

# **GIF AMME Workshop on how modelling and simulation can enable the qualification of advanced manufacturing.**

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# GIF-AMME-TF Background

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

# GIF-AMME-TF History

- A survey establishing industry interest in Advanced manufacturing was held in 2019
- Workshop on Advanced Manufacturing held on Feb 18-19<sup>th</sup> 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](https://www.gen-4.org/gif/jcms/c_115848/workshop-on-advanced-manufacturing)
- Recommendations of workshop were to focus collaboration on:
  - \* *Qualification, Demonstration and Deployment*
  - \* *Design and Modelling*
- Second survey held in 2021 confirmed community interest in *Qualification & Standards* and *Modelling & Simulation*
- This workshop focusses on how modelling and simulation could accelerate the qualification of advanced manufacturing
- As in our 2020 workshop, it will contain several interactive small group sessions with your peers where you will be asked to discuss and assess options and opportunities for the qualification of advanced manufacturing

## Current GIF-AMME-TF Membership

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# Structure of workshop

Mon 8 Nov	Workshop on Advanced Manufacturing DAY 1	
<b>Session 1 – Overview of workshop</b>		
13:00 – 13:10	Welcome and Introduction, overview of AMME-TF, purpose of workshop! Lyndon Edwards ANSTO, AMME-TF Chair	
13:10 – 13:35	How Modelling and Simulation could be used to support the nuclear qualification of advanced manufacturing Albert To, University of Pittsburgh	(20mins+5 min questions)
13:35 – 14:00	Challenges to the use of M&S to support the nuclear qualification of advanced manufacturing: a nuclear engineer’s perspective Pierre-François Giroux, CEA	(20mins+5 min questions)
14:00 – 14:25	NRC Action Plan for Advanced Manufacturing Technologies Carolyn Fairbanks , NRC	(20mins+5 min questions)

<b>Session 2 – Vendors and designers perspective: the view from the innovation front line</b>		
14:30 - 14:50	David Huegel & Clint Armstrong, Westinghouse	(15mins+5min questions)
14:50– 15:10	Jean-Marie Hamy, Framatome	(15mins+5min questions)
15:10– 15:30	George Jacobsen, General Atomics	(15mins+5min questions)
15:30– 16:00	Summary, Panel Discussion and Group Activity Briefing	

<b>Session 3 – Group activity 1</b>		
16:20 – 18:00	Attendees split into allocated groups, which undertake the following activities with the group Moderator/Rapporteur:	
Includes break as necessary	a. Discuss and identify opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing	
	b. Analyse each identified opportunity (SWOT analysis or similar)	
	c. Prioritise, by likelihood of success, best opportunities for 2030 deployment	
	d. Agree communication for Rapporteur to give to meeting at start of Day 2 (Can develop presentation overnight if necessary)	
18:00	End of Day 1	

# Structure of workshop

<b>Tue 9 Nov</b>	<b>GIF AMME Workshop on Advanced Manufacturing DAY 2</b>
<b>Session 4 – Comparing Group Outputs</b>	
<b>13:00 – 14:15</b>	Whole workshop undertakes the following activities: a. Rapporteurs from each group presents group output b. List agreed areas to be addressed and potential collaborative opportunities
<b>14:15-- 14:45</b>	Break
<b>Session 5 – Group Activity 2</b>	
<b>14:45 – 16:00</b>	Attendees split into new opportunity specific groups (those identified as having highest priority) and undertake the following activities:  a. What needs to be done  b. How can collaboration help?  c. Identify and prioritize areas/ideas for AMME activities/projects  d. Agree communication for Rapporteur to give to meeting after break
<b>16:00 – 16:20</b>	Break
<b>Session 6 – Final Group Reporting and Meeting</b>	
<b>16:20- 17:30</b>	Each Group present their findings and recommendations
<b>17:30 – 18:00</b>	Summarise discussion and consensus of meeting
<b>18:00</b>	End of Meeting

# Group discussion essential to success of workshop

- Sadly, Face to Face participation still not possible due to Covid -19
- So Group discussion will be in ZOOM Breakout Rooms



Group discussion



# Structure and purpose of workshop

Presentations designed to help define the workshop area and purpose

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Where we ask you use your experience and to expertise to Identify a community consensus

Session 3 – Group activity 1		
16:20 – 18:00	Attendees split into allocated groups, which undertake the following activities with the group Moderator/Rapporteur:	
Includes break as necessary	a. Discuss and identify opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing	
	b. Analyse each identified opportunity (SWOT analysis or similar)	
	c. Prioritise, by likelihood of success, best opportunities for 2030 deployment	
	d. Agree communication for Rapporteur to give to meeting at start of Day 2 (Can develop presentation overnight if necessary)	
18:00	End of Day 1	

