>>Paul Turinsky: Welcome to the U.S. Nuclear Waste Technical Review Board, Spring meeting. I'm Paul Turinsky, Deputy Chair of the Board. This meeting will focus on the U.S. Department of Energy's activities to evaluate advanced nuclear fuels including accident tolerant fuels for commercial light water reactors and the impact of these fuels on spent nuclear fuel management and disposal. Due to the COVID-19 pandemic, it is obvious we are holding this meeting in a virtual format. Also we are holding the meeting in two half day sessions, today and tomorrow, instead of our usual format of holding the meeting as one full day. This was felt to help both sessions within the working day for the board members and attendees on both the East Coast and West Coast of the United States and in addition in Europe. Mr. John [Hatton] of Precon Virtual will serve as host of the meeting.

I will now introduce the other Board Members, then briefly describe the Board, outline what we do and tell you why we are holding this meeting and our agenda for today and tomorrow. All the Board Members, like myself serve part-time and we all hold other positions. I'll ask each Board member to introduce themselves as I call their name, and I'll begin. As I noted I'm Paul Turinsky, the board's Deputy Chair. In my case, I am a Professor Emeritus of nuclear engineering in Department of Nuclear Engineering at North Carolina State University. Allen, will you introduce yourself?

>>Allen Croff: Background in nuclear chemical engineering and waste management.

>>Paul Turinsky: I think we missed the first part. Can we try?

>>Allen Croff: Okay, Allen Croff, faculty, Vanderbilt University, Department of Civil and Environmental Engineering. Background in nuclear chemical engineering and waste management.

>>Paul Turinsky: Okay, thank you. Tissa? Audio, your mic. Tissa, your mic's not on. Well let me introduce him. Tissa is from the Colorado --

>>Tissa Illangasekare: -- My name is Tissa Illangasekare, I'm a Professor of civil and environmental engineering at Colorado School of Mines in Boulder, Colorado and my background and specialty in subsurface foreign transport chemical, including nuclear-type chemicals and also I do numerical modeling.

>>Paul Turinsky: Thank you. Lee?

>>Lee Peddicord: Good morning, thank you Paul, I am Lee Peddicord. I am a Professor of nuclear engineering at Texas A&M University and my areas of workforce include nuclear fuel performance and advanced nuclear systems.

>>Paul Turinsky: Okay, thank you. And Steve?

>>Steve Becker: Good afternoon everyone, I am Steven Becker, I am Professor and Chair of the School of Community and Environmental Health at Old Dominion University in Norfolk, Virginia and my work deals with emergency planning, preparedness and response, environmental health science and public health and risk communication.

>>Paul Turinsky: Okay, thank you Steve.

>>Steve Becker: Thank you.

>>Paul Turinsky: As you can see, all our Board members aren't joining us today at this time. When we are a full board, we have 11 members on the Board. The Board currently has two vacant positions and four board members, Dr. Jean Bahr, Dr. Efi Foufoula-Georgio, Dr. Susan Brantley and Dr. Mary Lou Zoback are not able to join us today. As we usually do at board meetings, I want to make clear that the views expressed by Board members during the meeting are their own, not necessarily board positions. Our official positions can be found in our reports and letters which are available on the Board website.

Now, on to the description of the Board and what we do. As many of you know the Board is an independent federal agency in the Executive Branch, not part of the

Department of Energy or any other federal department or agency. The Board was created in the 1987 amendments to the Nuclear Waste Policy Act to perform objective ongoing investigations of the technical and scientific validity of DOE activities related to the management of spent nuclear fuel and high level waste. Board members are appointed by the President from a list of nominees submitted by the National Academy of Sciences. We are mandated by statute to report Board findings, conclusions and recommendations to Congress and the Secretary of Energy.

The Board provides objective technical and scientific information on a wide-range of issues related to the management and disposal of spent nuclear fuel and high level radioactive waste that will be useful to policymakers in Congress and the administration. All of this information can be found on the Board's website which is shown on the slide along with Board correspondence, reports, testimony and meeting materials including webcasts of recent public meetings.

If you would like to know more about the Board, a two page document summarizing the Board's missions and presenting a list of the Board members can be found on the Board's website.

We will have a public comment period at the end of each day of the meeting. Because of the virtual format of this meeting, we can only accommodate written comments. You can submit comments by using the "Comment for the Record" feature on the public meeting website and you can find the public meeting website on the Board's website, which was previously stated under the "Latest News" heading. Information on how to submit comments will also be displayed during breaks and before the meeting starts tomorrow.

Comments we receive before the end of each day's break period will be read in the order received by Board staff member Bret Leslie. Time for each comment may be limited, depending on the number of comments we receive but the entirety of the submitted comments will be included as part of the meeting record. Comments and any other written material may also be submitted later by mail or e-mail to the points of contact noted in the press release for this meeting, which is posted on our website. Also comments will become part of the meeting record and will be posted on the Board's website along with the transcript of the meeting and the presentations you will see during the meeting. The meeting is being recorded and the archival recordings will be available after a few days on our website, meeting agenda and presentations have been posted on the Board's website and can be downloaded.

So, why are we holding this meeting? Since the Fukushima nuclear reactor accident in 2011, several countries world-wide have conducted substantial research and development to improve reactive fuel performance during normal and accident conditions. The U.S. Department of Energy is supporting a significant portion of the development of advanced light water reactor fuels and under current law the department will be responsible for taking possession of the resulting spent nuclear fuel for management and disposal. Therefore, it is important for DOE to understand the implications that these new nuclear fuels may have on spent nuclear fuel management, including extended storage, transportation and disposal. These are topics of interest to the Board, and the DOE activities in these areas will be the focus of this meeting. In this country and abroad, nuclear fuels under the development include designs having a multitude of fuel and cladding materials. We cannot consider all of these designs in this meeting so we have chosen to limit the scope of the meeting to Advanced Nuclear Fuels, including accident tolerant fuels for light water reactors that may be introduced or widely produced in the U.S. in the next decade. More specifically, the scope of this meeting will include, mostly near-term fuel technologies that utilize new cladding designs, new fuel pellet designs or higher uranium enrichments. Please see the detail listing on slide 8. These new fuel technologies reflect those designs that have been subjected to in reactor testing and will soon be tested in research reactors or commercial reactors. Other than new fuels being considered for advanced research reactors, small modular reactors and Generation-4 reactors such as molten salt reactors, sodium fast reactors and high temperature gas-cooled reactors, will not be discussed -- these will not be discussed in this meeting. However, they could become the topic of a future meeting.

Now to the heart of the meeting, today's session will start with an opening statement by Bill McCaughey from the U.S. DOE Office of Nuclear Fuel Cycle and Supply Chain, who will tell us about the DOE support of R&D for accident tolerant fuel. Then we will have a presentation that presents a technical description of many of the accident tolerant fuel designs and provides the status of testing and qualifying these fuels for use in commercial nuclear reactors. Next, we will hear a presentation from Lightbridge Corporation on its R&D efforts to develop a metallic fuel for light water reactors. After a 20 minute break at about 2:20 pm Eastern Time, we will continue with a presentation from Nuclear Regulatory Commission about the NRC's Project Plan related to the use of accident tolerant fuels and the regulatory perspective on the potential impact of accident tolerant fuels on storage and transportation of spent nuclear fuel. Next, we will hear from the DOE Office of Spent Fuel and Waste Disposition on its approach to integrating new fuel designs into its plans for spent nuclear fuel management and disposal. The final presentation of the day will be by -- from Sandia National Laboratory and will cover recent evaluations of the potential impacts of advanced nuclear fuels including accident tolerant fuels for light water reactors on spent nuclear fuel storage and transportation. Then as I mentioned earlier, we will have a public comment period during which staff member Bret Leslie will read the public comments we have received. We will adjourn today's session at about 5 pm Eastern Time.

We will resume the meeting tomorrow at 12 pm Eastern Time, starting with speakers from Switzerland, Sweden and United Kingdom who will each tell us about efforts to develop new fuels in their countries and to plan for the management and disposal of the resulting spent nuclear fuel. We will end the meeting tomorrow with a panel session that will bring back most of the speakers from both days to discuss overall implications of new fuel designs for light water reactors on spent nuclear fuel management and disposal and how and when these implications are considered.

Much effort went into planning this meeting and arranging the presentation. I want to thank our speakers for making presentations at the meeting today and especially those who participated at the Board fact-finding meeting that was held virtually on April 26th. I also thank Board members Allen Croff and Lee Peddicord who along with myself, acted as Board leads and coordinated with the Board staff to put this meeting together. Now it is a pleasure to turn the meeting over to Bill McCaughey who will get the meeting started. Bill?

>>BILL MCCAUGHEY: Can you hear me okay?

>>Paul Turinsky: We can.

>>BILL MCCAUGHEY: Okay and my video is coming through?

>>Paul Turinsky: It is.

>>BILL MCCAUGHEY: Very good, okay well thank you very much. I am Bill McCaughey. I'm the Director of the Office of Advanced Fuels Technologies in the DOE's Office of Nuclear Energy. Also participating on the line are or calling in are Frank Goldner who is the Federal Program Manager for the accident tolerant fuel program and works with all of the participants on a day-to-day basis. And I believe also on the line is Andy Griffith who is the Deputy Assistant Secretary for the Office of Nuclear Fuel Cycle and Supply Chain. He -- is my boss.

So let me just say, we have, we did -- observe the 10th anniversary of the

Fukushima accident, been working after soon after the accident, Congress directed the Department of Energy to embark on a program for developing accident tolerant fuel. Two key parts of this that are guiding us to this day that are important are the fact that first of all this is for the existing fleet and secondly it's to be developed as quickly as possible and so those two aspects of the program are important -- have been important to us from the start and are guiding the work that we do. The Office of Nuclear Energy has three primary missions -- we've been guided by this for several years now. The first is to support the existing fleet of reactors. The second is to promote the development of advanced reactors for the future and the third is to strengthen, improve the fuel cycle infrastructure. And so we're doing that and the accident tolerant fuel program is one of the highest priorities for the Office of Nuclear Energy and fits under that missionary of supporting the existing fleet.

The program, up to this point, has also benefited from strong Congressional support, both Democrats, Republicans, House, Senate, over the years has strongly supported the accident tolerant fuel program. And it has been reflected in, in continuing and consistent appropriations over the years. And, I do believe too, the accident tolerant fuel Program, one of the strengths contributing to the success to date is also the communications and the coordination among all of the program participants and it's very, very large. We have hundreds of people working on accident tolerant fuel from activities, the major fuel vendors who are part of the program, the national labs who support the industry and the Nuclear Regulatory Commission who've also done a great deal of effort to stand up and accident tolerant fuel regulatory framework that is contributing to the success of the program so far today.

Also now -- I would add the -- back-end of the fuel cycle is important, it has always been an important part of accident tolerant fuel. We can't neglect any aspect of the fuel performance in operation during accidents, beyond design basis accidents and also for the ultimate, for the storage and ultimate disposal of the fuel. And that's why this is an important meeting to discuss that aspect of the accident tolerant fuel development and we're glad to be here to do that.

So let me introduce to you Dan Wachs, who will be providing you a great deal of the technical details on the accident tolerant fuel concepts and where we are with the development, the research and development aspects of that. Dan is the, he's what we call the National Technical Director for all of our advanced fuels work that we fund in the Office of Nuclear Energy. In that role he coordinates with all of the laboratories who do the work, research and development on advanced fuels. Also, coordinates with all of the -- our vendor teams and also -- with the utilities so he is in a very good position to brief you. It's a demanding job and he does it well. And he has put together a presentation that the Board was looking for to kind of kick off this meeting today. So, with that I would be happy to take any questions you have for me at this point or I could turn it over to Dan if you don't have any questions for me. Okay. Dan?

>>Dan Wachs: I guess, well thank you Bill I appreciate that introduction, as Bill said, I'm Dan Wachs, I'm the National Technical Director for the Advanced Fuels Campaign here and I do have slides that I'd like to share with you today kind of review the state of the technology and what we think is the next stages of that. Wait for you to bring those up.

Okay I should have control -- all right so it is a pleasure to be here. Bill already did a nice job kind of covering the history of the program and the motivations here, as he mentioned the, this was largely a, the accident tolerant fuel program is largely a response to great Tohoku earthquake and tsunami that led to damage at the Fukushima facility in Japan. We were asked by DOE to and larger industry to look at developing fuels that would provide increased, enhanced accident, in the event of similar types of activities. And so when we launched that program in 2012, we laid out what we believed was a very aggressive and challenging ten year program plan that would culminate in insertion of Lead Test Rods and assemblies in the commercial facilities by 2022. I think a great number of people thought that was maybe overly ambitious, but I think we grabbed on to that, that mission aggressively and I think the larger community did as well. And that, basically, when we look at that development of those technologies we envisioned three distinct phases, beginning with the development of concepts, so, you know, working with industry to come up with the best ideas that might be out there that could be deployed and solve some of the challenges we were interested in. That includes performance evaluations, including early phrase radiation testing and manufacturing technology development and many other things. Second phase here would be a licensing phase where we take concepts we agreed were viable and start performing, performance demonstrations in their real environment, both steady state and transient environments and start to see the development of topical reports and culminating in a regulatory approval, with a final phase looking at deployment of the technology. One of the, one of the key things to highlight here is that when we originally envisioned the transition between development phase and licensing phase, we are targeting 2022 for the insertion of those first Lead Test Assemblies. They were first inserted in 2019, representing the significant acceleration of the program and quite accomplishment by all those involved. There are many Lead Test Rods in many different commercial facilities and I'll talk more about those later on.

To accomplish this mission requires an active participation and engagement from multiple sectors of the nuclear, nuclear technology enterprise, beginning with the research community that is being anchored by DOE, the regulatory community, the NRC and also larger user community in the deployment phase and industry, both in the utilities and the fuel vendors and it is critical that all of these organizations be engaged meaningfully in this process in order to see technology advancing. And we clearly have seen that, as Bill mentioned, has been very, very effective and we have seen each of these organizations take accident tolerant fuels development very seriously and it’s been reflected in the wide variety of public documents that have been made available, funding that's been made available and regular interactions between all of these organizations that's have played a meaningful role in accelerating the deployment, accelerating towards deployment that we're on now.

Just briefly to highlight the technologies that have been the emphasis. Obviously, we evaluated many technologies, some technologies were dropped early on, others have been carried forward to the forefront of near term deployment and some are being maintained in a longer term development space. But primarily two pieces are envisioned for near-term deployment starting with the coating of zirconium cladding, so using state of the art claddings, but applying a thin coated layer to that surface. Primarily the objective of this coating is to reduce oxidation and hydrogen release when exposed to steam under a LOCA [loss of coolant accident] or severe accident conditions. This is the primary criteria established for ATF technologies, but we’re also [inaudible] these coatings could provide significant benefit related to normal utilization, so minimizing in-service oxidation which would reduce cladding wastage, reduce hydrogen pickup in the claddings and improve mechanical properties. Also, we're seeing improved resistance to debris fretting which is an important failure mode for normal operations of facilities. The wide variety of R&D needs are necessary in total to realize this technology. One is demonstrating that the coating performs as a diffusion barrier both for oxygen and hydrogen, the development of the manufacturing processes to reliably apply it and minimize the occurrences of defects. Also, demonstrating that the coatings are stable throughout the life-cycle of the fuel and manufacturing, handling, irradiation, and so forth. And also leading to finally demonstrate the integrated performance of all of these things in order to receive licenses under both the steady state operating conditions and design basis accident conditions. And these needs cross-cut all the different technologies in this category being evaluated and developed by industry.

Second major technology is looking at enhanced fuel pellets. So what the vendor teams are looking at are the enhancement of the pellets either through dopants or modified manufacturing processes that lead to much larger grains in the fuel. That effectively increases pellet density, you get greater uranium content in the fuel and less densification during the early phases of irradiation. And, this has important on consequences to subsequent fuel performance, including potentially reduced fission gas release and improved pellet-cladding interface interactions due to enhanced pellet plasticity that allows the flow better and applies less stress to the cladding. We believe that, well, as the industry has argued that the these dopants and modifications have minimal impact on overall thermo-physical properties of the fuel and so they can be implemented with minimal change and that they will provide higher resistance to post-failure degradation. In particular, they reduce oxidation and [inaudible] you have failed fuel. There are significant R&D needs here as well, although they are not as important as the coated claddings, but in order to implement microstructure based improved fuel performance criteria, we need to better understand and model these different properties and their evolution during irradiation. So there are a number of organizations working on those, those kinds of questions.

And lastly, again, we need to demonstrate the integral design basis accident behavior, and particularly in respect to fuel fragmentation, relocation, and dispersal phenomena that are being considered in, in burnup extension to support burnup extension beyond 62 gigawatt-day per metric ton.

So, specifically which we talk about the individual fuel vendors, each fuel vendor has their own product that they are working, that revolve around these ideas. The first is looking at Westinghouse, their products that are focused on PWR applications. They are using a chrome-coated Zirlo cladding so they're also considering axiom but with a focus on Zirlo currently. Their coating is applied using a cold spray technique that's followed by polishing. There are some questions about the high temperature performance of zirconium-chrome interfaces due to potential formation of eutectic layer that melts at 1300 degrees Celsius. That is beyond the current design basis limits for LOCA which would be around 1200 degree C, but it's a transition and phenomena that we would like to understand better. For the pellets they are using a chromium and alumina doped pellet to accomplish the higher, the higher densities discussed before. This is a product they've deployed in Europe for over 15 years and it the strategy for licensing is based on two topical reports, one is a near-term topical, seeking approval to use the current fuel without taking credit, where there's new fuel without taking credit for new fuel performance enhancements. But, also in the long term, coming back to take full credit for all of the improved performance potential of their new product. Westinghouse is continuing to maintain and interest in long-term ATF concepts or longer-term ATF concepts, primarily focused on higher density, higher thermal conductivity fuel pellets that are centered on uranium nitride.

Framatome is working on concepts to support both BWRs and PWRs. Their coated cladding is a chrome-coated M5 alloy, so using their current state-of-the-art alloys. The coating is supposed to be tens of microns thick and they're applying it using physical vapor deposition. Demonstration testing is underway for this fuel. They have lead test rods in commercial plants and have mid-range burnup test rodlets currently in the Advanced Test Reactor on the order of 30 gigawatt day per metric ton and we will push higher over the next several years. Again, there is concern over this zirconium-chrome eutectic that may form and might be considered as you get closer to design basis accident conditions. They are also using chromia-enhanced fuel pellets, same kinds of targets as we've discussed before. They're working on topicals to submit to the NRC for the same licensing purposes. Long-term, Framatome is interested in -- is pursuing silicon carbide (SiC) composite cladding for PWRs. It's a multilayer system based on a zirconium liner, SiC-SiC composite and chrome coating on the outside to manage erosion and corrosion questions in PWR environment. This is important -- of all the ATF concepts, silicon carbide's performance under severe and design basis is anticipated to be the highest potential, very, very resistant to high – to melting and good mechanical strength at very high temperature. We would maybe call it, consider it to be the Holy Grail of ATF technologies.

