Opportunities for Generation-IV Reactor Designers through Advanced Manufacturing Techniques
Dr. Isabella van Rooyen, INL, USA

Berta Oates
Welcome everyone to the Next Gen-IV International Forum Webinar presentation. Today's presentation on Opportunities for Generation-IV Reactor Designers through Advanced Manufacturing Techniques be presented by Dr. van Rooyen with the Idaho National Laboratory in the USA.

Doing today's introduction is Dr. Patricia Paviet. Dr. Paviet is the group leader of the Radiological Materials Group at Pacific Northwest National Laboratory. She is also the Chair of the Gen-IV International Forum Education and Training Working Group. Patricia?

Patricia Paviet
Thank you, Berta. Good morning everyone or good evening. It's a pleasure to have with us today Dr. Isabella van Rooyen from the Idaho National Laboratory. She holds a Ph.D. in Physics, a Master in Metallurgy, and an MBA. She is currently the National Technical Director for Advanced Methods for Manufacturing Program for the Department of Energy-Nuclear Energy Enabling Technology.

She is also a distinguished staff scientist at INL where she has lead as principal investigator, a variety of research projects for nuclear applications through competitive awards by industry strategic partners, lab-directed research funds, National Scientific User Facility, and the Nuclear Energy University Program. Dr. van Rooyen's engineering and scientific exposure includes hands-on experience in a wide variety of pursuits. Examples include heat treatments, surface treatments and coatings, welding procedure, casting processes, powder fabrication, and consolidation processes. Prior to Joining INL in 2011, Dr. van Rooyen has various technical leadership roles, in nuclear, aerospace, and automotive industries in South Africa; most notably the research at Pebble Bed Modular Reactor Company and NECSA and DENEL Aviation. So, without any delay I will give you the floor, Isabella and I thank you again very much for volunteering to give this one hour. Thank you, Isabella.

Isabella van Rooyen
Thank you very much Dr. Paviet. It is really my pleasure today to discuss this interesting topic for us. And I would like to start to say that nuclear is definitely very dear to, I believe, all the participants' heart because 55% of the United States' clean energy is resulting from a nuclear energy and 30% of the world's energy is related to nuclear energy. Also furthermore, it plays a very important role in the US economics where it supports

approximately 475,000 jobs, give and take, and it adds to $60 billion to the US GDP.

Especially now in this pandemic environment, the nuclear reactors keep the air clean, removing thousands of tons of harmful air pollutants that contributed to acid rains, smog, lung cancer, and other cardiovascular diseases. And therefore, going forward in this presentation, I would like to provide you a background of the Office of the Nuclear Energy with the four Mission Pillars and the mission really is to advance the nuclear power to meet the nation's energy, environmental, and national security needs, focusing on resolution of technical, cost, safety, security, and then also regulatory issues through the research and development and demonstration. You can see from this slide here focusing on the existing fleet, the advanced reactor pipeline, fuel cycle infrastructure, and global competitiveness. This presentation here will focus here on this first two mission pillars of the Office of Nuclear Energy.

Also, as part of this presentation, I will provide information about the advance methods for manufacturing program which is part of the enabling teams here under leadership of a Dirk Cairns-Gallimore and with his team lead Melissa Bates and the Director Suibel Schuppner and with Alice Caponiti as the Deputy Assistant Secretary for the NE-5 office which is the reactor fleet and advanced reactor deployment.

Also during this presentation, I will provide some wider information on other enabling technology team programs, for example the TCR, and a certain portion of the NSUF project or program.

With that then, the Advanced Methods of Manufacturing, or as I will call it through the presentation as AMM program, is to improve and demonstrate the methods by which nuclear equipment, components, and plants are manufactured and fabricated and assembled by utilizing state-of-the-art methods with a goal to reduce cost and schedule for new nuclear plant construction. And that really shows you the vast diversity of the work that can be covered or is covered under the AMM program. And we all do that, the goal is to make fabrication of nuclear power plant component faster, less expensive, and reliable.

As part of this slide, here are some examples to show you already the diversity and some of our initial analysis of the previous awards that we have provided as part of this program. Now, continuously we are working with stakeholder input to identify the very important AMM focus areas. And the reason for that is obviously to be able to support the industry and to advance the technologies and demonstration of new reactor plants and maintain the current fleet to the base and maintain into the base to our ability and to support when necessary.

And you will see here are six key focus areas and because the AMM program is predominantly competitive, funding awards sponsored by the DOE-NE, we cannot address all these aspects and key focus areas at one time. And with the green arrows here are indicating the current priorities of the past 2 years, both in 2020 and 2021.

With a focus on modular manufacturing and not only limited to the areas indicated here by fabricated forgings, piping systems or [Unclear] metallurgy [Unclear] but much wider than that, that is examples. And being as well as most of you know in the audience, it doesn't help if they have new technologies and we cannot use it in licensed or obtained licensing. So, our focus, we are searching proposals to relook at the acceleration of qualification and certification to accelerate licensing in the end.

