GIF AMME Workshop on Advanced Manufacturing

Mark Messner

Argonne National Laboratory, United States

Agenda for this afternoon

Track 2: GIF AMME-TF Advanced Manufacturing Qualification Workshop		
Time	**Location**	**Event**
11:30 am	Plaza A	Lunch
12:45 pm	Ottawa room	Workshop Overview Mark Messner
1:15 pm	Ottawa room/Plaza B	Breakout group discussions
2:45 pm	Plaza A	Coffee break
3:15 pm	Ottawa room	Plenary discussion
4:30 pm	Ottawa room	Workshop outcomes
5:30 pm	*Workshop ends*	

GIF-AMME-TF Background

- The nuclear industry has recently seen a very substantial resurgence of interest in advanced reactors and, in particular, small modular advanced reactors.
- Distinguishable from other nuclear renaissances of the past 30 years present activity is based on the development of novel future technology rather than the refinement of present technology. Although some SMR’s under development are based on simplified LWR technology, many are based on Gen IV technology and utilise the inherent safety capability that can arise in non-water-cooled reactors.
- Key to the successful mass deployment of SMRs is the assertion that the agile manufacture of components and structures in factory-like environments enabled by large scale production will substantially reduce the capital cost of new nuclear build.
- This requires innovation in the nuclear supply chain, particularly in the areas of advanced manufacturing and materials engineering, if they are to be delivered on-time and on-budget.

Advanced manufacturing innovation: the problem.

- Getting new manufacturing processes or materials qualified for use in nuclear reactors can be a long and tortuous process
- These long lead times produce an effective and consequent barrier to market entry of advanced manufacturing processes and materials
- Developments in advanced manufacturing are occurring much faster than our ability to introduce new materials and methods into nuclear design codes
- These issues need to be addressed if advanced reactors are to be brought to the market in reasonable timeframes
- GIF AMME Task Force formed in 2018 to assess and address these issues

Expertise | Collaboration | Excellence

GIF-AMME-TF History

- A survey establishing industry interest in Advanced Manufacturing was held in 2019
- There was substantial interest (59%) in pursuing collaborative R&D opportunities and overwhelming support (87%) for workshops as the mechanism to design, initiate and promote these activities
- Workshop on Advanced Manufacturing held on Feb 18th & 19th 2020 engaged the private sector, including SMR vendors and supply chain companies
- Details and video of workshop available at: https://www.gen-4.org/gif/jcms/c_115848/workshop-on-advanced-manufacturing
- Recommendations of workshop were embodied in revised 2021 Task Force Terms of Reference that defines objectives through three task groups:

  * Requirements Capture
  * Qualification, Demonstration and Deployment
  * Design and Modelling

Q1 What is your organization's primary role?

Responses	%	Number
Designer / developer of new reactor technology	37%	20
Research Institute / National Laboratory / Consultancy	37%	21
Manufacturer of equipment and components for nuclear power plants	13%	7
Trade, Industry or other association	7%	4
Code and standards setting organization	4%	2
University	2%	1
Safety Authority / Regulator	0%	0
Other (Utility)	2%	1

Survey recipients are deployment focused

Q2 Where is your organization located?

Location	%	Number
North America	35%	22
Europe	33%	17
Asia	29%	14
Oceania	2%	2

Expertise | Collaboration | Excellence

GIF-AMME-TF 2021 Survey High Level Conclusions

- Community and interest has grown
- Community has become more focused
- Interest in *Qualification* and *Modelling & Simulation* identified in 2020 Workshop confirmed
- Strong interest in collaboration and attending future AMME-TF workshops
- Both areas seen as important but there was no identified consensus on way forward or activity prioritisation
- Thus, Task Force produced a plan for a series of workshops on both Qualification starting with how Modelling & Simulation can be used to accelerate qualification

Expertise | Collaboration | Excellence

(Virtual) follow on workshops

- **Workshop on modeling and simulation:**
  - The 2021 workshop, held on November 8th and 9th focussed on how modelling and simulation can enable the qualification of advanced manufacturing
  - Workshop attended by 52 attendees from 13 countries,
  - The workshop series is designed to develop a mature community that can understand the difficulties in implementing advanced manufacture in nuclear build and work collaboratively to surmount them
  - Paper summarizing the outcomes of the workshops will be presented at the G4SR conference
- **Workshop on qualification:**
  - 2022 virtual workshop held on June 23rd, around 60 attendees
  - A “preview” of this in person event!

