer the question? Anybody like to volunteer?

MEMBER CARNESALE: Well, why don't we have Mr. Abkowitz?

DR. ABKOWITZ: Okay, I guess we'll go by alphabetical order here. I don't -- I can't answer. I agree with what you just said, that it's not clear that there are any advantages in the next fifty to sixty years, for sure.

So I'm not here to argue the

tradeoffs. We've not yet found a compelling argument for reprocessing and recycling in the world as we know it today and in the foreseeable future.

DR. KHALIL: I think we need to distinguish between implementation of these technologies in the near term to address existing spent fuel stocks and the like, which is probably not going to happen and may not make that much sense. On the other hand, there's a tremendous incentive for the future to develop an emission-free energy source that produces less waste, that uses uranium more efficiently. And that's the benefit from recycle.

When those technologies for fast neutron reactors and recycle become available, they can help manage the accumulation of spent fuel from other types of reactors, as well as just generate energy independently from Light Water Reactors and perhaps supercede Light Water Reactors and provide you an energy, a sustainable energy form.

So, I see a lot of incentive to develop these technologies. I don't think there's an urgency to their commercial implementation. I strongly suspect we wouldn't see a commercial implementation until, say, decades from now.

But the technology is very compelling and, I think, worth developing and worth commercializing in the future.

DR. MCCARTHY: I think what you have pointed out is one of the biggest challenges that we have, and I spend a lot of time going out to talk to various stakeholders to try to explain what it would mean to implement some of these other fuel cycles, and what are the advantages and the urgency argument is the one that's difficult to argue.

And that's because our political system sort of works in four year bites, and if something is further than four years out, it tends to be infinity. But I don't think that that means that we ought to not pursue this, and the sooner that we begin to implement this, the sooner we'll see the advantages.

Albeit, it will take a while. It is possible to start earlier than, for example, the analysis that I've shown and it's to a large extent a matter of political will to do it, the technical risk that one wants to take on and the political risk associated with it.

DR. CARSON: It's a fascinating design challenge and I think one of the sets of people to pose that to is the political scientists, who may be able to bring in, personally, as a historian I can't think of any, but are there any success stories of designing for a long term payoff with short term benefits that are hard to define?

I would also suggest that if

there are lessons to be learned from other nations that have taken on the interest in either reprocessing or other kinds of advanced reactors, that analysis be done of that, of both the reasons for their success and the limitations that they have run up against.

DR. MAKHIJANI: I would just add one thing. There is no short term pay off. That's very clear. And by short term we mean thirty, forty, fifty, sixty years. I, I would question the framework that there is a long-term payoff, because it assumes that nuclear energy will be the non-carbon energy of choice fifty years from now.

Anybody who's got a crystal ball for technology that looks out fifty years, is better than me, certainly. The crystal ball we do have, that at least I look into, and not as a Hindu, the technical crystal ball I look into is pretty murky. But from what we can tell is solar energy costs are coming down very rapidly.

The technology is not where wind energy was twenty-five years ago. If you look at the evolution of wind energy in the last twenty-five years, it's quite remarkable and it's still developing extremely rapidly. The issues of indeterminacy and so on, I've looked at all of that. I've sent you copies of some of that.

But I would say that betting a huge amount of public money on payoff fifty years from now from a technology that has failed after 100 billion dollars of public expenditures globally over the last, is a poor choice, of public policy, especially as we can see other benefits in the much short -term.

And if it doesn't, if the crystal balls about solar energy are wrong, you don't lose very much. You don't risk very much. You will have a lot of choices open to you, including existing LWR technology, right, I don't think the nuclear renaissance is coming about anyway.

But you don't lose anything by investing large public dollars in a fifty-year technology payoff, I don't think. Look at fusion, my chosen discipline for my doctorate, it's always thirty years away. And if we don't have a good crystal ball on fusion after untold billions of dollars of public expenditures and some of the best scientists in the world, I think the idea that you're going to have benefits fifty years from now is really far fetched.

DR. KHALIL: And nuclear energy, I'm not sure I understand the reference to a failed development. I mean, it's 20% of electricity generation in this country, it's 70% of emission-free electricity generation. It has a non-negligible fraction of energy and electricity generation worldwide.

Its development is being

accelerated in other countries that are looking at population growth and economic development, including fast neutron systems and more sustainable versions of nuclear energy. And, by the way, as a component of the energy mix of the future, not as the only option.

So, I think we are not-- when I mentioned sustainable nuclear energy, I mean it as part of the portfolio of energy supply options for the future.

DR. MAKHIJANI: Just for the record, you know, when I say failed development, I'm referring to sodium cooled reactors, and you've heard my presentation before. Frank has talked about this. I mean, it's very clear that the public estimate of around 100 billion dollars expenditures worldwide in the development of sodium cooled fast breeders, and we still don't have a commercial system.

It's quite simple, we do have a

commercial LWR system. Now, how it became commercial and whether it is still commercial is a separate argument, but I'm not talking about LWRS. Just for the record.

CHAIR PETERSON: Next? Allison?

MEMBER MACFARLANE: Okay. If you'll indulge me, I have questions for three of you. Okay, so let's start with Kathryn McCarthy. Would you characterize the difference between the burner breeder and the other cycles that you showed us as significant in terms of long term radiotoxicity and decay heat and in regards to their repository impacts?

DR. MCCARTHY: So, the two groupings were basically continuous recycle --

MEMBER MACFARLANE: Yes.

DR. MCCARTHY: -- versus once-through and single recycle. Okay. And there was on the order of one to two orders of magnitude depending on where you look.

MEMBER MACFARLANE: Okay, and do you characterize that as significant?

DR. MCCARTHY: Depends on the repository. It depends on what's important to the particular repository. It depends on the mobility of the particular --

MEMBER MACFARLANE: So, basically --

DR. MCCARTHY: -- elements.

MEMBER MACFARLANE: -- is it a reducing or oxidizing repository.

DR. MCCARTHY: Right.

MEMBER MACFARLANE: And then, have you looked at MIT's report? Because they say the opposite of what you're saying, that these aren't significant differences.

DR. MCCARTHY: You know, it is subjective and in the end, you have to look at the whole system, including the repository. One thing we're doing here is focusing specifically on the repository, understand that. But in the end, you have to take into consideration waste package, environment, the entire thing.

MEMBER MACFARLANE: Okay. Question for Cathryn Carson. So, in your writeup, you say that our, my, us, the BRC's design challenge is to build in societal concerns from the beginning. I just want to push you here, take off your historian hat, just leave the social scientist hat on and, you know, how would you do that?

DR. CARSON: So, if we were thinking about how to bring in societal considerations, which you can include social science, largely reaching over into public outreach, my suggestion would be first to look at other countries that have given a shot at this. I believe the full Commission has heard from representatives of the Canadian program.

MEMBER MACFARLANE: Yes.

DR. CARSON: And my understanding, though I don't have direct contact with them, is that social scientists have been brought into the framing, at least, of their process definition. And, as I understand it, they have made a commitment to continue funding, particular relevant kinds of social science research for that process.

MEMBER MACFARLANE: Yes.

DR. CARSON: Believe there's something similar that's done with Sweden, though I know that case even less well. So, there are models for this that have been, begun to be tried out in other countries, again, specifically around the waste problem.

But I think that can be the basis for generalization for the questions facing this Subcommittee as well as the Commission at large. The other place to look for models is in programs like the Human Genome Project or the National Nanotechnology Initiative, which I mentioned. Which, in their case, designated a certain proportion of funding to go to outreach, education and what, in the jargon of the domain, is called ELSI, Ethical Legal and Social Implications research.

Now, I'm not sure the percentage model for funding social science research gets you where you want to go. But, given the fact that it's a model that has been tried out and can be queried to the people who have been involved in it, overseen it, managed it, and in some cases, seen what the payoff is, I suggest that there's a scoping out process that can be done that will give guidance about what could be useful in this particular case.

MEMBER MACFARLANE: Great. Thanks. And then, finally, for Mark Abkowitz, a couple questions. Let's see. So, one thing it seemed like that was missing from your, what did you call it, NUWASTE? Whatever it is. Analysis, is whether you really quantify the gases, the liquid effluents, the decommissioning wastes, that you have in these different processes.

And then, secondly, you know, I noticed that -- and this isn't just limited to you, but a number of you have spoken about the repository, singular. Is that what, really what you believe? Or are we looking at repositories, plural?

DR. ABKOWITZ: Okay, let me take on the two of those questions separately. First of all, we've taken great pains in taking that schematic that you saw in one of the slides, with the little icons and everything, to make sure that we have complete enough balance between --

MEMBER MACFARLANE: Right, you didn't have any, you didn't have any liquid effluence or decommissioning wastes, I don't think, I saw in that.

DR. ABKOWITZ: Okay.

MEMBER MACFARLANE: You had the gases.

DR. ABKOWITZ: Okay. To my --

MEMBER MACFARLANE: -- a cloud.

DR. ABKOWITZ: I'm not the programmer, but to my knowledge, we are taking into consideration everything, and if it hasn't, if it hasn't been discretely shown in the manner that you would like to see it, we can certainly produce that information in that form. But we've been very careful to make sure that we account for everything that comes in to each of those boxes and how it comes out, and we have benchmarked that against quite a bit of literature and in communication with a number of industry professionals.

MEMBER MACFARLANE: Right, right. I mean, I think that that's really important to emphasize because that is what gets lost. All we end up discussing about is the high-level waste and the low-level waste and intermediate-level wastes, especially for the cycle that you looked at --

DR. ABKOWITZ: Yes.

MEMBER MACFARLANE: -- are huge.

DR. ABKOWITZ: Absolutely.

MEMBER MACFARLANE: And they, and the intermediate level wastes, greater than class C, call them whatever you want, they require a repository.

DR. ABKOWITZ: Yes. When we get --

MEMBER MACFARLANE: There we are, into repositories, plural.

DR. ABKOWITZ: Right. Let me answer that part of the question. When I made reference to the term repository in the singular sense, it was really focused predominantly on what to do with spent nuclear fuel and high level waste. The argument I was making is that we're not going to avoid the need for that.

Clearly, the extent to which we're generating large volumes of other wastes implies that we would need to have other repositories as well. Or expand on whatever repositories people were thinking about for those other situations.

MEMBER MACFARLANE: Yes.

DR. KHALIL: Some of the quantities of wastes are not fundamentals of nature, and improvements are clearly, they're targeted, they're desired, they're being pursued in R&D programs around the world. So there, there is, clearly there's room for improvement, but I don't think we should, just, be, adopt the attitude that the current state is the way, the way that it has to be.

MEMBER MACFARLANE: No, but I am chastened by the fact that we cannot dispose even of our low-level waste in this country. So, we have a problem across the Board, and if we are going to be producing more than just high level waste, you know, if we're going to be producing low-level waste in addition and we don't have a solution for that, we have to keep that in mind as we look forward.

CHAIR DOMENICI: Let's see who is next. Dick?

MEMBER MESERVE: Just a quick followup on that. I did notice, Dr. Abkowitz, that you had lumped together the low-level waste with greater than class-C waste, and it really would be important, acknowledging that, may not necessarily be a technologically defined mind, but separating those I think would be very important given the current lack of any pathway for greater than class-C wastes, a problem certainly with low-level waste but aggregating them is, I think, would be very helpful-- disaggregating them would be very helpful.

DR. ABKOWITZ: Point well taken. This was the manifestation of five to ten minutes and trying to point out that there are other wastes that are generated, but you are absolutely correct, they are different animals and, and we can produce that information for you.

MEMBER MESERVE: To follow up on that, it does seem to me, although we have not agreed on this among the group, that the kind of modeling that at least three of you have discussed about what the waste forms are, where the flows are, and so forth, are, under various scenarios, are going to have to be something that we include on our report at some way.

You've described I think at least, maybe I think, at least three different models. That there's the Idaho model, apparently there's an Argonne set of models that may be different from those at-- and then, Mark, I'm not sure whether your models include the fast reactors yet.

But it does seem to me that if we have a, a, some scenarios that we need to examine as a Commission and models that we need to evaluate and I'm wondering the extent to which you have communicated with each other already and have some consensus, at least consistent models, whether you've done the evaluation that gives us some confidence that there's a foundation on which we can build.

DR. ABKOWITZ: Let me, let me respond to that. This question actually came up about three weeks ago at the DOE used fuel workshop that was actually held here in DC in which I was participating, I was with some folks from Idaho who used the, what's referred to as the VISION model.

And there are, there are other models out there as well. Argonne referred to one. There's actually some internationally. And it's actually spawned a discussion that, that our Board is now taking up and, at our business meeting a couple weeks, about the idea of having some type of modeling workshop, most likely in the early, late winter, early spring, where we bring together all these different parties and somehow go through the gyrations of trying to understand how we're each designing our approaches and what types of results we get when we're all given the same set of inputs, so, so that we can try to get at this very question.

DR. MCCARTHY: Let me quickly address what has been done with respect to VISION that Dr. Abkowitz referred to. VISION is actually the fuel cycles R&D code, it's not an Idaho code. It's developed by multi-laboratories. It was Idaho folks who presented it.

We had gone through several benchmark activities, both nationally and internationally. We participated in a benchmark via MIT, their study. We participated in two international benchmarks, one through the OECD nuclear energy agency and the other through the INPO activity, another international activity.

What you find with systems codes,

first of all, to specify a set of assumptions does not mean--or, input--does not mean you're going to get the same answers. What you tend to find is systems codes have certain things built into them, and that will come out in these benchmarks.

But, there are two, one already published report, and I think two that are coming out soon, that speak to the bench marking of systems codes if you're interested.

MEMBER MESERVE: Well, I think that I for one would find it very valuable to get some sense of what the community thinks our least consistent, believable codes, and would be useful I think to have a wide range of people involved in that exercise so that their buried assumptions are revealed.

DR. MCCARTHY: One thing I want to add really quickly is what you get from these types of codes, systems codes, typically, is trends and sensitivities. If what you want is a fuel tracking code, that's a different animal and its important to keep those two separate.

DR. ABKOWITZ: But I think that, if I understand your point, it's really more to be able to evaluate a consistent set of scenarios and see whether we come up with similar results. And if we don't, then we need to go in and find out whether its because of some assumption that was made, or a very different way in which we're viewing the fuel cycle world.

But, one way or another, we need to be able to understand the differences so we're in a position to be able to respond to the types of questions that you people are asking us.

MEMBER MACFARLANE: Let me suggest that you have a science studies person there. Really, that, that might help.

DR. KHALIL: I just wanted to

clarify one point--

CHAIR DOMENICI: If I could make a comment--has your question been answered?

MEMBER MESERVE: I think the one--

CHAIR DOMENICI: --if he's talking about when he talked about a model, you all got, understand what he's asking for? You understand it, can we get it, I mean, is that what you're asking, Dick? Are you--

MEMBER MESERVE: Yes, yes.

CHAIR DOMENICI: --and what time, how long, time frame to get it?

DR. KHALIL: I wanted to clarify that, that none of the points that I made or the results that I showed were produced using an Argonne model. It's true we have a system modeling capability. I was referring to studies that were done by DOE in their systems analysis area and their used fuel disposition area. So these were DOE studies, they weren't produced using an Argonne model.

MEMBER MESERVE: Well, let me suggest to our co-Chairs that we probably ought to assign some staff to get work with these people, because I think we are going to want to have some of these scenarios, that we understand them and employ them in our final report.

CHAIR DOMENICI: I, I agree--

CHAIR PETERSON: I concur.

CHAIR DOMENICI: We're going to get that done by our staff if they don't have the expertise we ask them to get it, so that can be done.

DR. MAKHIJANI: Could I make a suggestion about these models, if I might? You know, I don't know if their outputs are geared to the existing low-level waste classifications. You know, we've got waste mass and then we've got a classification mess. And currently, the Chairman of the NRC has written the staff that they've got inefficient and ineffective way of trying to update the low-level waste group.

And I think when these models are being considered, it might be sensible to have two different types of bins in which you get the output. One set of bins would be geared to existing low-level, the 10 CFR part 61, so you know which is greater than class-C waste, and which wastes can be disposed of under existing rules and shallow land burial.

And the other might look to this Revision of part 61 that the NRC is considering and perhaps you might usefully communicate with a Chairman of the NRC on this question, because they, they clearly are embarked on this, and the industry is requesting it. They've got depleted uranium, unique risk forms.

There's, there's a huge problem and you might come out with your recommendations in regard to how to handle all these other things, and the repositories, and so on, and at the same time, there's a different part 61 coming out, which might throw your recommendations into some turmoil, depending on what kind of models and outputs you're relying on.

So, I really think the model bins should be geared to some forward thinking way of managing long lived radionuclides that's more sensible than what we've got.

MEMBER MESERVE: I have just one quick question--

CHAIR DOMENICI: Go ahead, before Mr. Abkowitz--

MEMBER MESERVE: You mentioned in your NUWASTE model that proliferation risk was one of the elements. You showed a chart about separated plutonium. Is that the extent to which that is included or is it broader?

DR. ABKOWITZ: Right now, that's kind of our proxy measure at the screening level. And, and I think what our general approach that, by running through some of these scenarios of what our, I guess, reasonably foreseeable options, we, we hope to identify issues that require a deeper dive, if you will, and that's our initial proxy measure for looking at proliferation and then we'll, we'll start to investigate the question in more detail.

CHAIR DOMENICI: I would like to proceed for a few more minutes. WE have how much time before we're supposed to go on recess?

CHAIR PETERSON: Fifteen.

CHAIR DOMENICI: Fifteen minutes. Let me just engage Al and Dick in, in, perhaps, Doctor. I don't believe that you're convincing me, Al, that because it might take 100 years to develop a reprocessing system, that that's not going to be accepted by the American public, because, let me suggest, everything we're about is going to be in terms of forty, fifty, sixty, and even

100 years, without reprocessing.

We're talking about dry casks as an interim storage, and acknowledging that they are already thirty and forty year licenses. That might extend beyond that once this, the engineering excellence of both dry cask is all in, it may be that the nuclear Regulatory Guide, if given authority, will extend those for 100 years.

It also may be, since this Commission is talking about interim storage and saying the nation needs one or two interim storage facilities, what are interim storage facilities? They are 100 year storage places. And if you write that in, you're kind of saying, if you buy the Al theory, you're saying that the public must accept the 100 years.

They're going to accept the 100 years, they already know that interim waste is 100 year, a 100 year problem. So it seems to me, whether you do reprocessing is not an issue of 100 years or being too long span for the American people. It's an issue of whether it fits economically in the, in the, action during the next forty or fifty years in the evolution of the use of nuclear power.

And, remember, just because we're not building one and have no renaissance, there are fifty four under construction in the world, now, all exceeding 1000 megawatts. And I don't know where they go next, but just because we're not going, they, the world is going, and we might come along with the small ones taking the place of the big ones, who knows, in America, in the next fifteen or twenty years.

But the point I'm making, we should not confuse how long it takes for some of these things to evolve if we have the knowledge about the necessity or the--not necessity--the certainty that it will happen. And I don't believe that the longevity is an issue of whether the American people will accept it or not.

This Commission is going to lay down the criteria, Guidelines and the like, for 100 year decisions. On interim--we can just as well lay down 100 year evolution criteria for the, for the, recycling that may occur. And it would appear to me that we're getting very close, everybody speaks, want to have a great deal, great quantity of our extra--

Excuse me, I'm very sorry about my voice, it's, it's really a part of what I have going wrong with me, I lose words and I'm very, it upsets me very much and I'm sorry. Let me try to go back for a minute and do this. And again, can't do it.

We have a great quantity, now, of energy locked up in the high level nuclear waste that has come from our 103 nuclear power plants, and it's accumulating rather significantly every year. And it has fallen upon us quite accidentally that the only way to store it is to store it on site.

And, and, we didn't have that in mind fifteen years ago, everybody was telling the public that was the wrong way to do it. There's very little opportunity, I see, as I see it, for the Commission to do anything but recommend that that's a good way for interim storage to happen.

It just happened upon us, much like we're now compliant with something else to be on us, which is the price of natural gas, which we didn't even have a idea that it would be $3.50, it was $15 and $16 three years ago. Now, it's entered in the American market, but not in the world market.

And it's effecting where we build nuclear power plants and how fast, because they found shale in others that they could produce in large quantities, looks like we have 100 to 125 years, okay? So that's in, the economics for America, but does it throw out the window that we can still plan and participate in 100 year decisions with the fuel, the spent fuel that we've got?

We know we're already leaning in the direction of first time through, huge quantity of it, and it'll probably be buried, from what I can read, it'll probably be buried in salt or something comparable. It's not big, people have in mind that it looks as big as the outside of these plants.

If you want to go see it, go see the spent fuel rods over in Europe, they're in a gymnasium. You walk on water and all the spent fuel rods are in one building, and you look down in there, there they are. But they're going to last fifty years. If we do it right, they're going to last 100 years.

Is the public going to say no because it's a 100 year decision? You don't know what's going to happen to it after 100 years? I don't think so. If we recommend it right, the time it takes is not going to be relevant. It's whether or not we should be doing it as a nation, the research and development, because we need it. And because it's an evolution in something we already invented.

I mean, we can't help it that we invented this stuff called spent fuel which has more energy in it, and energy we use to get, to make it energy loaded, it's a strange thing that that happened. And now we, making kind, we did that.

We put it into play, and here it is, and got more energy left in it and we don't even know in America what to do with the energy in it, so we're saying throw it away.