# Group Activity ONE

*The essential elements of Group Activity ONE are:*

- I. Discuss and identify opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing
- II. Analyse each identified opportunity (SWOT analysis or similar)
- III. Prioritise, by likelihood of success, best opportunities for deployment
- IV. Agree communication for Rapporteur to present to workshop in session 4

## How the Group Activities work: Zoom Breakout Rooms

- At the end of Session 2 you will be taken into a Group Zoom Breakout Room
- There are 5 groups, RED, ORANGE, YELLOW GREEN and BLUE
- Each group discussion will be led by a MODERATOR.
- The discussion and the conclusions will be recorded by a RAPPORTEUR.
- The MODERATORS and RAPPORTEURS are GIF AMME Task Force members
- The idea is to produce a consensus of ideas and conclusions. (Minority report are allowed.)
- The RAPPORTEUR will present the discussions and conclusions of each group on Thursday Morning.
- Please keep to the timetable. At the end of the allocated time the Breakout Rooms will close and everybody will be taken back to the full workshop session

# SUGGESTED Zoom Workshop and Breakout Room etiquette

## WORKSHOP SESSIONS

- Turn Video and Audio off during workshop introductory presentations
- Use CHAT function to ask a question or to request to speak.
- Turn on Audio and Video what asking a question
- Do state who you are and your affiliation

## GROUP BREAKOUT SESSIONS

- Turn on Video and Audio off during group breakout sessions. (This makes the moderator's job much easier)
- Do give your ideas and opinions. Everyone's view matters!
- Remember to keep to the timetable.

# Welcome to Second Day of GIF AMME M&S workshop.

<b>Tue 9 Nov</b>	<b>GIF AMME Workshop on Advanced Manufacturing DAY 2</b>
<b>Session 4 – Comparing Group Outputs</b>	
<b>13:00 – 14:15</b>	Whole workshop undertakes the following activities: a. Rapporteurs from each group presents group output b. List agreed areas to be addressed and potential collaborative opportunities
<b>14:15– 14:45</b>	Break
<b>Session 5 – Group Activity 2</b>	
<b>14:45 – 16:00</b>	Attendees split into new opportunity specific groups (those identified as having highest priority) and undertake the following activities:  a. What needs to be done  b. How can collaboration help?  c. Identify and prioritize areas/ideas for AMME activities/projects  d. Agree communication for Rapporteur to give to meeting after break
<b>16:00 – 16:20</b>	Break
<b>Session 6 – Final Group Reporting and Meeting</b>	
<b>16:20- 17:30</b>	Each Group present their findings and recommendations
<b>17:30 – 18:00</b>	Summarise discussion and consensus of meeting
<b>18:00</b>	End of Meeting

## Session 4 presentation order

- 1) Green Group
- 2) Red Group
- 3) Orange Group
- 4) Yellow Group
- 5) Blue Group

# *Opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing*

**GREEN GROUP**

- **Opportunity 1:** modelling the fabrication process
- **Opportunity 2:** simulation can assist the optimization of the manufacturing process  
High-fidelity simulation of the process can be done on an mm<sup>3</sup> scale (how can we extend this to the whole component)
- **Opportunity 3:** prediction of the microstructure (based on opportunity 1, 2 outputs)

# *Opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing.*

**RED GROUP**

1. Modelling to control, qualify the process for repetitive results (through online monitoring, data analytics, multi-scale modeling, and machine learning ..)
  - ✓ Round-Robin tests of computer codes among world-wide institutes
2. Modelling to predict relation between local microstructure and properties (due to variation in wall thickness, heat sink ...) (by multi-scale modeling, validation, and machine learning )
3. Establishment of properties of Advanced-Manufactured materials
4. New methodology to develop the additive manufacturing comparable with the conventional materials

# ***Opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing***

**ORANGE GROUP**

- Opportunity 1: M&S Database: AI to assess & share existing public data
- Opportunity 2: M&S common data framework: Consensus for application of data, identification of data needs and missing, validation of data
- Opportunity 3: Connect real-time data & monitoring (e.g. high speed camera) to support M&S qualification
- Opportunity 4: Sharing multi-scale models and associated data to support the general objective: use multi-scale models to support model development and complement/replace testing, accelerate testing.
- Opportunity 5: Staged qualification for long-term degradation (e.g. creep, irradiation)

