One Career in Physics

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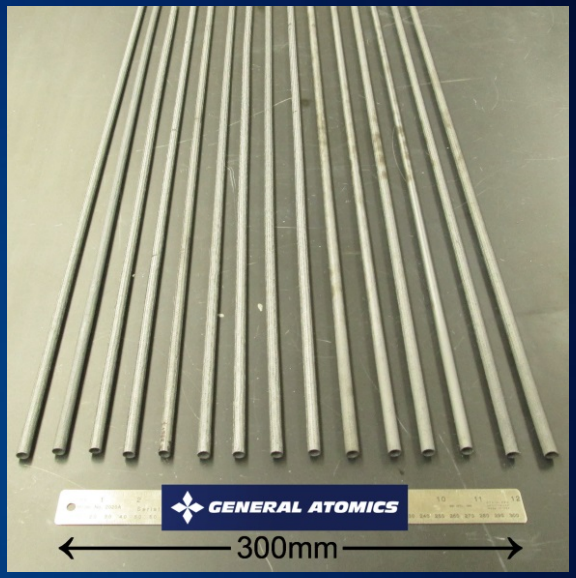

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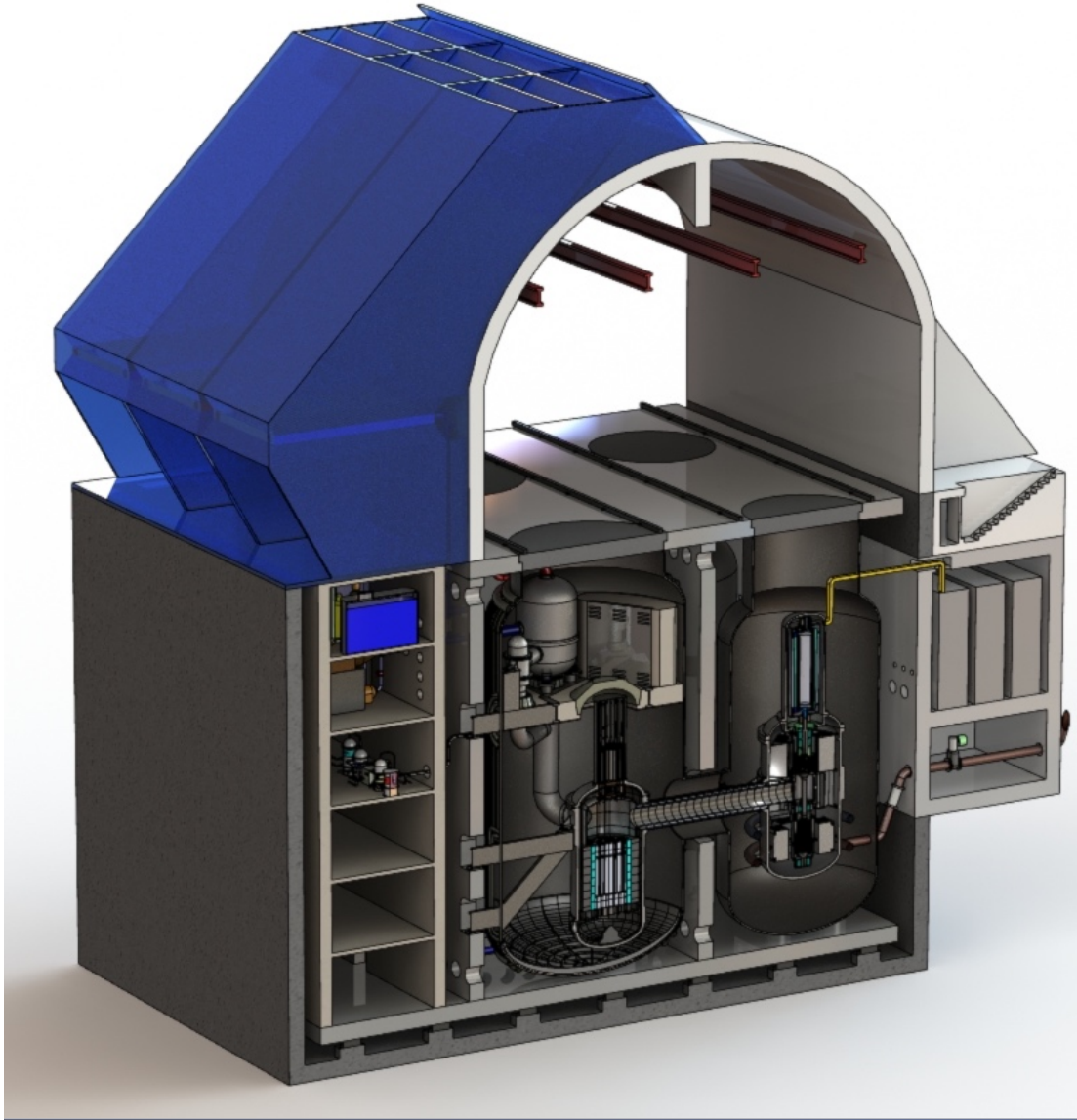
EM^2 is a Modular Gas-Cooled, "Convert and Burn" Fast Reactor