And I'm not, I came here thinking I'd fight that, but I'm beginning to think we've got to put a bunch of it in deep repositories that are not recoverable, gone, and I leave with one last thought. If we do that, it would seem to me that we ought to get some experts an idea of how much of that one time through waste is leaving for America's future, and we ought to create a reserve, at least saying we will never go below that in terms of preserving the option to use it for its energy.

And I'm sorry that I didn't engage the witnesses, but I engaged the fellow Commissioners, but it, if I said something that doesn't make sense, then one of you up there can comment as experts. But it does seem to me that I, that what I've said is not totally without some kind of common sense.

Let me make one last observation. I believe whatever has, has captivated the public mind in America whereby twenty years ago they were against nuclear power, I believe the Americans are no longer against nuclear power.

And pray to God we don't have another one of those things that happened in

Pennsylvania, accidents that killed nobody, hurt nobody, it'll change the American mind again.

But if we already have it written up, the American mind will change back again too, and it can, we have to proceed even though they may be against it for a while. They are for it now.

I'm talking too long but I guess a co-Chairman gets to, especially at the end, when there's plenty of time left. But I yield what's left to Al or anybody else. Thank you very much.

CHAIR PETERSON: I'll quickly, and then I'll--

MEMBER CARNESALE: I'd just like to--this is not the opportunity for us to debate the point, but--I do, I do, I think, an important part for this Commission and for the future of nuclear power is that the U.S. appear to have a strategy, what it is we're going to do, about the waste.

Not to solve the problem, but to appear to have a strategy. I think if you said to the average American, interim storage is 100 years, they would say "interim is 100 years? You've got to be kidding." So that may be a technical notion of, of what we believe.

But we need some sort of strategy that goes beyond that. If the strategy is, oh, we discovered there's no problem, you can just store it for 100 years above ground, we'll figure out what to do about the decommissioned reactors later, I think that probably goes nowhere and serves no interest whether you're for or against nuclear power. It's almost irrelevant.

We need more than that. We're not a site selection Committee, but we need something that says, "and what do you do after that", other than "we'll figure it out later".

CHAIR DOMENICI: And, I'm, let me

say, I don't disagree with you, okay. I just think that, that--agreeing with you does not mean that we should not have R&D directed at a concept that might not be in place for 100 years.

MEMBER CARNESALE: Okay.

CHAIR PETERSON: I'd like to try to shoo-in--shoehorn in two more questions before we need to close. The first is for Dr. Carson. And, this, this, this question relates to research and social science. And you mentioned that you may not, there may not be a way to define a proper percentage of funding and such that should go towards that purpose, in the waste area.

But, of course, zero is also a bad answer, so, and as a percentage, even though that tends to be about where it, it tends to sit. And as an engineer, you have to be hit over the head with a two by four to understand sometimes that this is relevant.

But, you sent me an article on nanotechnology by Cyrus Moody, and reading it, I found it striking, the fact that some of the research, for example, by Christopher Kelly, who's an anthropologist, working with people who are developing these technologies in the nanotechnology area, actually resulted in substantive change in the technology.

In other words, the path that these researchers were taking on the technical side. And, I think that's, that that actually provides an important insight and I wonder if this can be generalized, that when you bring social science in early on in a process that might appear to be a purely technical one, that it actually changes the physical outcome in addition to perhaps the social outcome, or it has the potential to do that.

DR. CARSON: That's clearly going to depend on a case by case basis, I think.

One of the differences between nano and nuclear technologies is that, at least as, a sort of well defined field of new funding, nano is an emergent phenomena of the last ten years.

Certainly, there was nano going on before, but there's a sort of moment of origin with nano funding and with nano consolidation that I think made an opening for anthropologists or other kind of open ended social scientists to become involved in the design process.

With nuclear, that's harder to see, and I think one of the challenges would be to figure out where the moments are for, where the spaces are for engagement that would lead to potential alternative outcomes.

As a kind of thought experiment, think through where your thinking would be on fuel cycle questions if there had not already been a group of people engaged with qu3estions around proliferation. Sort of, imagine removing that from the scene, and then bringing them into the picture at this point.

I think you would, there, see that there's potential for rather considerable engagement and intervention in the outcomes of the research program. Now, where beyond that it would fit into a fuel cycle research or waste research or anything this Commission has taken on, I think, is, is hypothetical.

But it would be something you could find out by trying. And here, I would think as well, the scale of social science research is relatively small. As an experiment, it's not a costly one. And there are folks at NSF who have experience in science technology and society studies who could surely give advice here.

CHAIR PETERSON: Thank you. My next, my, my--

CHAIR DOMENICI: Could I engage in the second witness, Dr. Carson, for one moment? You mentioned in your remarks two things that might, might be looked at in terms of looking at, at big program, took a long time. You mentioned a genome, genome program. Let me, so, so, so I can inject in the record something that's, that's way beyond this record but, interesting.

You know, the genome project of the U.S. is heralded. And at the same time, earmarks are the opposite. What's the opposite of heralded, very much held in disregard. Well, let's, the record show that the genome project was an earmark, and guess who earmarked it? I did.

Because the executive Branch would not fund the genome. So we just, kid of just wrote it in. The first time through was nineteen million, the second time through was about seventy. And then, Bush One saw the light and funded it and said okay, we're in here.

And Mark Hatfield saw it get, getting funded and he came down and said "set aside X percent", which I didn't, I wasn't for, but it wasn't my business. He said five percent should be held from that fund to look at the ethics of the problem, which I imagine is, let the people see what's going on.

And that's, continues to this day, to be set aside, to be used in that regard. But I don't know whether it's either that or the other one you mentioned have been effective. Do you know, whether they've solved, they've served any purpose?

DR. CARSON: Effectiveness is hard to define I this field. Thought experiments, for instance, how would the human genome project have been received if social scientists were not out there thinking through the difference between genomics and eugenics and making those clear for the public.

I think that's a useful thought experiment to go through. Again, it's hard to demonstrate, at least--I'm a qualitative social scientist, so I don't take that on. But it would be interesting, I think, to go back to the managers of the ELSI part of human genome, as to the NSF folks doing National Nanotechnology Initiative, and see what, what measures they've come up with for success or failure.

CHAIR DOMENICI: Again, I'd say, that would be good to do. My own, my own observation, being on the sidelines once we got it earmarked, it was not my baby anymore, we got it through and it belonged to somebody else. But I don't believe that the part you're referring to worked. But, nonetheless, it would be good to see what you think, sometime, maybe. Anything else, Mr. Chairman?

CHAIR PETERSON: Can I just take

us one or two minutes into overtime? There's, I think, one additional question I'd like to ask, which is important. The, the discussion here in this panel, related to the potential for technical changes to substantively or at least marginally effect the cost and difficulty of waste disposal.

This actually couples to an important question, which is, how much should we charge, and how should we base the charge in terms of fees and other things, to utilities who are generating these wastes, such that we have some confidence that there will be enough money to pay for these future activities.

And I, I actually, I, I, I have a related experience, last week I got a notice from the city of Berkeley that my trash bill is going to go up by another forty dollars per year, this coming year, because we have a new target of diverting 75% of our refuse to recycle and it's going to be more expensive to do that.

We also have a progressive system, so you can get a really tiny refuse bin for much less cost than a bigger refuse bin, and so on, so all of these things aimed at incentivizing behaviors. My, my, my question is, when you look at the various different technical options that are available that could effect waste disposal, are there low hanging fruit that one might start picking if there was at least some relationship between how much you pay and how difficult the disposal actually is?

And then, are there other things which actually probably wouldn't touch? Just because it wouldn't' be worthwhile economically even though it might be technically possible, it's a technical question, so maybe, just a few thoughts from the technical people. Actually may be a social dimension to it, as well.

DR. MCCARTHY: Let me just touch

on that very briefly. One thing I didn't talk at all about is cost, and, and it was a matter of time constraints. We had done quite a bit of studies looking at sensitivities to various costs.

We have looked at things like, for example, incentivizing certain outcomes with carbon taxes. We have looked at sensitivity on cost of electricity, depending on repository costs. We've looked at it depending on reactors.

We have looked at several of these things, and so, there's, there's actually a report that I can give to you that covers a lot of these topics. I don't think I can do it justice in my one minute answer.

But, suffice it to say, if you look at studies out there, in, in, as to what is the cost associated with recycling, you'll find a huge range of estimates out there. There's a lot of uncertainty. You'll see that the costs are overlapping.

And, to be perfectly honest, until you actually do something, build a, for example, engineering scale facility, it's going to be difficult to reduce the uncertainty and the costs. I think it's fair to say that on the order of 10-to-15% increasing cost due to recycling is reasonable.

But you can also find studies out there, depending on what you say is an economic advantage, you'll see studies out there that reduce that cost. It all depends on what's important to you, as, as a, as a society. But I will provide that report.

DR. ABKOWITZ: I was going to just piggyback on that. I think Dr. McCarthy's last comment is spot-on, which is it really depends on your objectives. I presented a list of different criteria that people have talked about being the important drivers in this process, and depending upon which ones you believe are the most important, and how important they are, that's going to drive whether it's low hanging fruit or not.

And, and then correspondingly, whether or not the investment is worth it. And I think that's one of the big challenges for this Commission is to try to figure out, what are we trying to achieve.

CHAIR DOMENICI: We, we're in recess for fifteen minutes. Ten minutes? We're in recess for ten minutes.

(Whereupon, the above-entitled matter went off the record at 10:19 a.m. and resumed at 10:32 a.m.)

MR. FRAZIER: So, we'll get started with the next panel session, and I'll turn it over to Dr. Peterson.

CHAIR PETERSON: Thank you, Tim. I'm going to briefly introduce our panelists, and then we will follow the same prompt procedure as we did with the first panel.

Again, reminding panelists that we're going to do our very best to try to keep within the ten minute time frame, because the question and answer period is also very important and valuable.

So, so, I will, I will crack a whip in addition to the beep and the red light. Our second panel is entitled "Evaluating the Advantages and Disadvantages of New Fuel Cycles".

Our first speaker will be Dr. Eric Schneider. Dr. Schneider is an Assistant Professor in the Department of Mechanical Engineering at the University of Texas at Austin. Thank you, Dr. Schneider.

Our second speaker will be Dr. Everett Redmond. Dr. Redmond was recently named Director of Non-Proliferation and Fuel Cycle Policy at the Nuclear Energy Institute. Thank you, Dr. Redmond.

Our next speaker then will be Dr. Andrew Sowder. Dr. Sowder is a Senior

Project Manager at the Electric Power Research Institute. The next speaker, then, will be Mr. Christopher Paine. Mr. Paine is the Nuclear Program Director at the Natural Resources Defense Council.

And then, finally, the, the final speaker will be a good friend of mine, Dr. Mujid Kazimi. Dr. Kazimi is currently the TEPCO Professor or Nuclear Engineering, Professor of Mechanical Engineering, Director and Director of the Center for Advanced Nuclear Energy Systems at MIT. Thank you also, Mujid.

With that, Eric, if you could start.

DR. SCHNEIDER: All right, so, before I move on into my--before I move onto my prepared statement, I'd just like to speak to a couple of the points that the Committee members raised in the first session that really go to, do go to measuring fuel cycles, which is the topic of this panel discussion.

And the first of the points had to do with discount rates, decision making going forward. And, while it would certainly, obviously, a cost analysis is an essential component of any decision making process here, and the costs need not be limited to direct costs, external costs will also play an important role, and I'll get to that in a moment.

But, I mean, short of using a discount rate of one, post eight years, something must, some reasonable choice must be made. And I think, was it Albert Einstein who said, "compound interest is the most powerful force in the universe". Right, so it's an important choice.

I guess I'd like to, in thinking about this context, that has an intergenerational consequence, I'll say the standard discount rates that are used in, let's say, governmental decision making may be 7% per year, would indicate that all measures should be put off.

Right, there is no urgency whatsoever. But Kenneth Arrow at Stanford University won a Nobel Prize in Economics in the seventies for introducing the concept of an intergenerational discount rate.

Right, and specifically, his words, when he introduced this concept, one of the societal problems that he indicated it should be applied to was nuclear waste. His words, in his seminal paper, that essentially won him a Nobel Prize.

And, so, what does an intergenerational discount rate mean? Well, it takes into account our responsibility to future generations, respecting the fact that in the future, as population growth takes place, economic growth takes place, right, that the relevant discount rate to choose, right, is still non-zero.

Right, it's small, but non-zero.

Right, and lots of folks have filled lots of papers trying to estimate what an appropriate rate would be, maybe 1-to-3% is a consensus. Right, but I'd say that whatever decision comes out of quantitative analyses having to do with cost, right, is extremely sensitive of that.

And, you know, I commend to the Committee's attention careful thought on that issue. Okay. And the second point I'd like to respond to, Dr. Peterson raised the question of incentives, right, at the end of the last panel discussion. And again, that gets to the issue of measures of fuel cycle performance, specifically cost.

Right, so, nuclear power, as we all know, is unique in some sense, being the only resource consuming electricity generation technology that internalizes, one could claim fully, although that's not, that will only be clear in the fullness of time, that internalizes the costs associated with managing it's wastes. Right, in the United States through the Nuclear Waste Trust Fund.

Right, and so, the Trust Fund is, is, I'll say it give sone a lot of interesting options going forward, All right, to redesign how the fund is assessed. Right, for instance, right now, systems analysis we all know, it's assessed on a basis of a one mil per kilowatt-hour, right, as a cost per Unit.

Electricity generated by nuclear fuel, right, and I think we're aware that there are interesting possibilities, right, in terms of providing incentives to utilities to going over to a mass basis, right, assessing a cost per Unit mass of fuel discharged.

Right, and what this does is it gets to some of the points raise by the earlier speakers, right, it fosters incentives to, on the utility side, to extract more energy, right, per Unit mass of spent fuel, so that their fee, right, per Unit mass goes down.

Right, but then one could make a counter argument that this is unfair to certain cycles, right, that produce low specific energy per Unit mass, but also relatively little waste, at least of the type that may be difficult to dispose of in certain geological repository concepts.

Examples of such cycles are the CANDU, the Pressurized Heavy Water Reactor cycle, which is a low burn-up cycle, right, but there's no enrichment involved, so there's no waste of depleted uranium. There's no stream along those lines.

Right, and thorium based cycles, right, seed-blanket cycles in general. Right, so then, one could also consider, I'll say, designing that feed to assess, to assess costs or payments on an isotope by isotope basis depending on, again, on the scope of the fuel cycle and the repository concept that's germane.

Right, depending on which of the highest or low, had the highest impact, you know, right, for, on the capacity of the repository on the utilization and subsequent reactors downstream. Right, so, so, I think that there are interesting possibilities for incentivization that the commercial sector could, down the road, respond to.

Okay, so now to briefly go through my prepared statements, the mandate here is wide. So what I've chosen to do is to focus on a relatively narrow part of this broad question, how to measure the performance of fuel cycles. IF you could go to the next slide.

I'm going to start out with kind of a zinger of a quote, and I'll read it out for you. "Nuclear power results in up to twenty-five times more carbon emissions than wind energy, when reactor construction and uranium refining and transport are considered".

Right, then that quote is from a paper by Dr. Jacobson of Stanford University, that appeared in Scientific American last year. Right, then, I bring up that quote to introduce a family of measures of, of performance of nuclear fuel cycles that people call without really getting into what it means, environmental and resource sustainability measures.

Right, I bring those to your attention because I feel that they're a very poorly understood corner of the family of measures of fuel cycles. I'll show you some illustrations of why I believe that to be the case. Right, and it's also difficult to understand not only how to define them, right, but also how to use them.

Because the costs associated with them are often external, right, in other words, they're not directly or easily monetized.

And some brave folks have tried to monetize these costs in the past, the ExternE project by the European Union is one example where they tried to take, I'll say, environmental measures of fuel cycle performance, not just nuclear.

All right, this was across the entire energy sector, and turned those into monetary equivalents, considering public health impacts, occupational health impacts, land use impacts, including farming, ecological impacts, and others, right, to monetize those.

Right, so it's a difficult challenge. But I'd say, even before getting to that stage, there's a, a interesting dilemma that crops up over the course of me looking at these, I'll say, environmental sustainability metrics over the past few months.

Right, and what this quote indicates here, right, I believe, is that there's really a poor understanding in this area of the environmental footprint, if you will, of the fuel cycle, right, or our fuel cycle choices.

Right, and he wasn't specifically referring to the fuel cycle in this quote, but the fuel cycle produces the lion's share of the impacts that he's describing. Right, and, and finally I'll conclude my statements by talking about maybe the most important component of all this, the uranium resource footprint.

Okay, so, this illustration here really provides the background for why the individual who made that quote was able to do so in a respected forum. Right, and so this is a review, and I'm not suggesting that CO2 emissions is the sole, or only, or best measure of the environmental footprint of a fuel cycle.

Right, but it's one that's maybe more heavily studied than some of the others. Right, and so therefore I'm able to present some nice data to you. Right. So, this is from a review that appeared in the journal Energy Policy a couple of years ago, of nineteen estimates of CO2 emissions associated with out contemporary fuel cycle.

Right, from the literature, right. And so as you can see there is a range that, you know, if we had uncertainty, or, I'll say, lack of confidence to this degree in some of our other metrics, the sky would be falling, right, and maybe the sky is falling in some sense.

Right, there's a real lack of understanding here, I think. These are all based on what the authors claim as life cycle analyses, right, but life cycle analysis like sustainability is a term that can mean different things depending on who's using the term.

Right, so I'll get back to that in a moment. But as you can see here, there are order of magnitude variations, right, in this measure, the CO2 emissions measure, between these nineteen different studies, from, basically the lowest estimates that are so close to zero that you can't see them on there, and the highest estimates are what gave rise to that rather astounding claim I showed on the first slide.

Right, so, to the extent that measures like this are incorporated in decision making, they first need to be understood, is my takeaway message. Right, and I could show you similar data for other environmental measures--land use, water withdrawals, and, and really what this is, what the carbon footprint is based upon is energy consumed per Unit energy produced, ro energy return on investment.

Right, which is, I'd say maybe a more fundamental measure than CO2 emissions because that folds in what's producing the energy that's used. Right. So, even the task of defining these measures, right, as I said, was complicated.

It's eased because there are international protocols for defining them. Let's go ahead, actually, because I'm running out of time. Okay, so, finally, I promised you I'd speak briefly about uranium. I'm running out of time.

So, this plot looks like a plate of spaghetti with some meatballs on it, the reason for that is, again, because of a lack of concordance between estimates of our understanding of a fundamental physical property. Right, and so what I'm plotting here--shoot, I'll be very quick--uranium ore grade, right, and right now, we're currently mining at .1% U-308, versus energy consumed in mining.

The dotted line, we have control over. Right, that's, that's 10% of the energy we get out of the uranium we've mined, right, that I choose 10% somewhat arbitrarily to say, well, if we go above that level, then the energy return on investment is no longer satisfactory.

And what each of those lines indicate is somebody's, right, a geologist, estimate of the energy intensity of uranium mining versus the ore grade. So, as we deplete the resource, the energy intensity of uranium mining will rise, right, but when it rises to exceed some unacceptably large share of the energy produced by here of the once-through fuel cycle, we have control over that, is of a, a, of great uncertainty.

Right, two orders of magnitude almost. Right, if the higher value proves true, to .02 percent U-308, that means that resources like phosphates, that are currently uneconomic to mine, will always remain so, barring major technological innovation.

Right, and if the most optimistic estimates are correct, then the resource problem is really a will of the wisp, it doesn't exist. So, I'll conclude with that.

CHAIR PETERSON: Thank you. The next speaker?

DR. REDMOND: Thank you. I want to thank the Committee for the opportunity to speak on some of the considerations associated with transitioning from an open fuel cycle to one or more advanced fuel cycles.

All nuclear fuel cycles require a robust used fuel management program. However, the technical details of these programs will vary depending on the specifics of the fuel cycle. For example, reactor design, thermal or fast, and degree of recycling, one or multiple recycling cycles, are some of the factors that will effect used fuel management.

While the technical details of the fuel cycles may differ, there are some common themes. First, consistent, sustained, political and policy support is required to create the foundation upon which private entities will consider investing in advanced fuel cycle technology.

Second, only mature and reliable technologies will be adapted--adopted on a commercial scale by the nuclear power industry, and the transition to a new fuel cycle or fuel cycles will take decades to accomplish.

Lastly, geologic disposal of used fuel or used fuel byproducts will be necessary for all fuel cycles. Moving beyond the open fuel cycle, currently in use in the U.S., will require a combination of recycling, advanced reactors, durable Federal policies, and sustained financial investment.

The sustained support and investment will only be justifiable if the advanced fuel cycle provides significant value compared to the open cycle. The question is, how to determine if the advanced fuel cycle offers significant value.

One could develop detailed metrics by which the various fuel cycles could be compared to an existing open cycle. Metrics would probably included items such as cost to construct and operate, cost to the consumer, reliability, impact on the environment, including disposal, and non-proliferation characteristics.

An exercise such as this, such as this, would certainly be informative, but in the end I think the decision to move away from an open cycle will be based more on a policy determination about the value of advanced fuel cycles rather than a technical comparison.

For example, recycling and using fast reactors would enhance the sustainability and economic viability of the nuclear fuel supply in the United States by reducing the demand for uranium ore. However, the current availability of uranium ore is not being challenged, and is not expected to be challenged for approximately fifty to 100 years, based on current estimates.

As another example, recycling and using fast reactors could enhance the management and siting of a geologic disposal facility by altering many of the materials destined for disposal. Reducing the heat load and radiotoxicity are two examples of altering this material.