They're also using Silicon Carbide for channel boxes in BWRs. For General Electric and Global Nuclear Fuel, they're focused on BWR concepts. Again, they're looking at a Zr-2 cladding, on their case it is it is a different coating that they, composition and it is manufacturing attributes are considered proprietary to GE, so we don't have publicly available data associated with that. Again on these, demonstration testing is underway, there are lead test Gen-1 design in commercial fuel plant, in commercial plants and there are test rodlets in the Advanced Test Reactor in our PWR loop we're working towards having a BWR loop to support them as well. Their long-term technologies are also interested in iron-chrome-aluminum alloys -- they're looking at multiple compositions in the types. These ferritic alloys offer resistance to stress corrosion cracking from the coolant side, they have higher thermal conductivity and a low coefficient of thermal expansion. They do exhibit higher strength than the current zirconium alloys at rector temperatures, allowing for thinner tubes and wall thickness that allow them to reduce the neutron penalty associated with using an iron-based cladding.

They're also interested in silicon carbide-based channel boxes for BWRs and advanced ceramic fuels primarily thinking about next generation dopants that enhance performance in a variety of ways.

So to support the development of these technologies the DOE facilities are available to the vendors to conduct their experiments and the -- radiation testing is really the central point for developing fuel technologies and so we have conducted a wide variety of test campaigns in the Advanced Test Reactor and that are ramping up in the Transient Reactor Test facility as well. So ATF1 was one of our early experiments focusing on screening concepts. ATF-2 is the flagship irradiation kit test where we're conducting experiments on small rod segments in a pressurized water loop in the Advanced Test Reactor. That is ongoing now. ATF-3 will focus on transient testing primarily designed basis accidents, RIA and LOCA on fresh and irradiated fuel samples.

Specifically we were going to use ATR as the foundational part of this ATR/HFIR for existing capabilities to support patient testing and be complimented by the work being done at the Halden Reactor facility in Norway. Two years ago Halden reactor was suddenly closed and many of the reactor programs, the fuel vendor programs were impacted by that. DOE was actively worked to try to close those gaps by creating new capabilities in the United States and additionally, particularly focused on adding additional test loops to ATR, accelerating our LOCA testing capability and implementing instrumentation and refabrication capabilities to conduct experiments on fuel extracted from commercial reactor facilities. This is an important piece of overall puzzle here.

Status of irradiations, so the big bullet here is ATF-2, PWR loop tests. We've irradiated 33 fuel rods, rod segments in the ATR supplied by the various vendors and with control samples that we use as reference for those. We work very closely with the industry on those irradiations to meet their needs and compliment the work they're doing at the commercial lead test rods. Currently, the Advanced Test Reactor is going through a regular core-internals changeout where every ten years or so they remove all the core-internals and replace them. They'll begin operation again here in March of next year. And, as I mentioned, we're adding additional, we're developing additional PWR and BWR loops to expand the capacity available to industry and hopefully continue to accelerate their deployment and licensing programs.

Ah, the TREAT reactor, we've actively begun testing under the first design basis accident conditions reactivity insertion accidents. You can see two examples that were subjected to those experiments defining the, confirming the regulatory limits are still applicable for coated claddings is currently the focus. In the future we'll look to refine those criteria and eliminate unnecessary margin to improve the utility of those fuels. LOCA testing will be coming up very soon as well.

The major accomplishment, we alluded to this a couple of times, is the insertion of lead test rods and assemblies in commercial facilities. We currently have eight reactors that are hosting full scale fuel rods of the vendors designs. Two of those facilities or -- one set of those lead test rods has been transported to hot cell facilities at Oak Ridge National Laboratory. A second set is being prepared to ship shortly to both Idaho and Oak Ridge, so making great progress here. There's tremendous data that will be available over the next several years. This does support the, keeps us on schedule to be able to conduct batch reloads in the mid-2020s as requested by the utilities.

So one of the challenges we face is we imagine deploying technology that is safety focused is to accelerate deployment we need to make sure we identify economic incentives that would encourage vendors to adopt these technologies. And one of the key enablers of that is the use of accident tolerant fuels to help with burn up extension. Many would like to go to 24 month operating cycles rather than the current 18 month operating cycles. And to do that will require pushing the burnup limits from 62 to greater than 75 gigawatt per day to metric ton and also increasing enrichments to support those longer operating cycles. So the, an R&D road map has been developed as part of a collaborative industry DOE NRC program, The Craft Program collaboration, Collaborative Research on Advanced Fuels Technology is what that stands for that's laying out a plan to enable burnup extension by mid-2020s as well. That really revolves around resolution of LOCA-type burnup fuel at the end of life.

International collaborations, so the accident tolerant fuels program is a national program focused on supporting the fleet in the United States, however we do have active partnerships with many, many countries. Particularly the fuel vendors are typically international organizations that are using their network around the world to accelerate deployment of this technology. But, the DOE program works actively with many of its partners in, around the world, some integral programs like NEA committees focused on fuel safety and nuclear science. We are working actively with irradiation test facilities around the world since there is a shortage of those to support safety testing, so particularly the CABRI reactor and NSRR reactor in France and Japan respectively. We are actively engaged in joint irradiation campaigns in support of the JAEA, and we are routine members of the large international joint projects including Halden Reactor Project , the New FIDES program which is about access to irradiation test facilities, Studsvik Cladding Integrity Program and others.

So in conclusion, I think it's important to highlight that the key nuclear fuel technology stakeholders are all collaborating on the development and deployment of a ATF. That includes research, industry and regulatory sectors. The key milestones that were laid out at the beginning of ATF program to achieve Lead

Test Rods by 2022 have been exceeded by three years. That's a great testament to the work being done by everybody involved. Significant irradiation testing is ongoing; this is the basis for licensing requests and refinement of the, of the technologies. These are being conducted both at research reactors and commercial facilities around the country. Batch reloads are of the near term concepts are targeted to be deployed by mid-2020s. So this is technology that is coming down the pipe and it will be important to address it whole fuel life-cycle, with a focus on coated claddings and enhanced UO2 pellets. I think we can consider long-term concepts still in development with meaningful amounts of work left to be done before they can be ready for deployment.

And lastly, it's important to incorporate an understanding of burnup extension, increased enrichment in the, as a part of this package enabling ATF deployment and the economics of ATF in general.

So with that I'll conclude and if there are questions I'm happy to, to answer those.

>>Paul Turinsky: I'll open first questions up to the Board.

>>Lee Peddicord: Um, Paul, if I may.

>>Paul Turinsky: Yes, please, Lee.

>>Lee Peddicord: This is Lee Peddicord, Dan, member of the Board. So, you know, I think it's particularly interesting your second to last slide ..losing the Halden facility was a major impact in so many ways. I think it's the slide after this one. So a couple of questions came up after, while we are looking at all of them. Any rate, the question I wanted to ask is you notice the Halden is still an active project, even though the reactor's shut down, has been for two years. So I wonder if you could just say a little bit more of what's still involved in the Halden project. And then, you mentioned FIDES as another effort to bring together international capability. Could you just talk a little bit about what that would entail.

>>Dan Wachs: Yeah, so first the Halden Reactor Project, so they had a number of irradiation experiments that were still in progress and so they are currently in the remainder of the five year Halden Reactor Project to complete the PIE activities associated with those experiments. They're also, as we often see when a project or facility like that closes, the legacy data becomes unattended and it tends to become lost to the future. So they are working very hard on a databasing effort to try to capture the historical knowledge and document it in a way that can be preserved for people to come back to in the future, because they've been a very, very important part of that, of the LWR industry for the last two decades. They, they are pivoting slightly towards being able to conduct more hot cell type experiments, but I think that's going to be a stop-gap thing that is slowly dwindling. Very important program, we're sorry to see them go and there are some activities to try to take advantage of what is still there.

With respect to the FIDES program, I think that the Halden closure was a wakeup call to the international community that we had maybe unknowingly consolidated much of our LWR R&D at one facility that was not a primary nuclear player in the world. Norway is not, not considered a major actor and so the FIDES program was proposed as a way to integrate together the key national irradiation facilities around the world, with the obvious ones ATR, HFIR in the United States, TREAT, the United States, the NSRR reactor in Japan, CABRI in France, maybe [Jules Horowitz] in the future, the BR2 reactor in Belgium and to formulate irradiation test programs that could be collaborative around the world. And so that idea has been something that has been socialized well involving and in fact the, the final agreements are in the process of being signed off by many countries. I think --. Last I heard there were 27 countries signed on already to participate in that, the NRC had already signed on, Bill can maybe comment on where DOE is, but I think we are very close, haven't signed off final participation in that. There are currently -- the way the system works is projects are proposed. There are currently four projects that are proposed to be the beginning of the project. One at BR2 that's focused on power to melt, one at -- in the Czech Republic that's looking at cladding performance. An experiment at the TREAT reactor looking at reactivity insertion accident performance, and LOCA test conducted at the [inaudible] facility in Russia. We expect there will be additional projects that are proposed in a rolling matter as we complete and perform work in the future. So that is a very promising program. I think it's one that we are committed to participating in and it will be meaningful impactful to the R&D community going forward.

>>Lee Peddicord: Yeah that's very good, thank you. Is Petten a possible participant or are they not suitable?

>>Dan Wachs: Yeah, Petten certainly has capabilities that would be of interest to the program. The, they, to my knowledge have not proposed a partnership at this point. But that could change in the future.

>>Lee Peddicord: Well, I think the attraction there is that is already an international facility as part of EURATOM, this is as you know is becoming an increasingly international collaborative endeavor, so a facility like that would seem to be pretty attractive for this sort of thing. Thank you very much, appreciate that.

>>Dan Wachs: Yeah. Thank you.

>>Paul Turinsky: Allen, you have a question?

>>Allen Croff: Or two, or three. Croff, Board. You mentioned early on that some of the earlier ATF concepts had been dropped. How's that decision made and who makes it?

>>Dan Wachs: I think that's -- think that's in, so what gets active in the program is based on vendor proposals to DOE. So the vendors develop their program plan, they propose that to DOE and the awards are built around those programs. So I would say that it really is the vendors that are choosing the concepts that they want to continue to carry forward.

>>Allen Croff: Then it is the vendors that choose to withdrawal at some point, not DOE?

>>Dan Wachs: That's correct, that has definitely been correct to date.

>>Allen Croff: Okay, second question: uranium nitride, how does it react with water?

>>Dan Wachs: It has some challenges; that is the primary focus of the R&D currently is evaluating corrosion behavior and if there are methodologies for, you know, waterproofing, to use a loose term.

>>Allen Croff: Okay well to uh, what is the reaction product of uranium nitrite in water, or products?

>>Dan Wachs: I don't have that off the top of my head.

>>Allen Croff: Okay. Third question, you noted at the outset that one of the primary goals of developing ATF fuels is to reduce oxidation which makes a lot of sense. Is there any thought or activity trying to extrapolate the oxidation behavior in a reactor setting to oxidation behavior say, in transportation or dry storage?

>>Dan Wachs: I know that in informal conversations with the fuel vendors, they are talking about things like that. That's not an active part of the DOE program.

>>Allen Croff: Okay, thanks. That's all I had.

>>Dan Wachs: Okay.

>>Paul Turinsky: Thank you Allen. Tissa?

>>Tissa Illangasekare: My name is, Tissa Illangasekare, Board. So I have, I'm not a nuclear engineer, but I have a more general question, mostly to understand terminology. So in one of your slides you looked at the deployment so you mention steady state and transient environment. What do you mean by the steady state and transient environment, just for me to understand?

>>Dan Wachs: So typically steady state would be normal service conditions, so, startup, operate, shut down, typical power movements. We usually define transient as off normal events, both class 3 and class 4, so design basis and severe accident type conditions.

>>Tissa Illangasekare: Thank you, the second question is that you mention in your technology

development, so you are looking at post failure degradation. When you say, post failure degradation, are you looking at, in the context of the reactor itself or with the degradation involved in an accident, this may end up anywhere in the immediate environment? So, what do you mean by post degradation, failure degradation? What is the environment are you looking at?

>>Dan Wachs: They're focused on in-pile behavior, so if you have defective fuel rod, what is time constant before you need to extract that rod. I don't believe they are looking at long-term disposal stability.

>>Tissa Illangasekare: Yeah, the reason the question, the Fukushima situation when this happened, so they are worried about the ultimately that it enters the environment and then my question is again, naive in some ways, but I was wondering whether this, this compounds get into the environment it is degradation of the environment become a factor in long-term performance.

>>Dan Wachs: Yeah I think it has, it has been beyond the scope of the program to date. We've emphasized more design basis accidents or industry has emphasized more design basis accidents and avoiding those kinds of environments rather than addressing the performance in them.

>>Tissa Illangasekare: Thank you, that's all.

>>Paul Turinsky: Okay thank you, Tissa. Steve? Oops.

>>Steve Becker: There we go. Thanks, Bill and Dan, for very interesting presentations on an extremely important topic. I have a question for either or both of you, however you wish to handle it. Particularly having recently marked the 10th anniversary of the events at Fukushima Daiichi, there could be considerable public interest in the topic of accident tolerant fuels. Are there fact sheets or other non-technical materials on accident tolerant fuels research and its significance currently available for the public? In other words where should interested members of the public go to learn more about this important work?

>>Dan Wachs: Bill, would you like to do that one first?

>>BILL MCCAUGHEY: Um, am I coming through?

>>Dan Wachs: Yes.

>>BILL MCCAUGHEY: Oh, okay, all right good. Well thank you, thanks for that question. That's this is primarily a,.. this is really an industry-lead effort that the Department is supporting through research. So I would say the first place to go would be the Nuclear Energy Institute's website which has, I know they have, they have a significant amount of material available on accident tolerant fuel and what the potential benefits are for, for accident tolerant fuel.

>>Steve Becker: Dan, you want to add anything?

>>Dan Wachs: Yeah, I think Bill is correct that's the primarily place to go for the high-level descriptions. NEI is very active in advocating for it. I believe also the NRC has some materials on their, on their websites that talk about progress in accident tolerant fuel and their role. The, even the fuel vendors have quite a bit of press release-type materials associated with it. We have generated overview documents, but I don't know that they are necessarily targeted the general public. But if you are interested we could identify a few of those and share them with you.

>>Steve Becker: Absolutely. Thank you both.

>>Paul Turinsky: Okay, before I turn over to the Staff for questions, I have a few. It would seem at this point that you could do some scoping calculations of the implications of going up to higher burnups. I guess I'm thinking all the way up to 75 gigawatt days per metric ton. Have you done that and what's the net coping time advantage that you get from where we are today with our current fuels and our current burn up limits?

>>Dan Wachs: Relative to the current, it's uh, I think it's measured in, and I don't know, have the number on my tongue, but I think it's measured in minutes and it's very dependent on the events that you're characterizing. Uh, so, the, uh, yeah, I wish I had a better, succinct answer for you on that. The vendors have done quite a bit of

calculations along those lines to do those evaluations, but it's not been a task they've delegated to the labs to do on their behalf. We did a lot of preliminary work in the last five years, but the emphasis on those analysis have been shifted over to the, to the fuel vendors.

>>Paul Turinsky: Okay, okay. Wouldn't you think that's important to know to know for DOE whether they can --?

>>Dan Wachs: Yes.

>>Paul Turinsky: -- support that activity or not?

>>Dan Wachs: Yes, I agree. I should know that.

>>Bill McCaughey: There has been, uh, you know, that kind of analysis, that's happened several years ago and the outcome of those sort of analyses have been that the, um, coping time for these concepts are, it's not as great as what was, uh, what was anticipated or, uh, I shouldn't say expected, but hoped for.

>>Paul Turinsky: Yeah.

>>Bill McCaughey: So, it was not a matter of -- days. It was -- like Dan said, it's a matter of, maybe, a couple of hours. But what the industry has said, also, is that's very, that's also significant because, when you couple that with emergency procedures and what can be done in that short amount of time just that extra bit of time for coping allows you to do a lot in the reactor and so if you couple that with emergency procedures and staging equipment and that sort of thing, it's significant. --I think that's pretty much the, you know, overall that's what we found at this point. You know these other -- concepts like Silicon Carbide -- and maybe the iron-chrome-aluminum cladding will get you -- significantly more coping time. But, at this point, the industry is very happy with what they are finding with these near term concepts and that's why they're still-- pursuing these -- and looking to pursue these and make sure that we have -- a path to get these into reactors within the next few years.

>>Paul Turinsky: Are the thoughts now that DOE will be part of this program as they go to increased enrichments and higher burnups.

>>Bill McCaughey: Well, at some point in time, the government role -- diminishes -- I mean, right now it is a resurgent, it's still very much a resurgent development program. They're learning a lot about -- the performance of these claddings and -- the fuel with the dopants and -- it is still R&D, but certainly by the time we have batch reloads going into the first reactors, that the role of the government and the investment of the government is going to diminish to the point where -- you could look now -- there's still a role for the government in supporting the existing nuclear fleet and there always will be, but, as far as --the level of investment by, you know, for, by our appropriations is going, -- they will go down quite a bit.

>>Paul Turinsky: Okay. And, next question, I'm going to show how little I know, uh, why should I care about the zirconium eutectic forming? What are the negative implications of that?

>>Dan Wachs: Yeah, I would say the key there is the NRC has always worried about cliff edges, right? When do you get large transitions in degradation behavior. That really is the only, the only potential issue we are seeing out there associated with coated cladding type phenomena. And the --

>>Paul Turinsky: Yeah the mechanism, what is it though?

>>Dan Wachs: Oh, okay, so when you have, --

>>Paul Turinsky: Does it crack at that point or --?

>>Dan Wachs: You get a low melting temperature eutectic, so you get liquid formation at that interface and then decohesion of the, of the coating from the fuel.

>>Paul Turinsky: Okay, it's degradation basically of the coating at that point?

>>Dan Wachs: Yes, exactly.

>>Paul Turinsky: Okay and then one more and I'll turn it over to other people. Who owns the samples that are going into ATR that haven't been used, destroyed yet for testing

and likewise, will DOE have access to any of the lead test ins that are in any of the commercial plants to do testing? I'm thinking particularly on the back-end stages now, they are going to need material.

>>Dan Wachs: So the samples are irradiated in test reactors both ATR and HFIR are irradiated under cooperative research and agreements (CRADAs) with the individual vendors. And, so, in those agreements there are rights that are outlined for intellectual property associated with those, so they are, we are viewing it as a partner, we do own, own those materials for those experiments and can conduct subsequent R&D on those. There's limitations on public dissemination of the results, depending on parts of that product. The Lead Test Rods are similar, there are agreements that are generated when the DOE takes ownership of the material to do examinations at the hot cells and the terms of those, the terms of those CRADAs are, have been negotiated and associated with each one. I think there is room to do additional R&D work, it's something we do need to do additional follow-up to, to confirm the constraints and options there.

>>Paul Turinsky: Okay, thank you.

>>Dan Wachs: It is our expectation there would be follow-on, be potential for follow-on work.

>>Paul Turinsky: I see Steve Becker has another question, so back to --

Steve Becker: Actually I do not have another question, my hand was left up.

>>Paul Turinsky: Okay, put your hand down. [LAUGHTER]

>>Steve Becker: I will indeed.

>>Paul Turinsky: Okay any other questions from Board members? If so, I will recognize the Staff and I know Nigel has a question.

>>Nigel Mote: Yeah, Nigel Mote, Staff, Dan, thanks for the great presentation, clear, and as Steve said, very interesting. I have a question on a comment you have on slide 8, this is on the Westinghouse fuel, the doped fuel, you say the product has been deployed in Europe for 15 years. And, yet, the R&D program in the States, is essentially a new start. Can you tell us what is the difference between the regulatory requirements in the States that needs so much additional R&D and how does the experience in Europe play into the ability of utilities in this country to meet the requirements for loading, in this case, doped fuel in US reactors?

