Development of Fusion Sub-components with Additive Manufacturing

RE Nygren and DA Buchenauer¹

In consultation with experts in AM at

¹Sandia National Laboratories
Albuquerque, NM – Livermore, CA

DEMO Fusion Reactor

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corp., a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.
Development of Fusion Sub-components with Additive Manufacturing

RE Nygren and DA Buchenauer¹

In consultation with experts in AM at
¹Sandia National Laboratories
Albuquerque, NM – Livermore, CA

Status: Tungsten (W) is tough choice but not a tough material. It’s hard, brittle and difficult to fabricate.

Needs: New W-based materials system to face plasma (PFM); New high performance gas-cooled substructure for DEMO plasma facing components (PFCs) in a DEMO-engineered materials architecture through AM.

Path: A multi-process fab sequence (Direct Write + other) may be the best way to accomplish this. AM and micro-fab open many opportunities.
Outline

- **Fusion PFCs status for AM applications**
  - W-based plasma facing material (PFM) with high performance heat sink (He-cooling, Youchison)
  - Emphasis: W-based AM (SLM, LENS, e-beam)
  - also multi-process, AM + Subtractive + other

- **Direct Write**
  - powder met. particles, slurry ⇒ green form
  - multi-process approach

- **Comment on AM, R&D Path Forward**
  *Multiplicative effects and other fusion applications*
  - Liquid surface PFCs
  - Smart tiles, diagnostics, meso-machines
  - blankets, heat exchangers
  
  Advanced manufacturing methods (includes AM) offer the potential to design and create a suitable materials architectures for PFM and a suitable engineered structure for PFCs.

Dennis’s presentation (next) includes jet cooling of PFCs and AM activity at ARL.


8” disc and 3” tall thin-walled nozzle made with field assisted sintering.

A gas-cooled DIII-D tile with complex coolant passages could be made.
Sandia has AM work in multiple locations on its Livermore and Albuquerque sites.

AML (Advanced Materials Laboratory) is the location for Direct Write R&D. AML staff also use other processes. U. New Mexico also shares AML.

Dave Keicher operating LENS station. Dave is also an innovator in Direct Write.

- understand & control materials & processes
- characterize materials
- develop, design & prototype materials & components
**Thesis:** Additive manufacturing is an essential element in the combined solution for a robust PFM-PFC solution.

To realize robust PFCs for FNSF, we need:

- **suitable materials architecture** for PFM devices,
- **engineered micro-features** (microjets for gas cooling),
- **advanced manufacturing methods**, and a
- **new vision** of the R&D path for materials and PFCs.

---


**DL Youchison,**
Flow instabilities in non-uniformly heated helium jet arrays used for divertor PFCs, TOFE 2014, *Fusion Technology* 2016

---


OK – So how do we get there?

Status: Tungsten (W) is tough choice but not a tough material. It’s hard, brittle and difficult to fabricate.

Needs: New W-based materials system to face plasma (PFM); New high performance gas-cooled substructure for DEMO plasma facing components (PFCs) in a DEMO - engineered materials architecture through AM.

Path: A multi-process fab sequence (Direct Write + other) may be the best way to accomplish this. AM and micro-fab open many opportunities.
OK – So how do we get there?

Limitations of Powder Fed 3D Metal Printing Processes

- Surface Finish
- Dimensional Accuracy
- Material Use Rate
- Layer Thickness Control
- Ability to Build Overhang Structures
- Open Architecture Software
- Enhanced Build Speed
- Residual Stress

Bigger issue for high $T_{\text{melt}}$ metals (power, circuit time, T gradients)
Progress in AM delivery of dense W (heat build plate, induction heat build)
Do we want fully dense W?