However, when considering the potential benefit, it should be recognized that used fuel, in its current form, can be disposed of in various geologies with a combination of natural and engineered barriers, and it is highly unlikely that the entire inventory of used fuel, currently 60,000 metric tons and growing, would be recycled.

In both of these examples, there does not appear to be a technical case for switching fuel cycles at this time, based on my oversimplified assessment. However, there is still potential value, as I discussed, in enhancing nuclear fuel supply sustainability, and enhancing management of siting of a geologic disposal facility.

Another policy area that should be considered when discussing nuclear fuel cycles is non-proliferation, a topic for this afternoon's panel. Considerations and goals in this area will influence the implementation, if not the choice, of an advanced fuel cycle.

Once a policy decision is made to move beyond the open cycle, the task is to create the foundation upon which the commercial nuclear industry can successfully develop, finance, and implement advanced fuel cycles in a competitive marketplace. The foundation will primarily be based on economics and maturity, reliability, and ease of implementing the advanced technologies.

Regardless of the value added by and advanced fuel cycle, the ability of the nuclear fleet to produce electricity reliably and efficiently must be maintained. Currently, the Light Water Reactor fleet in the United States has a greater than a 90% capacity factor.

This capacity factor should be a design goal, if not a requirement, for reactors operating in an advanced fuel cycle. Experience to date indicates that additional research and demonstration is necessary to achieve this goal for fast reactors.

Research, development, and demonstration of advanced recycling technology and advanced reactors should be pursued in a timely manner with a goal of creating real, practical approaches that will be successful in the marketplace. The RD&D should not necessarily strive for a single viable technology. Rather, it is conceivable that more than one technology could be commercialized in the United States, to create advanced fuel cycles.

With the large number of operating reactors, 104, and a substantial inventory of used fuel, 60,000 and growing, more than one recycling will be necessary. Since alternate fuel cycles create different types of used fuel and byproducts, for example, used MOX fuel and vitrified waste, geologic disposal of these alternate waste forms should be considered to the extent practical when contemplating the change from the open cycle.

As an illustration, if a policy decision is made to simplify the disposal of high level waste by recycling currently available used fuel and creating MOX fuel for use in Light Water Reactors, consideration should be given to the ultimate disposition of the used MOX fuel.

Will it be placed in a geologic disposal without being recycled, or will it be recycled into fuel for use in a Light Water Reactor or fast reactor? In this scenario, direct disposal in a geologic disposal facility seems unlikely, since the challenges associated with disposal of used MOX fuel are larger than those associated with disposal of current used fuel.

Therefore, it would appear that a key element to a fuel cycle which utilizes MOX fuel and Light Water Reactors with the goal of simplifying disposal will be more advanced recycling technology and possibly fast reactors.

In contrast, if the policy decisions primarily to enhance the sustainability of nuclear fuel supply, direct disposal of used MOX fuel may be desirable. Research and support of advanced fuel cycles should continue and be conducted with target dates specified for phase development and demonstration of commercial scale ventures based on advanced--advances of current day technology.

Consistent with the evolutionary manner of technological changes in the commercial nuclear power industry, it is not necessary to wait for decades of research to be complete before implementing new technologies.

If fast reactors are to become an element of advanced fuel cycles, a demonstration project should be conducted in the United States. Under any scenario, the efforts currently underway to revise the NRC regulatory framework for licensing of recycling facilities must be completed to permit industry to license commercial facilities at the appropriate time.

Thank you, and I'm happy to answer questions.

CHAIR PETERSON: Thank you. Our next panelist is Christopher Paine. Sorry, excuse me, Andrew Sowder. Just a little excitement to spice things up in the morning. I came in on the redeye, so I needed to wake myself up, if nobody else.

DR. SOWDER: Good morning, and I want to thank the Commission and the co-Chairs and the staff for the opportunity to speak today on challenges and strategic choices for sustainable nuclear fuel cycle.

And, the content of this presentation is largely based on a report that EPRI put out last month that examines the key attributes of a sustainable nuclear fuel cycle and attempts to identify promising options and approaches as well as key challenges and barriers in light of National energy contexts.

So, let's see here. Any button will do? Oh. Okay. Simple enough. So, the intent of this presentation is, of course, to answer some questions. I took the liberty of paraphrasing them a little bit, but I have structured the talk around them, so, I won't repeat them here.

Okay. First, before going into the presentation itself, I want to just give basically a perspective on the current U.S. energy context for electrical generation of power. And, this is mainly from a utility perspective. EPRI is comprised of U.S. and international utilities, as are members.

First and foremost, Light Water Reactor technology is the current workhorse and will likely remain so for the coming century. Industry is comfortable with the technology. It works, it's available, and it's reliable.

Secondly, the once-through fuel cycle is the current reference in the U.S.. And again, for the coming, at least next fifty years or so, it appears to be the most economic option. Uranium resources are not limiting for the near term, and at current prices, in fact, most U.S. resources remain untapped, for example.

Introduction of advanced fuel cycle technology such as recycle of plutonium as MOX is not economically competitive unless it is driven by external factors, such as the need to manage a plutonium stockpile, and there's also arguments to be made for gaining industrial experience, given that recycling and reprocessing is not a trivial endeavor.

Let's see here. So, what are the performance criteria? EPRI's September report presents four principle criteria for evaluating a fuel cycle. They are economic comeptitiveness, natural resource sustainability, waste management, non-proliferation, and I've listed here a fifth, safety, because it, it is essentially assumed to be a global requirement that must be satisfied regardless of which fuel cycle you choose, and the industry accepts this as the cost of doing business in this area.

Now, the relative ranking of these criteria depends on the National context. For the U.S., cost competitiveness is the primary driver. However, when energy security is heavily embedded in the National policy such as in France, Japan, other places, natural resource sustainability may well rise in its importance.

So, in terms of economic competitiveness, EPRI has done some modeling, as have many people, examining a number of fuel cycle scenarios. Here, I'm just presenting one as an example, comparing the once-through fuel cycle in the black line with two regions of interest, the red representing single recycle in PWRs, that's MOX and current Light Water Reactor technology. And the blue region of interest would be an advanced fuel cycle partially closed in which plutonium is recycled in fast reactors.

Again, I said an economic case could be made, but--and the buts are big here--because capital costs for example, for the reactors are not included and that, there's a good reason for that. First of all, is, people don't really know how much those will cost, so it's difficult to really incorporate those.

But this recycling is, I mean, this modeling is strictly for the fuel cycle costs. But again, I'm using it for purposes of a comparison. Now, the take home message here is that recycling of plutonium as MOX can be shown to be economically feasible when uranium prices rise.

But again, that's as long as your reprocessing costs and your fast reactor technology costs are, first of all, known, and reasonable. And finally, for the industry, probably one of the most important things is that the technology is reliable and available when you need it.

I mentioned earlier that current uranium supplies are projected to be adequate for the next fifty to 100 years, and here I'm just illustrating that through a simple calculation that relates basically years of supply to projected growth rates. And so I've, from one to three and a half percent, using a simple relationship.

And the three colors here correspond to three different bins, if you will, that you can subdivide uranium resources per the IAEA NEA red book. So, for example, for projected constant growth rate of nuclear in the world, you have, essentially, fifty and 100 years of supply at present.

Now, again, the key thing here, is as time goes on, one, more uranium resources are identified, but the fact remains that Light Water Reactors use less than 1% of the energy content of the mined uranium.

And, so, consequently, should the fuel supply become limiting, or become a concern, this is a compelling case for a RD&D program on advanced reactors and fuel cycle technologies.

So, again, the availability of uranium is not a call for inaction in terms of, of a, a prudent research and development program. Now, for waste as a criteria. Waste management is often emphasized as a principle criterion for fuel cycle selection.

But the actual impacts and consequences are far more nuanced. And so, what I would posit to you today, is that, really as a criterion for distinguishing one fuel cycle from another, on a technical basis, waste management is really a secondary criteria at best.

And, to illustrate, for example, I, EPRI worked with Electricite de France, using their state of the art dynamic fuel cycle codes to model a specific scenario here of GNEP type fast burner reactors with a conversion rate of about 0.5, I believe, with the intent expressly of maximizing the burning of the actinides in the fuel cycle.

Now, you can burn the actinides, but as you can see here, on the vertical axis, you have the number of years it takes to achieve a stated goal. So to achieve about 50% takes on the order of seventy years, and this is again for the U.S. fleet, the U.S. situation.

But once you start talking about significant reductions on the order of 90% or above, you're looking at hundreds, to a, to a, hundreds of years to a thousand years. The other thing that's important to notice is that, should you decide to move away from, or cease this activity, you will be left with the inventory in the reactors.

So, during this process, you're

not sending the actinides to a repository while the fuel cycle is operating. You are actually managing the actinide inventory in reactors. Which, is maybe a prudent action.

Now, in terms of non-proliferation, and again, it's a topic for this afternoon, certainly a critical consideration, and, by many, I think, many a primary consideration. But in terms of technically distinguishing one fuel cycle from another, we would argue that it's probably not that useful on it's own.

Because the institutional issues tend to really dominate the non-proliferation concerns, whereas it's the intrinsic characteristics that tend to make it into these technical debates, such as the attractiveness of the material, et cetera.

Again, not to, not to downplay the importance of non-proliferation, but the take home message here that we would like to leave is there is no silver, technological bullet for non-proliferation. All fuel cycle, as with safety, require adequate safeguards and measures.

And so, these can be accomplished through a combination of both intrinsic and extrinsic measures. So, to answer your second question, this is how these various criteria rank. For the U.S., economics is, or cost competitiveness is number one.

Basically, someone has to build, operate, and maintain the technologies, the reactors, and other facilities. For, and to not be forgotten, for the actual, reliable, affordable power generation, that's often forgotten in the debates.

Secondly, resource utilization. Uranium is more of a medium concern. Uranium supply is not limiting for the next fifty or so years. But resources amplification is the primary feature of advanced fuel cycles and is a compelling driver for future fuel supply, beyond fifty years.

Waste management is really, we would consider it a low priority. Technical solutions exist for waste management for all fuel cycles, and again, we move, basically, the non-proliferation issue off more to the safety realm that it must be adequately addressed regardless of the fuel cycle option.

And again, those institutional issues tend to dominate. I know my time is up, but the question was asked in terms of what the community is doing of research in terms of modeling, et cetera. So, in terms of what's, most importance, is really to understand the benefits, the issues for consideration, and provide a framework for supporting a phase adaptive technology deployment.

This is the EPRI approach. Of primary importance is your decision analysis framework, but it's supported by both risk assessment for human and environmental risks of all aspects of the fuel cycle, your dynamic fuel cycle modeling.

For example, EPRI has licensed code from Argonne National lab, but we certainly are in communications with Idaho National Lab and others. Again, it's a relatively small community worldwide. You've got to incorporate your economic modeling as well as some metrics of proliferation resistance.

So, in summary, the focus has to be on cost competitiveness power generation. Better utilization of your natural resources is a desirable feature and may be needed, depending on your resource identification and nuclear growth in the future.

Ultimately, waste management, non-proliferation, and safety can and must be appropriately addressed for all fuel cycle options. So, with that, I thank you for your time, apologize for running over. Thank you.

CHAIR PETERSON: Thank you. And now, Christopher Paine.

MR. PAINE: Thank you for providing the NRDC the opportunity to present its views today on the advantages and disadvantages of new nuclear fuel cycles. Since it's founding in 1970, NRDC has been engaged in a wide variety of nuclear fuel cycle and advanced research reactor and development issues.

All too often, I think, discussions about the future of nuclear fuel cycles occur in a kind of economic and energy policy void, where all that matters at their discussed are the alleged technical advantages of the nuclear technologies under review.

We need to look comprehensively at the economic rationality, broader benefits, and collateral risks for society and the environment that are often neglected, when, in fact, these are the essential questions.

Going forward, all nuclear fuel cycle options and indeed, all available technologies that can supply energy services should be measured against five primary criteria. Does the technology present a cost effective path for abating carbon emissions relative to other available low carbon energy technologies?

Given the reality that carbon emissions accumulate in the atmosphere and therefore abatement options have a time value, how soon can the technology be deployed, compared to other low carbon options?

What are the available non-carbon--what are the harmful non carbon environmental impacts of the technology compared to other low carbon technologies, and can these impacts be sufficiently mitigated to provide wider use?

The fourth criterion, is the

technology socially and geopolitically sustainable, which in nuclear's case, we're worried about aggravating regional security concerns or having to invoke invidious political distinctions between states.

And fifth, what other electricity resources will the technology either support or displace on the grid? We never seen to talk about that, and how will this affect the overall rate at which genuinely clean, renewable energy and efficiency resources are deployed?

So, let me just briefly discuss each of these criteria in turn. With respect to the first criterion, the cost effectiveness in cutting carbon, I think everyone understands that all full and partial recycle options today are quite distant from the cutting edge of cost effectiveness in reducing carbon emissions.

The only new nuclear fuel cycle option in the running today is the current

LWR cycle. But, electrical end-use efficiency, industrial waste heat co-generation, combined heat and power systems, wind, bio-gas, are all currently cheaper and faster targets for new carbon reducing investment, the new build LWRS.

So, where does this lead advanced fuel cycles? Adding a twenty-five billion dollar reprocessing plant, MOX recycle, and fast reactor development program would add nothing to nuclear power's decarbonization potential over what might be achieved with LWRS alone, and it would represent a very heavy tax on the National decarbonization effort for at least several decades, if not indefinitely.

I believe that in a few years, and the data, the recent data shows this, before construction of the U.S., the first U.S. nuclear new build is on, is online, that we will have achieved grid parity for solar energy in many electricity markets around the world, including parts of the U.S..

And solar is going to become a ubiquitous feature of our energy supply system by, I believe, the end of this decade. This does not mean that solar and wind are going to displace nuclear, but rather that nuclear will be operating in the future on a grid with a high market penetration of variable renewable resources.

And we have to think about what this means for the type of nuclear plants we should be looking to build. I'll come back to this point later.

With respect to the second criterion, the relative time value of alternative, low carbon investments, that number from the Stanford researcher that showed a very high carbon penalty for nuclear, a large part of that is derived from the time delay of actually implementing nuclear plants.

And, a large nuclear, large new build LWRS have historically required about six to nine years to construct, and even longer when you include the whole project management time frame. Almost every other low carbon technology beats nuclear in this criterion.

During this long gestation period, power's being procured from carbon emitting sources and the low carbon nuclear asset is not producing. If you add reprocessing facilities and fast reactors to this mix, it would only further delay nuclear's contribution and add to a nuclear project's carbon debt.

Japan's Rokkasho plant, for example, has been under construction for seventeen years, costs more than twenty billion dollars, and commercial operation has been postponed again until October 2012.

This criterion suggests that DOE should focus its development program on more cost effective LWRS with a reduced, with reduced construction times, and or modular plants that can begin generation within three years and add bankable capacity increments when they are needed going forward.

The third criterion involves assessment of non--carbon environmental impacts of various nuclear fuel cycles. The current new fuel, nuclear fuel cycles cleanly, in my view, preferable to coal mining and burning. But that does not, that comparison is not the end of the comparison.

You have to compare the current LWR cycle to the current range of renewable energy options. These, too, have environmental impacts that must be considered and compared. This obviously doesn't mean that we should discard nuclear as an option, but only that it's near term investment priority for the nation should be lower than clean energy technologies and energy efficiency.

And the near tern R&D focus should be on reducing the non--carbon environmental impacts of nuclear power and improving its cost competitiveness. These non--carbon impacts, we really don't focus on very much. Mill tailings that leak radon and heavy metals, pollution of aquifers, mined, mined by in, in situ leaks mining.

Overheating of inland fresh water bodies and coastal estuaries, huge fish kills in some reactors, massive consumptive use of fresh water for evaporative cooling, and tritium leaks from operating the reactors and spent fuel storage pools.

And then of course there's the task of storing and ultimately disposing of spent fuel and other nuclear waste forms, a task that I believe, with patience and good will, will be soluble, I view as eminently soluble.

Now, in theory, a full

implementation of the closed cycle could reduce the uranium impacts. But shifting to a closed cycle, shifting to a closed cycle on that, on a large scale, is not likely to occur for many, many years.

And, more likely, we're going to see a deployment in parallel with existing LWR cycle for a long time, in which case you aren't going to get the uranium reduction, the uranium mining benefits, anytime soon.

And so, you should really think in the short term, or, in the medium term, about reducing the environmental impacts of the LWR fuel cycle, which DOE spends no money on, as far as I can tell.

And that's one of the, you know, getting to, efficient air cooling of units, and eliminating the pollution that occurs in the uranium mining cycle, to me, are two very high priorities if we're serious about making nuclear power relevant in the current era.

The fourth criterion is social and geopolitical sustainability. That's a very broad criterion, and, obviously in the case of nuclear power, we're talking about the proliferation impacts.

But I want to just dwell on this problem of making invidious distinctions between states. That's one of the problems with nuclear power today, forces us, especially when we think about advanced cycles, about trying to make distinctions between states.

The U.S. Government is already tied up in knots, if you've been reading the news lately, confronting the problem of making invidious and politically unsustainable distinctions in the case of Jordan and Vietnam, to Section 123 agreements where one agency is leaning heavily towards giving Vietnam access to enrichment technology, whereas we're trying to deny Jordan the same prerogative.

So, irrespective of the fuel cycle option, this criterion on social and geopolitical sustainability, suggests that international institutional innovation to provide stronger non-proliferation insurance, is the key path going forward.

It's more important than technological innovation, and I think that's also, EPRI came to the same conclusion. Finally, let me say a word about the fifth criterion, the effect of large nuclear deployments on the electricity supply system.

If new reactors have excess capacity at night, will that be used to recharge legions of electric cars, or result in taking cleaner, less costly wind generation offline? Rather than debating the future evolution of the fuel cycle in isolation, we should be discussing it in terms of alternative grid paradigms.

And then planned--and then in

terms of concrete plans for transforming the energy sector into an environmentally sustainable configuration. What we're trying to optimize is the overall grid, it's not to maximize the deployment of nuclear power, although some in the community might want to be doing that.

The social objective is a sustainable energy grid, and how to make nuclear relevant and sustainable within that context. The Department of Energy needs an indicative National energy plan that's comprised of sustainable, Regional plans, and within those plans, some of our regional grids may escape coal and nuclear altogether.

I think the prospect of the western United States escaping both coal and nuclear dependence is quite bright. Other parts of the country may decide to sustain both or one of those technologies.

But in all cases, application of

the criteria I've been suggesting suggests that it's the LWR cycle that we're talking about, and possibly innovative extensions of it, such as small modular reactors or thorium substitution in the existing fuel elements. And that should be the primary focus going forward.

CHAIR PETERSON: Thank you. The final speaker for this panel session is Dr. Mujid Kazimi from MIT. Mujid?

DR. KAZIMI: I also suffer from jet lag, arriving less than thirty six hours ago from Abu Dhabi, where a new city that is deriving its energy from solar is being built, as well as a plan to house, to, six reactors are being made simultaneously.

I think the world has realized that we need all sources of energy, and the continuous building of criteria to, or, shall we say, shifting criteria to one angle or the other, is not really going to lead to the most optimum approach in securing the energy we need in the future.

Particularly when it comes to clean energy, nuclear gives us a vast source of energy, as well as wind and solar, and each has its strong points and its weak points. But, let me, let me respond to what I just heard from Andrew, relative to the question of, you know, which one, which approach will demand more of the grid.

If you wish to go to 80% reliance, let's say, on renewables, it is clear to me that we can't even implement this, even if we wish to, today, because we don't have the investment and, and the storage technology that will tell us what we can do in order to benefit from the intermittent sources of solar and wind in a really comprehensive way.

Until we solve the storage problem, the renewables will have a role, but it will have to be a complimentary role to other sources on the grid. Let me start with my presentation. There are many interesting discussions perhaps that will occur afterwards.

Can I have the first slide, please? Maybe I have it here, okay. More or less, you've heard this from other speakers already. We have to look at economics, we need to look at the overall environmental impact. We need to look at the maximization of resource utilization, and finally, we need to be concerned about the implications for non-proliferation.

So, in looking at fuel cycles for the future, to me, these are the major criteria that we should note. If you look outside the nuclear, than you can add few other factors to them. But, with, with this in mind--next slide--we have, let's see, okay.

Today, we have an economic system based on Light Water Reactors and the once-through cycle, which has proven itself. It's a predominant choice all over the world for a nuclear power option, mostly because it proved to be an economic option and a reliable option.

The fact that we can provide more than 90% capacity factor in the U.S. is because the choice of the utilities to exercise their lowest option for producing electricity, and this is another thing that we can note, that once the investment in the plants have been recovered, the operation of nuclear power plants are among the least costly options in, in the energy sector.

So, we do have a fairly large technology base for Light Water Reactors, it shares that technology with other plants as well, and therefore it is something that is, that will benefit the future fuel cycle if it is to be based on Light Water Reactors.

Now, we could say that, at some point in the future, we're going to need to look into alternatives that make better use of uranium internal energy or potential energy. And, I think I'm going to come back to that one once we describe, you know, why did we think we need to go outside that technology for a choice of our fast reactors.

But, let me, let me say before I got to that, is I don't think we have reached the optimum prize or optimum economic positioning of Light Water Reactors. There are many ways by which we can further reduce the cost of Light Water Reactors. I listed some of them here.

Standardization, we know, Korea and France have applied them, they have realized the benefit of that. Power uprates, you know, if we can extract 20% more energy from the same volume as France, and this requires some design innovations and improvements and monitoring and so forth.