And there is a variety of manage how it can be done and more of different viewpoints on that later in this work. It does not say that we are not working or some of our principal investigators are not working on some of the other focus areas like the advances in the manufacturing processes, surface engineering etcetera but we have put additional focus on these two key focus areas.

So, how do we communicate, how do we ensure that we are addressing the right needs for the DOE's national industry. We are having connections with other programs, the DOE R&D programs and all the stakeholders – I have listed only a few here, but the NRC is very crucial to understand their needs and how the information should be addressed and include them from the beginning of some of the programs or most of the programs. And then very important, we cannot do this without understanding the industry needs and there is a variety of outreach activities that AMM program really focused on this past 2 years to increase our involvement. So, all the advancements of manufacturing work are not being performed under the management of the AMM program. A variety of other R&D programs are already working on this domain. So, our purpose is really to understand what is happening where, what is the synergy activities so that we can either identify where the gaps are or what do we need to go forward. So, from this slide here we can see that really the AMM is crosscutting and we want to support and we want to understand so that we can support where we are not currently supporting. And together with that also absolutely lessons learned. What can we learn from work that has been done in other programs that can be beneficial to the next program or the current program. So, here is a less of a variety of the programs and my apologies for all the abbreviations but it is on the two slides back you will see more details there.

So, the long and the short is we do not focus only on our program. It is very important crosscutting and enabling technology. Part of our work that we have done and you will see that our [Unclear] draft here because we are continuously busy updating it and display it differently. What did we learn from our previous research programs? And how do we display it? So, currently, we have a certain display showing the material types that we have done awards on, and the bulk of it has been done on stainless steel and predominantly on the 316L stainless steels and also the variety of advanced manufacturing projects that we have used so that we can see and understand why the decision was made there, do we need to further explore in that area, or which program can be target and make sure that this information is out there not only for the specific program but for the wider industry.

Going forward here, as I mentioned we have really focused on outreaching and communication and how do we do that. And we are open for suggestions as well from the audience at any time. One way is we have two AMM newsletters where we demonstrate and showcase selected awarded projects as well as on the top page some new news from the AMM program itself. And also, we have started doing it from last year to include another facility, manufacturing facilities or methods that is available out of the not necessarily in the DOE-NE space but in any of the universities or that I would like to showcase or any of the other national laboratories to ensure that our researchers and our industry partners really know what equipment is available there, so that if they would like to do benchtop or upscaling, that they can progress very fast by reaching out to the right people here. Also, we are advertising or list in this newsletter all our publications that our researchers produce as part of this competitive funding work. There are specific conferences, so for the last 3 years I and other teams members are organizing a symposium for additive manufacturing for energy applications. And the reason why we did not do it only for nuclear applications is because we really understand that other energy applications, the work that has been done there, there are a lot of lessons that we can learn from there. We have really expanded our contact list and we are open to anybody that is interested in this work. We are doing outreach presentations and visits as well to plants and obviously during the pandemic the visits did not progress but at least we have continued to outreach to a variety of the groups.

We have also been very active in participating by invitation from nuclear energy initiative workgroups and we are very thankful for that. And specifically on the advanced methods technology workgroup led by Hillary [ph] and we are very excited about that. Also, every 3 months, we are reaching out or approximately 3 months we have meeting with the NRC team where we share a progress on the awarded projects and talk about the important matters here.

Yearly, we do the AMM technical review meeting which is an open forum. And the last 2 years we have done it in the beginning of December, so keep your eye out for that. And very important now, we are planning to have a workshop sponsored by GAIN, EPRI and NEI specifically on the qualification methodologies, and I will provide further information about them.

This all that we are doing is to first understand what are the needs and how can we communicate it over. Now, for this specific presentation I would like to highlight only a few of the current or past work that was competitively funded to provide you with an understanding of the diversity of the type of work that is necessary and has taken place already. It is definitely not the only work and I refer you to the DOE-NE AMM website to read more about the interesting work.

This specific project I want to highlight because it was a successful code case that was submitted in the fall of 2020. Led by David Gandy from EPRI and the team members were Oak Ridge, Westinghouse, and Rolls-Royce, and working to integrate the computational materials engineering, in situ process monitoring, and rapid qualifications of components made by laser-based powder bed AMM processes for nuclear structural material. This is really a very successful project and that set the basis for many work that is currently in place already and that was on AM welding of 316L stainless steel.

The next example that I want to show is – my apologies, let me go back. It is nondestructive testing. We have a few of those and highlighting here Alex Heifetz from Argonne National Laboratory's work on the pulsed thermal tomography nondestructive examination again for additively manufactured reactor materials and components. This is really in the – well, mature project, already 3 years going. And also lot of scientific publications resulted from this work. But as important, also outreach to a variety of industry partners, specifically I remember Westinghouse outreach on how they can apply it potentially in their work. So, this is a good case study where additional outreach to the normal PI principal investigators and DOE partners took place.