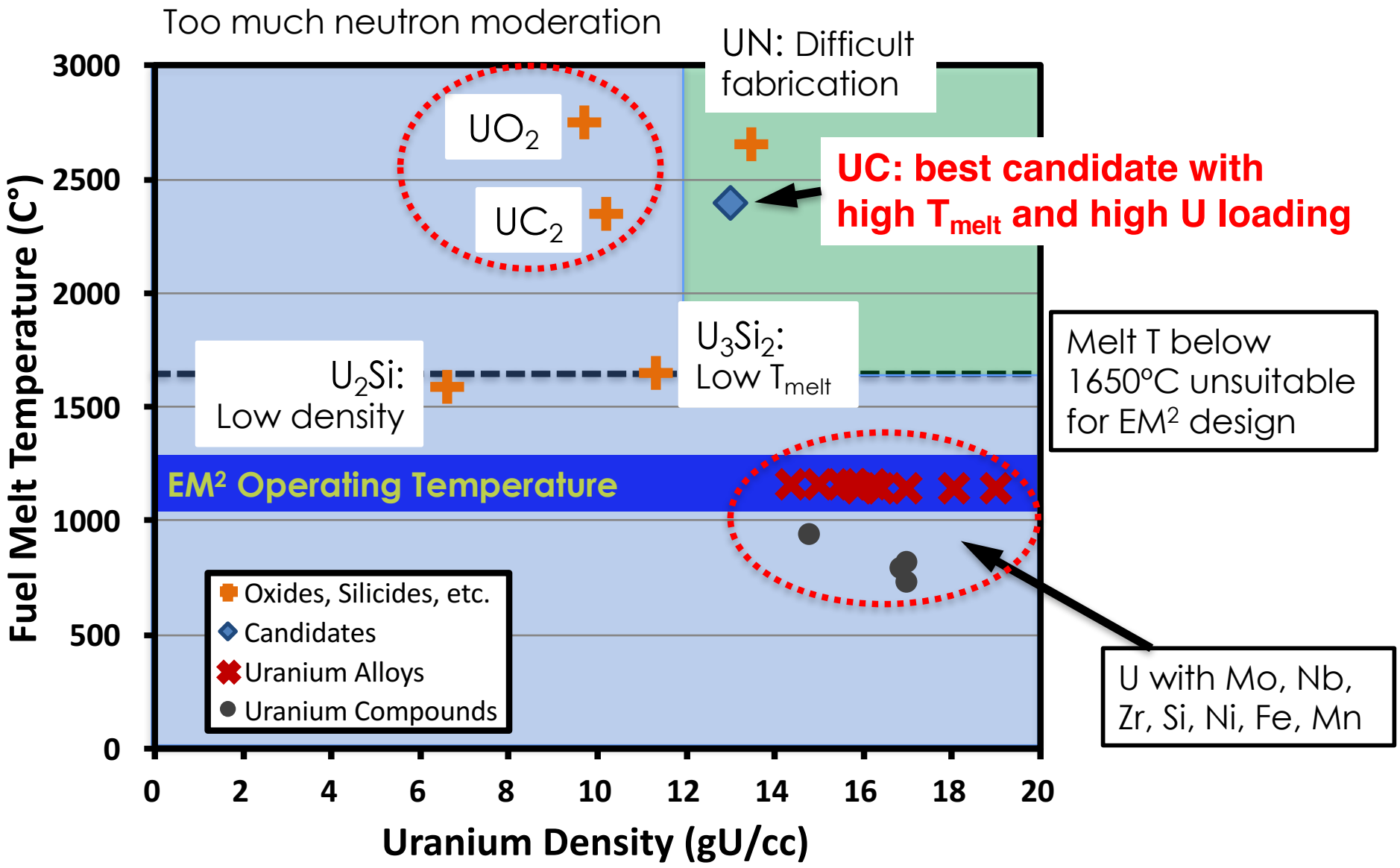
Two reactor systems on one seismically isolated module