Construction techniques, you know, in Japan, they build their plants in

48 months. Here, we haven't done it yet, but at least there are demonstrated fact that you can build a very large Light Water Reactor, the ABWR was built in approximately 48 months with prior planning.

So, the, what we have done in terms of streamlining the licensing process and in terms of trying to get the construction techniques also embedded here, so that we can, perhaps use prepoured concrete and so forth for the containment, that's going to lead to a reduction of costs as well.

The elimination of the premium on the financing of power plants is another important difference between, you know, in order for us to achieve more economic nuclear power. And hopefully, this is going to be happening with the demonstration of the first few plants coming online in the next few years. Next.

Now, if we look at the fuel cycle

to try to differentiate between them, we have to realize that there are some similarities as well as some differences. And, to choose the path forward is somewhat dependent on what is the expected growth rate.

If our growth rate is going to be relatively low, I think sticking with the Light Water Reactor and not worrying too much about introducing recycling and recycle is the best plan for forward marching.

On the other hand, if our needs imply that we're going to use nuclear energy in a sizable way, expanded from its 20% or so today to about 40% or so in the future, that might require at some point in the future looking into recycling in order to increase utilization of the uranium energy.

And, luckily, we don't have to do that this decade, we have time to do it, because of, from all, what we have heard already, uranium is available to satisfy the demand for decades before we have to worry about the uranium recycling.

Now, from the back end point of view, all fuel cycles produce approximately the same amount of fissile energy per Unit, energy per, derived. And therefore, for the first 200 years, the care of the spent fuel, if you wish, is going to be somewhat similar, because of the amount of decay heat, the amount of high level radioactivity is going to be roughly similar.

It's only after the first two centuries that differences will start to appear that will make a difference in the system.

And, finally, I want to say it's going to take quite while to get to a new system for nuclear energy, moving nuclear energy from what we know today to a nuclear energy system that is based on a different technology, recycling reactors or high temperature reactors, whatever it's going to take, a long, long time, because the penetration rate is dependent on the demand rate, as well as what feed to we give to that fuel, to, what fuel do we give into the reactor.

And if we look at a couple of characteristics--next slide--you find that it takes quite a bit of time to just prepare the fuel needed if we're going to start the new technology on the basis of extracted plutonium from Light Water Reactors. It takes Light Water Reactor to operate for almost thirty years to produce enough plutonium to constitute one core in a fast reactor.

So, it takes a long time to, to get there if we're going to depend on plutonium to supply that fuel. And we have to look for alternatives to make this penetration somewhat more fast if we need it in the future. Next slide.

So, as you know, we have been

looking at fuel cycles in a dynamic way at MIT, and we released some of the results recently. We looked in particular at the impact of limited recycle, in a, at a, MOX like, and then recycle in fast reactors with three different conversion ratios, .75, 1, and 1.23.

And the results are--can you see? Next slide, please. Yes. That, because of this dependence on the fuel derived from the reprocessing of Light Water Reactors, you will find that the Light Water Reactor is always a sizeable part of the total capacity in the system.

Even if we introduce fast reactors, let's say by 2040 or so, there is--I don't have it, but you can see in the bottom two lines, these are conversion ratio 1 and 1.23 fast reactors. They, they allow us to move faster into the new technology, but we still depend more on, at the end of the century, more than half of the energy is derived from Light Water Reactors. Next slide.

In terms of the demand for uranium, there certainly will be a reduction in the demand for uranium if we recycle. But it's not going to come very quickly, and it will be limited if we only have, let's say, a dependence on recycling in thermal reactors the way we do it now.

If we go to a fast reactor, it would be better, as you can see, but frankly, going to a conversion ratio of 1 is all that it takes to fully utilize the energy in uranium, and to enable a new era of recycling in reactors to occur.

And, going to a higher breeding ratio will have implications for us. It will restrict the technologies that we can use, it will demand more fuel to be supplied, because to breed in those reactors or to have a higher conversion ratio requires that you fuel them also with larger amounts of energy.

So, on balance, reaching the critical, the conversion ratio of 1 is potentiality better for us in the long term. Next slide. This shows, basically, the same picture, whether you're looking at 2.5% or even a more aggressive 4% growth, where you think that the breeding will be needed in a bigger way.

But it's about the same effect, this shows the 1.0 conversion ratio. Next slide. The other thing that sometimes people discuss is that recycling is a way to consume the transuranics that are produced in Light Water Reactors. And while it is true that we recycle we consume transuranics, but we also need much more transuranics to be stored in the reactors after we use for recycling.

So, on, when you add all the transuranics in the system, you end up having less of a reduction than one might thought in the overall system, and that shows the variation of all these scenarios in terms of transuranics. Where it will be different is where the location of that amount of transuranics--next slide.

You see that the amount of transuranics in reactors, that's a, a fast reactors will be the red, the black is the Light Water Reactors, and then in the storage and fabrication, that's a green and the blue, with, that's where the transuranics would be.

And, it is still a growing system in terms of total transuranics. Next slide. The amount of transuranics that goes to the repository will be distinctly different. There will be quite a bit of reduction in the amount of transuranics that goes to the repository and therefore if one is to look at a payoff for the investments in recycling, it will be for a while in that area as opposed to in the area of reduction of the total transuranics in the system.

With that, let me conclude by saying, I think--one more slide--in our looking at the fuel cycle in the future, we have to try to amplify the performance of Light Water Reactor to benefit the fuel cycle. We have to take the time that we have before we, our energy demand becomes much higher and try to perfect the technologies that we'll deploy for recycling.

And, this way, we, we can look at the future that might be brighter. In particular, because nuclear energy costs are mostly in reactors, depending on a more expensive reactor for recycling technology will be an unoptimum way of moving into new reactors.

Yes, recycling is going to be a costly endeavor, but it's relatively a small portion of the total system cost. The total system cost depends much more on the reactor cost and we have to look for ways to reduce the reactor costs and the cycles for the future. Thank you.

CHAIR PETERSON: Thank you. We now have time for questions. Why don't I start at the end and work towards me. Yes?

MEMBER MESERVE: I have just a few questions. Dr. Sowder, you made the case that non-proliferation should not be a differentiator among these various fuel cycles, and I know from looking ahead that many of our presenters this afternoon are going to talk about the disadvantages in proliferation risks associated with separated plutonium. And, I'm puzzled at your assertion, given that perspective.

DR. SOWDER: Yes. And I did not mean to say that non-proliferation was not an important concern. But in terms of a, seeking a technological solution, I think the concern is that, given that the security situation and non-proliferation concerns tend to evolve over time.

And you also are looking ahead in terms of advances in technologies, that if you use, if you use the technology as a primary driver for your, addressing your non-proliferation concerns, you may find further down the road that the issues have become decoupled almost entirely from the fuel cycle.

For instance, you could have, you could have technologies that allow folks to enrich uranium that is just not related to the fuel cycle, for example. So, pinning all, pinning a lot of, putting a lot of your confident or interest into the technology itself to solve the problem, you could end up solving the, using the wrong tool.

For instance, using a, using a sledgehammer when a tack hammer will do. That's not to say that, you know, non-proliferation is, could not be considered once you get your fuel cycle in place. But again, you have both extrinsic and intrinsic measures that you can apply.

For instance, no matter what fuel cycle you choose, you're going to require safeguards and security. I'll just use another example, is the issue of separating plutonium. Let's say you extract or separate uranium with plutonium. You're still one step away from separating plutonium.

And I'm not going to make too many comments about the, the challenges involving separating uranium from plutonium, but basic radiochemisty shows that it's a fairly straightforward process.

So, again, I, I did not mean to say that non-proliferation wasn't a concern, but in terms of differentiating on a technology basis, it may not be as useful. That's, that's what I was trying to posit.

MEMBER MESERVE: I guess I agree that, obviously, there are dimensions to the non-proliferation issue that extend way beyond technology and they're very important, maybe more important than the technology issues.

I think that the discussion has been very much on recycling or not. And, the dangers of recycling having non-proliferation dimensions that are not associated with the once-through fuel cycle. And that, and that, that, and your talk suggested that was not a factor, or not, should not be a significant differentiator.

I take your point that, we all agree that proliferation is important. I'm pushing you on the point that, that one can't distinguish between fuel cycles on that basis.

DR. SOWDER: And, you, you can, and certainly that could be the path you choose to select your technology. But in terms of looking, when we're talking about the time frames involved, fifty to 100 years down the road, if it becomes a primary differentiator, I guess the concern is that you may not have really solved anything when you, when you actually get to the point where you deploy the technology, that you, you focus on the wrong issue when in fact the primary matter is, is more the extrinsic measures such as safeguards, international regimes, et cetera.

And, again, if we're talking about the U.S. situation, I, I think it comes down to--well, I'll, I'll just leave it at that. Thank you.

MEMBER MESERVE: Dr. Kazimi, I, your presentation, of course, was consistent with the MIT report that you've issues and your discussion was consistent obviously with that. I'm familiar with it.

I, I'd be interested in knowing whether there has been any controversy or criticism of your conclusions that have come out for the ones you've described today, including, since you've issued the report. And, what has proven to be controversial, what, what seems to be contested by others?

DR. KAZIMI: Let me summarize what I remember, basically. Two, two types of criticism seem to come more than, in one source. One is, people worry that the recommendation for taking our time to develop a path forward and relying more on storing this spent fuel now without trying to dispose of it or recycle it, is simply delaying an action item that would be useful for the country to move into in order to build experience with technologies that are needed, whether its disposal or recycling.

So, that's one type of the criticism, are we simply delaying the action. And, by and large, our reaction is that, you know, if the delay buys us improvements in understanding the choices and therefore making better choices for the future.

And if the delay does not imply that the future generations are being deprived of any option that suits the technologies they would be having at the time, then, there is really no harm in, in the delay.

The other type of criticism came from those, a little bit more, you know, on the technology costs and its implications for recycling, you know, there are certain countries, that say, industrial outfits, that are more confident about containing the costs and the consequences of recycling than others, as, as you can imagine.

MEMBER MESERVE: I was more interested in your system modeling and the number of reactors that were needed and the flows back and forth, that dimension of it has not been challenged?

DR. KAZIMI: No. I, I haven't heard any criticism from the system description point of view.

MEMBER MESERVE: I--you also made the point that you believe with existing, or at least conventional, Light Water Reactors, that 20% power uprates are feasible. Obviously we're doing a lot of that now, but you pointed at, in particular, the new fuels and new fluids, nanoparticle fluids.

And I presume the fuels you may be talking about, they're annular fuels. I'm quite curious about the time line in which you think that those, that capacity might be available, and the level of certainty that those are going to be acceptable from a safety perspective.

DR. KAZIMI: The new fuels certainly could be in the form of annular fuel, but there are other ideas that could be implemented. With the basic premise being increasing surface to volume ratio of the fuel, and water, as a coolant, that gets you a long way towards more power extraction if you let it run.

But, we can also go into more compact conditions. For example, Hitachi is known to have developed a system that has a much higher power density than typical boiling water reactors. They developed it more with a purpose of going to a hot spectrum so that they will improve the conversion ratio.

But I don't see why the same principles can't be applied for regular BWR. So, it's a type of lattice, and it almost has two and a half times the power density that BWRs have today. If, you know, you can prove all the safety features will work right.

So, I would say that there are ideas on the table. Development takes testing, that's a matter of time. On the order of fifteen years would be the minimum to get the testing needed to be comfortable. And as far as the nanotechnology is concerned, I think that could be a little bit less than that.

There are two aspects there. One

is the thermal hydraulic characteristics, another one is the material implications. And I know that some of the industrial outfits are looking at both, but I don't know whether they put the time line for application.

MEMBER MESERVE: Good. Thank you.

MEMBER CARNESALE: Thank you. Dr. Sowder, I'd like to return to the same thing, because I too found it rather remarkable, especially given that in previous sessions we were told that the, that the National Waste Technological Review Board uses stockpiles of plutonium as the surrogate for the proliferation risk.

So, it, it focuses largely on that aspect of the fuel cycle. Tell me how it could be better, from a proliferation point of view, to have separated out the plutonium rather than not having done so.

DR. SOWDER: I wouldn't characterize it in that simple fashion, but, the point I was making was, in terms of distinguishing between your fuel cycles--well, let me go to the other extreme.

If you are to use non-proliferation as your primary--and this was, the purpose here was actually ranking, to answer the question, and not to remove it completely from the table, but, in terms of ranking your technologies, one, one, one thing that can happen is if you make your fuel cycles so complicated, again, looking at someone being able to operate it, deploy it, reliably, not incur enormous workers doses, et cetera.

You run the risk of actually making your technology practically unusable. So, the idea here isn't that non-proliferation isn't important, but in terms of, I think, as a primary driver, it's not as useful in terms of selecting your technology.

That, if, if your primary driver,

and, again, that was the premise of my presentation, was the primary driver is simplicity, cost effectiveness, et cetera. Never, I don't, did not mean to ever imply that non-proliferation should ever not be a consideration, but that the primary drivers there are the extrinsic factors.

You always will need security, you will always need your safeguard regimes in place, they'll need to be effective. And the concern is to not believe that your technology, whatever it is, whether, bringing neptunium in, or carrying everything through the cycle is going to somehow magically alleviate concerns.

So, again, in terms of answering the question that was posed, my attempt was to rank them in terms of giving you some practical approaches, and maybe, perhaps, at, at minimum, it is least, allow you to look at, at things from a different perspective.

But again, this was, from a viewpoint of actually using technology as your primary non-proliferation tool. And again, I would posit that it's actually, it's your extrinsic measures. And again, the two work together.

But you'll never have a fuel cycle where it's, where you can walk away from it, you don't need some measure of material accounting and control, et cetera. So, again, I did not mean to diminish the importance of non-proliferation but in terms of the ranking, I, I, I meant to--

MEMBER CARNESALE: Well, then, it may just simply be a distraction from your presentation, because the simplest cycle, the most economical--

DR. SOWDER: Right.

MEMBER CARNESALE: --right now, is the once-through--

DR. SOWDER: Sure.

MEMBER CARNESALE: --in which you

don't separate plutonium. So, it may be that they all go in the same direction right now, so it simply distracts from your presentation. Dr. Kazimi, 2.1 is just a point, and that is, it's just something that's always concerned me somewhat, is the notion of standardization, to reduce cost.

I mean, Toyota standardized on the braking system. And one of the great dangers of standardization is if you standardize on the wrong design, and in five to ten billion dollar a piece facilities, that could be--I understand the other side of the argument.

Standardization has it's own risks, as well as rewards. I did want to ask you a little bit about the, the figures you show about how much TRU waste would have to go to the repository at different stages.

That's true, but it strikes me as a little bit, could be misinterpreted quite easily. The problem of the TRU waste, if instead of being in a reactors, you could just store it.

And so, the, therefore the requirements for the repository, since it's going to be the same in the end anyway, could look the same at any stage, instead of insisting to have the repository available for the TRU waste that's not in reactors immediately. Is that, is that a reasonable interpretation?

DR. KAZIMI: Yes, I'm not so sure I put any time line on when this is have to be going to the repository--

MEMBER CARNESALE: But don't the same amount--

DR. KAZIMI: I, what I--

CHAIR PETERSON: --eventually have to go to the repository?

DR. KAZIMI: No, no. Certainly not. With recycling, multi recycling, there is potential for reducing by orders of magnitude, at least one or maybe two. No, the issue of when to, when do you need it to go to the repository.

Because, this is a, an activity that's going to be around for a long time, taking a few decades to decide how to do it, I don't think, is going to have a big impact on the overall consequences of the system.

And, basically we do have a, proper technology for storage of spent fuel including the TRU, so we can handle it that way.

MEMBER MACFARLANE: Thanks. Okay. Do you want to jump in?

DR. SCHNEIDER: If I may, just to add to Dr. Kazimi's point. I think what your figures showed, with a substantial inventory of transuranics still in the reactor at the end of the century, would indicate that something that needs to be borne in mind, I believe, is that if that recycle strategy is committed to, right, to achieve the order of magnitude or two orders of magnitude burndown.

Right, it's not just the century long enterprise, right, it's a multi century long enterprise.

MEMBER MACFARLANE: Right. Yes.

DR. SCHNEIDER: Because one has to continue recycling and feeding the material back into the reactor, getting maybe a 10-or-20% burn each time.

MEMBER MACFARLANE: Many centuries. Okay. Let me first make a comment, and then I have a couple questions. And my comment comes from my expertise as being a geologist, and it's about uranium availability and uranium resources.

And, we've been having a lot of discussion about that, with no geologic basis in reality yet. I just want to point out that there's been very little geologic investigation into uranium resources for over twenty-five years, okay? We haven't looked for this stuff for over twenty-five years.

So, and, and I know, because I've looked into it a little bit myself, I haven't looked for it, but I have looked into the literature, uranium is distributed--and I've done a little bit of my own research, a long time ago, on this, but.

Uranium is distributed very widely in a variety of different geologies, in a variety of different aged rocks, and in a variety of different rocks in different settings all over the planet, even in the ocean water. So there's a lot of it out there.

And, I think when we really start putting money into looking for it, we'll find that there's a lot more than we understand there to be now. And so, all of the analyses that we've been presented so far have been based on Red Book numbers, for the most part.

Red Book numbers have a political

aspect to them, because countries don't always like to disclose all that they think they have. And we need to keep that in mind, as well.

So, I guess, I, this is sort of just a, a general plea to maybe hear from an economic geologist on this topic at some point in time. Because it is an important aspect to whether, whether, you know, a number of you have made the point that one of the, and the previous panel, and other panels that, that one of the advantages to recycling or closed cycle is the uranium resource one.

And I think we, that's still an open question. So, and let me ask a couple questions, or. And then one is to, is to Dr. Sowder. You showed, and this is, okay, so I may know a little bit about uranium resources but I don't know anything about economics, I don't like money. So help me here.

You had, you showed this economic competitiveness plot, and it seems to me that there are many assumptions in this. And what I want to understand is whether you've included in your analyses, clearly you haven't included capital costs for reactors, but have you included the costs for the repositories for the high level waste?

For dealing with the other waste streams? Have you included the storage costs for plutonium? Have you included the additional transportation costs to come up with the two analyses? Because they seem pretty optimistic, maybe, is one way of putting it. So, that's my first question.

DR. SOWDER: Thank you. And, again, I, there could probably be several pages of assumptions --

MEMBER MACFARLANE: Yes.

DR. SOWDER: I certainly would be happy to follow up with those reports. These were fuel cycle costs only, but they do incorporate both front end and back end fuel cycle costs.

This was, the OECD/NEA's model was utilized, so it does attempt to include everything from front end uranium mining, milling, processing, and then once you get out of the reactor, the back end as well-- waste management, including disposal.

MEMBER MACFARLANE: That means a repository?

DR. SOWDER: Yes.

MEMBER MACFARLANE: Okay.

DR. SOWDER: So --

MEMBER MACFARLANE: But -- you know, I think some of these other analyses that I've seen often don't include things like storage costs for plutonium and the additional security involved, and transportation costs and things like that, so.

DR. SOWDER: One of the key things here is that once you factor in the costs, the capital costs of the reactor, though, given that it's the big, the 800-lb gorilla in the room, we have done the parametric sensitivity analysis on what if your repository is ten times more expensive than you initially thought it was going to be.

Waste management is still a very small component of your overall electricity costs.

MEMBER MACFARLANE: Right. You know, I understand that.

DR. SOWDER: So --

MEMBER MACFARLANE: I just, you know, okay --

DR. SOWDER: But, the model, again, and it's the model --

MEMBER MACFARLANE: So, I understand the results here.

DR. SOWDER: -- all, you know, all models are wrong, some are useful. The point of this model was to tease out the basic argument when, possibly, plutonium recycle, for example, could be economically feasible. That doesn't mean it is, but this, based on solely, fuel cycle costs alone, was what we are using this for.

And it -- basically what it's showing you is, based on your uranium costs, those fuel cycles that maximize resource utilization do better. But, that's, that does, that's just based on whether or not your uranium costs are --

MEMBER MACFARLANE: Right.

DR. SOWDER: -- your concern.

MEMBER MACFARLANE: Right, and if you have plenty of uranium, its probably a moot point.

DR. SOWDER: Right.

MEMBER MACFARLANE: Okay. Second question is for Mujid. Nice to see you. And it's another economics question. So, early on, you claimed that, you know, that the economics for nuclear will improve and are improving.

But, I'm thinking about the recent Constellation Calvert Cliffs decision, which seems to go in the opposite direction. And then, in terms of the standardization issue, which Al also brought up, it seems to me that standardization really hasn't helped France, at all, vis-a-vis Korea.

Because the French deal to the UAE was fifteen billion dollars, approximately, more than the Korean deal. And so, standardization didn't really help them. Maybe there's not much to say, but.

DR. KAZIMI: You know, standardization is not going to replace the cost, the design, or the cost of the labor assumed, engineering costs, and so forth. So, standardization has, and it certainly helped France because that's how they built their fifty reactors.

They standardized, essentially, on two designs. And each twenty or so reactors are built with one identical design.

MEMBER MACFARLANE: I think that's a good plan in general, definitely.

DR. KAZIMI: Yes. So, but it's not to say that you can gold plate a reactor and then try to compete with a silver-plated one. So, you have to have a design that is adequate --

MEMBER MACFARLANE: Fair enough.

DR. KAZIMI: -- that provides a safety, and. The UAE deal, sort of, is an interesting one because the Koreans are offering a reactor that they haven't built yet. It's a new design, but they think that -- but this is their choice for their new build, and they are counting on at least ten of these reactors of the same size.

So, certainly, and in answer or response to an earlier comment, you know, we should never plan to standardize forever. I mean, technology changes. We learn from operation.