And another good example and showed the diversity of our work is really this work from University of Wisconsin under the leadership of Kumar Sridharan with a concept of manufacturing of ODS tubes via cold spray process was extremely important. This is the three-step process. These are really examples of the success. And often, the critique provided by cold spray and the manufacturing of components using cold spray is critiqued due to concerns on scalability. This was really proved quite successful, demonstrated in this project. Also, it grew up further to apply then a very thin layer of a chrome-containing material on to the ODS to further enhance the corrosion protectiveness of this material. And there is very much interest in some of the advance fields projects for the cladding of the two. And it really provided now the faster and cheaper manufacturing process.

Here is the second-last example of one of our industry projects, partially funded by industry and DOE-NE and that is for the small modulary reactor pressure vessel manufacturing and fabrication technology that started in 2017 until this year, and it is led by EPRI, David Gandy, and a variety of international partners like the UK Nuclear Advanced Manufacturing Research Center, Carpenter Powder Products, Synertech, TWI, Sheffield Forgemasters, Sperko Engineering, and many others.

And you can see from this year it is quite large components that is necessary and really a very interesting variety of fabrication processes. And although [Unclear] static pressing might not be, can I say, one of the new technologies, it is really new in the sense on how it is applied and the size of the actual component that needs to be done. The plus point of this project is really to demonstrate a 40% cost reduction in the fabrication processes by applying these technologies differently, and it also have a 18-month schedule reduction as well, which is enormous in our time to have new technologies demonstrated in a shorter timeline so that we can all streamline and ensure that nuclear energy provide to the rest of the nation and globally the support that we need to go as an international workplace, the benefit to their communities.

And then I think this is the second last demonstration, I wanted to show here that we also have small – we are supporting small businesses where again there is a partial funding and the DOE funding. And here is currently I wanted to highlight here three examples, and there is the real-time non-destructive examination from LER technologies as shown over here for a surface void detection, and again 316 was used as a demonstration. Then there is the two NovaTech projects for the lower tie plate concept and some of the low fatigue that is also for hold-down springs and upper nozzle features. So, there is a variety of funding mechanisms how we can support AMM work.

Also, a joint partnership between us the AMM program, and the NSUF program from DOE-NE of which this specific research of Colorado School of Mines by Professor Jeffrey King is yielding excellent results now at the end of neutron irradiation where 316 stainless steel parts were fabricated using different conventional additive manufacturing processes and compared through with [Unclear] stainless steel. As you can see here, it’s powder bed fusion from two different facilities or technologies and then a free form and electron beam wire feed as well.

Obviously, a variety of students have been benefited from this work and the other programs. I didn’t say that earlier, but we are also very supportive of proposals and funding awards that lead to the benefit not only of the technology but the next generation of the workforce development.

And last not least, an example, another example of the diversity of the work is this excellent work by Professor Haiming Wen from Missouri Science and Technology University. And it is again where it was a funded project first as part of a NEET AMM funded project, and followed up by irradiation, neutral irradiation as sponsored by the NSUF program resulting in nano-structuring through severe plastic deformation, yielding quite interesting result on different manufacturing technologies that we all are not necessary yet to know of in our normal part of life, namely high pressure torsion and equal channel angular pressing. So, it is a solid state manufacturing process.

Showcase the diversity of what is really in this interesting domain of advanced methods for manufacturing. So here is I provided you now with a background of work that we have – or the diversity of work that we have done. But what next? How can we have the industry and the global AMM to have it really as an enabler to grow a nuclear energy and support industry going forward. You can see that there is a variety of nuclear reactor technologies that is currently being developed and on various levels of funding levels. There is a variety of additive manufacturing processes and there are so many material types. So, the key here is we cannot do that alone only from researcher's point of view. We really need to have a very strong research focus needed. It is not only for solving individual or specific manufacturing techniques and material problems, we need to identify holistically with all stakeholders the strategic part forward in technologies, so that we can identify capabilities of resources that will broadly benefit the application of these methods for operating in harsh service condition.

And we can argue, so what, we know that we need to talk with our stakeholders. The next step, it's really on a next level what we need to work with but because I have called this slide the 'gaps or technology challenges' and I really should have renamed this one, crossed this out and said, 'our technology opportunities.' Because we have now the opportunity with this new life that we have and can contribute to it in the nuclear energy domains by prioritizing the methods and materials. Use the complete set of need to our advantage to find synergy because there is synergy that we can find and how do we find it by a different way of thinking? To see it not as a challenge, but to see it really as an opportunity for us to explore to the betterment of mankind. We can use that as a risk reduction method to speed up industry deployment. We should ask the question what can we do differently in qualification process while learning, while [Unclear] upon the excellent work that has been done by all researchers and industry and institutions over past number of years, multiple years so that we enhance the maturity level of these manufacturing processes and moving forward. My personal view here is as well. Let us use this opportunity not to fall back only because we have to or we think we have to fall back on status quo. But let us understand really what is our needs and translate that to something that we can use to accelerate our likelihood [ph] going forward.