>>Dan Wachs: So for doped fuel in the US, we expect that Westinghouse will rely on their European experience to generate the --to generate the topical reports necessary to deploy it in the US. I don't see that as a major barrier to first use. The NRC would like to see some, some confirmatory work and there are still some open issues related to design basis accident performance that -- the NRC would like to see resolved. So I would say in the area of doped fuel there is modest R&D necessary to support deployment, the -- to take advantage of the full potential requires additional R&D to demonstrate improved understanding of why the materials behave the way they do and what would the new limits be if you were to substitute them for old limits associated with standard UO2.

>>Nigel Mote: Okay, thanks I have a second question. On slide 6 you characterized increased ductility as being an improvement in the chemical properties but we're also looking at silicide which is a ceramic, and is presumably less ductile. Can you say something how the difference in ductility is overcome in looking at the silicide fuel to offset the fact that improved ductility, increased ductility is characterized as an improvement.

>>Dan Wachs: So, in this case talking about ductility of the cladding, right, primarily due to reduced hydrogen pickup and those things. In most cases what we have seen is Westinghouse is now abandoned uranium silicide as part of their program so we haven't been worrying about that, that particular interaction.

>>Nigel Mote: But it is still on slide 9, it's still down as one of Framatone's long-term concepts.

>>Dan Wachs: Oh, do you mean silicone carbide?

>>Nigel Mote: I beg your pardon, I beg your pardon. Yes.

>>Dan Wachs: Yes, silicone carbide, there's too many of those things mixed in there. Yeah, so, thinking about coated claddings, one of the major advantages you get there in coated claddings, is you get performance that is similar to what you are accustomed to with zirconium alloys. Yeah, the steady state performance of silicon carbide is probably one of the more important challenges because you don't have this, this, you know mechanical response behavior you get from a metallic fuel that's pretty forgiving in that way. That is a primary question, if you get pellet-clad contact, you know, how much strain can you handle in a silicon carbide cladding, it's virtually none, right? It's a very, very small amount. So, managing pellet-clad interaction and that mechanical behavior is one of the key R&D questions that needs to be resolved before we can get to deployment.

>>Nigel Mote: I'm looking at post discharge transportation, the shock experience during transportation is a key issue.

>>Dan Wachs: I agree. We still have in-service questions about silicon carbide that have not been resolved as well.

>>Nigel Mote: Okay, thanks.

>>Paul Turinsky: Okay, Dan Ogg.

>>Dan Ogg: Hi, yes, thanks very much Bill and Dan, excellent presentations, I think it is really good information and I'm sure everybody really appreciates seeing all of this being presented. I've got a question for Dan regarding post irradiation examination. I'm sure you have stated that the first campaign that ATF, I'm sorry, at ATR, those materials have been out and have been examined. Have you started doing post irradiation examinations of the second campaign at ATR?

>>Dan Wachs: Yes, so they are, they are, they're underway now. The first non-destructive characterization has started. We've also been conducting some in canal examinations at ATR to support some of the vendors, so that work is going full ahead right now.

>>Dan Ogg: Okay and one of the key issues, certainly for storage and transportation and you mention it as a goal for the new fuel development is a reduction of hydrogen absorption in the cladding which then could lead potentially to in Zircaloy-based claddings. With the PIE that you have completed so far --do you have information on the hydride absorption and how does that look for these new ATFs?

>>Dan Wachs: We have not done those measurements yet. Right now..we're still on non-destructive characterization with fuel pins. Once we begin destructive characterization we will start doing both mechanical testing of the claddings and hydrogen measurements. Again those are done under CRADA , with the fuel vendors and so we will have limited ability to disseminate that data publicly, but we are doing, we have been tasked with doing those measurements by the vendors.

>>Dan Ogg: Okay and I assume you have all the right equipment and facilities for doing those kinds of things?

>>Dan Wachs: Yeah, so we are doing the, we had to install some new capabilities to respond to those and those are in place now. In some cases we are doing demonstration, qualification testing prior to studying the ATF materials.

>>Dan Ogg: Right and I know I we will hear this later from Sylvia Saltzstein, I know you are aware that there is quite an extensive network of facilities and equipment for doing the examinations of irradiated, like at Oak Ridge and Argonne National Lab I hope you coordinate, collaborate and make use of all the facilities that are available as much possible.

>>Dan Wachs: Yeah I think that's absolutely true, some of these, some of the Lead Test Rods are actually going to Oak Ridge to utilize some of the facility capabilities there. You know, as part of the preparations for this meeting we actually had some interactions with Sylvia and I and we're working to try to integrate some of those ideas together. The most important thing is the flow of technical capabilities and how --to do certain measurements.. that's much easier to move than irradiated

materials, but I think there will be active and meaningful collaboration in that area going forward.

>>Dan Ogg: Great, thank you.

>>Paul Turinsky: Are there any more questions from other Board members or staff? Okay. Hearing none I would like to thank Bill and Dan for their fine presentations and making us a little wiser on understanding accident tolerant fuels. We'll move on to our next presentation at this time. The presentation is characteristics of Lightbridge Fuel for light water reactors, the presenter will be Aaron Totemeier from Lightbridge Corporation. Aaron, the floor is yours.

>>Aaron Totemeier: Thank you Paul for the introduction and on behalf of Lightbridge thank you to the Board for invitation to present today. Am I coming through clearly on audio?

>>Paul Turinsky: Yes. Speak perhaps a little louder.

>>Aaron Totemeier: A little louder okay I seem to have lost the interface with the slides here, they are all showing up blank. --Let me try to, let me try to logout and log back into the system.

>>Paul Turinsky: Okay. Okay I'm back, still coming through clearly Paul.

>>Paul Turinsky: Yes.

>>Aaron Totemeier: Sorry about the technical delay, thank you for the invitation at Lightbridge to present today, my name is Aaron Totemeier, Vice-President of fuel cycle technology and fuel fabrication for Lightbridge Corporation. My presentation today is an overview of the Lightbridge Fuel technology for light water reactors to provide a description of some of the design features and performance characteristics of the fuel, talk a little bit about some of the on going R&D activities and implications of the fuel design for used fuel management.

Then I will jump right in here. This is a schematic of the fuel rod you can see here on the right-hand side, as I said it is a metallic fuel rod and you can pretty much instantaneously tell that it is different than conventional fuels -- It is a metal fuel rod, instead of a ceramic and it also has this unique multiload twisted geometry. So, those two key features, being metal composition and the twisted geometry really give the rod most of its performance benefits and differences to conventional fuels and some of the other ATF fuels that are being developed. In terms of the composition of the fuel, there are three components that make up the fuel rod starting from the outside edge. You have a cladding alloy which, right now, is a zirconium-1 niobium alloy. We could use some other metal alloys as well depending on the application of the fuel. The fuel core makes up the bulk of the rod. That is a delta phase, uranium-zirconium alloy with high assay LEU enrichment inside of it. And, then in the very center of the fuel you have a central displacer which would be a zirconium alloy, potentially alloyed with burnable absorbent material to bring down, to help control reactivity for the fuel. Those three components during the manufacturing process are all metallurgically-bonded together so, there is no gap between the fuel and the cladding, there is no plenum inside the rod. All of the components form one solid metal rod throughout the length of the fuel rod. Talking a little bit about the geometry, I'll go into more detail later on, as I mentioned as, helically twisted and with that multilobe shape, you get fairly significant increases in surface area for heat transfer into the coolant water in the range of 30 to 40% depending on the specific dimensions of the rod. And, that allows us to increase power density, linear power density in the rod without encroaching on thermal design limits. This also enables the rods to be self-spacing when they are in an assembly or in an array; I'll show you schematic of that later on. That allows us to also increase the coolant mixing through fuel assembly because it is no longer relying on intermittent grids and mixing vanes to lead to coolant mixing in the assembly. The rods themselves keep the coolant mixed across the assembly.

With that I'll move on to what I call my "good news, bad news" slide. The good news is that Lightbridge's metal fuel is based on a – it's an evolutionary LWR fuel design based on fuels that were used in nuclear powered ice breakers. These ice breaker vessels utilized a similar delta phase uranium-zirconium alloy fuel, demonstrated the metallurgical-bond of the fuel and the cladding, demonstrated the twisted rod geometry and self spacing in the assembly. They also had – operated at much higher power densities and faster power ramp rates than you would see with conventional oxide fuels and they've demonstrated their -- the fuels ability to withstand very high burnup in a water cooled reactor. Some of the characteristics of some of that maritime reactor fuel experience, several thousand fuel assemblies were irradiated. Average burnup of approximately 200 gigawatt days per metric ton of uranium. Just a side note, there is a lot less uranium in this fuel compared to UO2, so when you look at metrics that have metric tons of uranium in the denominator you can't make a one to one comparison to UO2. So, that 200 gigawatt days is not quite the same you would see with 200 gigawatt days with the UO2. I'll discuss that in a little bit further. So, that's the good news. This fuel technology is not brand new; it has a pedigree to it and it has demonstrated many of the aspects and many characteristics of the fuel and Lightbridge has a very high confidence in how the fuel we've designed for light water reactors will behave. The bad news is all of the ice breaker fuel performance data was performed with high enriched uranium fuel, and, therefore, that data is not available to Lightbridge to use in its current program. So we have to go through as fuel developers and essentially redevelop the wheel in some areas to redevelop the technical basis for this fuel and the safety justification for the fuel. Excuse me. And as you heard in the previous speaker, Dan, speak about Halden that was a pretty big hit to our fuel development program as well. Lightbridge had a substantial irradiation program planned at the Halden reactor, and so, therefore we have now have to reposition how we are developing the fuel and looking at getting that data for the technical justification using modern US nuclear standards and quality assurance requirements largely within the US DOE complex. So look a little bit closer at one of the rods you see here, the image on the right of a three-load variant of the rod, we describe this rod as a very robust fuel rod. You imagine the cylindrical fuel rods, pellet-and-tube rods, the majority of the mechanical strength of that rod comes from thin-walled cladding tube. And, due to the metallurgical bond in this fuel, the strength of the rod is actually ..depends, or is provided by the fuel material and the cladding material, so the fuel is much more robust in terms of its stiffness and mechanical strength compared to conventional pellet and tube designs. The monolithic fuel rod design and self-spacing of the assembly actually lead to increased strength in the fuel assembly. Once you array these fuel rods into a bundle, the stiffness of that assembly is significantly higher than conventional fuels so the fuel assembly does not bend and flex as much during lateral loads that might occur during seismic events.

The self-spacing feature of fuel assembly also allows us to eliminate spacer grids within the assembly and interim spacer grids which eliminates the possibility for grid-to-rod fretting and reduces a potential for debris-trapping and fretting in the assembly which of course also brings in the new issue or concern of rod-to-rod fretting as each rod is touching its adjacent neighboring rods at various points along the fuel assembly. And, you'll note in the micrograph on the right the thickness of the cladding actually buries along the perimeter of the fuel rod at the lobe tip, at the top of the image, you can see the cladding is in this image nearly three times as thick as the cladding in the valley between the lobes. Part of the reason for that is to provide additional durability for the fuel at those points of contact between adjacent fuel rods. The flow testing and thermohydraulic testing that we've done to date on assemblies and bundles of this fuel have not shown any concerns with rod-to-rod fretting but it is an area that will be new for this type of fuel and something we'll have to validate as we move forward with our irradiation testing program.

I also mentioned that there is no fuel-clad gap that eliminates a mechanism for rapid release of fission product gasses. Most of the fission product gases are maintained within the matrix of the fuel, which I'll discuss in a few slides, due to the low temperature of the fuel. And also the..I want to briefly discuss the fuel rod extrusion process as the primary forming mechanism for the metal fuel and that process is a..in a single step essentially we take the billet and cladding, the displacer, and the fuel alloy and form a full helically twisted rod whatever length is needed for the reactor in one process step. It eliminates the concerns of pellet chipping and all the various components--that have to go into..and process steps that go into other fuels.

I'll talk a little bit on this slide about the delta phase, uranium-zirconium alloy that comprises the Lightbridge fuel. Have a simplified binary phase diagram here just to show where the delta phase is. Some of you may be familiar with uranium-zirconium fuels developed for fast reactor applications which utilize primarily uranium 10 weight percent zirconium. This fuel, as I mentioned, is delta phase. It is nearly a 50/50% by weight composition of zirconium and uranium. It's not quite 50/50..there is a window there that you can see of compositions that will result in the delta phase and you'll notice that in some of the graphics in this presentation, they don't always show the exact same percentage of zirconium and uranium. That's just part of this fuel. The maximum fuel operating temperature you can see on the graph here, by design is 560 degrees Celsius, and the average fuel operating temperature is significantly low compared to conventional fuels at about 370 degrees Celsius. The melting temperature of metal fuel is about 1600 degrees Celsius. So that low operating temperature limits all thermally activated processes within the fuel, diffusion of species, diffusion of fission products, accumulation of fission product gases and the formation of fission product gas bubbles and pores in the fuel. So that's where the fuel matrix itself becomes part of the first barrier to fission product release. And, due to the metallurgic bond and this retention of fission products in the fuel, the, in the event of a cladding breach only products that are local at the breach site are available to be released into the coolant.

I'll show you a little more here on this slide with some micrographs of a zirconium-40 weight percent delta phase alloy. The dark "splotches" you can see in these micrographs are a zirconium rich phase. The lighter alloy – lighter colored regions are delta phase region. There are three burnups here shown in these graphs on the left we have approximately 100 megawatt days per kilogram of heavy metal. The middle image is about, about 200 megawatt days per kilogram and final graph on the right is 260 megawatt days per kilogram. So, as I mentioned the low operating temperature of this fuel keeps the fuel very stable during its lifetime. Most fission products including fission gases, fission product gases behave as solid fission products and you get..you do see the formation of some porosity in the fuel and fission gas bubbles but remain a very small network of bubbles and very isolated network. They don't form the interconnected network of porosity and you don't see the significant cracking and degradation that you see with ceramic pellets. So the fuel retains its fission products within the fuel matrix itself during the lifetime of the fuel.

I can't speak to the temperature or power history that these images are from, so I can't really relate the size of the amount of porosity or size of pores to the specific operating performance of this fuel that was used, but our preliminary models suggest that this would be at the high end of the type of porosity we would see of the Lightbridge fuel in a light water reactor environment.

The next I'll talk a little bit about the use of high assay, low-enriched uranium and Lightbridge fuel. Obviously, there are numerous advanced fuels and advanced reactors looking at high assay LEU. Lightbridge sees itself as kind of a bridging technology to demonstrating high assay LEU and bringing the supply chain for high assay LEU into the market now and making that available for the advanced reactors when they are ready. Due to the much lower uranium content in the Lightbridge metal fuel, we have to have an increase in enrichment of the uranium in order to have the same fissile loading as conventional fuel. So you'll see in the chart here on the left-hand side we have a conventional UO2 fuel assembly, about 88% of the fuel weight is from uranium, out of that 88%, 4.95% of the uranium is uranium-235 and provides the fissile load for the fuel. Compare that to the Lightbridge Fuel assembly where approximately half of the fuel is uranium material, in order to have the same loading at the initial, at the start of life of the fuel, we would need to enrich the fuel to about 13.5% to have the same initial fissile load. And by and then to add to that Lightbridge Fuel using a 19.7% enriched uranium, which is limit for high assay fuels equivalent to UO2 fuel assembly enriched to approximately 7.2%. Just to give a sense, of although this is high assay fuel that does have implications both on front end and back end of the cycle,once the fuel has been fabricated into an assembly, the performance of the fuel from a neutronics and criticality perspective is not quite the same as what you would expect with UO2 fuel enriched to the same amount due to the lower uranium content.

Now I want to talk a little bit about the geometry and the implications that has for the design of fuel assemblies based around the metal fuel. Lightbridge is developing the metallic fuel rod as a platform whereby numerous fuel assemblies can be developed for specific light water cooled reactors and specific applications within those reactors both PWRs and BWRs and CANDU reactors and any SMRs that are water cooled, could utilize this technology. So I'm not going to show tremendous amount of detail on specific fuel assembly designs but I do want to give a sense of how these cell spacing array works due to the helical cruciform geometry. So, I already mentioned the increased surface area of the rod and the increased power density, linear power density the rods can operate at due to increased heat transfer. The other aspect of removing the spacer grids, due to self-spacing rods is that the fuel assemblies are..don't require mixing vanes and that allows us to reduce pressure drop across fuel assembly by nearly 50% which has some implications for natural circulation in the fuel. You can see here on the right-hand side, I'll show another image of this, but to just describe simply with a short array here, a small array of 2 by 2 rods, the self-spacing plane which exists in fuel bundle where these four adjacent rods all touch one another and you can imagine the repeated array here and then if you, as you move axially along the fuel up or down away from self-spacing plane, due to the twist of those rods, this channel opens up. Although it appears to be a closed channel in this plane, that plane is just a plane. When you get away from that, halfway between two self-spacing planes, you have a fully open matrix of coolant flow and mixing of coolant. What we’ve seen with some of the modeling we have done, coolant mixing within the assembly is actually quite good compared to conventional fuels with mixing vanes.

Talk a little bit about how that would look in a fuel assembly. On the left-hand we have a picture of a mockup fuel assembly of Lightbridge’s thorium, seed and blanket fuel for a hexagonal fuel reactor. Not that we are developing thorium at the moment, but a thorium, seed and blanket fuel does utilize the tri-load version of our metal fuel rod in the seed region that you see kind of elevated in the center of the assembly here. This this also includes all of the control rod guide tubes that would be standard in a conventional fuel assembly for a PWR reactor. This is just to demonstrate that the metallic fuel can integrate well with existing fuel assembly designs and it enables the design of a new fuel assembly that can be a one to one drop in replacement for a conventional fuel assembly without changing control rod guide tubes or any, excuse me core internals. Now on the right-hand side here two schematics looking at the corner of what would be a 17 by 17 fuel assembly you can see the peripheral row of fuel rods are off set slightly in the array and brought in a little bit and that's due to spacing requirements for the 17 by 17 assembly you can see a small control rod guide tube location there in the middle and we do not show a corner structure of the assembly here, but there will be some structure, structural element in the corner of the assembly that provides structure for the assembly and a location for a shroud or potentially bands to go around the assembly as well. Again, that's not shown here and that would be specific to the assembly design for any particular reactor.

Looking at the fuel mass and enrichment comparison, this is a slide just showing how much material is in a fuel assembly of Lightbridge's metal fuel. The table on the, in the top left looks at three different fuel assemblies on the first four loop PWR, this would just be a conventional 17 by 17 UO2 fuel assembly. Then we would have a Lightbridge replacement assembly for 0% power up right 18 month cycle, so essentially one to one replacement of conventional fuel. On the right-hand side this would be a Lightbridge fuel assembly, still a one to one replacement but now designed to operate with 10% power up rate and 24 month fuel cycle. Looking at the total mass of the, of the fuel rods themselves, not taking into account the assembly hardware, you'll note that Lightbridge Fuel is a little lighter than conventional fuel assemblies by about nearly a hundred kilograms. I think when you put the final fuel assembly design I expect..we expect that will be a little closer but we do anticipate this assembly being somewhat lighter than conventional fuel in terms of the total mass. The bottom row is the uranium-235 mass per assembly. You can see the four loop conventional PWR fuel is about 19 kilograms per assembly, the Lightbridge replacement assembly would have 22 kilograms, we do need a little bit additional to account for reduced plutonium generation at the end of life of the fuel and fissions from plutonium. And, then the 24 month, 10% [outbreak] fuel cycle, there is about a 12 kilogram increase in KGs of U-235 for fuel assembly.