Workshop objective

How can we accelerate the qualification of AM materials and components for use in Gen IV reactors?

1. Identify any unique characteristics of AM materials that will affect qualification, versus conventionally manufactured components.
2. Identify the key factors that slow down the qualification process.
3. Identify strategies for accelerating qualification – how will we qualify AM components for use in Gen IV reactors?
4. Prioritize qualification strategies by likelihood of success.
5. ***Identify and rank definite actions the community can undertake to promote the qualification strategies identified in #4.***

We will break into two discussion groups

Group A (stay here)	Group B (Plaza B)
Isabella van Rooyen **(Moderator)**	Eric Abonneau **(Moderator)**
Manuel Pouchon **(Recorder)**	Lucian Ivan **(Recorder)**
Wendy Reed	Richard Russell
Rosaura Ham-Su	Marc Albert
Neil Alexander	Lindsey Butterworth
Takuya Funahashi	Hideki Kamide
Scott Read	Suibel Schuppner
Antoine de la Chevrotiere	Brent Smith
Rachel Lai	Yevgeni Brif

Group activity

Note breakout room for your group

- **Group moderator will lead discussion, recorder will take notes to help focus/guide the plenary discussion and to serve as a record of the workshop.**
- **Each group should address each of the five questions, *with the final topic being the most important.***
- **Each group is free to determine the best means to brainstorm and rank ideas, however SWOT analysis can be useful here.**
- **Please return with some thoughts on each question – we will ask the moderators and recorders to report back to the entire group**

Group discussion ends at 2:45 pm, coffee break in Plaza A, resume plenary discussion at 3:15 pm

Analyze each identified opportunity (SWOT analysis or similar)

Opportunity 1. XXX

Strengths	**Weaknesses**
xccxc Xcccc Xcccc xccccc	xccxc Xcccc Xcccc xccccc
Opportunities	**Threats**
xccxc Xcccc Xcccc xccccc	xccxc Xcccc Xcccc xccccc

Plenary sessions

Back to Ottawa room

- **Group moderators/recorders will present the outcomes of their group discussion**
- **I will then moderate a plenary discussion, where the entire group can provide input**
- ***Goal is to provide collective answers to the five questions, again with a focus on definite actions the community can undertake to accelerate the qualification of AM components***

QUESTIONS?

Reminder on groups

Group A (stay here)	Group B (Plaza B)
Isabella van Rooyen **(Moderator)**	Eric Abonneau **(Moderator)**
Manuel Pouchon **(Recorder)**	Lucian Ivan **(Recorder)**
Wendy Reed	Richard Russell
Rosaura Ham-Su	Marc Albert
Neil Alexander	Lindsey Butterworth
Takuya Funahashi	Hideki Kamide
Scott Read	Suibel Schuppner
Antoine de la Chevrotiere	Brent Smith
Rachel Lai	Yevgeni Brif

Plenary discussion

GEN IV International Forum

Goals

Come to a consensus list of answers to our five questions:

How can we accelerate the qualification of AM materials and components for use in Gen IV reactors?

1. Identify any unique characteristics of AM materials that will affect qualification, versus conventionally manufactured components.
2. Identify the key factors that slow down the qualification process.
3. Identify strategies for accelerating qualification – how will we qualify AM components for use in Gen IV reactors?
4. Prioritize qualification strategies by likelihood of success.
5. ***Identify and rank definite actions the community can undertake to promote the qualification strategies identified in #4.***

Short agenda

1. **Report from Group A**
2. **Report from Group B**
3. **Discussion with the goals of:**
    1. Merging answers from the two breakout groups
    2. Prioritizing/downselecting answers
4. **Final discussion: summarize consensus and get any last thoughts**

Question 1

Identify any unique characteristics of AM materials that will affect qualification, versus conventionally manufactured components