What that we say is, let us look analytically to the performance data that is not available in all the nuclear environments. So, if we make proposals now for researchers, if we make proposals, let us do a next better job by really understanding what information is out there. Let us also do cross-cutting analysis. Let us do a little bit more of what we have done in the past because we are in a growth period yet. This is exciting. How do we measure or gauge now our applications of the new advance manufacturing methods or let us rephrase it? It is not necessary new advanced manufacturing methods but how can we enhance our conventional methods by applying some of the newer measurement technologies for example for in situ measurement analysis so that we don't need to do potentially destructive characterization but potentially non-destructive testing.

How do we look at standards? Do we know about all the standards and codes and methodologies like the AMM [ph]? Do we understand it, do we know what is out there, do we really use it to our optimum? Do we understand the requirements and performance specifications? Yes, some of you might be not like what I am saying here, but I am taking myself as an example. Because often I thought that I know it or only to realize later that I really was so excited about the technology that I did not listen very well to the end customer.

So, that is why it is so important that we need to continue strengthen our multiple disciplinary teams for developing work. And expanding our team members, that is really knowledgeable about digital engineering, the machine learning approaches. Because in property modeling, in fabrication readiness, in fabrication optimization, in prediction, qualification, machine learning can be applied in conventional fabrication processes basically in every form of life what they are. I often say to a colleague of mine, don't let us use this now as the next big thing and buzzword, let us really utilize it to our benefit. And often for me typically, I am an experimentalist, it is a step, a learning curve for me as well. But I am so excited to learn from my colleagues globally about this. Going then hand in hand with the embedded sensors that is really necessary for the operation of the nuclear plants.

I must speed up here. I get so excited about this technology of ours that I just want to talk. Luckily, there are many expertise available and a very good team member as well at Idaho National Laboratory under the leadership of Dr. [Unclear] going forward, in the operation or the reactor digital twin, but we are working together here now together with TCR on the manufacturing process digital-twin conceptual architecture. And for this presentation, I thought it was so well described as part of the Deloitte University Press that I have included here. So, again, in one of the recent presentations from Oak Ridge National Laboratory, Ryan [ph] he really highlighted for us to be 'I want to produce a very good digital twin of the manufacturing process. We need to understand the manufacturing process.'

So, we are not saying here we are going to have the magic wand and say because we have now a digital twin it can do everything. It is still the product of what we with our knowledge and the lessons learned from the past and the current lessons learned. That is very important that we continue doing that so that we understand really what is important, do we do a digital twin only of the manufacturing process, how can this be utilized for other manufacturing processes? Can we after we have identified the parameters, say, for example, the direct energy processes, can we utilize for laser powder bed fusion. Immediately people will say, oh, no it’s totally different. And I beg to differ because we don’t know. We have not done it fully so that we can identify the synergistic. And furthermore, do we know if we want to have now another performance, a different reactor type, how do we proceed utilizing the digital twins for different material types, different environments so that the next time around it really can help us.

So, the decision here is to understand the manufacturing process and further expand it over so that we understand the product. We know we can manufacture the product repeatedly at a variety of places. We can decrease the uncertainty of this. We can also then determine how this product worked in an integrated system and later on how is it going to perform as part of a reactor in real life operation.

And then together with that on the sideline, but as important, what is the supply chain management activities that needs to in place and the risk associated with that? And with that then there is a variety of business values that we can argue and supported by this excellent study that they have demonstrated here from the source of Deloitte analysis. Specifically here, the new product introduction cost and lead time. And not only following the record retention and serialization as part of the more experienced people like myself in the earlier days carrying a hand manual completed record through the part, but to have a digital record. It is more than having a digital record. It is really to understand and to show and have demonstrated quality data to prove the overall quality of the project going forward.

Going forward, as part of this digital twin aspect and a variety of research projects, embedded sensors are an extremely important part of our advance methods for manufacturing. And very exciting, we are having a very good cross-cutting technology, again, as part of the advanced sensor in instrumentation program led by the National Technical Director at Idaho National Laboratory, Pattrick Calderoni, where they are really doing a very good cross-cutting work but also directed funding work focusing on a variety of advanced sensor as well as two-dimensional sensors as well as embedded sensors. Here again typically, these embedded sensors, there is work that is done specifically in other DOE-NE programs. For example, with TCR there are other researches over the whole nation that is working on that and then specifically as part of this project as well. So here, it is important that we all talk to each other that we can focus on complementary work to highlight the use of this work and then important to get it tested in a real-life reactor neutral environment and it can support both advanced reactors, existing reactors, and fuel cycles. And I urge you as well to look on their website.

And this next slide I am going to change a little bit direction. And I was so excited when two AMM colleagues reach out to me when I started to talk about my exciting role in the AMM program. Chandu Bolisetti and Efe Kurt, are civil engineers and they provided me these slides, the following few slides, showing that in the MIT report of 2018, well, 47% of the work is related to the civil and structural and craft and labor cost designs.