And, then on the right we have a graph that looks at K-effective for all metal fuel assembly, all rods enriched to 19.7%. This is as a function against the gadolinium content in the displacer. I mention that central displacer can be used to include burnable absorber material, to control criticality against the function of the gadolinium content in the displacer. I mention that the central displacer can be use to include burnable, absorber material to control criticality and this shows, this model shows that the gadolinium density that you would need to keep the fuel assembly subcritical is less than1%. So once the fuel, as I said the high assay does have implications on the front end and back end of the fuel cycle. Once the fuel has been fabricated into fuel rods, the performance from a neutron physics stand point is quite similar to what's known today and expected today with conventional fuels.

And I've mentioned as well, the cold fuel operating temperatures. That's really driven by a couple different features of the fuel. Obviously the metal composition of the fuel has a much higher thermal conductivity, approximately three times higher than ceramic fuels and UO2 fuels. The stability of the microstructure of the fuel during irradiation also has some significant implications as we don't see that cracking and degradation and that you would see in a ceramic pellet so the pathway for heat to be conducted into the coolant is continuous. And it is also a shorter pathway compared to cylindrical fuels due to that multi-lobe shape. And you can see in the bottom left here a graph of the temperature distribution inside of a fuel rod of the four-lobe variety, this would be operating at 17.7 kilowatts per foot which is about 30% in higher linear heat generation rate than conventional

UO2 fuels would see for a 17 by 17 PWR and you'll notice it is a very shallow temperature gradient across the fuel rod.

I'll talk briefly about the swelling of the fuel. Obviously metal fuels do swell more than folks are used to with conventional ceramic fuels. I did mention at the beginning that the alpha phase, Uranium, U10-Zirc family of fuels that see extensive swelling early on in life, that is not what occurs with delta phase material. The delta phase alloy actually swells almost linearly with respect to burnup as I said all of the fission products and fission product gases behave like solid fission products. You do tend to see an increase in the.. at the valley between lobes, that is where the bulk of the swelling occurs in this rod. The circumscribed diameter of the rod doesn't really increase nearly as much. Essentially the rod is trying to take on more of a barrel shape. In an unconstrained case you do see some swelling at the lobe tips and what we are seeing with other fuel designs of this type is that the lobes can accommodate the swelling of their adjacent rods where the point of contact of adjacent rods may move up or down slightly as the rods bow, not bow, sorry, swell and the lobes bend during irradiation to accommodate swelling.

Will also comment on that increasing the swelling does, decrease, rather, the coolant flow area in fuel assembly where our model suggests that is consistent with decrease and power output of the rods due to burnup. No issues of not having sufficient coolant flow in the assembly due to swelling.

So talk a little bit about benefits of Lightbridge Fuel and why we think Lightbridge Fuel is a good option and what we have heard from some of the utilities about the fuel. The, really the benefits can be summed up with operational flexibility. The light water reactor fuels.. conventional light water reactor fuels.. based on UO2 pellet-and-tube design compared to the metal fuel, the metal fuel offers increased power up rate which I said, extended fuel cycle length, enhanced natural circulation, and all of these things can kind of be designed and each fuel system can be tailored to provide these benefits or certain benefits over others can be optimized over others depending on what the fuel cycle needs or the reactor vendor, reactor owner desires. We also do see some improved safety in normal operation and design basis accidents. You may have seen some of the work we have done on LOCA situations and other design basis accidents. In terms of beyond design basis accidents there may be some improvements in coping time due to this fuel but similar to the ATF fuels, it doesn't look like it would be very much. One of the benefits, again, of the Lightbridge Fuel is that we can incorporate some of the technologies developed under ATF programs such as the coatings. Some of the coatings, and potentially am some of the advanced cladding alloys can be incorporated into this fuel to bring beyond design basis performance as well. One of the other benefits in terms of reactor operation as you see in Small Modular Reactors come on the grid, increased in renewables are, the fuel is capable of very fast ramp rates compared to pellet-and-tube fuels, if you think about diagram of ice breaker reactor siting a thousand kilometers from anywhere, the reactor on those vessels does have to go from low power to high power very consistently, reliably and quite frequently. So, this fuel would eliminate the fuel being the weakling in the chain of a reactor's ability to load follow. And although if, contrary to what you might think with using a high assay LEU fuel, we do see improved proliferation resistance with this fuel when you consider both uranium and plutonium vectors on both the front end and back end of the fuel cycle. So those are some of the benefits that the fuel can provide; we do have a tremendous amount of work to do to demonstrate all of those benefits and to see exactly where the limitations are on how much improvement and optimization we can provide in any specific area and we look forward to working with the utilities to -- identify what benefits they need to see in order to make a fuel a reality.

Now I'll talk briefly about the manufacturing process. I did mention that primary mechanism of forming the fuel is a co-extrusion process. The first step is casting of the uranium zirconium ingot. That's a melting process where uranium and zirconium metal as melted together, that ingot then goes through hot working steps, form co-extrusion billet, which would include the central displacer, uranium zirconium fuel kernel and the cladding alloy all in one single component. That component is heated to a high temperature and extruded to deliver the metallurgical bonded rod helically twisted rod. Then that would go through some finishing operations, chemical cleaning, heat treatments and into NDE and final inspection.

Then a brief slide on our ongoing and near-term development activities. As I mentioned the closure of the Halden program really caused some delays for Lightbridge, but we're back up and running on developing, two different fronts of the program at the moment. First the fabrication process development and demonstration. We've recently announced that production of another set of surrogate fuel rods which don't contain uranium. But, these are co-extruded fuel rods which will enable us to do some validation of the process and optimization of the co-extrusion process. We will also be validating a computer model simulation of the extrusion process that we've developed based on the analysis of these rods. And, we'll also be doing some corrosion testing and hydride evaluation of the, as-fabricated fuel rods at this point; we don't have irradiated fuel to do that testing on yet -- that will come later. Also related to the fabrication side we recently were awarded a DOE GAIN voucher with Pacific Northwest National Laboratory to demonstrate casting of the uranium-zirconium process. We expect that that work should commence very soon. Then the other aspect of the program is obviously demonstrating the fuel performance itself in irradiation. In that regard we have a second DOE GAIN voucher with INL that has been on-going to design a uranium zirconium fuel irradiation test in the ATR. That will provide PIE data for the fuel material as a function of burnup and lead into other near-term demonstration activities which would include prototypic fuel rod production and irradiation testing likely in a loop at the ATR that we would expect – we're hopeful to get that started in a four to five year time frame. Following that are the design of the program is that the loop of radiation test in ATR and maybe some additional fresh fuel characterizations and testing would provide sufficient data to move on to lead test rod demonstrations of fuel in commercial reactors. And then into Lead Test Assemblies.

So a brief statement here to finish up on considerations for use fuel management, as I said we do not have at Lightbridge any of the performance data from the historical fuels that were developed in this family of fuels, so we don't have a lot of information that we can provide in terms of hard data at this point other than to kind of make the comment that, based on the robust design of this fuel rod and the stability of the fuel during irradiation, the absence of fission product gases in a gap or in a plenum; we anticipate this fuel will meet or exceed the performance of conventional pellet-and-tube fuels during storage and transportation both during, fresh fuel conditions and used fuel conditions. I mention the fuel assemblies, the intent is to design those as one to one replacements for conventional fuels. We don't see any issues there from a mechanical performance issue with, you know spent fuel pool storage or even dry canister storage. You know, looking at the dry storage solutions is something that we will need to do in more detail once we get closer to having fuel ready for dry storage. A preliminary review and assessment by our team really identify no show-stoppers with respect to the fuels Lightbridge Fuel design. Although there are clearly, there is clearly a lot of R&D that needs to be done to develop the technical basis for that. But based on the fuel rod integrity and robust nature of the metal fuel we don't see any issues where this fuel would perform worse than conventional pellet-and-tube during dry storage. In terms of fuel storage, I mention that fuel is a little lighter, expected to be a little lighter than a replacement assembly. There may be a difference in how we, how the fuel is loaded in terms of the hook that connects to the fuel assembly and moves it around, but that's to be determined and really dependent on those specific reactor. In terms of subcriticality of the fuel, looking at the high assay LEU fuel at 19.7%, the discharge enrichment for that fuel is approximately 4%, so that's equivalent to a UO2 assembly of around 1 to 1 and a half percent enriched so does have a slightly higher discharge enrichment but, looking at what we showed earlier in terms of the neutronic performance of the fuel, we don't see that being a show stopper. It may cause some increase, may need to have increases in burnable observe conversation in the dry canister but nothing that couldn't be addressed. In terms of retrievability of the used fuel again we think the metal fuel is a much more robust fuel than the pellet-and-tube fuel, so should not be any issues there. In terms of heat generation with this fuel, realistically the products are what drive the heat generation and those fission products are – fission product concentration is dependent on power output of the fuel. So, in a one to one replacement scenario, UO2 fuel to Lightbridge Fuel, we really don't see any difference in the fission product heating from the assemblies. If you do have a power up-rate with Lightbridge Fuel, that would lead to increase in fission products, increase in fission product heating and an increase in spent fuel pool storage time. Based on the changes in composition of the fuel, there are -- we do expect some differences in actinide heating just as there is, as I said, there is less uranium and less plutonium in the fuel. The minor actinide composition is different. However our preliminary evaluations of that, not certain the code is telling us the right answer, we will wait to make further comments and detailed comments on that once we have done some of the irradiation testing currently being planned. So with that I would like to thank you for your attention and open the floor to the Board for any questions.

>>Paul Turinsky: Thank you very much, Aaron, for your presentation. Lee Peddicord has a question.

>>Lee Peddicord: Aaron, very nice, thank you. Interesting stuff, really interesting. Of course it's been also interesting kind of to watch the evolution of this as we're involved and so on going back quite a ways. One kind of geometry question, I think this is back on slide 9, yeah so you talk about the corner situation there in the self-spacing arrangement. So the thought that comes to mind is can you maybe do variations of your form that would be like two-load designs to fill that corner spot? Because you are going to have implications from the additional moderation, you talked about equipment here, putting a fuel rod in there would be awful good. You had some creative ideas on what you can do there with your designs.

>>Aaron Totemeier: Yes, yes, Lee, we definitely do. Being this is a public forum I really can't speak too much to those at this point in time. You are correct. There is – there would be an issue with no structure there or, part of the design of that corner structure for any specific fuel assembly would have to take that into consideration. There is nothing that would prohibit using different number of lobes and rods there or maybe a smaller rod or something to that effect but really can't get into too much detail on that at this point.

>>Lee Peddicord: Yeah I think nice thing about the design is you have a lot of flexibility in the way you can approach things as well too. You are not locked into the traditional cylindrical pellet and tube and so on. The other question I had is, is there anything to be gained from the metal fuel experience with EBR and the IFR concepts, obviously you know different application, different forum, but in terms of storage, retention of fission products [inaudible] is there data there that is useful to you?

>>Aaron Totemeier: It is an area we would have to look at in more detail. I think due to the inherent nature, differences between those two fuels, the U10 Zirc family, sodium bonded,

high density fuel, this being metallurgically bonded would likely lead to some differences may be some value in evaluating the data that they do have there.

>>Lee Peddicord: Yeah, I was thinking primarily of some of the long-term storage and back end issues and the retention of the metal matrix. For fission products and so on, which of course is the interest here on the part of the Board. And in any case thank you very much, appreciate it.

>>Aaron Totemeier: Yeah, thank you.

>>Paul Turinsky: Tissa?

>>Tissa Illangasekare: Yeah so this is a very simple question, thank you for the presentation. So this idea of, very interesting idea to increase the surface area, but if you take the same vertical space, if you twist something and the mass goes up too, is that correct? The area increases at the same time the mass of that material goes up, doesn't it? If you're going to call a certain vertical space and then take a non-twisted rod and a twist it and then it is going to, you have to have more mass, so surface area increases but that also increases the mass.

>>Aaron Totemeier: Correct, yes. That's accounted for in the both the composition of the fuel, you know, I showed that delta phase window where there is a variation in the composition to achieve the delta phase and also in the enrichment that would go into the fuel assembly. We do take into account there is essentially increased mass in this fuel than if it was, you know, just a straight rod at the same length.

>>Tissa Illangasekare: Yeah so how much difference does it make because of the extra mass with respect to efficiency or, to look at the performance?

>>Aaron Totemeier: It's difficult to say from a comparison of apples to apples. We have not tested the, this metal fuel rod as a straight rod; we don't think that would --

>>Tissa Illangasekare: I see.

>>Aaron Totemeier: Yeah we are really focused on using a rod as a twisted design.

>>Tissa Illangasekare: Thank you.

>>Paul Turinsky: I have several questions. One is while we have this slide up, what holds the rod in position? Is it the top and bottom nozzles where it is attached and then no grids in between?

>>Aaron Totemeier: That's correct Paul. The top and bottom nozzles would be the primarily elements to hold the individual rods in place, as I mentioned the, there would be some type of shroud structure or, or banding structure around the outside of the assembly potentially similar to a BWR canister that would also provide some structure and then the structure of the assembly would actually be contributed to by the corner structure element that's not shown here. But for the individual rod, yes, the rod would sit in the bottom plate and it would have a mechanism to control the alignment of that rod so that we can control where the self-spacing planes occur with the fuel.

>>Paul Turinsky: Okay with the can, extending the whole length..that will certainly effect the typical PWR hydraulics.

>>Aaron Totemeier: That's an area we need to look at. The can idea, the canister idea would need to have some flow holes to allow assembly cross flow and that's something that we will need to look into depending on the specific reactor design for the fuel, yeah.

>>Paul Turinsky: Yeah, yeah, PWR people do some [inaudible], but it is not like a BWR because they have lots of cross flow going on to equalize the uneven flows coming in from the lower plenum area. Okay the fuel matrix, is its composition similar to what was used in, in fast reactors?

>>Aaron Totemeier: --Most of the fast reactor fuels, --U10 Zirc family, 18Zirc, and some plutonium were over in this region of the diagram. This alpha phase uranium is what causes that, well for lack of a better term, gross swelling of the fuel barrier early on. That's why those fuels needed to have a high smear density. Moving to the delta phase region over here and getting rid of that alpha phase uranium material is what leads to a much more stable swelling with the fuel, that coupled with a low operating

temperature.

>>Paul Turinsky: Why didn't the fast reactor people do that?

>>Aaron Totemeier: Well, if you are over here in this region you have a lot more Uranium, so you can get more enrichment.

>>Paul Turinsky: Okay I got it because basically the fast spectrum, the cross-sections are much, much smaller. And they have to get very high density fuel. Okay, and then have you done any in-pile testing at all at this point?

>>Aaron Totemeier: --Yes but we don't have any of the data associated with that. I mentioned before, the high enriched uranium issue in getting data associated with that and that, it turned out that test, the in-pile testing that was done, was performed on the fuel rods that were fabricated for that were above 20% enrichment and, therefore, the data that came out of the PIE was not available to be sent so the in-pile testing that we have done to date is not available and that's why we're looking to recreate the program, first at the Halden reactor and now within the DOE complex.

>>Paul Turinsky: Okay and fluid testing, what has -- have you actually done DNB tests?

>>Aaron Totemeier: We have not done DNB test but we have done some fluid flow testing of the, of this assembly here, a mockup of the trial, of the thorium seed and blanket and some different variations of that. We've looked at just mockups of region, mockup of blanket region and the whole assembly together. So we do have some flow testing related to the three-load version of the rod. We will need to do more of that type testing of course and specifically when it comes to DNB testing an area that we need to look at. How do we, one of the challenges there is recreating the power density in these fuel rods. As you can imagine, being the multi-lobe shape of the rod we don't have a constant power shape radially or I'm sorry, as a [inaudible] around the rod. So recreating that in a test situation without nuclear material in it is a bit of a challenge so. Thinking of creative ways to address that issue.

>>Paul Turinsky: Okay, yeah thank you. Any more questions from Board mutually exclusive before --? Ok, Nigel has a question.

>>Nigel Mote: Thanks Paul and thanks Aaron for another great presentation. As I'm sure you know, in light water reactors end cap failures have been, at least early on, a major problem. Your fuel you make like spaghetti, see if I can bring you down to basics. So what's the mechanism for putting the equivalent of an end cap on to complete the containment provided by the cladding?

>>Aaron Totemeier: That's a good question, Nigel. During the fabrication process, again public forum I can't really show too much here, well actually, if you go to the Lightbridge website we just released some images of this most recent fabrication. So I could have included those in here. But the billet that we make for each fuel rod is a canister of cladding alloy, a bottom, cylindrical slide and a top of the zirconium alloy. Inside that canister is where the fuel and displacer go. That canister is then welded shut prior to extrusion, when the rod gets extruded it comes out of the extrusion press with the fuel material fully encapsulated in the cladding alloy both on the top and bottom and on the sides. But there's no --real step to add an end cap after the extrusion process. It's effectively done prior to extrusion.

>>Nigel Mote: I understand that, so what stresses are generated in the end parts of the rod by swaging or whatever the term is for how you extrude that in, as a single piece. What might the end cap characteristics be that would give a problem?

>>Aaron Totemeier: It is difficult to say at this point, again after the rod is extruded we actually machine the ends of the rod to fit into the top and bottom nozzle. So it's quite likely the region that was welded prior to extrusion has been removed in terms of the stresses that get developed at the top and bottom of the rod we don't see any evidence in our initial modeling and from data we have seen on the previous fuels for ice breaker reactors where there were any problems associated with swelling or with stresses in the top or bottom of the rod.

>>Nigel Mote: Okay, thanks. And, I have a second one, on slide 9 where you have the self-spacing plane with the rods actually touching at the peaks of the lobes, when you get touching like that, that means to me that there is actually zero flow if you look minutely at the point of contact. What's the impact of, even if that point of contact might mean there's zero flow is only microscopic and therefore very small, an interruption of flow on a basis around the point of contact. What is the impact of that in terms of cladding performance and also neutronics, can it effect the neutron spectrum?

>>Aaron Totemeier: That's a good question, as you said its a point of contact or if you move axially above or below it begins to open back up. From a neutronic stand point the modeling we have done to dated suggests the impact of that twist doesn't really need to be considered in most of the neutronics modeling. We can model this as a straight element and it will, it will get this nearly the same results if we model them as twisted elements. From a fluid flow perspective, you are right. It does create at that point contact where you cannot get cross-flow from one coolant cell to the other, but it is such a small point of contact. The modeling we've done and the measurements we have done on fluid flow show that coolant mixing through this assembly is quite good, at least on par with what you would have with the latest and greatest assemblies with advanced mixing vanes. So it doesn't seem like fluid flow across this point is an issue. And also add that from a thermal perspective these are, this is the coldest part of the fuel out at the end of the lobe tip, so there is unlikely to be the development of hot spots in that region due to any coolant flow abnormalities. But, again this is all information, very good questions, but these are things we will need to address and develop the technical basis for as we move through the fuel development program. Part of the output of this irradiation program we're currently working on with Idaho National Laboratory is to develop some of the underlying -- measure some of the underlying performance and thermal physical properties of the fuel so we can feed that information into fuel performance codes and start to address some of those questions for fuel assembly as a whole.