Direct Write may offer another path.
Option with Potential:
Direct Write + Other Processes

**W-base powder stock**
metallurgical features

- self interstitial atom defect clusters
- He vacancy
- nano-features NF
- Climb-glide

**Subtractive Manufacturing**
- Machining of soft green form
- Infill stabilizes fragile features

**Subsequence Process**
- Melting of infill
- CVD coating of cooling channels
- Final finishing

**Direct Write:**
Green Form

- **meso features**
  - Controlled porosity
  - Crack mitigation (slots, keyholes)
  - Graded material transition
  - Jet-cooling array

**Feature Infiltration (stability)**

**Subcomponent Assembly**

**PFC cell**

**Subcomponent Installed**
Comments on R&D Path:
Elements and Vision of Fusion Power
How planning reports are written and interpreted.

Our fusion planning studies to report issues and challenges and needs. **No mention = no chance.** (unstated message)

Path Scenario: Direct Write +

Lack of information ≠ negative correlation for potential. **Write to preserve the path of opportunity as well as challenge.**
Jointed superconducting (SC) coils.

- Vertical remote maintenance (pull off top half of coil set)
  
  [# sectors for vacuum vessel (VV)] ≠ [# SC toroidal coils]
  
- Unibody VV in pool of molten salt breeder (pool reactor)

Power launch (RF) from inside wall (high field side)

- Smooth outer wall, no neutral beams, few/no midplane ports
  
  fast flow liquid surface outer first wall

Low power meso-scale devices (MESA fab)

- Dense real time data on plasma edge and wall
  
  Benchmark models, enables better/faster solutions for fusion power exhaust.

Power harvesting: PFC power transfer to plant system

Heat exchange inside VV (Majeski); radiative coupled heat pipes
Comment 1 on R&D Path: Interim Elements

The PFM solution can differ from that a robustness PFC. Long term neutron damage is still an issue for the PFM but the radiation damage to the PFM is not now a feature of subsurface materials system of the PFC.

We separate the ion-damaged PFM (weak, ?porous) from the engineered substructure (strong, vacuum boundary) in early R&D.

Significant implications for models & tests, e.g., surrogate materials.

Developing predictive models of performance and converging on workable PFCs at a reasonable cost will be challenging due to the number of variables (porosity, nano-features, composition gradients, appropriate data on radiation effects, processing temps, ...)

Corollary: Modelers not only use data, but are integral in identifying needs for data and for designing experiments, e.g., what can and should be measured.
Developing models of performance (with neutron damage) in complex materials systems, and converging on workable PFCs at a reasonable cost will be challenging.

Separate the neutron damage from the cooling technology.

AM transition region.

AM enables fine jet array; simplifies target prep for R&D studies.
Comment 3 on R&D Path: Interim Elements

Engineered architecture may best or even the only option for reactor PFCs.

Separate the neutron damage from the cooling technology.

Ti-6Al-4V  Inconel 718

LENS graded materials

AM transition region.

AM enables fine jet array; simplifies target prep for R&D studies.

Developing models of performance (with neutron damage) in complex materials systems, and converging on workable PFCs at a reasonable cost will be challenging.

PFM-PFC Performance
Developing models of performance (with neutron damage) in complex materials systems, and converging on workable PFCs at a reasonable cost will be challenging.

Engineered architecture may best or even the only option for reactor PFCs.

Separate the neutron damage from the cooling technology.

AM transition region.

AM enables fine jet array; simplifies target prep for R&D studies.

PFM-PFC Performance
Comment 3 on R&D Path: Interim Elements – Near Term Tasks

• Materials and PSI experts identify PFM s for DEMO or FNSF.
• AM materials experts identify fab methods for FNSF and reactor.
• Identify materials (surrogates as needed) for lab facilities as well as exposures in DIII-D and elsewhere including foreign devices.
• Working Groups (WG) identify overlapping multiplicative benefits from TEC that make a fusion reactors simpler and reduce cost.
  - Technology-physics cross-over WG
  - Industry-fusion WG
• Participation by US technologists in foreign programs becomes more effective. OFES needs to develop “apples for oranges” exchanges, e.g., US expertise on divertor Smart tiles coupled to Chinese build for experiment gives access to EAST and crosses over to experiment in DIII-D.
Thank you