- Impurities caused by added surfaces, potential not measurable and/or different from wrought/cast equivalents
  - Potentially different across manufacturing methods
- Potentially larger variability in final properties (even for well-controlled inputs)
  - Multiple machine vendors even for a single technique – not necessarily different from welding
  - Larger number of smaller manufacturing sites?
  - Variability caused by geometric differences (thin section versus thick section…)
  - Higher gradients (temperatures, cooling rates, translating to properties)
- Unknown what flaws/defects/impurities will be typical for different processes (and if we can resolve critical defects)
- Lack of experience compared to conventional manufacturing processes
  - Lack of common understanding between computer science/manufacturing/end-user communities
- At least the potential for large datasets from in situ process monitoring (but it's not necessarily common now)
- The potential for more complex component designs
  - But difficulty in inspecting more complicated components
  - NDE techniques, acceptance criteria, and standards
- Control of local material properties to optimize performance
- Need to identify key processing parameters – are they known for likely techniques? (R&D/collaboration idea)
- Need to collect *representative* data – not just large volumes of data (and how can we know what is representative)
- Lack of standardization for AM processes (feedstock through final components)
- Who should have responsibility for each step in the process – could/should we consolidate responsibility
- Is there a strong economic drive to come up with new qualification methods for AM materials – and what time frame does industry need
  - Margin creep – tendency to add conservatism for new technologies to the point of eliminating any economic incentives

Question 1 – consolidated and ranks

Identify any unique characteristics of AM materials that will affect qualification, versus conventionally manufactured components

- Potentially larger variability in final properties (even for well-controlled inputs)
  - Multiple machine vendors even for a single technique – not necessarily different from welding
  - Larger number of smaller manufacturing sites?
  - Variability caused by geometric differences (thin section versus thick section…)
  - Higher gradients (temperatures, cooling rates, translating to properties)
- Unknown what flaws/defects/impurities will be typical for different processes (and if we can resolve critical defects)
  - Impurities caused by added surfaces, potential not measurable and/or different from wrought/cast equivalents
  - Potentially different across manufacturing methods
  - Need to identify key processing parameters – are they known for likely techniques? (R&D/collaboration idea)
- Lack of experience compared to conventional manufacturing processes
  - Lack of common understanding between computer science/manufacturing/end-user communities
- At least the potential for large datasets from in situ process monitoring (but it's not necessarily common now)
- The potential for more complex component designs
  - But difficulty in inspecting more complicated components
  - NDE techniques, acceptance criteria, and standards
  - Control of local material properties to optimize performance
- Need to collect *representative* data – not just large volumes of data (and how can we know what is representative)
- Lack of standardization for AM processes (feedstock through final components)
- Is there a strong economic drive to come up with new qualification methods for AM materials – and what time frame does industry need
  - Margin creep – tendency to add conservatism for new technologies to the point of eliminating any economic incentives
  - Who should have responsibility for each step in the process – could/should we consolidate responsibility
  - Which parts to do

Question 1 – consolidated and ranks

Identify any unique characteristics of AM materials that will affect qualification, versus conventionally manufactured components

- Potentially larger variability in final properties
- Unknown what flaws/defects/impurities will be typical and important for different processes and what processing parameters relate to these
- NDE techniques – new techniques, standardization…
- Lack of experience compared to conventional manufacturing processes
- At least the potential for large datasets from in situ process monitoring (but it's not necessarily common now)
- The potential for more complex component designs
- Lack of standardization for AM processes (feedstock through final components)
- Is there a strong economic drive to come up with new qualification methods for AM materials – and what time frame does industry need

Question 1 – ranking

Identify any unique characteristics of AM materials that will affect qualification, versus conventionally manufactured components

1. Lack of experience compared to conventional manufacturing processes
2. Lack of standardization for AM processes (feedstock through final components)
3. Economic drive for AM components – and ensuring we don't eliminate it

- Potentially larger variability in final properties
- Unknown what flaws/defects/impurities will be typical and important for different processes and what processing parameters relate to these
- NDE techniques – new techniques, standardization…
- At least the potential for large datasets from in situ process monitoring (but it's not necessarily common now)
- The potential for more complex component designs and new materials

Question 2

Identify the key factors that slow down the qualification process.