Therefore, standardization would work for a number of reactors, let's say ten to twenty. But, we should make use of improvements that we learn about in our other reactors.

CHAIR PETERSON: Okay. I have three questions I'd like to pose to panelists. The first is for Andrew Sowder. Going back to the same economic competitiveness graph that Allison was referring to, and with the big caveat on it that the reactor cost is left out.

Would it be fair to say that in fact those costs associated with the fuel are second order drivers for the economics? This would be an important point, that the major element of economic decision making with reactors is the capital cost and the reliability of operation once built.

If that's the first order driver, would this then have some connection to the discussion of what the future is likely to hold, which is more Light Water Reactors for the foreseeable future?

DR. SOWDER: I think the answer is -- it kind of depends on probably the time frame you're speaking of, but certainly reactor costs, including construction and operating them, maintaining them, is about 80-to-90% of the nuclear electricity costs.

So, the remainder are these other things, including the fuel cycle costs. So, from the front end, yes, the fuel cycle costs -- that's one, actually, one benefit of the nuclear energy, is, really fuel costs are a small fraction compared to the volatility you see in natural gas.

But as the costs of those reactors are largely amortized, as you pay them off, the fuel cycle costs do suddenly become larger and larger components. So, you know, I think it depends on where you are moving down the road in terms of fifty years form now, once you've paid off your reactors, and suddenly the world growth rate scenario changes, et cetera.

You know, that's when you start worrying about your uranium supply. If indeed there -- the other thing that happens with uranium is that as it gets more expensive, people start looking for it, and certainly got a lot in the oceans, and if you can recover it from the oceans, for example, then you don't have a problem.

Right, and I totally, would totally agree with that, even though it's often a matter of cost.

CHAIR PETERSON: Next question is for Mujid. And, I want to challenge on one of the statements that, that you had made, which was that the fission product burden is not affected by the fuel cycle, certainly, but, I'd like to put in a plug for MIT's work on supercritical CO2 power conversion systems.

It's an interesting point that, looking at those various different curves, you could get as large or possibly even larger effects on spent fuel inventories and other things simply by transitioning from ranking cycle to supercritical CO2.

So, is that an area of leverage that may be just as important as the fuel cycle area?

DR. KAZIMI: Yes. I am glad you mentioned this, Per. Certainly, the CO2 cycle will give us a much higher efficiency in converting thermal energy to electrical energy, and that in turn will reduce the amount of waste, including fission products, that are needed for production of a certain amount of electricity.

But that also goes for other improvements. As you know in the Gen 4 exercise of reactors, supercritical water was also proposed as a way to get to a higher efficiency. If that was to be achieved, then we would get that benefit of reduction of fission products per unit electricity produced.

And, very recently, we just finished a study of achieving superheat within a light water, BWR type reactor, which looked feasible from this conceptual stage point of view, but of course, it would take a while to develop.

Of these three items, I would say the supercritical CO2 one is one that depends on the availability of reactors that can reach that temperature. Water, we're a little bit more accustomed to and perhaps we can manage to change it, to either superheat or supercritical.

But certainly if reactors can achieve the appropriate temperature, which is probably on the order of 600 or 650 degrees C, then the CO2 cycle would be very attractive.

CHAIR PETERSON: All right. Thank

you. The final question I have will be for Christopher Paine, and it relates to this list of things that we do need to consider in terms of comparing different energy options.

There's two dimensions to the question. One is sort of the crystal ball of what's going to happen with the costs of these different technologies.

And there I'd like to push back a little bit on some of the projections about potential increases in Light Water Reactor costs from the, sort of the first of a kind costs that we're seeing today, for the first few that are being built by noting that the experience in Japan, Korea, and in China has been that replication brings down costs, substantially, over time.

And so, if you look at the overnight costs today maybe for an AP1000, might be around $4,000, $4,000-4,500 is what Westinghouse might charge. Very reasonable, one might expect that you could see those prices coming down by similar percentages, possibly, or not, depending on the experience, which would affect the mix.

The other dimension of this is how to try to internalize this large list of additional externalities, with, I think, you know, Eric would probably agree, the security related dimensions are really tough to do, but when we get to public health and environmental impacts, NRDC has essentially done analysis that shows that, for example, particulate air pollution from fossil and biomass combustion is causing somewhere on the order of perhaps around 63,000 premature deaths per year in the United States alone, which is catastrophic in terms of the magnitude, if you compare it with other things.

So, when it comes to this list of other things, you have the mill tailings, the fish kills, the fresh water consumption.

If we try to scale that to the power production, does that sort of change the criteria or not, in terms of trying to pick between different technologies?

MR. PAINE: Well, with respect to the coal cycle, I think I say in my statement that I believe the nuclear fuel cycle is superior, even with the fish kills and the excessive thermal discharges. The point is that I think that, you know, with more focused attention by the regulators and DOE on the specific problems that nuclear has, the current incarnation or reasonable extensions of the Light Water Reactor cycle with some concerted attempt to focus on those problems, we could make nuclear better and thereby enhance its near term contribution.

The problem with DOE is that it has this genetic code built into its laboratory structure that always carries it into the next generation of reactors, or three generations down the road. And we spend billions over time.

If you look at the billions of dollars that we've expended on fuel cycle research in this country, to no tangible effect, when we sort of learn that these cycles aren't economic. You know, why doesn't the DOE focus, for example, on a major environment hurdle for nuclear power and it will be a significant environmental hurdle, people are not anticipating how serious it's going to be, which is the thermal discharges.

You know, let's build an LWR that's scaled appropriately so that each unit can be air cooled. That will also, you know, that should facilitate deployment of nuclear power in certain instances, and it should improve the economics.

CHAIR PETERSON: That's certainly a good plug for supercritical CO2. Eric, or Everett? Any thoughts on this question?

DR. SCHNEIDER: I had, I guess maybe a followup on the uranium issue that, that Allison raised. An update for the Commission. Actually, later today I'm hopping a train to go to Boston for a workshop on uranium resources that'll actually have substantial participation from economic geologists.

So, I think there is awareness, maybe the Commission would like to hear from this uranium resources task area within DOE that's formed up. Also, the USGS is starting a five year reassessment of uranium supply in the United States, that's just spinning up now.

So, I think that a lot of concerns you raised, we haven't looked at it for twenty-five years, are resonating in, in many areas. That having been said, your point is well taken, that there's a great deal of uranium out there.

We kid ourselves sometimes that

it's an exceptional or exceptionally rare element in the crust that it's not, right, it is not at all. Right, it's rather an average element, in fact, on the list of elemental concentrations in the Earth's crust, it's almost dead in the middle.

Right, and, so, I think a key part of the question, which neither remains out there, as we look harder, the Red Book itself states, correct, in the 2007 Red Book, I wish I could remember the exact quote. Right, they are aware that people are misusing the Red Book in the way that you described, as this is the be-all and end-all of what's out there.

Right, the 2007 Red Book itself makes very clear, these are snapshot estimates only, right. They're not meant to convey what may be discovered in the future. So, we have to be aware of misusing the Red Book data that way.

Right, but I think the flip side

of what else will be discovered as we look harder, and certainly there will be a great deal of uranium, is how recoverable will it be? Right, and to take seawater uranium as an example, that's going to be addressed at the workshop as well that's coming up.

Right, MIT did good work in the seventies and eighties that showed that an earlier incarnation of seawater uranium extraction using anhydrous titanium oxide didn't meet energy balance requirements. Right, it would take more energy to recover the uranium from the seawater than you could get from a reactor.

Right, so I think that this side of the picture is the more poorly understood side. If it's feasible to extract that uranium that is a little less economically desirable right now.

CHAIR DOMENICI: Mr. Chairman, is the time up? Have we used all the time?

DR. REDMOND: If I may, just for a

second. One thing I just want to touch on again is the research. And I would agree with Christopher that research needs to be focused on certain areas, certainly applicable to Light Water Reactors nowadays, but also in terms of long term recycling processes.

As I said, if we're doing fast reactors as part of that, that's something that needs to be focused on in the short term, I think, or focus a little bit more research in that area because we need to make sure that they're going to be reliable and can meet the same sort of performance criterias that are currently existing. Thank you.

DR. KAZIMI: May I, Mr. Chairman, add to this. Sometimes, we have embedded assumptions and we talk about fast reactors and people have images of sodium-cooled reactors immediately in their heads.

Fast reactors goes beyond sodium-cooled reactors. So, we should encourage looking at the broad spectrum of options for hard spectrum or fast reactors, and not assume this is a sodium-cooled reactor.

CHAIR DOMENICI: Mr. Chairman, could I have a couple of questions? Thank you very much. First, I want to thank the panel for the way you've presented the facts and the evidence to us. I think it's been very exceptional, and in particular, I want to thank, I think this was a very interesting approach, and thank you for it.

When it was finished and I looked at it, I, no offense to anyone, but I said to my co-Chairman, this is the kind of presentation you would expect from somebody who was working in the field, and I think that's correct, and that's what you all do up there at your place, is you help each one of these decide what the facts are all the time, and I assume that's what you're giving us.

And I want to say to the professor from MIT, I was very impressed, and thank you for your testimony. I hope you'll give us written remarks --

DR. KAZIMI: I will send it in, I haven't yet.

CHAIR DOMENICI: I know you didn't have, need them, you're very skilled, but we need them, some of us who are not so skilled, need them. Like me. Let me ask you, Doctor, if you would answer this for us. First, let me talk about uranium reprocessing.

Why are the countries in Europe in such a hurry to quote get recycling and reprocessing, and here we're talking about, it may never be needed in America? What's the difference between them and us?

DR. KAZIMI: One of the major differences, say, in the case of France, is they already have the facilities that they need to recycle, and they don't have to design it and build it from scratch. And, the other difference may be that they don't rely on uranium that is extracted from within their country.

They're on uranium imported from other parts. We have -- we're endowed with uranium that's present, perhaps today it's not economic to extract it, but we can, we can be more assured of the availability of uranium in the future than they do.

CHAIR DOMENICI: So you're saying there is a degree of concern about the adequacy of supply or the reliability of supply, and that's why they are on this bent of reprocessing, even though it's difficult and expensive? Is that what you're telling us, that's why?

DR. KAZIMI: Yes, I would say that's part of it, yes.

CHAIR DOMENICI: What's the other part?

DR. KAZIMI: Knowing that they

already have the recycling facilities. They invested in the past --

CHAIR DOMENICI: It's already done.

DR. KAZIMI: It's already done.

CHAIR DOMENICI: Okay. Now, let me, let me make an observation here about uranium supply. I don't know if any of you know where America got all of it's uranium, to win the war with, but it was New Mexico. They found it out there, and it's a very famous story about it, an Indian man who brought the rock into the store, to the trader, and put it on there, and it was radioactive. That's where the first gigantic field was.

It's all closed down now, and it will open up again, I assume, and inventoried, depending upon political leadership whether it will be open or stay closed, it's not -- has nothing to do with the availability of lots of uranium there.

I do want to say, Dr. Schneider, I met, met you while you were washing your face, you were certainly intent on waking up, and you did. I saw people wash their face before, but might I tell you, you are really a face washer. No question about it, you look very good, too.

I wanted to ask you, Doctor, what, tell us, if you would, how would you articulate the situation that you described to us? You said, so long as we stay at around 20% of the electricity that comes from nuclear, we will get by with Light Water Reactors, and we won't have to worry.

But if it got to forty, he said, 40%, he would have to have something else, like recycling or reprocessing. Is that not what you told us? Or something like that? Tell me more.

DR. KAZIMI: I think if we get to 40% we will need the recycling faster than if we stay at 20%.

CHAIR DOMENICI: Yes. But if that's the case, how would we decide to be serious about recycling? It looks like we've got nothing to get serious because it's not economic, we have plenty of -- between uranium and what we've got stockpiled already, we have plenty. So, so how are we going to get the impetus to get going with recycling?

DR. KAZIMI: You know, my recommendation is, first, we have to reexamine our technology options for reactors, because reactors will make the largest cost contribution. So, to move into recycling requires a reactor that is competitive in the market.

And, at the moment, we can't say that about the technology options that have been developed. So, I think one of the things that will be needed will be an investment in examining options for less costly advanced reactors that enable recycling.

The second thing is, we have to make also some assessment of what kind of recycling would make sense for us, you know, the last five years, they reinvested in the various fuel cycle programs and there are ideas on the table, which have been experimented with in small quantities but one question is whether you can extrapolate that into the engineering phase.

The third thing I would say is, to move into a recycling fast reactor technologies require a much higher fission rate in the fuel and the confidence that we have in the fuel to be deployed in the fast reactors is now -- not at the same level as it is in the Light Water Reactors.

We prefer, for example, metal fuel, whereas in France the experience has been always with the oxide fuel. And there is this debate as to which way we should move. So, at least our three enemies, at least, that I think, we can use the time that we now and when we really need it, to try to make a choice in technology.

CHAIR DOMENICI: Thank you very much. Thank you, Mr. Chairman.

CHAIR PETERSON: Thank you. I would like at this point to thank all of our panelists for their excellent presentations and insightful answers to questions. At this point, it is time for us to draw this session to a close.

We will take a lunch break. We will reconvene at 1:15 p.m. sharp for the next session, which will be on the topic of limiting future proliferation and security risks. Thank you everyone.

(Whereupon, the above-entitled matter went off the record at 12:19 p.m. and resumed at 1:17 p.m.)

MR. FRAZIER: Okay, we really are going to get started now, so if I could have everybody grab a seat. Okay, everybody is going to sit down. Yes, Senator Domenici, take it away, sir.

CHAIR DOMENICI: Yes, thank you very much. Hello, everybody. Panelists are seated, and if not, they're in the process of doing so. And as with other panels, let me remind each of you to keep your presentations to ten minutes, if you can.

Our last panel of the day is entitled, and I quote, "Limiting Future Proliferation and Security Risks," close quote. Our first speaker is Dr. James Acton. Dr. Acton is an associate in the Nuclear Policy Program at Carnegie Endowment and a Stanton Nuclear Security Fellow. We thank you very much, Dr. Acton.

Our second speaker is Dr. Robert Bari. Dr. Robert Bari, he's a Senior Physicist at Brookhaven National Laboratory. Thank you for coming. I met you today, and thank you for what you do up there at the laboratory.

Our next speaker is Dr. Richard Garwin. He's currently a Fellow Emeritus, IBM Fellow Emeritus at the Thomas J. Watson Research Center. Thank you for giving us your time, Doctor.

Our next speaker is Dr. Edwin Lyman. He is the senior scientist of the Global Security Program of the Union of Concerned Scientists. Thank you very much, Doctor, for coming.

And our next speaker is Dr. Robert Gallucci. He's currently the President of John D. and Catherine T. MacArthur Foundation, and prior to that he spent many years in the service to our country in a senior diplomatic position focused on issues of non-proliferation and nuclear safety. Thank you, Doctor.

Now, with that -- do you have comments, or do we go right to the witnesses?

CHAIR PETERSON: I think we can

start.

CHAIR DOMENICI: All right, we'll start, go to the witnesses. And we'll start in the order that I introduced you.

DR. ACTON: Thank you, Senator. Let me say, first of all, that it's an Honor to appear before this Committee today. And let me also add, by way of introduction, that I am a strong supporter of nuclear power. I believe that if we are to significantly and meaningfully mitigate the effects of climate change, nuclear power must be part of the solution.

The challenge we face is how to expand nuclear power safely and securely. And I'd like to focus my remarks today on the question of non-proliferation, and specifically whether a policy -- a continuing policy of the United States restraint of not reprocessing spent fuel is likely to prove an effective non-proliferation tool.

In sixty-eight years since the first nuclear reactor went critical in a squash court at the University of Chicago, in that time the U.S. has adopted three basic strategies for managing sensitive nuclear technology.

Its first strategy, employed from 1946 to 1954, might be labeled "develop and deny." That is, the U.S. developed sensitive fuel cycle technologies, and denied them to everybody else.

A variant of this strategy, in which sensitive technologies were to be shared with just a few carefully selected safe states, was embodied in the Global Nuclear Energy Partnership.

A second, different strategy, was first adopted by the Ford Administration for reprocessing, was subsequently supported by both the Carter and Clinton administrations, and that is, desist and discourage. The United States desisted from developing reprocessing and discouraged other people from doing so, too.

There's a third strategy, develop and disseminate, which has been applied, quite rightly, to Light Water Nuclear Reactors and other types of reactors. But for obvious reasons, it's not on the card for reprocessing.

The choice facing the U.S. when it comes to reprocessing is therefore between develop and deny, and desist and discourage. Or, put more simply, between denial and restraint.

Critics of restraint argue that it has done very little to slow domestic reprocessing programs in China, in France, in India, in Japan, in Russia, and in the United Kingdom. This is correct, although the U.K. program is slowly dying of it's own accord, for other reasons, anyway.

However, it misses the point. And this is the central point that I want to make today. The real value of restraint by the U.S. is not that it encourages existing reprocessors to stop. It's that it doesn't encourage new ones to start.

The seminal 1976 study, "Moving Towards Life In a Nuclear-Armed Crowd," which was conducted by a team led by Albert Wohlstetter, actually, observed that, given contemporary plans, seventeen states would have a significant reprocessing capability within ten years.

Today, thirty four years later, just the six aforementioned states have reprocessing programs.

CHAIR DOMENICI: Sir, sir, would you go back thirty seconds?

DR. ACTON: Sure. The seminal 1976 study, "Moving Towards Life In a Nuclear-Armed Crowd", which was led by Albert Wohlstetter, observed that, given contemporary plans for reprocessing, seventeen states would have a significant reprocessing capability within ten years, that is, by 1986.

Today, thirty four years later, only the six states I mentioned above have civilian reprocessing programs. The fact that the growth in the number of reprocessors have been much smaller than anticipated is, I believe, the primary mark of U.S. -- of the success of the United States policy of restraint to date.

To understand why a U.S. decision to procure sensitive nuclear technologies might encourage others to do likewise, it's necessary to realize that states make procurement decisions based on reasons other than cold, hard economic analysis demonstrating that some fuel cycle choice is the cheapest way to produce electricity.

Or even that it provides other essential economic benefits, such as energy security or simplified radioactive waste management. The decision making of states is more complicated. They are strongly affected by non-economic factors, in particular, prestige and what I term "received wisdom."

I think prestige is probably a well understood phenomenon, I mean, I don't want to belabor the point. I do want to talk a bit more about received wisdom though. And this is where states make decisions about nuclear technology, because they see other states doing it, so they assume that it's got to be the right thing to do.

Received wisdom, particularly from the U.S. but also from the U.K. explains why, prior to the mid-1970s, every state with a nuclear power program outside the Soviet bloc, apart from Canada, planned to reprocess spent fuel.

Few, and I don't think any, of these states surveyed their uranium resources to work out whether they needed to close the fuel cycle for reasons of energy security. They didn't make detailed cost estimates of the cost of nuclear energy from fast reactors.

They just copied the U.S. and the U.K. because they were the global leaders at the time, and that is a classic example of the role of received wisdom. Indeed, when the U.S. changed its policy in 1976 and opposed reprocessing, Japanese diplomats apparently were very fond of remarking that our belief in the necessity of the plutonium cycle is based on American teaching.

My concern, therefore, is that if the United States makes a decision to renew domestic reprocessings, it will create more received wisdom that separating plutonium is the right way to go. It will confer prestige on this technology and make it likely that other states will follow and go down this route.

And these concerns that I have would not be mitigated if the U.S. were to adopt a technology such as UREX plus, that does not completely separate plutonium but leaves it mixed with minor actinides. Even this fuel cycle choice would send out essentially the same message, that a modern nuclear state needs to close the fuel cycle.

And my concern is that a U.S. decision to go for UREX plus would encourage other states to go for more sensitive technologies, such as PUREX. New reactor technologies, I don't think, provide a solution to this problem either.

The Global Nuclear Energy Partnership provides a cautionary tale, I think, about trying to focus on one type of nuclear reactor and ignore others. When it was launched in 2006, GNEP advocated the development of burner reactors, reactors that could consume more transuranics than they would produce.

This was a reflection of U.S. waste management concerns, but was also argued to be consistent with U.S. non-proliferation goals. I think it's true that burners, the argument advanced by GNEP that burners aren't proliferative is correct, but only if you ignore the reprocessing technology that's necessary to make the fuel for burners.

In any case, the essential premise of GNEP was that the U.S. was going to focus on developing burners and not breeders. Realistically, however, it proved impossible just to focus on one reactor type and not the other.

The challenges to the development of burners and breeders are, certainly, at this stage of the research and development cycle, rather similar. So providing support and funding for the burner necessarily contributed to the development of its more proliferative sibling, the breeder.

Indeed, I point out that in 2002 when the Generation 4 International Forum Roadmap was launched, that stated explicitly that all of the technologies under consideration were equally appropriate to burning and breeding, and the only way it was possible to get political consensus amongst all the participating states who had lots of different goals.

So, just as I think that moving to a technology such as UREX plus does not solve the problem that the message sent out, the received wisdom and the prestige, so I think, new reactor technologies also don't provide a technical solution to the problem of proliferation.

This raises one final issue, which I want to touch on briefly, which is how can proliferation risks be assessed. Everything should be very clear by now. I believe that assessing proliferation risks is not just a technical exercise.

Criteria such as safeguard ability and material attractiveness matter. But so too do political factors, like prestige and received wisdom. I don't rule out the possibility of adapting methodologies designed for quantitatively assessing proliferation risks, and adapting them to be able to take these political factors into account.