>>Nigel Mote: Okay, thank you.

>>Paul Turinsky: And Andy.

>>Hundal Jung: Hello, yeah this is Andy Jung. Thank you so much for the great presentation. I have a two simple questions. On slide 5 in your phase diagram I understand that your helical rod consist of ..supposed to be 100% delta phase uranium zirconium alloy. And you say, the maximum fuel operating temperature is about 560 celsius.. that means allowable [indiscernible] temperature, right?

>>Aaron Totemeier: Yes, to determine that as our design limit for the fuel.

>>Hundal Jung: Okay. So that is the one clarification, in that case we also know that design basis accident case have such a high temperature, higher than 1000 Celsius degree. So, in this composition based on this phase diagram is it still possible to apply this composition for the design basis accident?

>>Aaron Totemeier: Yes that's a good question. What we have seen, because of the low starting temperature of the fuel and the low thermal inertia of the fuel, the fuel actually gets rid of its heat very quickly and it's doesn't have much sensible heat to begin with. During the design basis accident simulations we have looked at so far, we don't see any issues of prolonged temperature of the fuel being above the design limit. So this, consider maximum operating..maybe I should relabel this.. design limit for normal operation. There is the possibility that the fuel could, you know, go into a higher temperature region for limited periods of time during certain accidents, you know. In a Reactivity insertion accident scenario a design basis LOCA, you would expect to see this increase in temperature. Part of the fuel temperature effort will include evaluation and tests of those types of accidents so that we do have a justifiable understanding of time at temperature and, and what that does to the

fuel. Yeah, that's a good question, so should rephrase this graphic here as design limit operating temperature during normal operation.

>>Hundal Jung: Is there any public data to access to see the data?

>>Aaron Totemeier: I don't know if there is any public data related to that. I have to go back through the archive. I don't know that the data that I have seen from other researchers into this region show the temperature that the fuel was at.

>>Hundal Jung: Okay.

>>Aaron Totemeier: Just to follow-up on that, there have been computer models looked and computer simulations of this but in terms of physical testing, we don't have any. I'm not aware of any data at this point.

>>Hundal Jung: Okay, the second one is I have an interest in some potential degradation associated with the residual water, remaining after the drying process. So simply you increase the surface area to improve your thermal conductivity and then in that case the increasing of the surface area can be simply can interpret that as that the amount of any observed water on the cladding could be increased too, such as like chemically absorbed water is one of the potential big contributors to the amount of residual water and in this case higher surface area, so simply thinking ..higher residual water. So that is my interest but if you have any data or if you have a plan to study, that would be very great.

>>Aaron Totemeier: The program right now is really focused on getting the demonstrating the fabrication process, being able to fabricate rods we can then put into the reactor and get irradiated rods for those types of studies. It is a valid question to bring up in terms of the impact of the increased surface area. We have not done any investigations into that at this point in time but something that we need to address down the road. One could envision potentially modifying the number of drying cycles or the temperatures of dry cycle to take advantage of more robust fuel rod design to try to eliminate any additional residual water that persists, but I won't make any commitments to that at this point in time until we have some physical data to test with or physical samples to test.

>>Hundal Jung: Thank you.

>>Paul Turinsky: And Dan Ogg?

>>Dan Ogg: Hi. Thank you, Aaron, really nice presentation, good to see some of the data that you've included in your slides. My question is also looking to the future a bit and just curious to know if you've been in contact with any of the spent fuel cask manufacturers to discuss the possibility of using existing spent fuel casks for storage with Lightbridge fuel or if there would need to be modifications to any of the casks. Have you done any of that type of work?

>>Aaron Totemeier: ..Not officially but informal communications and conversations with folks about what things need to be addressed or might need to be addressed due to the differences in the fuel but nothing specific at this point in time. Yeah.

>>Dan Ogg: Okay, thank you.

>>Paul Turinsky: Are there any more questions from Board members or staff? And Dan I see your hand is still up.

>>Dan Ogg: No more questions. Sorry.

>>Paul Turinsky: Tissa has a question.

>>Tissa Illangasekare: Yeah sort of follow-up question. I don't think that's important so.. you mention that you have done a real run but I assume that you have numerical models to simulate what you are trying to go do, is that correct? Did it say the heat transfer processes and behavior can be simulated in numerical models?

>>Aaron Totemeier: For heat transfer processes, yes. We have numerical models.

>>Tissa Illangasekare: So my question is more for curiosity. Is it possible to compare that, you mention that you didn’t try the straight configuration. Just but it is quite easy if you have a model to compare the straight configuration verse the twisted. The reason I'm asking is twisting you can do to get maximize the..other benefits.

>>Aaron Totemeier: I'm sorry I missed the question --

>>Tissa Illangasekare: Is that like you are twisting the rod, my question is that if you are numerical models is it possible to come out at an optimum twist so that it can maximize the benefit of the twisting.

>>Aaron Totemeier: Yes, yes and that's what, what goes into that optimization is the.. not only the number of contact points within the.. within the assembly for that structural rigidity of the assembly, but also the fluid flow around the rod. You can imagine if we were to continue twisting the rod tighter and tighter and tighter, where you are not getting sufficient coolant flow. So yeah -- our preliminary design for the twist pitch of the rod is just that, a preliminary design. We would optimize that design for any specific reactor application to get the performance that the reactor wants to have.

>>Tissa Illangasekare: In the fluid flow, what type of flow happens in the.. is it slow laminar, laminar flow?

>>Aaron Totemeier: It is very similar to what you would see in conventional fuel in terms of the coolant mixing and the characteristics of the coolant flow.

>>Tissa Illangasekare: Okay. Okay, thank you.

>>Aaron Totemeier: Uh-huh.

>>Paul Turinsky: Are there any other questions at all? Okay, again our thanks Aaron for your presentation. At this time we have a break scheduled for 20 minutes. Since we're about five minutes ahead of schedule let's return five minutes earlier than on the agenda. So it will be 2:35 we will then start our presentation by the U.S. NRC. Enjoy your break. See you in 20 minutes.

[BREAK]

>>Paul Turinsky: Let's pick up the public meeting. I would like to remind folks that public comments can be made on the “Comment for the record” [link], on the NWTRB website. So if you wish to comment you have the opportunity to do that. Okay at this time I’d like to introduce our next speakers from the NRC; they will be talking about the NRC’s Project Plan for accident tolerant fuels. Our speakers will be Marilyn Diaz and John Wise.

>>Marilyn Diaz: Hi everyone, can you hear me? Okay, so let me just start the presentation. See if I can get to the first slide, okay, here, here it is.

Hi, good afternoon, everyone. I’m happy to be here providing the Board with this information. Like Paul mentioned, I'm Marilyn Diaz. I am the ATF front and back-end Project Manager in the Division of Fuel Management and ONMSS [Office of Nuclear Material Safety and Safeguards] at NRC. Let me go to the next slide. And today's presentation we will give you an overview of the scope and focus of the NRC ATF Project Plan and the implications of the nearer term ATF concepts on storage and transportation. We will cover the following topics during the presentation. I will provide an overview of the Project Plan, ATF concepts, and the revisions to the ATF Project Plan that we have planned. And then turn it to John Wise, my colleague, to cover the implications of ATF on storage and transportation, including some of our research activities and findings.

Let me go to the next slide. The U.S. NRC is committed to enable the safe use of emerging ATF technology and has developed the ATF Project Plan which describes the high level concept-independent strategies to facilitate efficient and effective licensing of ATF while still providing reasonable assurance of public health and safety at US nuclear facilities. The ATF Project Plan is assigned to increase regulatory stability and certainty and enhance and optimize NRC review while providing information on activities to prepare NRC staff for the licensing of ATF. ..the Project Plan covers entire field cycle from front end to back end. It describes NRC preparatory activities that we are undertaking; for example, it describes that we will be conducting phenomena identification ranking table exercise, also known as PIRTs, to identify significant issues introduced by a specific ATF concept that will help staff refine its regulatory infrastructure. It also describes how we're taking advantage of stakeholder interactions to ensure we do an efficient review with the focus on safety.

…For the purpose of developing this plan, ATF concepts are broadly categorized as near-term and longer-term. The near-term ATF technologies are those that we expect submittals in the near term. In general, the industry is pursuing these near-term concepts for deployment by the mid-2020. For these concepts the NRC can largely rely on existing data, models and methods for safety evaluations depending on level of licensing credit requested by vendors. I think DOE has done a great job of providing the details and information of ATF concepts. So I will just provide a quick run through of them.

The first here we have, coated cladding which consists of adding thin layer of chromium or other proprietary material to the outside of the cladding. We also the doped pellets, which consists of fuel pellets that are mixed with other materials, known as dopants, into the pellet during the manufacturing process. The third one here is FeCrAl cladding which is an Iron-Chromium-Aluminum based alloy, that has some advantages and disadvantages compared to zirconium alloys. There is only one fuel vendor pursuing this concept and design and the NRC understands this is still a few years away from being a viable technology.

The next slide… Longer term ATF concepts are those for which substantial new data, models. and methods need to be acquired or developed to support the agency safety findings. The long-term ATF concepts are silicon carbide cladding, uranium nitride pellets, and metallic fuel. I won't spend much time on these long-term concepts. I just want to say NRC staff continues to follow developments in the long-term technologies. I would also like to point out the nearer-term and longer term are terms of convenience used to indicate the current expected regulatory framework work that we need to do with the consideration of the deployment timeframe for each ATF concept. Regulatory requirements do not vary between near-term or longer-term concepts and the NRC will evaluate all designs based on their individual technical basis.

The next slide. So this slide presents how we're approaching ATF fuels licensing differently than the past to prepare for both near-term and longer-term ATF designs. The staff has established a new paradigm as described in the Project Plan. The old paradigm started with industry with developing the technical basis then in the series of sequential steps, staff will develop guidance, update their confirmatory codes, and build on expertise so that we will be ready for any regulatory activity. The new paradigm, as described in the Project Plan, takes on innovative approaches and have many of the steps being conducted in parallel. We have the development of guidance, confirmatory codes, and staff expertise in parallel with industry efforts to develop the technical basis for ATF. We're also doing work in advance of regulatory actions; for example, we're conducting PIRTs to inform guidance and build staff expertise early. The staff completed a PIRT for coated claddings which led to an interim staff guidance. In addition, in September 2020, another PIRT was conducted to address performance in severe accidents of current ATF concepts, high burnup fuel..higher burnup fuel and fuel with enrichments above 5%. We're also being proactive in our activities by obtaining information we need via research activities, literature reviews, and code enhancements to ensure readiness while we process licensing actions. We have completed five literature reviews and there are more to come. We're also communicating early and often. We’re conducting public meetings, updating the Project Plan regularly, conducting pre-submittal meetings, attending conference and workshops to keep up with the latest information and continue early engagement. The staff has and will continue to use innovative approaches to support licensing of ATF following the ATF Project Plan.

Let me go to the next slide. So as mentioned previously, the Project Plan covers the complete fuel cycle, including consideration for the front and back end. And that [inadudible] the strategy for preparing the NRC to license ATF designs with the focus on the preparation review and approval of regulatory action. The Plan groups its preparatory activities into four tasks. The first focuses on the in-reactor regulatory framework. The second task focuses on fuel cycle, transportation and storage regulatory framework. It describes how the staff will evaluate the applicability of existing regulations and guidance and identify any key technical and regulatory challenges. John Wise will go into the details of the test to you in our regulatory preparedness activities but at a high level, the NRC does not expect that tendency of Part 70, Part 71 or Part 72 regulations will need modification to accommodate the fabrication, transportation or storage of ATF, increased enrichment, and high burnup fuels. In this task we describe our expectations as far as the front end and the back end and identify potential challenges that the NRC or the applicant may need to address at the time of licensing. The next task is task 3 which focuses on Probabilistic Risk Assessment and task 4 focuses on Independent Confirmatory Analysis Capabilities.

Going to the next slide. So the staff is currently working to revise and update the Project Plan. Many of the updates will be for fact-of-life changes. This Project Plan was designed and meant to be a living document that may evolve as ATF concepts are more clearly defined, schedules are refined, and the knowledge of knowledge level of specific concepts increases as experimental testing programs are completed. Some of the revisions will be to update the information and streamline the format of the Project Plan to avoid any redundancy. Another item we will be revising is currently guidance assessment. Currently the plan provides a high level regulatory guidance assessment where guidance was identified to being impacted by ATF, increased enrichment, and high burnup. This new revision will expand that initial scoping assessment and provide a detailed gap analysis for a regulatory guidance. The new version will also have a discussion on the efficiency of the new paradigm and how we're measuring our readiness. And lastly, we are planning to issue the draft version and hold a public meeting in summer of 2021 and our plan is to publish the new version in fall of this year.

Now I'm going to turn it to John Wise. Thank you. John?

>>John Wise: Alright, thank you Marilyn. As Marilyn just went over, she gave a nice high level overview of how we're using the Project Plan to position the agency to review licensing actions when ATF technologies come to us. So, what I am going to do is, I'm going to kind of drill down into a greater detail, specifically with specific focus on storage and transportation or back-end issues. Although, I will talk a little bit about some of the preparatory work we've done on front-end issues and in the reactor. So I hope that at the end of our presentation today, you get a sense of the kind of issues we're looking at as far as.. are we in position to effectively review a licensing action? And so, I hope at the end of the day, you get that sense and, as well as the gaps that we see, data gaps that we see that we will be looking to the applicants to fill in when they submit an application.

So, let's go to the next slide and just briefly talk about what's been happening in the reactor side. Marilyn and I work in fuel management side, but there's been a lot of activity in preparing the agency for reviewing licensing actions for use in the reactor as Marilyn already mentioned. For example, as seen on this slide as far as chromium-coated concepts are concerned there was a phenomena identification ranking table exercise performed a few years back which was an exercise to bring the experts together, review the state of knowledge on chromium coated cladding, identify, rank, the phenomena of interest; you know, for example potential damage mechanisms and really use that information to guide what research we need to do as well asareas where we might be able to improve our regulations or our guidance more practically in this case. And coming out of that, as Marilyn mentioned, was specifically the creation of an interim staff guidance, which again is specific guidance to the NRC staff on how to approach the review of chromium-coated cladding in a reactor. And so and you can, you can find, you know, the PIRT activities as well the ISG report on our public website and I'll explain a little bit further later on how you get there and can access all of our information and reports related to ATF. As Marilyn mentioned, chromium-coated is ahead right now as far as a more developed technology. So, you know, where we stand now from the reactor side is we're, you know, we're waiting [on] the vendors to submit their topical reports for the use of chromium coated technologies in a batch, batch loading and we're more or less prepared to review those applications when they come in. Iron-chromium-aluminum cladding is a little farther behind so they are a couple steps behind. And again everything we do is the scope of our work and the timelines of our work are driven by conversations we have with the applicants. And, so when you see us a little bit ahead in the chromium-coated area, as compared to the iron-chromium-aluminum cladding area, well, that represents the conversations we have had with the fuel vendors on when they anticipate coming into the NRC for an application.

Moving on to -- from the reactors to the fuel cycle side both front end as well the back end .. this slide shows a summary of the main activities that work, the main areas where we see licensing actions related to ATF coming up. For example, on the front end because of the increased enrichments that you see in conjunction with these ATF technologies, you know, there are implications of having transportation licenses for UF6 of increased enrichment, the fuel facilities. There are specific licensing actions that need to occur to allow higher enrichment and transporting, you know, transporting the fresh fuel or unirradiated fuel to the reactor also likely requires licensing actions to demonstrate that that fresh fuel can be transported safely. On the back end, what I suspect you're more interested in today is, you know, we're interested in how does the irradiated fuel cladding perform in the storage, transportation and ultimately disposal. So, I'll touch briefly on these today focusing in on the back end.

So, what we have done already mentioned and as Marilyn showed in her graph that showed like the approach we take, we're trying to do things in parallel with the industry. Asyou know, when we are approaching what we need to do to be prepared to review an application we need to identify the critical paths, in other words, have conversations with the industry to figure out when are they going to be coming in.. what do we need to do to be prepared to review those applications. And I'll talk a little bit today about some of the research activities we have been doing. And when I say, research from the NRC's perspective, we're not doing that laboratory experiment or measurements that you heard about that DOE is going to be doing or fuel vendors actually getting their hand those rods, doing the measurements of the mechanical properties, et cetera. In our parlance, we talk about research in a sense of performing those technical assessments, those literature reviews, participating or supporting expert elicitations, those PIRT exercises and also making sure that all of the codes we use, you know, for the codes we use to predict fuel performance as well the neutronics codes. We're doing everything we can to make sure that those codes are prepared to assist us when we review those applications. So on the third bullet, as I said, we really are expecting the fuel, actual fuel performance data, mechanical properties, et cetera, to be obtained by our applicants, fuel vendors or in conjunction with Department of Energy and so, so when I talk about the NRC being prepared and I think Marilyn said, you know, we don't see any gaps in our regulatory process for reviewing these near-term concepts. That doesn't mean there are not data needs that need to be filled by the applicant when they submit an application, but we do feel we're in position to review those applications. And as I've already mentioned, scope of

what we do and the timelines of what we do have all been driven by the industries targets for batch loading.
Quickly, on the front end I already mention these broad areas that we are examining to make sure that we can support, do everything to support bringing the fuel to the reactor, such as the transportation of the raw material, the fuel facility work, as well as the transportation of finished fresh fuel rods. And there are no real large hurdles to need the licensing actions that need to be performed in order to allow the transportation and fabrication of the fuel. But, .. there are necessary regulatory steps or licensing activities that need to happen for that to be accomplished. And, so in keeping that in mind, in the next slide, I am showing – essentially, this is a summary of a letter we sent to Nuclear Energy Institute which was just to let the industry know and get it on record of.. okay, if you are going to be expecting to batch load ATF in a reactor at a certain date, here are the timelines you need to meet leading up to that date. So, ... there is very clear frequent and early communication between the NRC and the industry. So there's no surprises. And so, I have a little snapshot of the letter here and you can bring it up um I have ADAMS number which is our document database number where you can bring up this letter. And, it is a very simple letter with a flowchart that shows the Project Plan of how these front-end activities, you know, the timeline of those activities need to be completed in order to meet the batch loading.
So back to our research, which I'll spend the rest of the presentation discussing. The research we do, again literature reviews, PIRT exercises, model development, they touch both the front and back-end parts of our work and on the left-hand side of the slide you see the major..I'll call the technologies we're exploring..chromium coated, iron-chromium-aluminum, higher enrichments, higher burn up, really should be a doped fuel pellet box in there as well. And, what we are looking at predominantly in -- is how do all of these new technologies affect the cladding performance. Specifically in this case, we're talking about the cladding performance during transportation steps or later storage periods. And just broadly determining like the neutronics, understanding how the new technologies with increased enrichment, doped fuel pellets affect reactivity, radioactive source terms, fission products, et cetera. And so those are the two sort of major thrusts of the research we've been doing and those apply again as appropriate to their front end and back-end activities that I show there.
I'll step through this fairly quickly. I don't want to get bogged down in the fine details but I want you to understand the kind of activities we have been involved with. First looking at specifically cladding performance because in the back end when we're talking about storage terms, or later transportation, you know, the fuel cladding itself is dependent upon to provide some structural support to the fuel to maintain the fuel configuration. And so it matters, what the properties of those, of that cladding is. And so we have supported research predominantly at Pacific Northwest National Lab has been predominant source of our contractor support for fuel performance cladding, cladding performance activities, and they have generated a number of reports both on transportation of fresh fuel as well storage and transportation of irradiated fuel. And as you can see from that chart there, we still have some of that is still in progress. We have a, we do have a PIRT exercise or expert elicitation exercise planned for in the future to really look at, you know, the state of knowledge of the irradiated fuel performance of ATF. That originally was going to happen next year in Fiscal Year 22. We have pushed that back because we got a sense from looking at the timelines of those lead test assemblies and how quickly data will become available through either DOE or vendor testing of that data. We're conservatively kind of pushing out the target date for that PIRT exercise until we are confident there is going be a significant amount of information to review before performing that exercise. And I want to