- **Fear of change (not wanting to be first) and lack of experience**
  - Lack of framework/precedent
- **Decision on how/what to qualify (component versus material)?**
- **Lack of a model for component qualification (at least in current nuclear Codes and Standards)**
- **Time to qualify through codes and standards**
- **Data collection for time dependent material properties (especially radiation)**
- **Requirement for full datasets when one material property will control design**
- **Component-specific qualification (would be slow + expensive)**
- **In situ monitoring (could be good, but would slow us down)**
  - What should be monitored
  - Acceptance criteria
  - Standards
  - Equipment on production machines
- **Lack of knowledge of what are critical defects – what are the critical material properties (could be different for new processes)**
- **Cost/funding and economic case**
- **No widely adopted framework for collaboration (low risk components)**
- **Design methods for complex components**

Question 2 – downselection and ranking

Identify the key factors that slow down the qualification process.

- **Fear of change (not wanting to be first) and lack of experience**
  - Lack of framework/precedent
  - Critical defects/material properties
- **Decision on how/what to qualify (component versus material)?**
  - Lack of a model for component qualification (at least in current nuclear Codes and Standards)
  - Component-specific qualification (would be slow + expensive)
- **Time to qualify through codes and standards**
  - Data collection for time dependent material properties (especially radiation)
  - Requirement for full datasets when one material property will control design
- **In situ monitoring (could be good, but would slow us down)**
  - What should be monitored
  - Acceptance criteria
  - Standards
  - Equipment on production machines
- **Cost/funding and economic case**
- **Design methods for complex components**

Question 2 – ranking

Identify the key factors that slow down the qualification process.

- **Lack of strong risk/benefit case (not wanting to be first) and lack of experience**
- **Decision on how/what to qualify (component versus material)?**
- **Time to gather data and qualify through codes and standards**
- **In situ monitoring (could be good, but would slow us down)**
- **Cost/funding and economic case**
- **Lack of a framework for widespread collaboration on how to qualify components**

Question 3/4

Identify strategies for accelerating qualification – how will we qualify AM components for use in Gen IV reactors? Then prioritize.

- **Aerospace, automotive, and medical device experience – copy their strategies, collaborate on new techniques**
- **Replace (some) long-term data collection with mod-sim**
- **Start with less safety critical (or non-safety significant components) and work our way up**
- **Find AM "killer app" – strong case to rush qualification**
- **Establish centers of excellence in manufacturing/testing/characterization – particularly rare/unique capabilities**
- **Find a common place to do the work – outsource to avoid conflicts between competitors and reduce interfaces in the qualification processes**
- **Harmonization of Codes and Standards – within and outside of organizations**
- **Communication with regulatory bodies (while we develop other solutions) – and improving regulator's knowledge of AM technologies**
- **Correlate in situ monitoring data to physical properties (and inverse problem – how much monitoring do you need to ensure minimum performance)**
  - Identify critical flaws – what do we need to watch for? (Ask designers)
- **Identify critical areas of components and focus monitoring/testing efforts on (only) those areas – similar for material properties (only focus on what properties control the design)**
- **Accelerated testing (ion versus neutron radiation, throughput testing, accelerated creep testing) – plus conventional testing to benchmark/validate**
- **Staggered qualification for time dependent properties – don't need full data immediately**
- **In situ monitoring of components to (again partially replacing long-term data)**
  - Integrated sensors or features
- **Parallelize design/build/test sequence (including material properties – vary processing parameters)**
- **Design for AM, don't try to force AM components into traditional design methods**
- **Test to failure under realistic conditions**

Question 3/4 consolidation

Identify strategies for accelerating qualification – how will we qualify AM components for use in Gen IV reactors? Then prioritize.

- **Aerospace, automotive, and medical device experience – copy their strategies, collaborate on new techniques**
- **Replace (some) long-term data collection with mod-sim**
- **Start with less safety critical (or non-safety significant components) and work our way up**
- **Find AM "killer app" – strong case to rush qualification**
- **Establish centers of excellence in manufacturing/testing/characterization – particularly rare/unique capabilities**
  - Find a common place to do the work – outsource to avoid conflicts between competitors and reduce interfaces in the qualification processes
- **Harmonization of Codes and Standards – within and outside of organizations**
  - Communication with regulatory bodies (while we develop other solutions) – and improving regulator's knowledge of AM technologies
- **Correlate in situ monitoring data to physical properties (and inverse problem – how much monitoring do you need to ensure minimum performance)**
  - Identify critical flaws – what do we need to watch for? (Ask designers)
  - Identify critical areas of components and focus monitoring/testing efforts on (only) those areas – similar for material properties (only focus on what properties control the design)
- **Accelerated testing (ion versus neutron radiation, throughput testing, accelerated creep testing) – plus conventional testing to benchmark/validate**
- **Staggered qualification for time dependent properties – don't need full data immediately**
- **In situ monitoring of components to (again partially replacing long-term data)**
  - Integrated sensors or features
- **Parallelize design/build/test sequence (including material properties – vary processing parameters)**
- **Design for AM, don't try to force AM components into traditional design methods**
- **Test to failure under realistic conditions**
- **Like for like qualification – may be more straightforward but could be long-term hinderance**