So, he also showed that our current AMM primary focus is really on the nuclear island equipment which forms 30% of the cost for nuclear. And therefore, not saying we are focusing on the right thing but saying that we are maybe missing the opportunity as a whole community to focus on an area where a big cost saving can occur currently. So, if you look here in graphical form, there is also a different source from EPRI showing that the civil and labor cost design. So, this is an opportunity for us. If we look at our key focus areas that we highlighted, we looked at modular work. But most of the proposals that we received was on this modularity of the equipment over there. So, that is also tell-tailing [ph] that we are maybe understanding that we need to focus on modality and definitely everybody contributed but there is a major area that we need to consider as well.

So as further part of the evaluation that they have done for AMM applications, they look at a variety. So, they believe that there is potential room for R&D in concrete construction. So, the efficient ways for modular construction that ensures safety, economy, and quality assurance. So, to maximize off-site construction, so use existing supply chains from the broader manufacturing work here and then avoid the need for specialized technicians such as nuclear quality welders. So, that brings us now back to some of our other technologies for future focus, we will focus on. And they found that according to their evaluation there is really not much need for new types of concrete per se but there is a linkage that is necessary between the knowledge gained from the non-nuclear industry versus the reactor types.

Yes, nuclear does have additional precautions. However, it doesn't mean to say that it doesn't exist already in the current work. So, here again examples of some of the nuclear constructions, and it is applications for pre-casting concrete. It is not in nuclear construction yet but what do we need to benefit from that.

So, they prepare a typical scope of research project going through technical background, physical testing, benchmark analysis, codes, and standards, and I am sure there are some circular activities as well. But the important part of this year is to go through demonstration and then the implementation. And all of this is needed for regulatory acceptance and industry. And currently, I am very excited with the NRIC focus, it is on demonstration. But before we get to the demonstration part of the construction technologies, there is really a potential opportunity for the codes and standards and regulations between these three. Those take place already but the codes and standards regulations and the industrial fabric manufacturing does not take place yet. So currently, we do not have a program that is focusing or activities under another program that is focusing on improving their TRL or the research readiness level in the construction technologies. So, here is a potential opportunity that needs to be explored.

So, some innovations that we really can focus on is, as highlighted by them, is – well, I would like to highlight the third one first, smart concrete with embedded sensors. Yes, so, this is an opportunity for us all to see that we can utilize technologies like some precast concrete that offered modularity but we don't have information on how it is going to behave over a long period, how do we predict that. That is where embedded sensors can play an initial role and even further for a lifetime, increasing the lifetime. The manufacturing of 'foldable and transportable' reinforced concrete structures, a question mark. Let us think out of the box. And then also concrete with superior radiation shielding properties. And getting a little bit closer to our conventional additive manufacturing is – although this picture doesn't show that but why don't we combine metallic and concrete additive manufacturing processes to be able to decrease the number – the time building these concrete structures and what is the road to get that technology sorted out.

So also, how do we compare the work on concrete that was necessary or is necessary for light water reactors versus the advanced reactors. So, the current light water reactor containers are designed for high pressures, and they need it as containment that withstand these pressures and temperatures. And therefore, modular construction was more challenging than the many advanced reactors that involve passive safety system and are operated in at or near atmospheric pressure.

So, therefore the playing field has changed, providing us more opportunities so that we can look slightly different at this one here. And it may be for – there is some upcoming regulatory changes that are more risk-informed and performance basis. So, therefore, this might be possible to adapt non-nuclear concrete technologies that have already existing supply chains and decade of experience. However, as we said before, they still need to be adopted in the two blue areas on the flowchart for the nuclear divide and to be demonstrated adequately. But the time is right for us now to do that.

So, discount for both the concrete and other material types. New materials took historically decades to be adopted in the nuclear industry. We need to adopt technologies. One strategy can be to adopt technologies that we have already a head start. So, nonnuclear industries are an obvious place to look for, for existing experience in supply chain. We don't need to redevelop in all cases the wheel. We just need to understand the differences or the additional requirements and how we are going to negate the risk for that. Advance reactors will have a structure with lower safety requirements and these structures are good candidates for technologies from non-nuclear construction. So with this, I also want to show you the success stories and this is not work of necessary of the AMM program but it is from our industry because we are all working together to advance and enhance the nuclear industry.

So, there are good examples of advanced manufacturing that is already now used in commercial nuclear power plants that will – that help us pave the way to get it more understood and more accepted. And one example is the fuel assembly channel fasteners that is introduced to Brown's Ferry in Alabama and it was Oak Ridge National Laboratory partnership with Framatome and Tennessee Valley Authority. I have put in the link over here so that you can read the newsletter about that. And then another example is from Westinghouse and Oak Ridge, the thimble plugging device which is installed in Exelon's Byron unit number 1 in 2020. Very good examples and very exciting for our technology. Also, globally, there is two advances recently highlighted in the news with the two newsletter links over there. The one is from the Korean Atomic Energy Research Institution where they have fabricated the chemical and volume control system safety valve. And this one particular is a good example of a variety of hybrid – the application of hybrid manufacturing processes, meaning more than one manufacturing process together. And this is a demonstration of a chromium and nickel component using direct energy deposition and machining process. Please read that. That is, it matched the class I safety aspect. And another example in the global industry is the Siemens impeller in a power plant in Slovenia with the one, the original obsolete water impeller versus the prototype 3D prototype, and this is the replacement 3D printed part. Very exciting for us. It is out there. Also, advance manufacturing and specifically additive manufacturing parts is widely used in safety-critical areas of the aviation and aerospace industry and we need to learn from that.