point out on this slide, you see at the bottom, everything we've done. All the research we have done and the contractor support, the reports associated with cladding performance and what I'll talk about in a few slides, the neutronics work, is all available on our public website and so if you're interested you can download all of these and I'll show you in a little bit what that, where you can find that.
And next, as well as, you know, the implications of the different cladding concepts, we do have to think about the implications of increased enrichment or higher burnup on cladding performance; we have work going on there as well. And we have some work ..was done on just spent fuel in general, that's on the top row which is informative of the ATF concepts, but then we have upcoming report coming up from PNNL on increased enrichment and higher burnup effects on accident tolerated fuel concepts.
So what we found, quick step through fairly quickly is ..when we review open literature, you know, it is not surprising, you know, when you talk about chromium-coated zirconium alloys as far as fresh fuel, unirradiated, it probably doesn't have a big effect on mechanical properties and there is some data that suggests maybe fatigue performance could be impacted …and iron-chromium-aluminum, just more uncertainty, there's less data. So, there is going to be some... there needs to be some additional data brought to table in order for us to evaluate whether cladding can perform in transportation of fresh ATF. And for spent fuel I would, I guess the.. you guys might imagine that the data needs are even greater because we just don't have data on the performance of chromium-coated zirconium. Either just mechanical property data, thermal property data, fatigue data, same goes for iron-chromium-aluminum. And so this is the kind of data, you know, we are waiting on. We're paying close attention to the work DOE or the fuel vendors do on all these lead test assemblies because this is the kind of data that we'll be looking at when the time comes to license the storage and transportation of spent fuel cladding.
And I'll skip through this fairly quickly; this is just a more granular look at what I just discussed which is..we have technical information needs when we get into the licensing process--mechanical properties, fatigue life. We have performance parameters that we use now--thermal metrics in our licensing process for insuring fuel cladding maintains integrity' will that change with these new ATF concepts? And thermal properties, et cetera.
And I'll move on to the next topic which is, I was just talking about the cladding performance or like the mechanical performance of the cladding aspect of ATF. But then there is just the neutronics aspect, you know, when you're going to higher enrichments, increased burnup, we need to make sure our modeling capabilities are capable of modeling these with respect to reactivity, decay heat, radioactive source terms, et cetera. And so Oak Ridge National Laboratory has ..predominantly supported us in this work and their reports are again available on our website. And we originally were going to have a PIRT exercise specifically looking at neutronics .. actually it is not actually going to be pursued anymore and the reason is, based upon the work that Oak Ridge did, there were actually no new unique phenomena associated with increased enrichment, higher burnup that we actually felt warranted a PIRT exercise.
And going on to the next slide sort of summarizes that. You know, research Oak Ridge .didn't identify any really unique phenomena associated with ATF, increased enrichment, higher burnup.. you can't analyze with the current models, However those models, there is still room to validate those models. And so we will be looking for opportunities for getting additional data to validate our neutronics models. Absent that, it just means you may need to..build in some conservativisms when you use the models that have limited validation at the higher enrichments and so we'll be looking at for applicants to supply, you know, their shield analysis in their design basis and we'll use models as well to validate.

Finally, disposal. Nobody has really spoken about disposal and I'm hardly going to talk about disposal and the reason is the first bullet I have up there. Preparatory work on ATF disposal hasn't been pursued at this time and it is not that we're ignoring it, it's just that for the near-term technologies, those technologies that the vendors have some timelines that are imminent, we haven't seen the need to conduct significant research in that area. And it's really because, you know, these chromium-coated zirconium and the iron-chromium-aluminum just aren't that different than the current technologies, the stainless steel and the zirconium cladding alloys that we're dealing with right now. And so, when these new technologies appear, we do, you know, we do take a look at them and try to understand do we need to perform some confirmatory research to understand the disposal implications, but for the near-term technologies for ATF, we haven't found that to be a need. But we continue to monitor, you know, the activities in the industry and internationally and as new, you know, technologies appear or become more serious, you know, we will certainly circle back to the issue of potential disposal implications at that time.

So concluding, as Marilyn said at the outset, we think our regulatory framework is adequate for licensing the ATF technologies, you know, these chromium-coated, iron-chromium-aluminum, increased enrichment, higher burnup. Our regulations are written in a way that are adequate to review. There are opportunities for us, though, to supplement our guidance. You know the staff has a standard review plan for reviewing applications and to the extent that we can bolster that guidance to make a more informative review and a more efficient review we are certainly going to do so. And Marilyn mentioned the gap analysis that we have been doing to see where we might be able to bolster our guidance when we can. So ultimately we always encourage our applicants to engage us very early, you know, so we can meet their timelines and I think we've been able to successfully do that to this point.

Finally, our ATF website, really encourage everybody to go to this website and the reason is it's, you'll find a lot of information that is very accessible to the public, that talks about the ATF technologies that are pretty high level, you know, what they are and why they are being introduced that like I find to be very accessible to the layperson. But you can also at that same website, pull up those very detailed technical reports, all the licensing actions that we have been involved with to date, the submittals of topical reports..it's all there on our website so it is just NRC.gov, and on left side of that home page just click on a link for ATF and you'll be there. With that I'm done, thank you.

>>Paul Turinsky: Thank you, Marilyn and John for your presentation. I'll now open this up for Board questions, Lee?

>>Lee Peddicord: Thank you, Paul. This is Lee Peddicord from the Board. So, Marilyn and John, thank you very much. That was really informative and certainly from my perspective I want to commend you all for what really impresses me is that a carefully thought out welcome [indiscernible] strategy. You're kind of getting ahead of the reactor mode and try to play smart and be ready and be responsible when it comes your way. A question that came to my mind is that the US not only country looking at implementing accident tolerant fuels and advanced fuels. I'm wondering if you at all get a chance to interact with your colleagues and counterparts and other regulatory authorities to see what kind of questions they are asking about advanced fuel from ATF and in, have to be a little more rigorous, I believe, in looking at the back-end aspects before some of these even go into reactors. So, if you could maybe expand a little bit on that and what you are looking at, not only looking at international data but the perspective from other regulatory authorities.

>>John Wise: Yeah I'll take that and Marilyn feel free to chime in. …As, you know, when you heard from the DOE application -- presentation before, you know there is a whole

host of international activities, you know, that are being pursued, you know, you heard the discussion like the NEA activities. All I can say is, we look for every opportunity to be engaged internationally, you know, when there is an opportunity we try to get tied in. And so, you know, I'll use an example of, you know, the IAEA for example, they're soon going to be launching a specific research project for ATF which all of the member countries, you know, can participate in and ..share experiences and share research. And so that's an example that's coming up pretty soon that we're certainly looking to join but just as you heard from, you know, DOE, we tried our best to tie ourselves into every activity that's happening around the world, you know, we have a good relationship with a lot of other regulators just across the board, you know, not only in these formal arrangements where there may be international projects, but it is not unusual for the NRC to have more, you know targeted one-on-one meetings with other countries, the regulatory agencies from other countries to understand what they are doing, what problems they are seeing, you know how they are tackling issues like ATF and so engaging with other regulatory agencies around the world is kind of just a regular part of, you know, our business.

>>Lee Peddicord: Very good, thank you. Marilyn, anything else from your perspective?

>>Marilyn Diaz: I'll just add in the NRC website there is actually a page that talks about our international activities that provides details on what specific programs and groups we are engaging on actively engaging on. So I invite you all to go look at it and like John mentioned we are heavily involved, looking for opportunities to continue to get involved in the different NEA working groups and any other international working groups so we're trying to be as engaged as possible. On the transportation side I'll just mention that we have been actively engaged on the front end with the criticality bench, with the criticality experts on that to make sure that we understand their benchmark studies and any information they have going on that will help us as we go, as we move forward and think about any considerations on the front end for the, for the ATF and increased enrichment portion of it.

>>Lee Peddicord: Very good, thank you.

>>Paul Turinsky:: Sorry, had my mic off, Tissa, go ahead. Tissa? Can people hear me? In can people hear me now? Okay, Tissa. You are on Tissa. Oops. Let me find him again. Tissa, if you would raise your hand again that would make life easier for me.

>>Tissa Illangasekare: Can you hear?

>>Paul Turinsky: Yep.

>>Tissa Illangasekare: Okay again so I thought, okay basically within your presentations, again thanks for the presentation, you mentioned that new data and models which probably interest you are the probabilistic and risk assessment. So these are two connected questions; so can you expand a little, beyond the scope of this assessment and I assume that you are using models to do some of the risk assessment, is that correct? What is the scope of this assessment?

>>John Wise: Marilyn, I don't know if you would know any better than I do, I think associated probably with more the reactor side, correct?

>>Marilyn Diaz: Yeah, that's correct, the Project Plan, I think you are talking about task three and four that describe our preparatory activities and what we're doing on that. I may have limited knowledge but what I understand is that when you look at the Project Plan it really is, it's very high level but it does say that as we, we're preparing for these licensing reviews we're looking at our PRA models and how those are need to be updated so they are looking at the risk informed licensing applications and what capabilities do we have to update or update any models so that we are capable of doing that on the independent confirmatory calculation capabilities, that's why part of the models and codes and enhancements on it. We're taking

information from our literature reviews, PIRT and any research activities such as John mentioned research activities just looking at the information out there, we're not actually conducting lab experiments but we're taking all the information in so that we can efficiently modify and enhance our codes so that staff is available to use them for independent confirmatory analysis. So, when I talked about the PRA and confirmatory calculation capabilities and how the Project Plan describes that, it’s just at a high level that we're looking at the different things that we use as tools to review the licensing of this technologies and how we're preparing those to the specific of it. I think that's more of the in reactor performance and John and I are more of the front end and back end kind of experts. [LAUGHTER]

>>Tissa Illangasekare: So the, also you mentioned that you don't do research, understanding the context of…, so if somebody applying, they will provide you with a model so they have to provide you information on the validation of the model, is that correct? So you basically rely on the applicant to show that the model, whatever captures the processes which are of importance in these particular evaluations. So basically when the part of that application I assume is a model and model validation, my question: do have any guidelines on expectations you place on these models?

>>John Wise: Yeah so to clarify we actually maintain our own modeling capabilities. So we, we lean on the national labs, for example, Oak Ridge National Laboratory for, you know, the neutronics modeling; you know, we have fuel performance modeling that we maintain ourselves. And we use those to benchmark against what the applicants submit themselves. We see value in independently being able to model these phenomena like decay heat and reactivity, et cetera. So, you know, yes, even though we have that capability we use that to confirm what the applicants submit themselves.

>>Paul Turinsky: In the materials area don't you basically start with the experimental data and then have PNNL develop the fuel performance models for you? You don't necessarily take the vendors model. You’re more inclined to take the vendors data.

>>John Wise: You’re correct. We are not just taking vendors models. We maintain own modeling capabilities so we have own modeling capabilities both for fuel performance as well as cladding performance, fuel behavior in a reactor and even outside a reactor as well as all the neutronics. So again, you’re right. We, we're not taking the vendors models; we maintain our own modeling capabilities.

>> Tissa Illangasekare: So you own model are basically.. what is the relationship between your models and the DOE national lab models, for example? So do they, I mean do you compare your models with their models? Do you work with them?

>>John Wise: We certainly have a close relationship. We collaborate with DOE frequently. We have regular communications with DOE on all aspects of, you know, fuel performance front end and back end in the reactor, so conversations about modeling between how we're doing it and DOE is again, it's frequent interactions, you know. We maintain awareness of what they are doing and vice-versa.

>>Paul Turinsky: But a number of your models really are to developed by N=national labs, is that not true?

>>John Wise: For example like Oak Ridge has a very big role like in how we model neutronics, for example. And PNNL does too as far as some of the fuel performance aspects so you are correct, yes. Yep.

>>Tissa Illangasekare: So these models, you are -- you are convinced that these models are, the data exists to validate these models. You have some sort of control experiments or control test settings?

>>John Wise: Yes, yes. Because we do, you know, we rely on the data, you know, that's out there in industry to validate our model. And so certainly the validation is the key aspect of that and as I mentioned, when we're talking about the things such as going up in enrichment and burnup, you know, the data is more sparse, right. And so that's what we're faced with now is, you know, we think by and large the models

are fundamentally modeling appropriate phenomena but there are some data gaps as far as validating it and that's what we're looking at now, like what can we grab from the industry DOE work to bolster the validation basis of our models. When it can't, you just need to build in some more conservatisms, you know.

>>Tissa Illangasekare: Do you require them to simulate certain scenarios like in the application they say don't do something but do you require them to do some type of validation scenarios?

>>John Wise: [No audio]

>>Paul Turinsky: We lost your audio John.

>>John Wise: I'm sorry, yeah. We're getting a little too far away from my area of expertise unfortunately as far as the details of the model development. And so it's again we, when the applicants come in, they model the phenomena, we're looking at them to show their models are appropriately validated, we're doing the same on our end and I guess, you know, that's reached the end of my expertise in that area.

>>Paul Turinsky: Tissa, the answer is vendors submit topical reports to get their models approved.

>>Tissa Illangasekare: My question has to do with the fact that – and I do model validation of various things, but when you do validate a model sometime when vendors gave you a model but then may require you to test a phenomena, it may not be really like a coupling phenomena is a good example that some kind of coupling validater well because the experimental data doesn't exist in those situations. My question has to do with the fact that you ask them to do that type of testing and they come back and say we don't have the data. I'm assuming that NRC has the authority to say we like to run these models around these scenarios.

>>Paul Turinsky: Yes. Okay, anything else? Okay Steve?

>>Steve Becker: Thanks Paul. Steven Becker, Board member. Marilyn, you did a very nice high level overview, thanks for that. And you already partly touched on the matter of engagement including international engagement. I thought it was also notable that you talked about the importance of communicating early and often and you actually made a point of including a pretty big bullet point about that in one of your slides. Could you perhaps tell us just a bit more about what is being done to facilitate early and frequent communication, including with the public?

>>Marilyn Diaz: So yes so this is an area where I think that's one of the things that has worked as we move forward for preparing for ATF licensing is the.. increased engagement with both the public and the fuel vendors and DOE also is that we have conducted several public meetings in the past and actually I'm going to keep referring to the ATF website but we designed the ATF website just to provide a lot of information on it, including all the public meetings that we have done so far. We are also having quarterly meetings with the fuel vendors that have public portions and then closed portions with the fuel vendors just to get that information, the latest information on what they are doing, the testing they are doing. It's mainly with the NOR, the nuclear reactor people but ONMSS is also involved on that so that we can take advantage of those discussions and prepare ourselves for what's coming. The one thing that we have seen is that a lot of focus has been placed on the in-reactor but the licensing actions that have come in are more on the transportation side, on the front end. And so we have done a lot of things and we're preparing for all the ATF concepts and this type of increased engagement and communicating with vendors, communicating with DOE on their plans and communicating with a public early on has helped us trying to navigate through that preparedness roadfor this ATF licensing action. So to, I mentioned public meetings with conduct public meetings we have another public meeting coming in June that will talk about high burnup. It is high burnup workshop so that's another opportunity that we will have with applicants, licensees and the public to meet on that specific topic of high burnup as it relates to ATF. I talked about meeting with DOE internationally interactions and so there’s a place in the website where we invite everyone to

submit any questions or any, anything they have to say on it so as far as .. increased engagement ..ATF I think the ATF program at the NRC has done a great job of trying to capture all that and be very innovative on how we're interacting with all the stakeholders on this.

Steve Becker: Thank you I can actually see from the slide from the website the ATF website that it looks like you are also trying to anticipate likely questions and have clear answers to those, including it looks like some video segments and so on. So that clearly will make it more accessible to more people. Thanks very much.

>>Marilyn Diaz: Sure.

>>Paul Turinsky: I have a question that is when you get to a stage, not LTA, not lead test assemblies, how deep will you be involved in considering eventual disposal? Because I can imagine with pellet compositions changing with the doping, that the dissolution rates may be different, the grain sizes are going to be different of that fuel. I mean that's what they are trying to do is upload your grain sizes. Honestly, I don't know if that's good or bad or different. The cladding material is going to be different and the chemistry inside the canister, the disposal package will be different. So there seems to be things there to consider and I just wonder when you eventually license a batch of fuel, how deep will you be, your R&D be basically so those the considerations for repository performance.

>>John Wise: Yeah it's, you know..it's hard because what we're faced with is an uncertainty of how disposal is going to be approached because, for example, if you are to look at Yaka Mountain, the final application Department of Energy didn't credit the cladding at all. So, but would that necessarily be the case when in a potential new disposal application? And so all of those, I can't disagree with all of the phenomena that you brought up, like what about the different, what is the doping, does it introduce something that's unique, something that could cause problems or need to be considered. All of those things, you know it’s a struggle because we're looking at a sort of an uncertain approach by what the disposal option may be. You know, is it conceivable that a future disposal option would want to credit the cladding in some way for example. But, you know, I got to say we're not, how do I say, not ignoring it all together because for example the work that's being done in the neutronics area, well, you know, you can argue well that is kind of informative to some extent of disposal because now we have a better understanding of the fission products on radioactive source term, et cetera. And so even though a lot of that work we were doing from the standpoint of transportation, criticality issues and issues like that. You can imagine that there is some applicability to the, you know, the disposal regime as well. But, you know I guess I can only say is, you know, we keep our eye open. We're looking at how when you have things are developing, when we see the potential for maybe unique phenomena presenting themselves try to prioritize that and, you know, you bring up some good points, you know, the doping phenomena, did we really cover all of our basis, do we need to visit that for disposal. That's a legitimate question, that's something we’ll need to consider.

>>Paul Turinsky: It seems your applicant at that point isn't fuel vendors anymore, it is DOE.

>>John Wise: Correct, certainly, certainly yeah.

>>Paul Turinsky: Okay are there any more questions from Board members before I turn to the staff? Steve you still have your hand up, is that by accident or -- okay let me go to Lee. I just noticed him.

>>Lee Peddicord: Am I on the air here?

>>Paul Turinsky: You are live.

>>Lee Peddicord: So John, I wanted to say I was impressed and pleased that you even had a slide on disposal and I, maybe you did that at midnight just to placate us because that's where we are coming from. But, what I want to say is, I’m really pleased because of where you are on this and that is kind of going through a thought process. In

some ways it is trying to know the unknowable, we don't have a location, we don't know the characteristics but I think you are really spot on in saying, okay here are things we might want to be thinking about, here are the issues that might be coming up and let's keep things in line as you go through the process you are going through. Again I want to commend you for that and your midnight efforts to do a slide for us. But again I think you are in exactly the right spot, and exactly in right space in terms of this. So, well done from my perspective.