# ***Opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing***

**YELLOW GROUP**

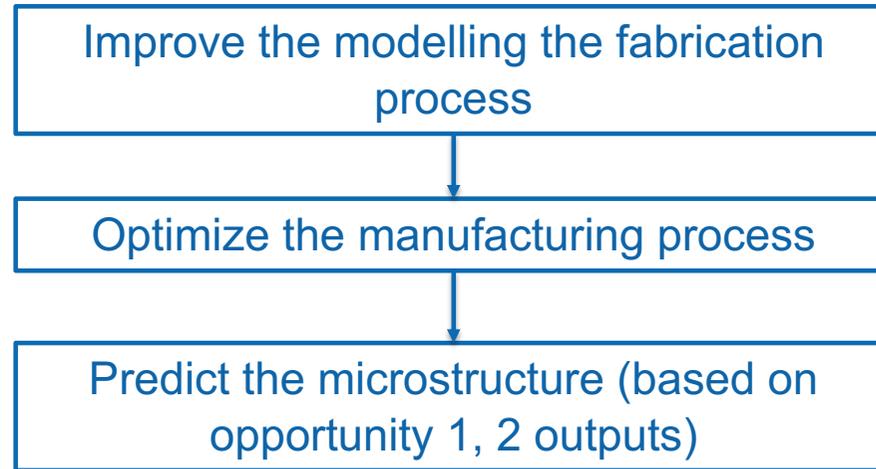
- Standardized manufacturing processes using Simulation and Verification (S&V)
- Catalog Modelling and Simulation (M&S) techniques and applications (even outside of nuclear)
- Use of Simulation to optimize the manufacturing process – replace/reduce iterative experimental approaches
- Connect processing and performance models (processing-Structure-properties)
- Document modelling and simulation efforts to reduce rework across international community
- Identify likely material/components types – ideally span as many reactor concepts as possible
- Develop relevant methods of uncertainty quantification
- Benchmark problems to understand and validate S&V techniques
- Predicting final properties – irradiation etc – using both physics-based and data-based techniques
- Benchmark hybrid Machine Learning-Simulation techniques versus physics-based approaches
- Topology optimization – Uniform properties across range of features sizes
- Codes and standards: How to define manufacturing process, Qualify parts & design/qualification properties
- Keep qualification up to date with new data/process improvements over long component
- Regulatory approval – consensus on what route to take

# *Opportunities for Modelling & Simulation to accelerate qualification of Advanced Manufacturing*

## *BLUE GROUP*

- Opportunity 1 is: How does one verify that the AM component meets the design requirements from various attributes
- Opportunity 2 is: Verify properties across the build
- Opportunity 3 is: Microstructure modelling
- Opportunity 4 is: Machine learning
- Opportunity 5 is: Physics-based models
- Opportunity 6 is: Upscalability of the processes

# *Prioritise, by likelihood of success, best opportunities* **GREEN GROUP**



## Recommendations

- Machine learning approaches could be one possible solution to bridge different modelling scales (see opportunity 1, opportunity2) and integrate them into a multiscale paradigm that would be likely to speed up the qualification;
- Need to generate representative data to be used by Machine Learning algorithm.

## *Prioritise, by likelihood of success, best opportunities* **RED GROUP**

### Best

- #1 Modelling to control, qualify the process for repetitive results
- reason (i): Each property depends on the starting process

### 2<sup>nd</sup> best

- #2 Modelling to predict relation between local microstructure and properties
- reason (i): Property of components are important for our system

### 3<sup>rd</sup> best

- #3 Establishment of properties of Advanced-Manufactured materials
- reason (i): It can be accelerated using the existing data

## ***Prioritise, by likelihood of success, best opportunities* ORANGE GROUP**

Best: Opportunities 1 & 2: M&S Access Public Database & Database Common Framework

- experimental data key point for AI, MS models;
- easy to implement

Second best : Opportunity 4: Sharing multi-scale models and associated data

- major scientific interest, brings understanding of physics

Third best: Opportunity 3: connect real-time data (high speed camera) to support M&S qualification

- more technology dependent than opportunity 1,2 & 3

Fourth best: Opportunity 5: Staged qualification for long-term degradation

- Less relevant with regards to M&S

## ***Prioritise, by likelihood of success, best opportunities* YELLOW GROUP**

Best opportunity – Catalogue and promote standardization of M&S techniques and applications. Need to know what is out there not to reinvent the wheel and obtain knowledge from cross-industrial applications.

- Workshop with cross-industry participation?
- Promote standardization of input/output for multiscale models?

2<sup>nd</sup> best- Benchmark problems to understand and validate M&S techniques. Main purpose to obtain confidence from regulatory aspects.

- Identify incremental steps – don't try for full processing-structure-properties
- Attempt to use vendor-relevant materials, component types, target properties, etc.
- Integrate/promote UQ, not just mean property predictions

3<sup>rd</sup> best - Apply M&S for code and standards. Support the standardisation process of advanced manufacturing with supplementary information.