Another specific highlight is the surface technologies that really does have large potential and for you all to consider. There is yet again a variety of technologies. And what I didn't say before when I asked the question to us all, what next? Is really to understand what is your need so that you can make the right choice of what is the basic knowledge in manufacturing technology, how you will address this requirement and need.

And here, I really would like us to start to think from bottom down and not from bottom up. It is not 'I love this technology there, I am going to make it a plaster for all our problems and concerns and needs.' Although I know we all have our pet subjects that we enjoy most, but there is a much better excitement that we all can get from using the right method to reach the requirement and to see that the component that we all have worked out on is going to perform very well or is performing well and is utilized in real life reactors. But before we get there, I understand and we all understand that there is a variety of ways how we can address that need. And therefore, I do not argue or I do not advocate that we must only do the down selection very early in the research stage. That's why there is a research and development in the earlier stages of maturity and we still need to go through that. But surface technologies, back to that, there is a wide application fields where we can address needs. For example, those that I have highlighted some in the green areas. Thermal barrier coatings, corrosion protective coatings, other environmental protection like where [ph] or flow erosion, waste packaging, especially in the nuclear of which this is a good example for a process used by at Caterpillar and there is the reference if you want to see further.

Also now, again, I want to show our exciting opportunities because depending on the application and the needs, we really can go for very thin layers. For example, the physical vapor deposition for very thin deposited coatings. And there again the technology and the science is there, how should we apply these coatings. Should it be 90 degrees or should it be with an angle? How does the angle influence the final properties for this exotic material or challenging materials that we want to do. Very exciting work going forward.

Also, it might be an opportunity furthermore to talk about engineered gradient materials and compositions. We can advocate, yes, it's just a coating, or we can advocate it just a welding process or a different manner of doing welding. It doesn't matter really how we see it as long as we see the potential advantages of these processes. And how we almost work together so that for the nuclear industry we understand the qualification processes, the standards that is necessary. So, all the in situ by digital twin – digital three, how we can use this to qualify these types of material because it does have a variety of examples already how it can be applied for ceramic to highly conductive material. You can have different titanium materials bonded so that you don't do welding, but both as one go so therefore become it is a more economic process. And therefore, you can really design your materials through an enabling fabrication process and also with this you can potentially design new materials that is more specifically for additive manufacturing and not using the same material composition that was designed for flowability of castings. So, is there a minor specific composition adjustment that we need to do for additive manufacturing processes. So, do we need to think differently if we want to do the one-to-one comparison between forged materials or cast materials versus additive manufacturing and should we better think about the performance of this material?

So AMM really provides any advanced manufacturing process, provides opportunities to discover and develop new materials.

And I will soon [Unclear] and I think I need to speak up a little bit here coming towards qualification processes. I already mentioned that we really as a community need to think at a new way. And with that, the workshop that we are going to have, the first virtual meeting for specific industry input during August 24 and 25 where we will discuss current regulatory processes, understanding our current gaps that we have identified already. There is a really good roadmaps available from NOC, from EPRI, from NEI, from other entities, American [Unclear] and then our own DOE-NE programs as well. So, this is our workshop to think about – well, to put us all on the same page what is the current status quo with soon in October, day to be decided, and hopefully face-to-face where we will really discuss in workshop the industry requirements, what is the wish list, with no preconceived ideas. And being with the output of these two workshops or two forms of workshop is to adopt new ideas and to highlight where there might be some improvements that we can do while really build upon this excellent work that has been done for decades and the wonderful opportunities that is there.

And moving forward to the next slide is how do we apply modeling for the acceleration of not only the development but also the qualification and licensing aspect as well. So, if we want to put it really in a block, we can say that there is modeling for design aspects, for process modeling optimization, and then for the process modeling, so that in the end we have multi-scale and multi-physics coupling modeling so that we can really decrease the product uncertainties and to increase the multi-scale and physics-based processes. By doing that, we will accelerate product development, accelerate qualification, and get closer to include modeling in the full lifecycle of the product. And specifically I think for this forum here, I personally think we have started – a lot of universities and companies have started now for the new generation of researchers and designers to work on designing for advanced manufacturing processes, but we are needing to accelerate that as well. And even more for experienced researchers, designers, developers, we still design our paradigms that were set as part of our experience. And that is normal. But I think we should do more as a community to enhance the advantages of the design processes to increase, for example, topology optimization. And how is that influence our process modeling so that we cannot not only start by working potentially on the manufacturing process modeling or the performance modeling of the material, but to see it as a holistic approach and where we can apply which will be beneficial for producing digital twins and going to the next generation of acceleration. So that is really my excitement for the future and I would like to continue.