But it seems to me an exceptionally difficult and long term task. In the final analysis, proliferation is a political problem, and the key to assessing proliferation risks, I believe, is political judgment. Thank you very much.

CHAIR PETERSON: Dr. Bari?

DR. BARI: Well, thank you for inviting me. It's an honor to present to you today. I should note that in this morning's session, the technologists tend to stand up the podium and show you view graphs, while the social scientists sat and read prepared statements, for the most part.

I'm not sure what that means about our relative paradigms, but in any case, today I'm going to talk about a methodology that's been in place now for most of the decade for assessing proliferation and security risks.

Also note that several times this morning, the idea of proliferation came up even though we're talking about America's nuclear future. But clearly the interest is global, and our impacts on going beyond just what we're doing here are very important.

So, what do I push. There we go. Okay, so, to that point of proliferation, there are really two topics here in this session. The proliferation and the security. The proliferation issues are ones, as we've defined in our methodology, ones in which the host state of a peaceful nuclear technology tends, is interested in going beyond the peaceful and proliferating to a weapons type of situation.

The security one is connected with physical protection, and here I show some distinctions between the two. So, for proliferation, think, host state acquires a facility and then is interested in doing things other than using it for peaceful purposes.

Whereas, in the case of physical protection, the actor is a substate, subnational or terrorist or somesuch. The threats on the proliferation side are diversion of materials of interest, misuse of facilities to make materials of interest, and possibly, not mentioned explicitly this morning, breakout scenarios where a country has a peaceful nuclear capability and then decides to break out for weapons purposes.

On the physical protection, on the subnational side, the threats are material theft, information theft, and sabotage of facilities. On the proliferation side, it's really international controls that come into play, like the ones put forth by the IAEA.

On the physical protection side, it's the security and the domestic safeguards put forth by the nation state to protect its assets.

The, on the proliferation side, the events tend to be slow moving. There's planning ahead for these events. The events themselves may be carried out very slowly, for example, a protracted diversion scenario.

On the physical protection side, it tends to be fast moving, an event occurs and something is damaged or stolen. But that's also not always the case, there may be insiders working with outsiders, and there might be extended planning in place.

Clearly, on the proliferation side, there are international implications on physical -- for physical protection, its regional implications, at least for physical effects that would be realized.

Okay, so, our approach to this

problem is to -- is that we call it a science-based approach. It was developed under the GEN4 program over the last decade by an international group, and what we did was we strived to attain consensus on our methodological approach.

And the one that we took was one in which there are challenges to the system that we recognized, so we pinged the system, so this is where the science comes in, you're probing a system. You look at the system response, and then you measure the outcomes and make an assessment of that.

And, for the threats, I think I've gone through these already. For Proliferation Resistance, acronym is PR and PP for Physical Protection. So, they're clearly, diversion, misuse, breakout. Also, possibility of replicating a facility clandestinely for nefarious purposes and theft and sabotage come to play, on the, for Physical Protection.

The system response, one needs to recognize both the intrinsic and the extrinsic capabilities for the system. And this is not just an additive idea that you have intrinsic and extrinsic, but, in working with some of the stakeholders in this area, we quickly realized that there is a very dynamic interaction between the two.

The designers are concerned that their facility, which they designed for performance, is not overburdened by institutional measures that would tend to detract from a performance.

And, conversely, folks at the IAEA have said, well, when they design these facilities, we want to make sure that we can still effectively and efficiently inspect them.

The assessment is done in terms of measures. The first six that you see there, and I don't think you can see all of them, they, with the fine print. But the first six represent the, what we mean by Proliferation Resistance. It's the, we measure material type, detection probability, technical difficulty of carrying out a proliferation activity, the time for the proliferation, the cost of it, and we've also added the cost of safeguards since this involves both a proliferator and the defender.

For the physical protection side, we very quickly recognized that we're dealing with lots of sensitive information very quickly here, and we've taken a broader view of measuring it in terms of adversary success probability and consequence, and the secure -- the cost of providing that security.

And we've used these measures to then develop metrics and guide our methodology through a inductive process here, which leads one into scenarios in which one looks at each of the threats and assesses each threat for its various outcomes in terms of the measures.

So, in terms of threat considerations, we have threats that are for the host state and ones for the outsider, the non-state actor, and one has to recognize the actor's capabilities, strategies, and objectives in this.

And these could be multiple, and this will determine the initiating scenarios. One needs to make assumptions about these, or needs to analyze as many of them as are relevant to the particular analysis.

The evaluations, when they're done, should consider several points. First of all, what is the question that one wants to answer in the analysis? What -- and this would come from some policy statement, what is of interest to the, to the problem holder.

The adversary context, what is

the adversary -- what does it look like, what are the objectives, capabilities, and strategies? What's very important here is country context. Who, for example, is the proliferator? Who is attacking a facility? These are the type of things that need to go into an analysis to, to make it meaningful.

One size does not fit all. One needs the system design features that are appropriate to the proliferation, or physical protection scenario. The fuel cycle architecture itself, is it a once-through or a recycle scenario?

The safeguards and security context are very important here. When, typically, in analyzing a system, would need to have a reference or baseline to compare with. Also, recognize that there are three broad stages in this process, the acquisition of materials, its processing, and then finally weaponization.

Proliferation threat and sabotage

scenarios, it involves at least two players, the actor, the adversary, and the defender. And both of these need to be recognized in the analysis.

We've performed a few studies since the development of this process. For the, in the international case, in the GEN4 arena, we very quickly adopted a model, it's, it's, in developing a methodology, you need some context, and we, we developed a model of a sodium fast reactor, we called it the example sodium fast reactor.

Loosely modeled on the integral fast reactor, which includes a full fuel cycle. SO that helped us to develop the methodology along the way, and we did a series of case studies for that.

The, the remaining bullets on this few graph refer to studies that have been done by a U.S. team for the NNSA connected with the GNEP program that went on from, I guess, about 2006 to 2008.

We started a first study where we compared the, the UREX plus 1A separations technology to COEX and PUREX as a baseline. Then, we broadened the study quite a bit to consider the entire suite of UREX technology, separation technologies, and COEX and the pyroprocessing technology, and compared all of those to PUREX.

We also, as part of the support for the programmatic environmental impact statement for GNEP, looked at specific reactors that were considered in that program as well, and they're shown here, sodium fast reactor, high temperature gas reactor, the CANDU and an Advanced Light Water Reactor.

In addition, we looked at, in another study, small modular reactors. One was, specifically, the IRIS reactor, an integral PWR, small PWR. And the other one was a barge reactor that the Russians are, are promoting, and implementing right now.

And we compared these as a baseline to the advanced large LWR.

So, observations from this evaluation process. Multiple pathway scenarios highlight that there's no simple answer. The, the analysis helps to give us, even at the qualitative stage, some insights before quantification is done. And given that it's a holistic approach, it tends to put the whole system together and, and look at it in a bigger context.

Finally, well, I'll go over this very quickly. Policy, technology, context, some of that was alluded to earlier. Start with policy to formulate what the questions are, do the technical analysis, and then policy should come in again to make choices based on the results and other information of interest.

And it's important not to put these policy ideas into the analysis up-front, because you might end up getting the answer that you wanted. Questions and issues of future studies, since we're talking about America's nuclear future, relative advantages of alternative nuclear energy systems for various applications, system architectures, once, for example, once-through versus closed fuel cycles.

Looking at international arrangements like fuel leasing, we didn't discuss much lately. And then, melding the proliferation and security information into the broader context of performance, environment, economics, and safety. So the many stakeholders here, one of the challenges to get the information in a form that's understandable and clear to the stakeholders. Sorry for going over.

CHAIR DOMENICI: That's all right. Thank you very much. Next witness. Dr. Garwin?

DR. GARWIN: Thank you. I do have a paper, and I will read part of it. These are thoughts on proliferation and security risk.

I say that U.S. policy and programs for commercial nuclear power should be guided by economic analysis and choice, including the internalization of costs of barriers to proliferation for any technology and fuel cycle, not proof against proliferation.

And that's all of them, none of them is proliferation proof. Domestic suppliers should not be given over foreign sources, and those, and subsidies, if any, should reflect objective estimates of risks and benefits, not the kind of automatic, triple-a rating that polluted the mortgage backed securities bubble.

In the discussion, which I will not address in detail, I emphasized proliferation by non-state actors. So, that was part of what Robert Bari spoke of. And, also, not part of the discussion here, the overall risk of high-impact sabotage, so, the acquisition of nuclear weapons is not the only way to cause large damage to the society.

The decision process should recognize proliferation resistant as a slogan, not a description, and the U.S. should reject reprocessing of Light Water Reactor fuel. It's costly, it has tiny benefits in reduced uranium feed, and it has no benefit in reducing heat load to the repository as practiced technically very well in France.

We should encourage dry cask storage for 100 years or more, if necessary, with realistic and imaginative evaluation of the risks of attack and of defense of the cask fields. And with the recognition of possible, if unlikely, reprocessing of that spent fuel when the technology and the economics favor it.

The United States should lead in

the supply of Light Water Reactor fuel under conditions of prompt take back and commitment to interim dry cask storage and eventual regional commercial competitive disposal in mined geologic repositories.

The United States should do the research and demonstration to benchmark current costs of acquiring uranium from seawater, where there are four billion tons, four thousand million tons, enough to support a thirty-fold expansion of Light Water Reactors in the world for 2,000 years, while exploring means to reduce future costs of seawater uranium.

And we should help initiate a cooperative world program to analyze and simulate several types of breeder reactors, complete with their detailed individual fuel cycles to result in the eventual building of a prototype, if it can be established to be safe, and economically competitive with the common Light Water Reactor, as it evolves.

And I note that if breeder reactors are to supplant the world's burner reactors, uranium burners, their rapid expansion would need to be fueled by uranium-235 from large-scale enrichment plants.

The autogenous growth rate breeder reactors is far from sufficient to take over from Light Water Reactors, let alone to take over from non-fission sources. Now, in order to save time, I'm just going to make a few comments from the discussion that I provide.

First, that I endorse the informative and authoritative testimony to the Commission by Matt Bunn and Frank von Hippel, especially the involvement of the local citizenry and benefitting local citizenry in the siting of repositories.

Furthermore, in the choice of repository types that can readily be expanded, which means a, a, a below ground water reducing environment, rather than the oxidizing environment of Yucca Mountain. Of course, there is plutonium in all of this spent fuel that has been produced, about 200 kilograms of plutonium a year from the typical gigawatt electric reactor.

And if, when extracting that plutonium, you could make more than twenty nuclear explosives from it. But, the plutonium is 1% intrinsic he spent fuel, so to get ten kilograms of plutonium you would need to dissolve and reprocess a ton of spent fuel.

And there is intense, essentially self protecting radiation field that makes it difficult to steal either in little bits, or, you know, a chunk, enough plutonium for nuclear weapons. It's unreasonable to imagine that any terrorist organization is likely to be able to steal a large fraction of accumulated plutonium in spent fuel.

But it's entirely reasonable to

imagine that such an organization could make off with twenty or so of the two kilogram welded steel cans, in which the plutonium oxide is placed after extremely clean separation from fission products in the conventional PUREX process.

Direct terrorist attack to acquire the weapon usable materials is not the only threat. Violent criminal gangs motivated by financial gain are also a problem. So, they can specialize in that aspect and other people can specialize in the fabrication of the nuclear weapons.

I think a mechanism should be established by which a facility operator contributes to the IAEA funds adequate for the inspection and monitoring of the facility and of the process. And that would give the operator the incentive to adopt approaches do design, operation and to monitoring that would minimize the overall cost, including that IAEA monitoring.

The influence that the United States and the blue ribbon Commission can have on proliferation is modest. I agree that adopting a policy of, of reprocessing and recycle of Light Water Reactor fuel would have a bad impact on proliferation, because it would encourage the reprocessing worldwide, and other countries may have less capable protection for their reprocessed material than one could expect in the United States.

But, since there's no benefit, that extra cost associated with reprocessing, it's not something that we should consider now. I did analyze GNEP several times in publications that are on my website, which is shown on the cover page of my presentation, www.fas.org/rlg or just plain www.garwin.us.

And there, I analyze the heat load on the repository, the size of the reactor park that would be required with reasonable conversion ratio, not 100% or zero conversion of the fuel into additional plutonium but 70% or 60% so one gets to a system in which, if these so called burner reactors are producing electricity, which they could do at higher efficiency than the water reactor, more electrical power is being obtained from the part of burner reactors in GNEP than would be obtained from the water reactors.

And that's as it should be, if one can have safe, economical burner or breeder reactors, that's what we ought to have, but we are far from that at present.

I've also published a but on, analysis on the terrapower, so called traveling wave reactor. I say so-called because last year, it was indeed a linear traveling wave breeding burning reactor, and with stationary fuel.

And this year, it is similar to a lot of conventional uranium 238, plutonium

239 breeder reactors with fuel shuffling with a stationary density of neutrons and fissions.

For all that, there is a lot to be said for the kind of analysis that they've been doing so far, but it needs to be carried much further in an open, collaborative effort, and that's why I propose a world reactor laboratory, much like the CERN, the European particle physics laboratory in Geneva, where people could share ideas, make progress as fast as possible, advance the state of the art in analysis, not only of the burning of neutrons and fission products, but especially the really difficult part.

In the evolution of accidents as fuel may melt, overheat, glow coupled to temperature can cause problems, despite the best efforts of designers. So we have to find these things out in simulation before we build large numbers of such reactors, or even the, take the big expense of building a single prototype. Thank you.

CHAIR DOMENICI: Thank you very much, Professor. Now, next witness. Do you want to stand, or--

DR. LYMAN: Yes, I'll stand.

CHAIR DOMENICI: All right.

DR. LYMAN: Thanks. Do you have my presentation?

CHAIR DOMENICI: Here it is.

DR. LYMAN: It's the one I just-- the one you just loaded from the memory stick here. Thanks. All right. I don't know what the problem is. I don't know what it is with me and Powerpoint in this Commission. All right.

I appreciate the opportunity to address the Commission again on the issues of reprocessing and the relationship to nuclear proliferation nuclear terrorism. You've given us a lot of questions today, and I do hope to touch on all of them in my ten minutes. But I'm not sure I'll be able to.

Oh, something happened--All right, I give up. Anyway, I'd like to--the overarching theme of my presentation--sorry, let's give a--

CHAIR DOMENICI: Can we help you in some other way?

DR. LYMAN: If I had two seconds, I could try to load it again.

CHAIR DOMENICI: Sure, go ahead. Maybe we could give you a little more time, and take the next witness. Would that help you? All right. We're going to go with--Mr. Gallucci, are you ready? Can you speak from there? All right, I mean, really need, we'll, we'll take the other gentleman after you've finished. Thank you very much for accommodating us.

DR. GALLUCCI: Not at all. Thank you, Senator. Thank the Commission, I thank the Commission for the opportunity to be with you today.

I have submitted two pages for the record, and I would, I would not propose to read from it, but to speak about the topic, hopefully not inconsistent with what I've provided you.

I believe that the President of the United States, the current one and the one before this President, essentially got it right, that nuclear terrorism, nuclear terrorism is the greatest threat to America's National security.

I think there's a pretty broad consensus about that, and the consensus goes a little further, that nuclear terrorism, the idea that a, a terrorist organization would introduce a nuclear weapon into the United States clandestinely, is a very high-consequence event, but a very low probability event.

I would submit to you, to members of the Commission, that you should do nothing that would increase the probability that this event would occur, and if possible, your recommendations should decrease the probability of that event Occurring.

With that focus, I, I propose to leave to others the question of the impact of these, of America's nuclear choices, with respect to the back end of the fuel cycle. The impact of those choices on nuclear proliferation, as it is normally understood, is the spread of nuclear weapons to additional countries.

I, I propose not to address that, except to make one note, and that is the linkage between the nuclear terrorism issue and the nuclear proliferation issue. And that is to observe that the nuclear proliferation issue is very often miscast, in my view, as, as a question of when a country will acquire nuclear weapons.

Such as, for example, when will

Iran have the bomb. This, to me, is the wrong question. The right question is, when will Iran, or some other country, have fissile material, and what will be the propensity of that country, to transfer the fissile material?

Because, again, I say, my principal focus is not on the National capability, but on the nuclear terrorism threat. Now, about nuclear terrorism and the work of the Commission.

The most plausible scenarios, I think, for most observers, involving nuclear terrorism, are scenarios that involve an improvised nuclear device, and the clandestine introduction of that device into the United States of America.

In other words, not the theft of a nuclear weapon, but the manufacture of an improvised device. If that is the dominant view of the most plausible scenario, then that scenario in turn turns upon fissile material availability more than anything else.

The first concern, if that's true, ought to be highly enriched uranium. And, indeed, I think it has been for this Administration. Leakage from research reactors, submarine programs, nuclear weapons programs, think Russia, think Pakistan.

Second is transfer from a nuclear weapons state. Think North Korea now, think Iran, possibly in the future. One state helping others, other entities. It's good, therefore, to see the focus at the summit in the spring, held by the President, the focus on highly enriched uranium.

That was welcome. What was not welcome, at least by me, was, a, a, an absence of any substantial reference to plutonium, as there was this concern about nuclear terrorism, the emphasis was, emphasis was entirely on highly enriched uranium, leading me to ask, how come.

And, it seemed to me, that there were at least three important ways in which the plutonium, as a fissile material, is different than highly enriched uranium as a fissile material for our concerns here today.

The first is, we should stipulate, it is harder to make an improvised nuclear device if you're a terrorist with plutonium as a core than with highly enriched uranium as a core.

Having said that, I would like to submit to you that the incremental difference between making an improvised nuclear device with plutonium versus highly enriched uranium should not be thought of as an obstacle that could not be overcome, should not be thought of as an obstacle that could not be overcome, two negatives.

It is an obstacle that could be overcome by the determined terrorist. This, to explore this, requires going into nuclear weapons design, and I think if we want to explore it, we should meet after class and have a conversation.

But, but I, that's, I put that out there as the first proposition. Second, plutonium can't be blended down the way highly enriched uranium has been blended down, to the benefit of humanity.

Saying that immediately tells that I do not believe COEX, UREX, UREX plus, and it's various varieties, pyroprocessing, produce anything other than more direct use material or material that may not be direct use but does not have inherent in it, that obstacle, again, that prevents the determined terrorist from producing a weapon.

Indeed, the Brookhaven study, in their, obvious, but having to read that one last night, the Brookhaven study says "yes, a little bit of an obstacle, something of an obstacle for the terrorist group, the non National actor, not much for a nation". Something of an obstacle, don't depend on it, is the point here.

Third difference. There are really a number of plausible reasons for reprocessing and for extracting plutonium that are non-weapons related, unlike highly enriched uranium, which we're kind of down to naval reactors.

And the reasons are usually four. For radioactive waste management, to save uranium and possible separated work, third, to prepare for a fast reactor economy, and fourth, to regain world leadership in nuclear energy, to put it bluntly.

But each one of these, and others have addressed these, I think, can be dealt with. The radioactive waste management argument has been a debatable one for forty years.

I personally have been debating

this for forty years. And now we actually have local, dry storage, which everyone tells me is good for a couple hundred or so. I recognize that's not long-term storage. Sounds like a long time to me, but not in your business.

Okay, it's something that one can engage in for quite a long time. Second, the uranium, savings in uraniums and the SWUs all depend on economics. The cost of uranium, the price of uranium, the cost of enrichment, the cost of reprocessing, the cost of recycle, mixed oxide fabrication.

Experience so far, and the projections, don't seem to support the economics of doing this, particular if you're not already involved in a lot of sunk costs. So it doesn't seem like this is a compelling argument. Third, fast reactors may come, but they're not going to come quickly.

Fourth, if I can use some

technical diplomatic language now, on the fourth question, it seems to me absolutely nuts to do what is politically dangerous, economically unwise, technically unnecessary, just so we can lead other countries in precisely the wrong direction.

I just don't get that leadership argument at all. What does all this mean for the Commission and your choices? I'd make three points.

First, you will not be surprised to hear, I don't think the United States should recycle plutonium. I'm even, would even question, and this is kind of an asterisk, or a footnote, whether that mixed oxide fuel fabrication facility being constructed at Savannah River is such a good idea.

Recognize some of my colleagues in non-proliferation think it's a great idea to burn, quote, "Excess plutonium", but I, I wonder, since I don't think you have a reactor now that is prepared to take this, this fuel, when the fabrication facility is finished and fuel rods are produced.

It's just, strikes me as a bad example for us. Second, I think large scale recycle in thermal reactors anywhere in the world will make it impossible to achieve plutonium accountability at the kilogram level.

The physical security, if you think about fuel moving from a reprocessing facility to a fuel fabrication facility to a reactor, and the transit involved in each of those, is going to be costly, difficult, and I think, fundamentally unconvincing that we can achieve that necessary level of physical security.

In a way, politically, to me, it nullifies a lot of what Nunn-Lugar and cooperative threat reduction has done over twenty years. It makes a kind of, and I say this with hesitation, a mockery of IAEA safeguards, which you'll be left to safeguard that which is easier to do, but not the most valuable and threatening of things.

This applies, this argument, to every country. It applies to recycle in the United States, to France, to India, south Korea, Japan, Russia, and especially China, given the number of reactors that are being planned.

Finally, would seem to me that it is simply not enough for the Commission to say the U.S. will not reprocess and recycle for the foreseeable future for economic reasons. I don't think that's enough.

I think the Commission needs to say more, it needs to say that as a matter of policy, reprocessing and thermal recycle of plutonium is too dangerous and thus unsupportable in any country, even the most advanced country. Thank you.