- Mod/sim provide target microstructures or relate key properties to simple room temperature measurements
- Start small: get something meaningful, but comparatively simple, approved and build on that

# *Prioritise, by likelihood of success, best opportunities* **BLUE GROUP**

## *List opportunities in priority order with reasons*

- Best is “Hybrid Machine Learning +Physics Based hybrid model” because:
  - both models contribute to the domain
  - Powerful approach
  - It will take you much further in the lifetime cycle of the product
  - Reduced order modelling; provides speed up PhyB models
  - digital threads
  - process controlling
- Second best is “Homogeneity of the sample”
- Third best is “Upscalability” because:
  - size of the samples; mini-samples

### Group Activity 2

*The essential elements of Group Activity TWO are:*

*Attendees move (by self selection) into into new opportunity specific groups (those just identified as having highest priority) and undertake the following activities*

- I. Discuss and identify what needs to be done for opportunity to succeed
- II. Identify how collaboration can help
- III. Identify and prioritize areas/ideas for future (AMME) activities/projects
- IV. Agree communication for Rapporteur to present to workshop in session 6

### Group Activity 2

*The Opportunity areas groups selected were:*

- I. Collaborative M&S R&D to control the process  
(process qualification and QA?)
  
- II. Collaborative M&S R&D to predict the microstructure and/or the material/component properties  
(enables component design code compliance)
  
- III. Collaborative R&D where you 'share' M&S models, software and data  
(includes idea of an advanced material property database)
  
- IV. Collaborative M&S R&D focused on codes and standards

# I. Collaborative M&S R&D to control the process (process qualification and QA?)

## *Identified and prioritised areas/ideas for collaborative activities/projects*

1. Benchmark process models & tests with validation test
  - Comparison same-level models
  - Comparison different models
2. Common software tools (available Open source and commercial + in house)

Long-term:

3. Develop extended monitoring (beyond temperature)

## II. Collaborative M&S R&D to predict the microstructure and/or the materials/component properties (enables component design code compliance)

### *Identified and prioritised areas/ideas for collaborative activities/projects*

1. Promote international framework for information exchange and collaboration (e.g. NEA material science related working groups);
2. Set standards on the testing, develop best practices (sample preparation, experimental protocols, post test analysis), perform Round Robin to verify best practices lead to reproducible data;
3. R&D on the relation between the material microstructure and material/component properties (need to review past R&D);
4. Standardization of in-situ data collection e.g. measurement of the porosity, monitoring of the thermal history. Collaboration for sensors development, measurements techniques;
5. Develop best practices and recommendations for scales integration in the simulation codes.

### III. Collaborative R&D where you ‘share’ M&S models, software and data (includes idea of an advanced material property database)

#### *Identified and prioritised areas/ideas for collaborative activities/projects*

##### 1: Develop a material properties database

- e.g. GenIV handbook; information sharing model; works internationally
- NIST AM-Bench (connects to benchmark problems)
- Figure out how to do this; information on the process or microstructure, or both

##### 2: Develop software that can exchange information

- Working to standardize interfaces to exchange information
- Open Source software as a potential model; might be difficult to get it started

##### 3: Take advantage of developments in other (non-nuclear) communities

- Joining their efforts in existing communities if possible
- Do these in a way that vendors would be comfortable

## IV. Collaborative M&S R&D focused on codes and standards

### *Identified and prioritised areas/ideas for collaborative activities/projects*

1. Identify how can we reliably use the data from previous cases to feed into new models e.g. from DoE code case done by Westinghouse.
2. Identify data sets from previous code cases and use this data to build reliable model to support code cases (use conventional manufacturing process data as a basis).
3. Use previous code case data that is available globally to build a database to support developing models required to support future code cases
4. Develop ways to use models to accelerate code cases.
5. Simulate components with experimental data in different organisations i.e. thermal history. This can apply for any AM processes. (Motivation & benefit - Thermal history will decrease the uncertainty and increase the repeatability and there for the qualification process for the supplier will be less burdensome.)
6. Use machine learning methods to correlate thermal history to properties such as fatigue data
7. Collaborate with other industrial sectors on similar work done in qualification of AM
8. Correlate thermal history to material properties

## Preliminary analysis: collaborative activity commonalities

- Software: Engines – Physics based, Machine learning based )or Hybrid?
- Software: Data (of all types) data sparse environment
- Software: I/O interface standardisation
- Benchmarks: soft and hard: computational and experimental
- Codes and standards: Community to set own standards? Past experience?
- Work together to share past and present data
- Microstructure: understanding and modelling? Correlation with thermal history
- Model process to understand and control process
- Model material development within process to predict microstructure
- Use microstructure and geometry to predict component properties
- Uncertainty quantification and V&V are critical to qualification

# The Future

AMME task Force will analyse results of workshop

Results will be used to:

- 1) Plan future workshops
- 2) Organise activities in the GIF Industry Forum 2022
- 3) Plan and implement collaborative R&D initiatives
- 4) Coordinate with other groups investigating or promoting advanced manufacturing for advanced reactor manufacture



**Thank you for your attention.**

**If you wish to know more about this initiative please  
contact the Task force (see Slide 4)**