Also, as I mentioned in that workshop planning, we really need to understand what is currently out there for the codes and standards. And INL's Dr. Sam Sham, previously from Argonne National Laboratory, is really a specialist in this domain. And as I always say to other people I wish I have the knowledge that he must have only in his pinkie already. He is an excellent resource and is leading the advanced-reactor technology advance materials research and is our contact with the codes and standards, the ASME codes and standards. And we need to understand – we all need to understand more about how can this help us and what is needed when we start working on these advanced technologies.

Going forward to the transformation challenge reactor provided by Ben Betzler, the current Director of the Transformational Challenge Reactor or TCR, they are working there for building blocks or pillars, the artificial intelligence informed design, advanced materials, integrated sensing, and control. And this is really both in the manufacturing process as well as the final component and then to do the manufacturing as part of a full digital platform. And I would urge you to do little bit more reading on that or reach out to Ben. They have started with a very good digital trait [ph] of the actual process itself, also work for digital infrared measurements to link defects produced during the fabrication and is currently working on a feedback loop then to correct also those specific work itself.

So, the agile design and development approach employed by TCR is being therefore also to intend to accelerate the work. And they are often working with specialists from the NRC so that they understand the needs and the communication through. I would like to highlight here specifically on the manufacturing side some nice work that they have done on the fabrication of uranium nitride TRISO although the AMM program is not specifically working on nuclear need per se, the fabrication of this, the silicon carbide work after the TRISO is embedded here by means of raisin-based additive manufacturing process that have done good work on the alternative manufacturing process for yttrium hydride slugs. And they have done very good irradiation work on grade 316 as well as another [Unclear] alloy and they are busy writing as part of this year's work, some work already, handbooks of properties that really can help us.

Another program for as part of the NSUF and part of DOE-NE work is the NMDQi in short, which is the Nuclear Material Discovery and Qualification Initiative led by Director Allen Roach from Idaho National Laboratory where they link the physics-based modeling and the rapid testing and characterization linked to the microstructure through also machine learning so that they can do for the industry property performance prediction in surface in the reactor specifically. One example of the acceleration opportunities that they do have, Michael McMurtrey, Mark Messner, and Allen Roach, did this work for the – they get to the challenge to have experimental validation up to 30 years of the design life. And obviously for new advanced reactors and new materials we do know that we cannot wait for 30 years to do that and they are having staggered qualification approach for qualification materials.

And with this, we want to recap again here what is the high impact materials and technology challenges? As I mentioned, design approaches for manufacturing. I am feeling very strongly that we are really neglect this so far. It can really leapfrog as even further so that the designers and developers can reap the full benefit of advanced manufacturing processes.

With that then, Dr. Paviet is the National Technical Director for Molten Salt and she and her program has challenges to develop high strength, corrosion protective radiation resistance materials and components. I talked about the new acceleration for qualification, a new paradigm, or just a differently lead that can accelerate that. All reactor types need to have compact heat exchangers. There is a such a wonderful opportunity for us all to have cross-cutting enabling synergistic techniques to work there. We don’t need to redo a lot of work for reach program. And then the scalability. Nothing is going to work if we only do it on a bench staff. We need to look and consider the scalability in early stages of our environment. And then sensors and sensors and sensors. We need to work on that.

With that the conclusions and I would like to end here with this call out here. Advanced manufacturing techniques really provide us with an opportunity to manufacture product and material simultaneously. So, let us do that. Let us bring together the diverse set of manufacturing methods and materials in our harsh environmental working capability to identify common barriers, technical pathways. Let us talk more and more frequently with each other and let us understand where we all are needing to go to. And with this, I provide you the contact information of myself and AMM DOE federal manager Dirk Cairns-Gallimore and also the website if you would like to read specifically on the AMM program or other enabling technologies.

And with that, if there are any questions and I will hand it back over to Berta or Patricia. Thank you very much that I could share with you this exciting topic and I am sure you can see where my passion lies. Thank you.

Berta Oates
Thank you, Isabella, for such a fabulous presentation. If you have questions go ahead and type in questions pane now. And while those questions are coming, we have some information to share with you also regarding upcoming webinar presentations. In June, a presentation on the In Service Inspection and Repair Developments for SFRs and extension to other Gen IV systems. In July, Evaluating Changing Paradigms Across the Nuclear Industry. And in August, a presentation on Graded Approach: Not Just Why and When but How. If you will give me just one second, we have some other information to share with you about the 'Pitch your Gen IV Research' competition.

Patricia Paviet
Thank you so much Berta. So, yeah, hi everyone. A couple of months ago on the first of February, the Gen IV Education and Training Working Group launched virtual 'Pitch your Gen IV Research' competition. I announced that through these webinars. And today I am happy to announce the winner. This 'Pitch your Gen IV Research' competition was really for junior researchers who were performing their Ph.D. or completed Ph.D. after the 1st of January 2019, to have a platform to present their work through a webinar series.