CHAIR PETERSON: Thank you. Next

up will be Ed Lyman, this time with slides.

DR. LYMAN: I apologize, looks like technical difficulties are corrected. I'll get right to the point. In our view, as I stated before the Commission before, we believe the risks of reprocessing today are already unmanageable.

And so the thought of actually expanding reprocessing either domestically or overseas could quickly escalate out of control. The reasons are fourfold.

First, the, the production and utilization of plutonium are not in balance today, and we've had large and growing stockpiles of surplus plutonium accumulating around the world in forms and locations where it cannot be adequately protected.

Material accountancy goals at both handling plants reprocessing plutonium simply cannot be met. The detection of, the timely detection of the diversion of eight kilograms of plutonium from a large scale bulk handling facility is simply not technically possible, and, despite allocation of significant inspection resources.

Complimentary measures, like containment and surveillance, which are intended to compensate for inadequacies in material accountancy, cannot fully compensate for these, as I'll explain later.

And, finally, physical protection systems in place today do not provide adequate assurance against current and anticipated future threats. Yet, the industry continues to fight increases in security requirements, and in some cases, are pressing for reductions for cost reasons.

This does not bode well, I think, for the future. A reprocessing system that would have adequate safeguards and security. So, we feel that the biggest message the U.S. could provide at this juncture is to discourage reprocessing around the world.

And the way it could do that is, first of all, to reinforce the geologic disposal of spent fuel to get the repository back on track and to demonstrate that it can be done both, that it's both technically and politically feasible to achieve direct disposal of spent fuel, thus ending, resolving some of the confusion around the fuel cycle that leaves the door open for reprocessing.

Both domestic and international standards for that plutonium, it's already been separated, have to be set at the highest levels, and they have to be set based on threat assessments that are conservative, both today and for the foreseeable future.

Because, plutonium is forever, and the capabilities of terrorist groups who are illegally conceiving inquiries over time. And, I think it would also be helpful if the U.S. would be realistic about the low potential for technological fixes that will render reprocessing proliferation resistant, or improve material accountancy technologies to the extent that we can resolve, through technical means, some of the problems that I've described before.

It simply appears that the, from an engineering perspective, you're never going to be able to get down to that eight kilogram level despite all the energy being spent today and the Next Generations Safeguards Initiative, other approaches.

Finally, the U.S. could, if it chose, use its bilateral nuclear cooperation authority much more effectively than it has. When people question the U.S. ability to lead, it had the tools, it has many of the legal tools, but it simply uses them with one hand tied behind its back.

Just to provide some more details, the IAEA still believes that nuclear material accountancy is the safeguard's measure of fundamental importance.

Yet, over the last couple of decades, numerous examples have come to light of significant failures in material accountancy at plutonium bulk handling facilities, where there have been undetected and unresolved anomalies for months, years, or even decades.

One of the most notorious was the plutonium fuel production plant, or PFPF, in Japan, a MOX fuel fabrication facility which could not account for about seventy kilograms of plutonium for a number of years. That was not fully resolved until the plant was shut down and cleaned out, at a, a, a cost of many hundreds of millions of dollars.

The Tokai Reprocessing plant in Japan lost track of over 200 kilograms of plutonium over a many decade period, and it still has not resolved that discrepancy down to below eight kilograms. More recently, the THORP reprocessing plant in the United Kingdom had an incident a few years ago where they spilled a solution containing about 190 kilograms of plutonium outside of the processing lines.

That was not detected for many months. And, finally, the Cadarache MOX plant in France, when it was shut down for decommissioning, it was discovered that they had underestimated the amount of plutonium that was stuck in the process areas of the plant, that, as much as thirty-nine kilograms were unaccounted for and it's not clear how long that was, since they didn't even know it was missing. It could have been for decades.

Now, these examples indicated or result from significant technical issues including the residual holdup in process equipment, the accumulation of scrap and waste and hard to assay forms, the inaccuracies in material estimates, which have not really improved over several decades, and operator complacency and incompetence.

Even in new plants, the Rokkasho Reprocessing Plant, which, if it ever starts up, will separate almost eight tons of plutonium a year, simple calculations indicate that unless almost 200 kilograms of plutonium were diverted, that you would not be able to detect that to a 95% confidence level and 5% false alarm rate.

And, for this reason, the IAEA requires containment surveillance and other methods to compensate for this inadequacy. But, I, I don't believe those, that you can ever compensate for poor material accountancy with containment surveillance.

And the reason is simple. If there is a loss of continuity of knowledge, the containment surveillance system fails for some period of time, and you have to account, you have to demonstrate that you have not lost a significant quantity of plutonium if you don't have a timely and accurate material accountancy systems.

You simply can't do that. So, in the case of an alleged diversion or theft, which is an issue that needs to be addressed, someone calls in and says "we've diverted two bomb's worth of plutonium and we're going to blow up New York if you don't respond to our ransom demands within twenty-four hours".

No facility in the world would be able to actually resolve that anomaly and say that it couldn't have happened, and that's, that's the problem. Theft, for, as we heard before, in response to subnational group attacks, binding international standards for protection of weapons, using material against theft do not exist.

Attempts to introduce binding

international standards failed in the international arena. The IAEA only has an advisory role, and even in the United States, which probably has the most well-developed regulatory system for enforcing physical protection of nuclear facilities, does not do a good enough job.

And, the standard which is not as a design basis threat, which is the instrument by which physical protection systems are developed and instituted at U.S. facilities, remain below the threat levels that we know exist today, which could be reasonably anticipated for the neat future.

In terms of the number of adversaries, the weaponry, the tactics, and the insider characteristics, there is enough public information to demonstrate that all, and with respect to all of these, they fall short of the kinds of threats that we know exist today that have been employed by paramilitary groups in, in the middle east and elsewhere.

Just to give an example of the level of protection of U.S. nuclear power plants, and there is no public data for the two fuel cycle facilities that are regulated by the NRC, but there is some aggregate data for the performance of security systems at nuclear power plants.

When force on force tests are conducted, in, between, prior to September 11th, it was known that about half the nuclear plants failed force on force tests, meaning that the guard force and the security plant could not prevent a mock adversary team from doing enough damage to the plant to cause radiological sabotage.

After September 11th, those standards were increased, but we're still seeing a ten to fourteen percent failure rate every year, and I don't believe that's an adequate, I think that that number is too high, certainly, for protection against sabotage.

And you can only imagine if theft of special nuclear material were involved. And here's an example of a particularly egregious security failure at the Peach Bottom Nuclear Power Plant. It's a serious issue because it's indicative of a lot of, it, workforce issues associated with the private guard forces at nuclear power plants.

Overtime, fatigue are all serious issues that have to be dealt with. We were asked, can security be risk informed? I would say the answer is no. Risk informing, generally refers to a quantitative, using quantitative risk information and safety analyses.

There is no way to adequately quantify the threat of a terrorist attack, either through the initiating event probabilities or the probabilities of self correction during the event. Risk informing generally means, in NRC parlance, weakening security on nuclear materials because of the, the belief that they are less attractive to terrorists.

And I just want to point out one example before the NRC today is an attempt to weaken security on the transport of mixed oxide fuel because it's regarded by some as, as less vulnerable to theft than separated plutonium.

If this proposal goes through, I would say it provides a terrible example for other countries that have large plutonium stockpiles and are planning to go into MOX fuel.

I'd just like to point out that one NRC commissioner dissented from the approach, but he appears to have lost the overall vote and the NRC is going ahead with examining that.

With regard to safeguards by design, I'd like to point out that the MOX plant that Dr. Gallucci referred to, there's public information, that there are serious design problems that may impact the ability to apply material accountancy, accurate material accountancy at that plant.

I can't say anything more about that, but safeguards by design should certainly be a requirement of any regulation for fuel cycle facilities in the future. And, I would--I'll stop there. Thank you.

CHAIR DOMENICI: Thank you, very much. I think that's it on the witnesses. Let's see if the commissioners have any questions. We'll start at that end. Dick?

MEMBER MESERVE: Let me, first of all, apologize to the panel, that I had, one, scheduled another appointment, which means I have to leave in a few minutes, but I did want to pursue just one question.

We've had an abundance of testimony from a variety of sources, including from industry, that recycling is not anything we should contemplate undertaking now.

And I think that it does, I to detect the possibility of a difference in view among the panel on the issue of what role is appropriate for the Department of Energy or others in contemplation over the long term of possible alternative fuel cycles that might involved recycling.

That, Dick Garwin's presentation, it advocated, for example, we ought to be preparing for the possibility in the long term for a, different technologies that would involved reprocessing, and I got the implication from several of the others of you is even opening that door might be too dangerous in that--

I mean, one could argue that we're saying it's not ready now, that, that might have a deterrent effect on others in pursuing it now. But I suspect you may have a different view. I just am curious as to whether there is a legitimate disagreement among the panel on the question of whether even R&D on the fuel cycle is inappropriate.

CHAIR DOMENICI: Who wants to take that first? Go ahead, Mr. Gallucci.

DR. GARWIN: This proposal is, you know, not R&D on--Light Water Reactors. But, in the, the long term future, a breeder reactor requires recycling, you cannot throw away the high enrichment or high plutonium fuel.

So, you must reprocess it in some way. But what we should do is lab scale design, we should do simulation with tools, which require generations of improvement, like the tools that we use for simulation of nuclear weapon explosions now.

So, a whole new capability to simulate in computers what we now do experiment on. And we shouldn't underestimate how long it will take to do this, but we need to simulate accidents. We need to take inputs for a simulated reactor and simulated fuel with little wires wound around it, and at all scales, see what happens.

So, that's what we ought to be doing, and, yes, reprocessing would be necessary if we're ever going to have a breeder reactor. But, we may never. It may take a long time. We may have uranium from seawater in such amounts that we won't need to have breeders until somebody has a really good idea in the great by and by.

CHAIR DOMENICI: Mr. Gallucci, I, this is in psych 101 terms, an approach-avoidance conflict for me. Because I do not see a circumstance in which, in thermal reactors, recycle can be done safely, given the movement of material from a reprocessing plant to fuel fabrication plant to reactors that are dispersed.

And, I am most concerned with the Commission think about the, the negative consequences of anything it says about preserving the option of recycle. If it is entirely in the context of breeder reactors, then I'm not certain even of what Dick Garwin was saying about whether there are implications of that for what we do with the plutonium that has now been produced and is contained in all that spent fuel.

The approach-avoidance conflict for me, is that I would be happy in, on one hand, if you discovered permanent disposal in a once-through fuel cycle, but I don't think you will. I, I think that dry local storage is the easy thing to continue doing.

That, that does preserve the option in the future of access to this material and recovering it, the plutonium from, from the spent fuel. An option I say, which does not appeal to me on energy terms, but if it makes storage, as opposed to reprocessing, more attractive, then I'm prepared to embrace it for that reason.

I think at the, at the end of the day for me, what's most important is what signal we send to the rest of the international community. Yes, I worry about reprocessing in the United States, and thermal recycle.

But I'm even more worried about it being carried out around the world and it becoming the standard for how the back end of the fuel cycle is managed.

MEMBER MESERVE: Let me just observe that it's going to be an option, in fact be an option in the future, you need, it's not going to happen magically. That there is some work that needs to happen in the interim.

CHAIR DOMENICI: Mr. Meserve, can you recognize the chair in this exchange so, so, are you finished--Mr. Meserve, are you finished with your comment?

MEMBER MESERVE: Some of the others wanted to react to my comment--

CHAIR DOMENICI: That's correct.

MEMBER MESERVE: I see a hands up from Mr. Acton, and--

CHAIR DOMENICI: I was going to call oh him just now. Going to call on him. Mr. Lyman, you're next.

DR. LYMAN: Okay. I think there's been substantial Government R&D on reprocessing and fast breeder reactors. My sense is that the, the DOE establishment, that's sort of, that's been the dominant focus.

And I think other approaches should be given more of a chance, you know. I think advanced once-through systems with high internal conversion like the reactor formally known as the traveling wave reactor, even, deserve further exploration.

And, as long as the door is open to consideration of reprocessing, I think it might complement people's vision on how to improve the once-through cycle, and perhaps achieve some of the advantages that people attribute to reprocessing.

So, I think, in the future, I'd like to see a greater focus on advanced once-through R&D and diminished focus on closed fuel cycle R&D.

CHAIR DOMENICI: Who else--who else wanted to--yes? Go ahead, Mr. Acton.

DR. ACTON: I guess that, I find it very hard to see, over the medium term, say, the next fifty years, the circumstances that would make reprocessing attractive. Over the longer term, I think it's much harder to judge.

I mean, you could imagine a world in which, hopefully, proliferation risks are significantly lower, in which fast reactor technology has become economic and competitive, in which uranium resources are depleted, maybe in which the process of extracting uranium from seawater hasn't, hasn't demonstrated any economic promise.

And in that kind of world, reprocessing in fast reactors might look attractive. The question that I think, as you rightly say, is now, when we are a number of decades out from that possible world, what kind of research and development should be done?

And, there was a, I think, there's a number of different considerations here, and I don't have an easy answer to that question. But firstly, there's the simple cost benefit analysis, which is, if you have a limited resource, limited budget available, where is that technology best, where are those research and development dollars best used?

Are they best used in technology that might take, the, the, might, and, and, and, and nothing stronger than might, be the right thing to do fifty or 100 years, or are they best used on nuclear technologies that are, are much more needed in the short term, including some of these other once-through options?

And then, the second issue, which is coming back to the, to the, to the focus on the evidence that I presented today about the message the U.S. sends out. You know, I think there's all the difference in the world between the research and development process largely based on computer simulations of the kind that Professor Garwin has, has, has outline, which seems to me to be making it very clear that this is nothing more than a basic research and development pro, program.

And there's no intention of deploying this technology in the short term versus, on the other hand, the much more extensive kind of research and development process in which you're kind of going into the wet labs and you're, and you're actually trailing this technology on a pilot scale. Which does look like, that you're trying to deploy in the short term.

CHAIR DOMENICI: Any, any questions from the Commissioners, any questions? Yes, go ahead.

MEMBER MACFARLANE: Great. Thank you. I have, I have three questions. So, let me see. My first one is for Dr. Acton and Dr. Gallucci. And, so, let's leave aside the idea that the U.S. can, you know, what the U.S. chooses to do might influence what other countries do. Okay, let's just leave that aside for a second, pretend that doesn't exist.

And, I just want to, you both to explore a little bit what's wrong with James' develop and deny strategy? So, what if the U.S. says, well, we're going to do this, but we don't think the rest of you should do this.

What, you know, is that, is that reasonable? Is there a way to support that? Or, if it's not reasonable, then why not? Is that--does that make sense?

CHAIR DOMENICI: They don't know what you're talking about.

DR. GALLUCCI: I'm--what I'm, I'm confused about is that, the antecedent to this was "let's make believe there isn't a rest of the world".

MEMBER MACFARLANE: No. No, the rest of the world is there--

DR. GALLUCCI: Yes.

MEMBER MACFARLANE: --just, you know, there's two parts to what the, in my mind, there's two parts to what the U.S. does. If the U.S. decides to reprocess, or holds that option open for the future, it might, as you so clearly outlined, influence other countries to do the same thing.

But, you could also imagine the U.S. advocating a two-tier world, and I'm saying, well, let's say, the U.S. advocates this two tier world. We can have it, but you can't. And play out that scenario a bit for me.

DR. GALLUCCI: I think we've got that scenario. I mean, we do that quite a bit. We can have nuclear weapons and you can't. Right?

MEMBER MACFARLANE: Right?

DR. GALLUCCI: We can have fissile material production facilities, enrichment plants and reprocessing plants, but--

MEMBER MACFARLANE: Well, the, the non-proliferation treaty says--

DR. GALLUCCI: Yes, but we're talking about the real world and United States policy. And we have taken a position for forty years, or more, that, and beginning with what was called the London Group before it became the Suppliers Group, the whole point of that London Group in 1976 was to say, a bunch of other things, but essentially we wanted to get to say "look, suppliers, we know there are good guys and bad guys, and we, it's okay for the good guys to have enrichment, you know who they are. And, while we don't like reprocessing, it's better that it be done at a small number of good guy plant, places, than bad guy places". Right?

So, and then we, but we took this position, and the question was, could we hold the technology that way, comparably to, not exactly patterned after, but comparable to, could we hold the weapons technology.

In both cases, we worried that we couldn't because the other countries would notice. Okay? And they would resent it and all the things that go with the declaratory policy of the United States which generally is, we respect the sovereign choices of other countries, et cetera.

There are enormous political problems with managing that kind of world. One can do it if one has, through the cartel, control over the technology with a death grip. But as soon as that begins to change, and there are huge economic incentives for it to change, as well as political disincentives to sustain it, then it's very hard.

MEMBER MACFARLANE: So, the death grip is no longer in existence.

DR. GALLUCCI: I think the death grip is not there, and it, it's slipping. But I will tell you that, quite frankly, what I'm arguing here, in part, is that we be serious about our belief that we do not wish to live in a world in which there is a lot of plutonium in motion in a civilian nuclear fuel cycle.

And, and, that we get together with other suppliers and say "you should not be doing this either, this will make the international community less safe and we will not be able to recover from it". So, it, yes, it's harder now, but I am for regenerating with, with the proper politics, an argument that the international community should embrace the control of this material.

MEMBER MACFARLANE: And James, you--go ahead.

DR. ACTON: And I would very strongly agree with that. I don't believe that a discriminatory system can be a sustainable system over the long-term. And let me give you some very recent, real examples of where this has happened.

The United States decided to make an exception for India, and the NSG waiver. Now, we can argue over whether that was a good thing or a bad thing, that's, that's, that's not the point here.

The point is that there was a very clear prediction at the time that if the U.S. makes an exception for India, China is going to supply to Pakistan, and that is going to happen.

MEMBER MACFARLANE: Right.

DR. ACTON: The U.S. is trying as hard as it possibly can to prevent that sale, and I really hope the U.S. succeeds in preventing that sale, but at the end of the day, there's almost no leverage the U.S. has, short of kicking China out the NSG, which is probably a solution that is worse than the problem it's designed to solve.

So, so, so that's a very clear example of where trying to change, to introduce a discriminatory system proved not to be sustainable. Let me give you another example.

The United States has given Japan prior consent rights to reprocess spent nuclear fuel. I think it is undeniable that one of the reasons, and I don't argue this is the only reason, but one of the reasons why South Korea wants the pyroprocessing, wants to go down the road to pyroprocessing, is because, you know, it strongly objects to the fact that its long-term, historical rival, Japan, is allowed by the U.S. to separate plutonium, and it wants that kind of formal equality, it wants the prestige, of being able to do so as well.

So, the reality is that we, we, we have a discriminatory system at the moment. It doesn't seem to me to be particularly stable, and we don't want to make that problem worse.

MEMBER MACFARLANE: Great. Okay. No, sorry, do you want to piggyback on that, or? I've got two more.

MEMBER CARNESALE: Go ahead.

MEMBER MACFARLANE: All right, so--

MEMBER CARNESALE: --in the queue.

MEMBER MACFARLANE: Okay, in the queue. You're in the queue. All right. So, Dr. Bari, I just wanted to, to say, and see if we can get into our record, a nice little paper that you authored in 2009 called Proliferation Risk Reduction Study of Alternative Spent Fuel Processing, where, I think, you implemented this modeling that you were discussing and got to some of the punchline there, which I think is very interesting, where you looked at all these different reprocessing technologies, pyroprocessing, all the different UREX's, COEX, PUREX, blah. And you found that there is very little difference among them. Is that correct?

DR. BARI: Yes, that is correct. What's very important also to emphasize in that paper is, I mention my talk, that there is country context here, that part of the assumption is that the would-be proliferator or, or the person who is going to abuse the technology is a non weapons state, a nuclear non weapons state, but with a, a, insisting PUREX type capability.

So they're fairly capable in what they're doing. And I think in the paper we also mention the other end of the spectrum, where it's a subnational or terrorist, and they're, there are more opportunities for abuse. So, it, it, the country context is very important in all of this.

But, yes, that was the statement that--

MEMBER MACFARLANE: So, and we can--

DR. BARI: Oh, yes, by all means--

MEMBER MACFARLANE: --get this. Great.

DR. BARI: Yes, that's--it's open literature.

MEMBER MACFARLANE: Great.

DR. BARI: Yes.

MEMBER MACFARLANE: Okay. Very much appreciated. And, final question is to Dick and Ed. So, you know, I'm not an expert on the nuclear engineering here, so I just want you guys to help me, and, especially, Dick, because you have such great and wonderful wisdom on all of this.

What technically has held us back from reliably operating burner or breeder reactors? Why don't we have them yet? We've been working on them for fifty years?

DR. GARWIN: Well, they were a matter of course. Every red blooded physicist reactor engineer knew that after the uranium reactors and the enrichment, the next step was this marvelous breeder reactor.

Because there are enough neutrons per fission not only to carry on the chain reaction and support the structure in the material, but to breed another fissile atom. And so, it's a marvelous gift of nature, it was a natural thing.

But, in order to do that, you need for, for the most part to have fast neutron reactors. You cannot thermalize the neutrons. That means you can't use water, either heavy water or light water as the coolant, with all of it's marvelous properties.

And so, you go to an open sodium,

or an open lead, or lead bismuth ally-- alloy, or sodium potassium alloy. And in sodium, the alkaline metals that are highly reactive chemically, they react with air and water, we live, as Frank von Hippel said in his testimony, in, in a world of air and water.