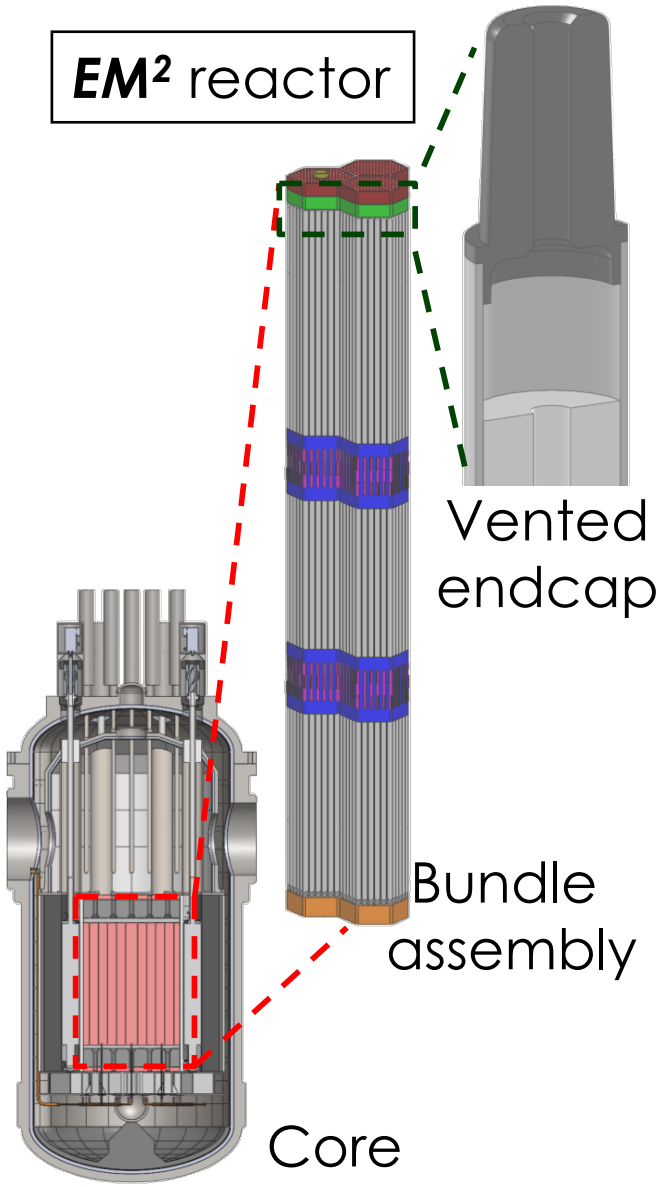
Specifications:

- 265/240 MWe per reactor for water/dry cooling
- 500 MW_t reactor power
- 4 modules per standard plant
- 60 year plant life; 30 year core life
- 60 year dry fuel storage
- 14 % average fuel burnup
- Multi-fuel capable
  - Fissile: low-enriched U or converted MOX
  - Fertile: depleted U, natural U, spent LWR fuel or thorium