>>John Wise: Well thank you but I believe Dan Ogg made me put that slide in. So you can thank Dan.

>>Lee Peddicord: Thank you Dan, thank you.

>>Paul Turinsky: And now Bret.

>>Bret Leslie: Thanks, Paul. Bret Leslie, Board staff, kind of a follow-up to Paul's question but also trying to draw parallel to what John and Marilyn talked about. It’s really incumbent upon the applicants to come in when they think they are going to have a novel application and John you were wise, not just with your last name, but yes Yucca Mountain they did not take credit for cladding, however there is a disposal criticality report, methodology report, and DOE and generic repository studies are now looking to take credit for cladding regarding criticality, and so it might be incumbent on DOE to come to you and say, pre-licensing, what else are we missing? Has DOE made any overtures to NRC regarding that?

>>John Wise: …Not that I'm aware of but I'm not necessarily the point person, I have to admit. So I don't want to --

>>Bret Leslie: Sure, that's fine.

>>John Wise: Misstate the situation.

>>Bret Leslie: Okay, thank you John. That's all I have.

>>Paul Turinsky: Are there any other questions for Marilyn or John? Okay well thanks to both of you for a very informative presentation.

>>John Wise: Thank you.

>>Marilyn Diaz: Thank you.

>>Paul Turinsky: We're now going to continue the discussion of the back end processes, but now hearing from DOE on the work they're doing on the back-end stages of storage, transportation and disposal. And our presenters will be William Boyle, Bill Boyle from the DOE office of Spent Fuel and Waste Disposition and Sylvia from Sandia National Laboratory. Bill, you are up?

>>William Boyle: Okay, can everybody hear me and see me? Is that affirmative? Okay. And people can hear me? I will assume that's a yes. So I have no slides, but there are the questions in the agenda that I will address here. What is DOE office Spent Fuel and Waste Disposition approach to accommodating the new nuclear fuel designs including accident tolerant fuels in DOE’s Integrated Waste Management System? That is, what effect does this have on planning for storage, transport and disposal? And really, it's the approach to accommodating these different spent fuels is to follow the terms of the contract which is what DOE is obligated to do, as are the utilities. You take the gentlemen from Lightbridge.. my sense from his presentation is Lightbridge intends to be a fuel vendor and probably won't sign a contract with DOE or won't need to. But, let's say he sells a fuel assembly to operating power plant in Palo Verde, nearest one to me probably in Arizona. And Palo Verde uses some Lightbridge fuel. I'm pretty sure that the Lightbridge spent fuel would be governed by the contract that Palo Verde signed with DOE, so they would have some obligations, they have reporting requirements to DOE, you know, with respect to the nature of the fuel. And DOE has some obligations which would be to pick it up some day according to terms of the contract. And that's the overarching theme and as with all the spent fuel that the utilities generated but also the government‘s spent fuel. It’s all..it’s not all the same. It's using Yucca Mountain as an example. There were all kinds of different varieties of commercial

spent fuel ranging from boiling water reactors, to pressurized water reactor, to the size of the assemblies, to the enrichments, to the cladding material, on, and on, and on. And DOE had to deal with it and did. These newer fuels.. same sort of thing.. it's.. DOE will do what it needs to do in terms of whatever lab tests or modeling it needs to do to get enough information for a day when materials are ready to be disposed somewhere. So that was question one.
Question two, to what extent do contractual agreements between DOE and nuclear utilities regarding the acceptance of spent nuclear fuel by DOE, allow DOE to influence the use of advanced nuclear fuel designs including accident tolerant fuels by utilities? I really don't think it is DOE's role to influence the utilities in their operations of their clients. DOE's role is to follow the terms of the contract, and DOE expects that the utilities will as well. There are certain obligations on both parties in the contract and if the utilities do, they uphold their part of the bargain, DOE intends to uphold its part of the bargain. I don't think it is really the role of the disposal part of DOE to influence the choice of fuels in a particular power plant.
The third question, how are the R&D activities on accident tolerant fuel development integrated with R&D activities regulated to spent fuel management such as characterization, managing decay heat, long-term storage, criticality, et cetera. Well, Ned Larson knows Bill McCaughey, and they communicate and they meet together. And, Sylvia Saltzstein knows Dan Wachs. They meet and they communicate. I know Andy Griffith. Andy had a question about spent fuel just last week. I don't think there is any issues with integration between the front end part of the Office of Nuclear Energy or the back end part with respect to these accident tolerant fuels or new fuels. So those are the three questions, and those are my answers, do you want me to take questions now before Sylvia speaks or wait until the end?

>>Paul Turinsky: Why don't we take them now at this point and we may come back to you after Sylvia. So I have a question, Bill and that is, in the contract are there technical specifications about the fuel under which the utility must satisfy these specifications for you to accept the fuel? Am I being heard? Okay. Am I being heard now? Bill apparently doesn't hear me.

>>William Boyle: I do now.

>>Paul Turinsky: Okay, all right, let's try again.

>>William Boyle: You were “spinning” [in reference to loading screen] for quite a while.

>>Paul Turinsky: Are there technical specifications in the Standard Contract that basically spell out properties of the fuel that it must have for DOE to accept the fuel for disposal… transportation and disposal?

>>William Boyle: Well, okay, yes, the Nuclear Waste Policy Act requires that the Secretary put in writing criteria setting forth the terms and conditions of the contract and that was done long, long ago and it was actually done through a rule making notice through the Federal Register. The original standard contract is part of the Code of Federal Regulations. It is a 10 CFR 961 and anybody, you can go and Google it and you'll find all sorts of, falling off the law.. easy enough to find it. And in number of things become apparent. I answered yes, it does, did the contract set forth publications? and the answer is yes. There aren't very many, you know. I can tell you that. In the original contract, one that does show up is that it had to have – the spent fuel had to be out of a reactor for a minimum of five years, right. That was created for the contract. There really aren't, I mean the contract goes on at length and there’s all kinds of conditions but in terms of the technical specifications of the spent fuel, they’re mainly dealt with in Appendix E of the standard contract. Which is largely a discussion of… well there is standard spent fuel and that’s I think everybody was contemplating that the standard spent fuel was light water reactor fuel either from a BWR or PWR. And then there were the other types of fuel, non-standard. And DOE was even going to take not standard spent fuels according to Appendix E,

but the utilities were told in the contract… well, the more non-standard it becomes it might be the last thing we pick up is what it comes down to. There was, if you will a time specification, if it is non-standard you got to give us more time to deal with it. And then a harder part of the contract to find is the contract was updated as a result of the lawsuits. For new licensing, DOE was not about to sign a contract that the instant they signed it they were going to be in default because there was no repository. So for the plant, Votgle, the contract they signed is a little bit different and it has even less specifications than the original Standard Contract did. It's one of the changes made in the update to the contract was to get out of the lawsuit caused by the non-performance related to January 1998. The pickup time was specified as no later than ten years after the end of the license of the generating facility. So that was, it gave the Department a lot of time but what the Department gave in return for that was Appendix E is much shorter. It's ..there's really no more discussion of standard, non-standard spent fuel… the Department is picking up the spent fuel, period. That's it. So the Nuclear Waste Policy Act does give the authority and responsibility to the Secretary to set forth criteria for setting forth the terms and continues. And that has been done and it has been done even more than once. For somebody who does not have a license today, I don't know what my colleagues will do in the future but people should not assume they would be able to sign the contract as it exists today. They should -- just as the NRC encourage people to come in early, somebody who expects to sign a contract really ought to come in early so that both parties really understand what they are signing up for. I'm not saying DOE would update the contract again but I also will not state that DOE will not update the contract in the future. When I speak about the update, they are not retroactive. The contact that Palo Verde has, it is good to go. That's why I use them as an example, they use generate Lightbridge spent fuel. DOE's picking it up.

>>Paul Turinsky: I'll ask the same questions I asked John and Marilyn, that is when NRC is approving to load a batch of new fuel, your office have any involvement in this that licensing process? Other than, yeah having a standard contract signed?

>>William Boyle: Yeah, sure. And DOE could always be a party to any NRC proceeding, but typically we haven't been. It's.. my group has not been. No.

>>Paul Turinsky: Okay, all right. Lee has a question.

>>Lee Peddicord: .. Two things, so this obviously highly speculative but, if they say look we're going to take our spent fuel and we're grind it to dust or something like and throw it in a cask, I assume if they can get an NRC license to do that, then you will be obligated to pick that up?

>>William Boyle: It will add depend on the details of the contract. It's all spelled out in Appendix E. I noticed one of the presenters from tomorrow had a question about failed fuel. The standard contract does cover that, so if this grinding it up was a result of, you know, some sort of failure it would be non-standard in that respect. But as I mention for the updated contract, Appendix E.. there is not much there. It's, but I must say contracts are supposed to be entered into in "good faith" and if the government knew somebody had 17 by 17 assemblies and robust metal clad tubes and they expected us to pick up ground up dust, that isn't necessarily "good faith" and so that's when courts settles such things, you but --

>>Lee Peddicord: Well, I'm cheered by that. That's a good answer, Bill. Other thing too is that I noted I think's very good is you were talking about interaction that you and Ned and Sylvia have with your colleagues Dan and Bill and so on. Is this something you kind of doing periodic basis…?just let's get together and see where you respectively are in our programs or is it more as a question rises on a, you know, this question's come up or a need-to-know sort of places?

>>William Boyle: Both. Yeah, when questions come up Andy had a question last week, that's an example, had a question. It was answered. But Ned and Sylvia meet with regularly

with Bill and Dan. So both approaches are used.

>>Lee Peddicord: Good, thank you Bill.

>>Paul Turinsky: Any other questions for Bill? Seeing none. We will then, thanks Bill, we will now move on to Sylvia's presentation.

>>Sylvia Saltzstein: Hello, so -- can anyone hear me? Okay, great. So I'm Sylvia Saltzstein from Sandia National Labs, and here to talk to you about the R&D that we are doing or plan to do for accident tolerant and advanced nuclear fuels and this is specifically focused on the back end.

So next slide please. I also like to say this work is not just mine it is just not Sandia's. This is a group that is comprised of Oak Ridge National Laboratory, Argonne National Laboratory, and Pacific Northwest National Laboratory. And the way we do our work for the DOE is these labs all get together. And starting in 2012 the group wrote a gap analysis to support the extended storage of used nuclear fuel. That was written in 2012 by PNNL, Idaho, Sandia and really established the methodology for how we think about our R&D and what problems we need to solve. So we started R&D in 2012 specifically working to close those gaps that we had identified. We updated that gap analysis in 2017 and then again in 2019. And in these two reports we have them divided into what we have learned from our R&D, what we still need to learn and how we will go about learning that. And our gaps are divided into three priorities. The first priority are really cross-cutting gaps, things that we need to know that impact many of the safety systems of for spent nuclear fuel, not just the fuel but also the hardware, the canister, the cask and external loads. And so we've gone the same way.

We can move to the next slide. We use the same philosophy and gaps to write our high level gap analysis for accident tolerant and advanced fuels for back end storage and transportation. This was written this year in 2021. And I'm going to give you the bottom line first so what our conclusions are that fuels that are in the typical and maybe we should say standard, PWR or BWR rod in assembly configuration, they can be tested using the same test plan that we have used for the high burnup demo Sibling Pins which many of you are aware of and I will go over briefly in the next slide. Our other conclusion is, the current transportation hardware can accommodate those fuels with modifications for their increased weight, increased radioactivity and higher temperature. TRISO and other designs that are different from the typical rod and assembly configuration they will need a new test plan to quantify mechanical properties, if we decide down the road that further testing is warranted. And then also the TRISO and other designs will not, most likely, fit into the cast current storage and transportation container designs and so those new container designs will containers will need to be designed, tested and manufactured.

You can go to the next slide please. So for the majority of the fuels, again we feel they can follow the same test plan that we are currently doing for high burnup rods from the sister pin project or the Sibling Pin Project from the fuel coming out of the North Anna Nuclear Power Plant and there we are testing some just as radiated, the others we are heat treating and we're heat treating two at a temperature of 400 degree C and this is because this is the just about the regulatory limit right now. We know that may change and so higher temperatures may be warranted. After we do that heat treatment, we do a series of tests at room temperature to measure the rod internal pressure, the gas communication from one end to another. We do optical microscopy to look at hydride formation and orientation. We are looking at hydrogen content, microhardness and ductility of the cladding. And that ductility is done at also 200 degrees C and 400 degree C. After we complete those tests… oh, I also failed to mention that we are doing this at, for the most part at two labs, PNNL and Oak Ridge National Laboratory. Oak Ridge is testing fueled rods. PNNL is testing defueled rods to understand specifically what is the mechanical

integrity of the cladding by itself. The ring compression tests are being done at Argonne National Laboratory. So after we complete those initial tests, we cut up the rods and we test at either 200 degrees C or room temperature. 200 degrees C is really the hottest that we would ever transport and so that's bounding for the ductile test. And room temperature is of course the coldest we would ever transport that's where rod should be, most brittle. So we're testing mechanical properties at that point using ASTM procedures for axial tensile tests, burst tests, four-point bend tests and fueled ring compression tests and then also Oak Ridge fatigue test using their CIRFT experimental apparatus. And then we're also getting particle release data to quantify the respirable fraction that is released upon breaking a rod. So again for accident tolerant fuel or advanced fuels that are in these same configurations, we would -- our plan is to follow this same test procedure. We have the equipment, we have the hot cells, we have the procedures and it is really ready to go if we choose to use those two labs which seems like a good way to go.
Next slide please. Okay and then for the purposes of the gap analysis the proposed fuels to be investigated are pretty much what we have been talking about today. The chromium doped pellets, chromium-aluminum doped pellets, modified and current and new cladding designs and those are again the chromium-coated zirconium based claddings, the iron-chromium-aluminum cladding, the silicide carbide base claddings and then looking at fuels with higher density than uranium that may facilitate higher burnup and higher power. So the uranium metals possibly uranium nitrides, possibly uranium silicide's. Then also enrichments 5 to 20%, I saw NRC maybe, you know, John your slide said just up to 10%. So we may adjust based on what the future holds and then increased burnup cycle length and power are the benefits of that. So again the TRISO fuel physically unique from the traditional pellets and so won't be tested the same way and we'llhave to figure that out as time goes as if fuels like that continue to be promising.
Next slide please. So the differences in accident tolerant fuels, you know, for zircaloy based cladding we are really focusing on radial hydride formation and the ATF based cladding, they are designed specifically to reduce that water side oxidation and therefore reduce hydrogen production and cladding uptake and these gaps that are related to the cladding oxidation, the hydride reorientation and the cladding embrittlement, and delayed hydride cracking are soon to be of lesser importance and we will continue to watch any data that's coming out in the front-end or anywhere else to see if that pans out. Then the lack of data with respect to higher temperatures and associated elevated rod internal pressures, they will require a testing programs similar to the EPRI/DOE High Burnup Demonstration program and the Spent Fuel Rod Test Plan. Some of the ATF fuel and the cladding properties and characteristics, especially for higher burnups will be obtained from examination of the lead test assemblies as currently planned by DOE and the fuel vendors. And like Bill said, we are keeping in contact with what's going on in those programs so that hopefully we can test some of that fuel. And then additional testing for the conditions of drying, storage and transportation of specifically looking at fatigue failure and then also potential accident conditions are needed.
Next slide please. So, then I'm going methodically through our analysis of the accident tolerant fuel looking at the Tier 1 gaps, these are the cross-cutting gaps. Next, next slide please. First is thermal profiles as we all know temperature drives everything so that is why this is the first of the cross-cutting gaps. The higher burnup fuels will be thermally hotter at react discharge and for longer periods. So it's likely that the higher burnup fuels will experience higher temperatures during drying and early dry storage and we've done a lot of work with this on the sibling

pins and so main the research question is, will the hotter fuel affect the mechanical integrity of the fuel, the cladding and the other structures, systems, and components over long-term storage and subsequent transportation. The way we will address this is through thermal modeling and simulations which can explore the extent of the expected performance while mechanical testing on representative irradiated accident tolerant fuels and advanced fuels can provide validating data for those models.

Next slide please. Stress profiles, this is where we were looking at external loads on the fuel during transportation and storage. But transportation is where the fuel will experience the highest external loads. So we will look at this for individual ATF concepts and the question we are asking, can the new ATF and AF concepts withstand the impact of storage and transportation loadings? So, the way we will answer this question is the test articles should be subjected to fatigue testing, possibly through the Oak Ridge CIRFT test apparatus and the four point bend test to assess accident tolerant fuel and advanced fuel response to realistic mechanical loadings. And then modeling and simulations can explore the extents of those expected performances.

Next slide please. And then drying issues. So while accident tolerant fuel and advanced fuel cladding concepts are designed to limit oxidation and within, with thinner oxide layers in theory the quantity of trapped and chemically bound water will be reduced. The impact of residual water and dry storage on accident tolerant fuel and advanced fuel cladding and fuel in failed rods still should be quantified because the reaction of residual water was some of the accident tolerant fuels, specifically the metals and uranium nitrides may be more aggressive than with the current fuels. So, is the effectiveness of the water removal process during drying different for accident tolerant fuels and advanced fuels? And so we will address that by component testing first on the retention of the water in the fuel and the hardware and then look at the effects of the water on the new fuel concepts over extended periods of time representative of storage.

Next slide please. Subcriticality, so the higher density and higher enrichment ATF and advanced fuels may increase the risk of criticality if the fuel relocates within a cask or if the cask floods as is typically assumed for the hypothetical accident conditions during transportation. So our research question is, are the current cask and canister designs adequate to address the criticality potential and we will answer this question by looking at the criticality codes in generation and depletion codes, such as ORIGEN. Those can be used to assist the criticality potential for accident tolerant fuel and advanced fuels under transportation conditions to determine if different cask design features, such as increased neutron absorber material and longer term performance of those materials are necessary. We will also have detailed radionuclide inventory studies, can be performed to validate codes and to facilitate the use of burnup credit.

Next slide please. Fuel transfer options, so accident tolerant fuels and advanced fuels, especially those with higher density will be heavier, they will be more radioactive and will have a higher temperature. Those changes need to be addressed relative to plant and transportation infrastructure and operational constraints. So our research question, can facilities handle these heavier loads and can potentially more brittle cladding types sustain these handling loads? So we’ll conduct studies to assess loaded canister weights relative to utility crane lift and railcar limits.

Next slide please. Okay so these are Tier 2 gaps and these gaps are specific to SSCs.

We can go to the next slide please. So consequence of a canister failure, so canister is a primary confinement barrier during spent nuclear fuel dry storage, failure such through stress corrosion cracking could potentially release radial with nucleotides in clad, oxide layers, fuel particulates or fission gas. Our research question is, are there differences in the form, size, distribution and radioactivity of accident tolerant fuels and Advanced Fuel designs? And we'll do this by determining the fuel particle size and fractional release under simulated burst and rod breakage experiments then conduct engineering tests using particle sizes to quantify potential release scenarios. Similar, similarly, we'll determine the extent of the oxide and crud layers spallation and their particle sizes to determine the potential contribution to dose upon a potential a release.