Question 3/4 consolidation

Identify strategies for accelerating qualification – how will we qualify AM components for use in Gen IV reactors? Then prioritize.

- **Aerospace, automotive, and medical device experience – copy their strategies, collaborate on new techniques (framatone)**
- **Identify critical flaws, material properties, and locations in components and correlate to in situ monitoring – including inverse problem of "what I need to monitor"**
- **Replace (some) long-term data collection with mod-sim**
- **Accelerated testing (e.g. ion versus neutron)**
- **Staggered qualification for time dependent properties including in situ monitoring as "canaries"**
- **Harmonization of Codes and Standards – within and outside of organizations**

- **Start with less safety critical (or non-safety significant components) and work our way up**
- **Find AM "killer app" – strong case to rush qualification**
- **Establish centers of excellence in manufacturing/testing/characterization – particularly rare/unique capabilities**
  - Find a common place to do the work – outsource to avoid conflicts between competitors and reduce interfaces in the qualification processes
- **Communication with regulatory bodies (while we develop other solutions) – and improving regulator's knowledge of AM technologies**
- **In situ monitoring of components to (again partially replacing long-term data)**
  - Integrated sensors or features
- **Parallelize design/build/test sequence (including material properties – vary processing parameters)**
- **Design for AM, don't try to force AM components into traditional design methods**
- **Test to failure under realistic conditions**
- **Like for like qualification – may be more straightforward but could be long-term hinderance**
- **Or just qualify AM materials as new (standard) materials**

Question 5

Identify and rank definite actions the community can undertake to promote the qualification strategies we identified

- **Identify and test to failure geometries, loading conditions, materials, and the corresponding critical flaws/limit states that are broadly representative of a wide range of likely AM Gen IV components (minimum requirements)**
- **Defect tolerancing (for a range of components) + identifying and validating NDE techniques that can find those defects**
- **Identify alternative qualification methods from other industries – direct comparison between multiple techniques**
- **Round robin benchmark studies for accelerated testing approaches, modeling and simulation, staggered qualification, and in situ monitoring approaches – demonstrate they can replace long-term testing**
  - Identify vendor tolerance for sharing data (and operate outside of that border)
- **Identify minimum standard for material pedigree for test data**
- **Setup a forum for summarizing/sharing/coordinating/harmonizing work at Codes and Standards bodies**

Question 5

Identify and rank definite actions the community can undertake to promote the qualification strategies we identified

- **Disseminate a "short-form" survey to vendors every year – limit questions to try to promote regular response. Aim to identify key manufacturing issues and how they change with time.**
- **Identify geometries, loading conditions, materials, and the corresponding critical flaws/limit states that are broadly representative of a wide range of likely AM Gen IV components (minimum requirements)**
  - Identify components, operating conditions, and materials (vendors)
  - Propose GIF project to identify cross-cutting geometries, conditions, and materials (and solicit feedback, perhaps through a workshop)
- **Round robin benchmark studies for accelerated testing approaches, modeling and simulation, staggered qualification, and in situ monitoring approaches – demonstrate they can replace long-term testing**
  - Develop a definite set of benchmark studies and solicit feedback (focusing on the likelihood of participation)
  - Goal would be to propose a GIF project to actually do the round-robin testing
- **Setup a forum for summarizing/sharing/coordinating/harmonizing work at Codes and Standards bodies**
  - Identify standards bodies in each member nation working on relevant standards (could also be overarching bodies Standards Council of Canada, IAEA)
  - Each country representative provides points of contact for each topic area – issue invites and coordinate first (virtual?) meeting

FINAL THOUGHTS…