And they're opaque, so when you have your reactor full of molten sodium and you want to lower a camera into it, have the reactor shut down to see what's wrong, you can't. So, the, even the people who were and have been enthusiasts for breeder reactors recognize that it's a very difficult technology.

In principle, it's fine, but everything has to be extremely reliable. Molten lead doesn't have that problem. It has other problems of chemical reactivity. It dissolves iron at high temperature.

So, there we are. We have the material problems, then we have the lower margin of error because the, the prompt delayed threshold for plutonium is considerably smaller than it is for uranium. So there's half the margin between delayed critical, which is how reactors work, and prompt critical.

And, it, it's a difficult--Edward Teller, who was a big fan of reactors, said even of breeder reactors, said that nobody could persuade him that 1% of the fuel in a breeder reactor could be somehow melt and get together and form a prompt critical, that is a nuclear explosion, not just a thermal steam explosion.

MEMBER MACFARLANE: That would be bad. So, so, do you think we can solve these problems in the next two decades then?

DR. GARWIN: Not to deploy a large number of these things, no.

MEMBER MACFARLANE: Okay.

DR. GARWIN: But we may be able to be on our way to having the simulation capabilities so that we can have, in principle, a very, a much more varied scope of reactor fuels and reprocessing and reactor configurations, all of which go together, versus TerraPower, it is a metal fuel.

But, the problem is that when you fission half of the heavy atoms, instead of having a density of eighteen or so, you have a density of six. And so the fuel has to expand. And, sometimes a little bit of reprocessing or repurposing will help, compared with making a fuel which I sufficiently expansible to do that.

MEMBER MACFARLANE: Okay. Ed, did you want to add anything?

DR. LYMAN: Yes, just briefly. And, in, with regards to the reactivity issues that Dick just mentioned, the NRC has a general design criterion that any reactor that's licensed has to have a negative, negative coefficient, negative feedback.

And, it's very challenging to try to design a fast reactor that has a negative void, void coefficient over all the operating regimes. And when you try to engineer around that problem, you end up creating other problems.

So, there are a couple of designs that claim, the Hyperion reactor claims that it has a negative void coefficient, but they still haven't work out all the details. And, so I think that, that's one constraint, at least in the United States.

MEMBER MACFARLANE: Great, thank you.

CHAIR DOMENICI: Al, are you next? You are next. Yes, have at it.

MEMBER CARNESALE: I'd, I'd like to try and capture in, in simple terms some of what I've heard, not just from this panel--tell me if, if I have it right, or if I'm missing important things. Because then I can, very briefly.

One, when it comes to, as you look at the back end of the fuel cycle and worry about it, it's the plutonium. It's the plutonium, stupid, right? That's the, simple.

Secondly, with regard to reprocessing and recycle, I think it's important that we're reminded, there are two problems. One is physical security as it relates to terrorism, or the, and the other is proliferation to states.

These are related but they're not the same. In that sense, it could go either way. Third, when it comes to U.S. grade processing and recycle, we seem to have two concerns. One is physical security and terrorism from our supply.

Secondly, is the example we set for others that may, may reinforce those in those countries who would choose to go to reprocessing and in the other countries, got both problems. You've got the terrorism problem and you have the fact that they may choose to use this material to produce nuclear weapons.

So, that, as I understand it, is how you, just summarize what the problem is, on the upside, on the other hand, for reprocessing and recycle, we hear two different kinds of things. One read is about reprocess and recycle in thermal reactors, the other is in fast reactors, whether they be burners or breeders.

For recycle in in thermal reactors, the first approximation we hear, it's not economical, that the conservation of uranium is very small, and the waste management column is not changed significantly. That's simply for recycle in thermal. LWRS, basically.

If you go to fast reactors, the economy, we don't know, right, because we don't know what the reactor would cost, so that seems, we just don't know. It's worth trying to find out. But we don't know.

On the conservation of uranium, over time, yes, not any time soon, we don't know how important it is, but it would certainly conserve substantial amounts of uranium if you had these, well, especially if you had breeders. But, going for a long time.

And when it comes to the waste management, here too the bless transuranic elements, that rip your in burner reactors, but it takes literally centuries before you see a very substantial difference because the inventory is in the reactors instead of in the ground.

So that's the summary on what I think, I've heard, from your perspective. Do I have it roughly right? Or, well, I don't know, that's an unfair question. How would you make it better?

DR. GARWIN: I assume, Al, you did all it that way, there's no passion here.

You know, there's just, there's just--

MEMBER CARNESALE: Sorry, I was trying to be analytical.

DR. GARWIN: This was, this was pretty cold. And, and when--if, in your shorthand, you were taking a count of the downsides, and you meant you could lose cities, but you didn't say you could lose cities, that countries that are non nuclear weapons states now could become, and we could have, instead of a world of nine, you could look and see we have a number of twenty-nine, instead of no nuclear terrorism, we could be losing cities. So long as you've got that, I'm okay.

MEMBER CARNESALE: Yes.

CHAIR DOMENICI: How long do we have?

CHAIR PETERSON: We have twenty-five minutes. We have plenty of time. I would like to take advantage of the very strong background of the set of panelists that we have in front of us to explore three areas where non-proliferation and security probably link fairly strongly into waste policy for U.S. in terms of what the U.S. might do in changing direction or adopting a new approach or somewhat modified approach to how it's going to manage storage, transport, disposal, and possibly, also, some type of recycle and reprocessing of used fuel and high level waste.

And, so, there, I think there's three key areas where that, at least three key areas, where that coupling exists, and I'd like to just explore each of them quickly.

The first would be the, the question of whether or not the U.S. might, might at some point in the future undertake to import foreign spent fuel. In cases where, in limited quantities and in cases where that might be a benefit, judged to be a benefit to the, the U.S. National security.

Of course, that's politically difficult to do if we don't have a domestic capacity to manage the material. But if you envision coupling this ability to, to, import limited quantities compared to domestic production, totally unsuccessful in having capacity to manage domestic as well.

Would that be of substantive value from the perspective of achieving non-proliferation and security goals? Would you be able to comment on that? Because it's clearly one way in which U.S. waste policy could couple to non-proliferation security. James, if you have a--

DR. ACTON: So, I strongly agree with the premise of the question. I think it would be an incredible non-proliferation good if the U.S. were able to take that spent fuel.

I do think reprocessing makes that harder, for the following reason, which is if the U.S. has a once-through fuel cycle, there is the political opposition to whatever final waste disposal solution there is, or no final waste disposal and interim storage at reactor sites.

Whatever it is, there is the political opposition to that. If you have reprocessing, you essentially create political opposition to two different things. You have the political opposition to the high level waste storage you still need, even with a reprocessing facility.

Plus, the political opposition to the reprocessing facility itself. I mean, it, it wouldn't that the residents would kind of, northern Georgia and southern South Carolina welcome Barnwell with open arms. I mean, there, there was a huge amount of litigation and complexity and opposition to that site.

And I can see people in the audience who would also probably start the lawsuits as well, against, against, against the, against the reprocessing facility itself. So, I kind of find it funny as somebody with a background in physics to say this.

But, you can't solve a political problem with a technical solution. The, the barrier to the U.S. importing waste from abroad is political, and you need a tech--I mean, you need a political solution to that, not a technical solution to that.

DR. GARWIN: I am in favor, not of importing and reprocessing, but of importing and direct disposal. But, the prerequisite is, as Matt Bunn says, in Sweden and Finland, people sue when they don't, when they are not allowed to host a disposal site.

So, what you need to do is somehow to turn this on its head, and I've always thought that competitive, commercial, direct disposal into mined geologic repositories should be popular. People should make money out of it, not only those who do it, but those who host it.

So, if we can do that, then it's another way to make money. We would be buying other countries in order to put the nuclear spent fuel underground. But, to reprocess it, absolutely not.

DR. LYMAN: Yes, just briefly. Per, you envision that would be, that offer would be coupled with a commitment on the part of the state that would be shipping spent fuel, not to engage in domestic enrichment and--or reprocessing?

CHAIR PETERSON: I think that that is quite open. The, the general question is--

DR. LYMAN: Right, because I, I, I don't, I don't see what the non-proliferation benefit would be unless, as part of that contract, and that's a significant sweetener, that we would be able to extract maximum constraints on the, you know, if we're offering to take back the nuclear waste, we should be able to expect significant commitments on their part.

Without that, I don't think just taking, physically taking back the spent fuel necessarily has a significant benefit if the country doesn't have reprocessing abilities.

DR. GALLUCCI: Just wondering, if the United States Government took responsibility for, what is now, utility managed, as I understand it, local dry cask storage, if after thirty or forty years, is that reverted to U.S. Government responsibility, so the Government was in the spent fuel storage business.

Then it might be more of a political solution to a not very demanding technical problem of managing an incremental amount of spent fuel coming to the United States. We have never thought that real volumes were, were physically challenging to any country's space.

It's a, it's a political issue. I mean, try Australia, for a start. And I think, certainly, the United States. But I think, it's correct to say that you'd have to get over substantial dustbin argument politically. But if, if, if the Government was in the business of doing this, that might, might be a lesser included problem.

CHAIR PETERSON: Okay. Thank you. Another area coupling to the waste policy is in the area of whether or not one deploys some reprocessing or research laboratory related activities coupled to centralized storage and or disposal to increase the set of incentives if you have a voluntary process for siting, to, to, to get more local communities and states to, to seat, to, to host these types of facilities.

And, of course, the panel here has thought very deeply about issues related to security, but, you know, we've looked more broadly across the spectrum of people who are both, say, technologists as well as the public, the concepts and ideas behind recycling actually have a high degree of popularity.

And this can be reflected, for example, in the fact that when you do, you know, we had Hank Jenkins Smith speak to the disposal Subcommittee. There was a huge impact on the level of public acceptance for storage or disposal if one has couple to it the idea that you'll also deploy reprocessing with some type of research facilities.

So, certainly, this is, this is a, a question that has to be taken up in, in trying to develop a policy that if you're going to go down the voluntary siting path.

And I guess my question is, given that, first of all, I presume that the majority of the panel would not advocate for deploying reprocessing, but that would leave you in the area of advocating for potentially, some type of research laboratories.

What, what would be reasonable activities if you did decide to have this as a part of the overall incentive package for voluntary participation in siting?

DR. GARWIN: I am not familiar with the basic facts as to whether you need to have research interview processing in order to make people accept disposal sites. It's not like that in, in Finland or Sweden.

So, I, I suspect it's not really a constant of nature. In France, they've always called their candidate disposal sites underground laboratories. And, there's a lot to do there before they decide on which is going to be the definitive disposal site.

But, what you do is to study different packaging techniques. You study the migrate of, of transuranics and fission products under various conditions in the shale, or whatever is the underground environment. So, there are a lot of, lot to do there and reprocessing doesn't really fit very well.

Although, a disposal site should, in my opinion, accept previously reprocessed and packaged waste as well as direct disposal of, of fuel rods, given appropriate packaged, under appropriate IAEA regulation. So, if somebody has already reprocessed, and they have no place to put the stuff, then commercial repositories ought to be open for that, too, at an appropriate fee.

CHAIR DOMENICI: Thank you very much. Let me, let me, I have a few questions here, some observations that may be, we're getting close to the end. First of all, I want to apologize again for my voice, which is separate and apart from, that's a problem I discussed with you this morning. Something's going on with my speaking and I already know what it is, if you can believe it, I have to exercise my vocal chords so you can hear me out in the halls singing.

Except what I was singing is "A, E, I, O, U", and then "Sunday, Monday, Tuesday, Wednesday, Thursday, and Friday". Sing those real hard. That's the exercise, I have to do that, so you'll excuse me if you hear that.

First, I want to say, for the record and for these distinguished witnesses, I was in the Senate with all kinds of Senators from all over, for thirty six years. I chaired some Committees here and there, and did a few things.

But, I'll tell you, to assemble a Committee like this, where the member who has excused himself is a PhD, the man sitting next to him is a PhD, the woman sitting next to him is a PhD, the man sitting next to the woman is a PhD, head of a Department in California.

And the last time I studied math or took anything in, in chemistry or math, was a freshman in college, and then I taught eighth grade math before I went to law school. So, I'm, I'm the youngster in the crowd that doesn't quite understand some of these things that, especially Al speaks of.

He's so proficient in these things. But I do want to tell you that I don't, I don't agree with a lot of your testimony. And I can't tell you, each one of you, what I heard that I don't agree with, but I disagree wholeheartedly with you that the Americans, American people and the Government of the United States should not engage in activities that deal with energy, because it might influence the world to do likewise.

I just, in this case, I think that's a lark. The Europeans and others are hellbent to do reprocessing. And they haven't asked us and they don't care what we think, they think it's the greatest thing they can do, and they're doing it in their own interest.

And regardless of what you say, Mister, Dr. James Acton, we have little impact on them by doing it or not doing it. And I question significantly your statement that there were seventeen that wanted to and it turned out six, only six did it after they made a commitment.

And I'll bet you, if you remind me to look that up, that that disparity in number, that disparate number between the two. There are many reasons they didn't do it, it was clearly not just because America chose not to.

Over here on this side, we hear Gallucci, and the only thing about him that I agree with is his is that we're both from Italy. His folks must have been born there, like mine. But other than that, has there ever been a Democrat or Republican President of the United States since we had the nuclear weapon that ever wanted, that ever chose anything other than we don't want nuclear weapons in the hands of others?

Even though we have them, has there ever been a President, we had them, they didn't, and that's the way the world was, and you tend to think that's wrong, because America has something and, the, and the other part of the world doesn't.

We did pretty well with our stewardship of nuclear weapons and I think the world still thinks we're pretty good stewards of it, and they still would follow us, and we still don't want anybody else to have them, and they're getting them anyway.

So, those are the kind of side issues that, Gallucci versus Domenici would make a good movie. You could be anti-America, and I could be pro-, for a change. That's good. And I throw a good right hand, all that's, I signed pro, even, I signed with the Brooklyn Dodgers.

But anyway, let me proceed for a minute. The charge to this Committee is--not the Subcommittee, this Committee--is that we're supposed to conduct a comprehensive review of policies for managing the back end of the nuclear fuel cycle, including all alternatives for the storage, processing, and disposal of civilian and defense used nuclear fuel, high level waste, and materials derived from them.

And then our co-Chairman has, for this Subcommittee, pulled out what it is now, it had nothing to do with most of what you all were saying. It, this charge is, should we do any of these things that I just described regarding the tail end of the fuel cycle.

You certainly, well, I'm not advocating that we proceed with any kind of dispatch to, to reprocess. I'm not doing that. But certainly, we don't have to bend over backwards to avoid the use of the word, because, my God, it's the, that's what we're supposed to do.

We're supposed to take a position and tell the American people the if's, and's, and don'ts about these things I just read, which I think any reading of it would include that you ought to look at these tail end of the fuel cycle options that the country has.

You ought to look at them and say something about them. You know, I choose to do that, and I don't choose in any respect to figure out what I ought to do based upon what the world might do or not do because America is going to do something or not do it.

That's not going to be part of my thinking. I regret you have not convinced me a bit on that. It may be the other things I have heard that will convince me that we can not proceed with reprocessing exploration at this point. Maybe I will agree with that pretty soon, if you come up with something that we all can agree upon.

Now, having said that, I, I just want to ask Mr. Gallucci, do you think that a, not proving years ago, that the United States of America in terms of reprocessing and if we don't reprocess, what's going to happen, what's going to happen good in the world if we don't reprocess, could you explain that to me one more time?

DR. GALLUCCI: Senator, I think if we make a decision, we recommend as America's position that we will not reprocess, and that will mean that we will not have separated plutonium in the United States. It means that we will not be fabricating mixed oxide fuel at maybe one or more different facilities, away from reprocessing plant, and we will not be shipping it--

CHAIR DOMENICI: I want to know

what, I want to know what the world is going to do, not us.

DR. GALLUCCI: I said, I'm talking about the United States of America.

CHAIR DOMENICI: What?

DR. GALLUCCI: You asked me, Senator, if I've got it straight, you want to separate out what happens in the United States.

CHAIR DOMENICI: No, sir. I said, what does the world do that it would not do--

DR. GALLUCCI: Oh, so now you do want to link, what, how do you think the world will respond--

CHAIR DOMENICI: You, you had already read it, at least I could say it again.

DR. GALLUCCI: I see.

CHAIR DOMENICI: What you said, you said, if we decided to do it, you were going to follow suit. And if we didn't do it, some would be more apt not to do it. I don't agree with either statement.

DR. GALLUCCI: I understand. I, I, Senator, I actually don't, don't know what South Korea, Japan, Russia, how these countries will respond if this Commission recommends to the President and it becomes U.S. policy that the United States is not going to reprocess.

You may be right that these countries march to their own drummer, and they don't care one whit about what we do. That's, that's possible. I don't know.

CHAIR DOMENICI: You won't even make that probable?

DR. GALLUCCI: I beg your pardon?

CHAIR DOMENICI: You won't even make that probable in today's market--

DR. GALLUCCI: No, no, I will make it probable. I will say, I will say I don't know. I mean, and there may be people who do know. But I, I, for me, it would be the wrong thing for the United States to do, for the United States, and it's the wrong thing for these countries to do, for the international community.

I, I would, my objective here, would have an outcome in which countries decided for economic and security reasons that thermal recycle was a bad idea. That's the outcome I'd likely get to.

CHAIR DOMENICI: Let me, let me just say so my fellow commissioners won't, because they don't know me, and you don't know me either, but I don't have to work with any of you anymore, but I do with these people, so I, I have to make a statement so they'll know who I am.

First of all, if you want to look up the record on terms of non-proliferation, you might find that the Senator who did more for non-proliferation next to Sam Nunn, and he was my buddy, next to me, is this fellow. I went into a Subcommittee one afternoon with a piece of paper that was an Amendment, and I got 535 million dollars appropriated and got it back from the Subcommittee.

You know what it was for? It was to buy plutonium that the Russians had stored and wanted money for, and to buy highly enriched uranium, money for reprocessing into weapons. We still are using the electric lights work, in America, ten percent of the electricity comes from the highly enriched uranium that was purchased with that money.

Russia wanted dollars, and they don't like it now, but they're still delivering that highly enriched uranium on boats. It comes over here and it gets mixed and it turns out being feed stock for the nuclear power plants.

The plutonium, for the united states, I would like to tell you ended up with us building a MOX plant as a result. I know you don't like that, but it did. And the Russians were supposed to get rid of thirty-eight tons of plutonium. They haven't done those yet, they've got it buried in a mountain.

But it's, it's been fused so they can't be used in the bombs, you know what they did to it, you all know that, it, it changed, they had, turned it around, can't be used. So, I'm not, I'm not anti-these things, I'm pro.

It's just that, you got to know, I don't believe any of you that testified, that America shouldn't do this because if we're good boys, we're good boys if we don't and the world will follow us. I don't believe, and that colors my belief in the rest of your testimony.

That at your mature ages, you would be that naive really bothers me. Unless you were to tell me you were that naive since you were twenty-one, and I'd say you'd been naive right to the bone. It's been acquired in college and I, I, don't know whether I forgive you or not.

But naivete creates what you all say, with reference to these things, so. It's hard to believe that, substantively, and in particular, Mr. Acton, I think you're far too positive about the reaction that we get in the world. It almost makes it feel like, like you, you don't know what you're talking about.

But I, since you want me to be honest with you, because I, I did take this kind of with testimony for thirty six years, and I sometimes got off base like I am today. And most of the time I didn't. But anyway, I'm the co-Chair, and that means that the meetings are not over until I've had a word.

Dr. Garwin would like to burn me instead--

DR. GARWIN: I would like to point out that I have always objected to reprocessing by the U.S. for the reason that we would be a hundred billion or two hundred billion poorer if we did it, and that's the reason--

CHAIR DOMENICI: I praise you, I praise you for that.

DR. GARWIN: --not, not to do it.

CHAIR DOMENICI: I praise you for that.

DR. GARWIN: Thank you. But I think that if we did it for some other reason, in order to be a leader in nuclear energy or whatever, then surely reprocessing fans elsewhere would take that to mean that the United States sees benefit in reprocessing and they would do it to.

And I don't know anybody who says that other people reprocessing is good for us, so, whether or not we have a big influence on them, we ought to do what's right for ourselves and try to encourage them to do what's right for themselves.

In my testimony, I take really quite a skeptical view of this rational approach. I say, you know, so much of so called economic activity is stealing from one another.

So, it's really hard to believe that we are in our system going to be able, you know, with all the lobbyists and advertising, to make correct decisions. But at least we can lay it out and try to make the right decisions and go down fighting if necessary.

CHAIR DOMENICI: Well, we can make the right decisions, we've made some in the Congress, at least, in spite of the mess we're in, we've made some. We've had two balanced budgets, if you go look at that, I was the sponsor who worked on that all alone as the Senator, done in a little back room.

We had a Democrat President and two Republicans, and we did that, so it's not, it's not like we don't, don't do those kind of things. I just wanted you all to know how, an opinion of the comment you made to me effects the rest of your testimony. I just wanted to make sure you all knew that.

And I think with that, as one of the co-Chairs, and the time is up, I thank the witnesses profusely for their terrific testimony. It was well received by others. Thank you.

CHAIR PETERSON: I have been--I have been asked that we have a short break and then we will return in just five minutes to, to move to, we have, basically we have public, statements from the public at this point.

MR. FRAZIER: There aren't any.

CHAIR PETERSON: There aren't any? Okay. So, then--so then--okay. Thank you very much. At this point, we can finish up. We're closed. Thank you very much.

(Whereupon, the above-entitled matter went off the record at 3:12 p.m.)

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