Next slide please. Fuel fragmentation, so in the reactor fragmentation of uranium oxide fuel results in formation of particles that can be dispersed upon a cladding breach. With finer particles produced, as the burnup surpasses threshold between 60 and 75 gigawatt days per metric ton of uranium. In uranium oxide fuel, higher burnup rim is produced where the fuel grains have subdivided into submicron grains and its thickness increases with increasing burnup. While chromium doped fuels increase grain size and are expected to reduce fragmentation this has not been confirmed with high burnup. So fragmentation of all fuel types, may result in fuel relocation that could impact gas communication within a rod and could affect release fractions upon the breach of cladding. Our research question is, are the fuel particles release fractions different for accident tolerant fuel and advanced fuel designs. So we will look at this from different axial locations in the rod and this can be performed to determine the extent of the fuel fragmentation and thickness in the high burnup rim. Gamma scanning a neutron radiography can be performed to determine relocation within a rod.

Fuel restructuring and swelling, higher burnup, results in increased fission gas production and will result in increasing pressurization over time by generation of helium from alpha decay. The chromium doped pellets are expected to release less fission gas. But the retained gas could result in pellet swelling. So our question is, will pellet swelling result in localized stress risers in the cladding, which in turn could facilitate other degradations mechanisms such as creep or stress corrosion cracking. So again we will look at these from different axial locations in the rod to determine the extent of fuel swelling and the possibility of pellet clad mechanical interaction.

Next slide, thank you. Fission product attack on cladding. Pellet cladding, chemical interaction is fairly well understood mechanism that has been reduced by changes to pellet geometry and then the introduction of barrier fuels. The compatibility of accident tolerant fuel and advanced fuel cladding with potential release of iodine, cesium and cadmium from oxide fuels must be understood for long-term cladding performance. Will fission products in contact with the cladding facilitate cracking and breach of the cladding via PCCI. We’ll answer this by detailed examination of the pellet/clad interface with high resolution tools such as TEM or EMPA to be performed to determine if fission products have been released and are present in this boundary. High resolution microscopy will be used to look for signs of cracking at the cladding inner diameter.

Next is fuel oxidation. Increasing burnup in uranium oxide fuels increases its resistance to oxidation which can in turn rupture the cladding and result in fuel release and relocation. The long-term lower temperature oxidation of various ATF/AF fuels and the susceptibility of ATF/AF cladding to rupture are not known. So our question is, will the kinetics of oxidation for ATF and advanced fuels, under the conditions of drying storage (from retained water, water vapor and radiolytically-generated oxidants) cause detrimental effects during long-term storage conditions? Could these changes produce the stress necessary to initiate and propagate a crack in the various accident tolerant fuel and advanced fuel cladding types. Thermogravimetric analysis of fuel samples under relevant vented temperature conditions in dry and humid air will determine the oxidation rates,

expanded ring testing and burst testing of irradiated cladding can be used to measure accident tolerant fuel properties.
Annealing of radiation damage. So radiation damage is a function of the fast neutron fluence and irradiation temperature, and higher burnup is expected to result in increased radiation damage. In zirconium-based alloys, radiation damage tends to increase the hardness and the strength of the cladding, with an associated reduction in ductility. The strength and ductility of the accident tolerant fuel and advanced fuel cladding at high burnup will be well documented for reactor operation. However in dry storage the radiation damage can be annealed, resulting in strength and ductility characteristics more consistent with unirradiated cladding. So will annealing during drying cause changes in cladding strength and ductility? So we can look at microhardness and compression tests on both as received and then thermally annealed samples to see if the annealing changes the mechanical properties.
Next slide, thank you. Creep. The main driving force for cladding creep is the hoop stress caused by internal rod pressure. The end of life rod, internal pressure of higher burnup fuels needs to be measured and then modeled for the temperatures relevant to drying and early storage. The new reactor, the ATF and AF fuels may creep differently than zircaloy and the limits before failure must be understood. Creep results in the thinning of cladding wall, which could then subsequently fail upon external loading, or with increased rod internal pressure related to high burnup. So question is will chromium, and FeCrAl creep differently than zircaloy? What are the limits before any failure? So we will address this by end of life rod internal pressures can be measured by puncturing rods and collecting the gas. Creep tests as a function of time and temperature can be conducted to determine if thermal creep is an issue for storage of the new cladding types.
Next is embrittlement. Chromium diffusion into the underlying zircaloy may result in embrittlement of the zircaloy. Other claddings are known to be brittle. Cladding embrittlement reduces positive performance of the fuel cladding under internal pressure, mechanical and thermal loadings? So what is the extent of the cladding embrittlement under realistic internal pressure, mechanical, and thermal loadings? So we can do our same ring compression tests, our axial tube tensile tests and burst tests of as-irradiated, heat treated irradiated samples can be conducted on defueled cladding to determine cladding properties and establish if embrittlement is an issue. CIRFT fatigue test and ring compression tests conducted on irradiated composite fuel segments, can be performed combined with metallographic imaging and chemical composition studies.
Next slide. Path forward.
Next slide please. So our current path forward because the lack of data with respect to potential storage and transportation degradation mechanisms for accident tolerant fuel and advanced fuel, especially for the expected higher burnups and higher temperatures and higher internal rod pressures require testing programs similar to the EPRI/DOE High Burnup Demonstration Program Sibling Pin Test Plan to ensure that the NRC requirement for preventing gross rupture is met. Attention should be focused on damaged spent fuel, particulate size and quantity, clad coding robustness, potential corrosion and hydride potential in areas of damaged clad coatings and any logistical challenges from increased container weight, temperatures and radiation levels.
Next slide please. So again as I went over.. this same test plan really does address pretty much everything that our gap analysis discovered and temperatures may need to be changed and using this same test plan really allows us to directly compare the accident tolerant fuel and advanced fuel design mechanical data with the High Burnup Sibling Pin data to be able to compare apples-to-apples and understand if any changes are warranted in storage,

transportation and disposal infrastructure that we have now. These procedures have been completed. The equipment has been purchased. It has been tested. It's gone through the quality rigor procedures and the data has been validated. And part of the benefit of doing this at two labs, at Oak Ridge and PNNL is that we have a lot of communication between the experimentalists here to ensure that data is correct and validated.

Next slide please. So again the conclusions are that the current storage and transportation canister and cask systems, rod assembly, advanced fuel systems that are very similar to the current existing commercial fueled systems. Modifications to handle the fuels increase weight, greater thermal and greater ionizing radiation loads may be required. And significantly different fuel systems will require new storage, transportation, and disposal container design, most likely. Next slide please. I'm ready for questions if anyone has any questions.

>>Paul Turinsky: Board members, do you have any questions for Sylvia? Lee?

>>Lee Peddicord: .. So I think we discussed previously when we were talking but you go through looks like kind of a periodic basis and again reminding me.. is.. do you have a regular cycle to revisit these on a kind of a need to know basis as issues arise.

>>Sylvia Saltzstein: So Dr. Peddicord, are you referring to our overall gap analysis or specifically accident and advance fuels?

>>Lee Peddicord: I'm going to make it easy on myself and say yes.

>>Sylvia Saltzstein: Okay, so our general gap analyses we plan to update those about every three years. We will… I'm pretty sure we will decide to not have two documents, not have and ATF gap analysis and regular gap analysis and we will combine those in to one.

>>Lee Peddicord: Good. And then how broad is the scope of the team that comes together to do these?

>>Sylvia Saltzstein: How broad is the scope of the team that comes together to do the gap analysis?

>>Lee Peddicord: Yeah, my assumption is you got all the labs, several representatives from the labs or how do you parse it out and -- ?

>>Sylvia Saltzstein: So we have representatives from all of our different teams that contribute to the document and so that is, you know, our fuel integrity team, our external load team, our corrosion team, our drying team, our thermal team and our security team. Everybody gets together, provides input. We discuss this also with our partners at EPRI, EPRI-ESCP which includes industry and international partners and we also discuss this with the nuclear regulatory commission.

>>Lee Peddicord: That's where I was going to go next, we heard from John and Marilyn I think on the PIRT evaluations. To what extent do you participate or get a chance to see these or have input or see them when they finally surface?

>>Sylvia Saltzstein: We are active members in the PIRTs. So we definitely have seats at the table in the PIRTs.

>>Lee Peddicord: Yeah, good. Thank you.

>>Sylvia Saltzstein: Thank you.

>>Paul Turinsky: Other Board members? Okay, Sylvia, you're going to guess, you know what my first question is going to be, following up on Lee's, I didn't hear you mention fuel performance folks being involved in the PIRT.

>>Sylvia Saltzstein: Oh fuel performance folks are involved in the PIRT. In the gross rupture PIRT and in the other PIRTs.

>>Paul Turinsky: So these are the people who are building like the folks out INL building BISON, they're involved in that? I don't mean individual models I mean the whole fuel performance code package.

>>Sylvia Saltzstein: Are those people involved in the NRC PIRTs?

>>Paul Turinsky: No, I said, PIRT, no, your gap I mean your gap analysis, no I misspoke.

>>Sylvia Saltzstein: We do not involve the MOOSE BISON developers in ours, no we don't.

>>Paul Turinsky: Or any, I mean. PNNL has its own capabilities too.

>>Sylvia Saltzstein: Yes, so, we have a lot of analysis going on within our program, and all of those modelers are part of the gap analysis. Not only our gap analysis but strategic R&D plan built off of our gap analysis and then it goes down to a lower level where every year we decide, you know, what work we want to propose to do for the following year. And both our experimentalists and our modelers are involved in that activity. We actually, a couple years ago, before we had an analysis group and an experimental group in the different areas. We decided a couple years ago to blend those, so that the experimentalists and the modelers for any specific topic, like external load or thermo testing and modeling, they work together on a daily basis. They are not two separate groups. So we have a continual cycle of model development, experimental results, model validation development, experimental results. And it's, it's a constant iteration.

>>Paul Turinsky: Okay I noticed again you are not addressing BWRs, do you think that some, because of the new fuel designs, new claddings, that they are looking at higher burnups whether you will be moving on to BWRs.

>>Sylvia Saltzstein: We would definitely like to test BWR. At this point, we still feel that PWRs bound BWRs but we would like to get fuel to validate that. That is one reason why we joined the Studsvik program a couple years ago was to get data on BWR, IFDA and maybe some additional fuels data through that program. We would not actually be testing it. That data would be proprietary but we would still have insight into that data to help us make a decision if we want to test how important it is for us to test BWR, IFDA and any other fuel type that we may want to look at.

>>Paul Turinsky: Okay I can't recall, the lead test assemblies are they going to the higher burnups? Are they planning to go to the higher burnups and is fuel matrix the new matrix that they are looking at?

>>Sylvia Saltzstein: So eventually they will go to the higher burnups.

>>Paul Turinsky: But, the rods in there now being irradiated have they been designed to go to the higher burnups, the gap volume, the plenum volume.

>>Sylvia Saltzstein: I'm going to have to give that question over to Dan. I'm not positive about that answer.

>>Paul Turinsky: Okay and then finally on the front end part of it there's close cooperation between the fuel vendors and DOE. And obviously some of that cooperation is because DOE is paying part of the freight on that. On the back-end so far seems to be not that "closer cooperation" as there is on the front end. Is there anticipation of having more cooperation, because when I looked at your list of gaps some of those items, I would think the fuel vendors actually have data on.

>>Sylvia Saltzstein: So that's one of the real benefits of us being active members in EPRI-ESCP, is we do have a lot of communication with the utilities and some of the fuel vendors, who that, we also have non-disclosure agreements with some, some other fuel vendors so we have the ability to have much closer communication than we have now. It is just not been necessary yet because we don't have the accident, a lot of accident tolerant fuel coming in to the back end right now. And so while it is being in the front end and it is a real active program on the front end, we on the back end still have a little bit of time to see how things play out and which technologies are successful and which technologies are maybe not as successful and sort of sit back and watch and then decide how we are going to spend our R&D dollars. Does that answer your question?

>>Paul Turinsky: Yeah, yeah, I'm thinking some of those dollars may be actually more efficient, this is a personal opinion, to actually buy the data from the vendors than repeat a bunch of experiments.

>>Sylvia Saltzstein: Absolutely, but we would want high burnup data.

>>Paul Turinsky: I understand that, but never too early to start conversations, I think.

>>Sylvia Saltzstein: That's right, that's true ..we can always start talking.

>>Paul Turinsky: All right. Are there other Board members who have questions? See none, Dan?

Dan?

>>Daniel Ogg: Hi, thank you, Sylvia, really good presentation, lots of great detail there. ..In fact so much detail it can be challenging to get your mind around everything you are proposing here. Given the scope of this, have you prioritized any of these things? Are there things you would like to do first and if so what are the next steps to, you know, address your highest priorities?

>>Sylvia Saltzstein: I think while maybe, maybe the presentation conveyed that there was just a million things we wanted to do, but in reality it is pretty simple to us. For the majority of the fuel types that are being burned in the reactors right now, that fuel can just follow the same test plan and process that the Sibling Pins are. So from our perspective, it is very simple. We don't need to redo a lot of things or develop a lot of new, new processes. It took us a long time to develop this test plan. You may remember.

>>Daniel Ogg: Oh I know.

>>Sylvia Saltzstein: It was probably two years to develop this test plan and it went through, you know, people, international, international input, NRC, you know, DOE, EPRI, the industry members, a lot of opinions and professional judgment was put into this and so again, from our perspective it is pretty simple if it can go with the same test plan it should. And so much input has been put into it and we have again bought the equipment, written the procedures, you know all the equipment has gone through QA and so to do something different in our opinion does not make sense.

>>Daniel Ogg: Right what would be the critical path. I mean it is it for example getting agreements in place with the vendors to get hand some of these ATF lead test assembly samples or is it transportation and logistics? Just, what's the critical path.

>>Sylvia Saltzstein: That critical path is already being worked by Ned Larson and Bill McCaughey, so they are working that critical path already.

>>Daniel Ogg: What about getting the hand samples --

>>Sylvia Saltzstein: Yes.

>>Paul Turinsky: Thank you. Nigel?

>>Nigel Mote: Thank you Paul. Hey Sylvia, thank you nice presentation, I heard it twice. I've still got questions. These are two specific ones. One is on TRISO fuel, I heard you say a couple times that TRISO fuel would not be compatible with the existing cask system or would need a new cask design.. if the fuel is being designed work in existing reactors there is something that says it ought to be able to work the existing cask designs. Can you put your finger on the specification difference that says that particular fuel is not compatible with a current cask?

>>Sylvia Saltzstein: So I wouldn't say it is not compatible, meaning it wouldn't protect it. But the internal hardware is sized for a, you know, 17 by 17 or 16 by 16 or what have you PWR or BWR rod and assembly dimension. And TRISO will have a different dimension and so it may be as simple as just designing a different basket and putting it in you know a similar canister and cask system, but that needs to be investigated. We can't just stick it in current basket.

>>Nigel Mote: So you're talking about TRISO fuel which is not used in existing reactors.

>>Sylvia Saltzstein: Right.

>>Nigel Mote: Okay that was not clear from …on slide 12 you have issue about weight because you are saying that the assemblies looking at ATF and advance fuels will be heavier as well the transportation casks, we're also faced with getting this underground in a disposal package. And as you know, Yucca Mountain had the advantage of being in a, there was no hoist required different repository location might well need a hoist and you know that DOE's been doing work on the maximum weight of hoist and how that would fit with a large canisters, the utilities you are using with an over pack and we know pushing right up on the limits. What sort of increase of weight do you mean when you say heavier if talking a few percent on a fuel assembly, then the assembly is a small part of the canister total

weight and that's an even smaller percentage of the all up weight in a disposal package. But give us an idea.. what do you mean by heavier how much are you talking percentage?

>>Sylvia Saltzstein: You know I did know that at some point.. I don't know that right now; I think different fuels have different densities so I would have to get back to you on the specifics of how much heavier and how that could be addressed. That can also be addressed by putting fewer assemblies in a cask, so I would have to get back to you on specifics of how much heavier.

>>Nigel Mote: I'm sure we'll find it some time. If you partially load a cask, then you've got all the economic benefits with not fully utilizing assets. So, okay. That's all I need, thanks.

>>Sylvia Saltzstein: Thank you

>>Paul Turinsky: Are there any more questions? Okay thank you, Sylvia.

>>Sylvia Saltzstein: Thank you.

>>Paul Turinsky: Okay I'll now call on Bret Leslie to relate to us the public comments he has received through our website.

>>Bret Leslie: Thank you Paul, give me a second while I pull up the file. There is only eight or nine comments. And I'll provide a little context before I actually read them into the record. So I got a couple comments very early in the meeting and what I will do is, I will identify the person, their affiliation if they provided it and then say what they said. So the first comment was Gordon Edwards from Canadian Coalition for Nuclear Responsibility and he stated, "very glad this is being discussed."

The next commenter was [Volker Goebel] from DBHD/GDF all he said was, "GDF plans."

Later in the meeting, around 12:30 Dr. Sandy Greer with no affiliations said the following, "I recommend that initial transcript, much appreciated, be proofread to find and correct mistakes prior to later publication. For example, during Dan Wachs talk, in his reference to coating on pellets the transcription reads, chromium and a human NAHI-doped capital DO2 pellet end quote, which seems incorrect. Very tricky in trying to listen and sometimes follow written words so that viewers like me will not be able to track everything while making our own notes. Thank you for the presentations."

I would note um for those that are listening to the meeting today that our meeting transcript will be available on, on our website by July 12th and what we were projecting along with the presentation was closed captioning and that is not our transcript.

At 1:39 after Dan Wachs talk, our next comment is from Joe Rashid, he is from SIA which is Structural Integrity Associated formally Anatech he states, "pursuing Paul's question further there is a number of performance challenges that can be addressed through modeling and simulation which DOE can and should support independently of fuel vendors and I might add independently of national labs. These include, two mechanisms that lead to outside in cladding failure, grid to rod fretting and differential thermal expansion between the chrome coating and the metal. And also with regards to coping time, cladding ballooning during LOCA, can lead to the early cracking of the chrome coating leading to rapid oxidation of the zircaloy cladding and rupture." That's the end of his comment.

At 1:48, [Volker Goebel] from DBHD/GDF stated the following, "is this a sales operation for fresh nuclear fuel with a chromium coating? All that got nothing to do with GDF for nuclear waste. Did somebody buy the Board for an advertisement?" That's the end of his statement.

At 1:58, Dr. Sandy Greer again no affiliation submitted this comment, "given the Lightbridge representatives reference to ''retrievability of fuel' I assume this aspiration speaks to not supporting the option of future deep geologic repositories (DGR) which still are experimental. Finland as first country globally continuing to construct tunnels for up coming high level fuel bundles. Please clarify regarding the presenters views about the wisdoms of DGRs versus doing better research on alternatives. Thank you."

At 2:51 in the NRC's presentation Barbara J Warren with no affiliation stated "what measurable performances NRC looking for that will define fuel as being 'accident tolerant.'"

And finally, the last comment that I've gotten so far at 2:59 Richard [Kellen] who listed his affiliation 'shareholder' he stated, "well done all."

And Paul if you'll give me a moment let me check the inbox again to see if anything else has come in. Paul that is all, that is all the public comments for today.

>>Paul Turinsky: Okay that concludes our meeting for today. Same time, same place tomorrow where we'll hear international representatives from the UK, from Sweden, and from Switzerland. And then we'll have a panel discussion made up of the speakers and the staff members. So thanks to all the speakers for their participation today. It was very, very informative and good day.