So next slide please Berta. We have received 51 executive summaries and from the 51 executive summaries we selected 21 candidates who presented their videos. They are 4 minutes long. Here you have the two platform where you can watch the videos, YouTube platform and Bilibili platform. So, if you have time I encourage you to look. The completion is over but I was very impressed by the work and the innovation of these junior researchers.

Next slide please. So, the winners for the 'Pitch your Gen IV Research' competition, we have three winners. The GIF Jury Category, we have two winners. The first winner will present a webinar in December and will be invited to attend the next GIF Symposium planned in 2022. The second winner will present a GIF Webinar in March 2022 and will be invited to attend the future GIF meeting in the region. And Popular Vote Category, which means that we looked at the likes and the views and this Popular Vote Category, the winner will be invited to present a GIF webinar in May 2022. So, next slide please.

So, the first winner is Dr. Flore Villaret from CEA. She did her Ph.D. in CEA and now she is employed by Électricité de France. She presented her work title Development of an Austenitic/Martensitic Gradient Steel by Additive Manufacturing.

The second winner is going to appear soon. Next slide please. Thank you. The second winner of the 'Pitch Your Gen IV' competition is Mr. Benjamin Jourdy from CEA, France. He presented Scan Effects Analysis on the Thermal Hydraulic Behavior of Impinging Jets in Sodium-Fast Reactors.

And our last winner, which is the popular vote winner, is Mr. Jiho Shin from the Korea Advanced Institute of Science and Technology presented his work on Development of Nanosized Carbide Dispersed Advanced Radiation Resistant Austenitic Stainless Steels for Gen IV Systems. So, you will have the opportunity to watch their presentation in the next couple of months. Thank you again for supporting these junior researchers. They are our future. Back to you. Thank you so much Berta.

Berta Oates
Thank you, Patricia. That's fabulous information to share. I do have one more thing I would like to say to the audience participants and that is an apology that the PDF of today's presentation for some reason did not upload as a handout. It doesn't appear that that's been made available to you. I apologize for that. I think that the file size prohibited that from actually uploading and being available. But I will ensure that that PDF is available to you. There will be links in the email that goes out with thank you notes tomorrow and it will be available on the GIF website at www.gif-4.org.

Just give me a couple of days to get that rendered – this recording rendered and the file uploaded and that link, and that information will be available publicly. So with that, let's do get to questions. Give me just a half a second. I apologize for the delay. Okay. So, Isabella, I have shared these with you. You should be able to see questions as well. The first I see is, is the August 24th through 26th qualification workshop planned to be virtual, in person, or hybrid.

Isabella van Rooyen
So, August 24th will be a webinar, virtual. We have moved it – originally, we planned it in May month, this month, but we extended it to August with the hope that we can have our hands on and then in the end we were not sure that August will be available for getting all the relevant participants together and therefore we have decided to split the workshop basically into two. The first one, August 24 will be virtual and then the October for which we still need to finalize the day, we hope that one will be hands-on where the more interactive workshop part will take place.

Berta Oates
Great. Thank you. Which advanced manufacturing technique has been ASME section 3b and PV code qualified?

Isabella van Rooyen
I will need to come back to you on that one.

Berta Oates
Okay. Great. Do you have an inter-agency agreement with NRC to facilitate the prioritization of R&D investments? And if so, how is that working?

Isabella van Rooyen
I will also need to go back to John Kelly through our program, US program manager.

Berta Oates
Okay. Could you please show me updates on additive manufacturer of fuel meet studies?

Isabella van Rooyen
No, it is not part of this presentation, nor the AMM program.

Berta Oates
Thank you. And that looks like the list of questions that we have… With new materials used in AMM that do not comprise pressure retaining structures, require any ASME BMPV [ph] code approval?

Isabella van Rooyen
There are different levels of approval. I will need to double check with our specialists, but I do not believe so.

Berta Oates
Thank you. That looks like the list of questions. I appreciate everyone's participation in this fabulous presentation. The slides were absolutely gorgeous. I know there was a little bit of lag in some of people's viewing and I apologize for that but that's just what happens when we have such beautiful images of such high quality. So, I think the visual is definitely worth the wait in this case. Isabella, I hope that you had a great time presenting and I appreciate your efforts to put this together for us.

Isabella van Rooyen
Yes, thank you very much and I know I ran a little bit longer than what I should be, but it's difficult to stop me if I start to talk about this exciting technology.

Berta Oates
No, it was great. I think we are right on the mark, given the limited number of questions. Again, I apologize that I couldn't get the handout to upload but we will share that information and don't hesitate to reach out if anybody has any additional questions.

Patricia Paviet

Thank you again Isabella?

Isabella van Rooyen
Yes, I wanted to say, and even afterwards you have my contact details. If there are any questions that I can help you with or advice that you would like to offer, please don't hesitate to contact me or Patricia.

Berta Oates
Okay. Thank you. Thanks everybody.

Isabella van Rooyen
Bye, bye.

Patricia Paviet
Bye, bye.

END