Reactor Physics, Material Properties, and Fabrication Lead to Choice of UC fuel



For EM², Achieving Multi-Decade Life Poses Challenges and Drives Fuel Design



- **EM² Design Features:**
  - Use wide variety of fuel materials
  - Long life without refueling
  - High burn-up and power density
  - High temperature/ efficiency
- **Challenges:**
  - Survive high dpa (400+ peak)
  - Achieve high thermal conductivity
  - Retain structural integrity with joints
  - Withstand fuel swelling and PCCI
  - Vent gaseous fission products
- **Use of Ceramic materials**
  - SiC-SiC cladding and UC fuel

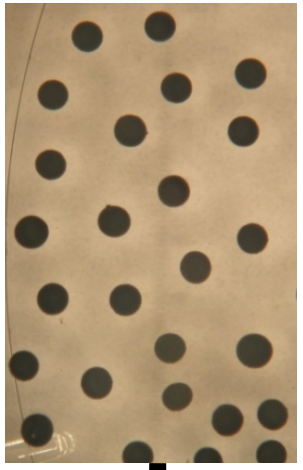
UC Fuel Fabrication via Droplet Generation Works for Both Fresh U and "Spent" Fuel

UO_2 Powder

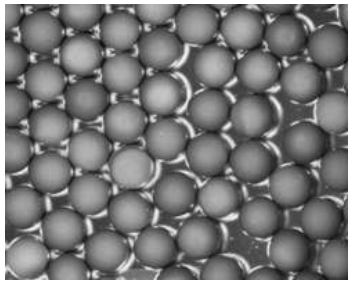
(or other feedstocks)

UO_2 Broth

Droplet Generator

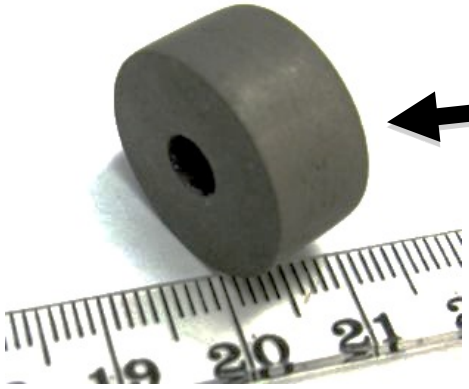


Converted to oxide at ~600° C



Converted to carbide (UC) at ≥1700° C

Sintered

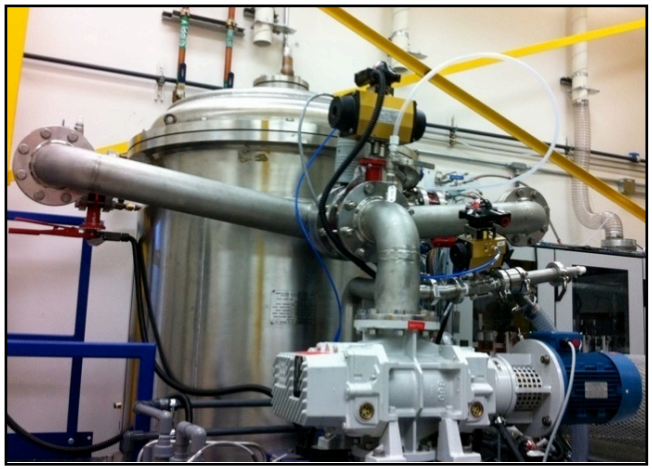


GA Has Established A State-Of-The-Art Nuclear Fuel Laboratory

Sol-gel column

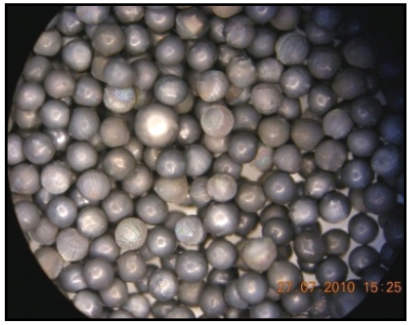
Sintering

SiC coater

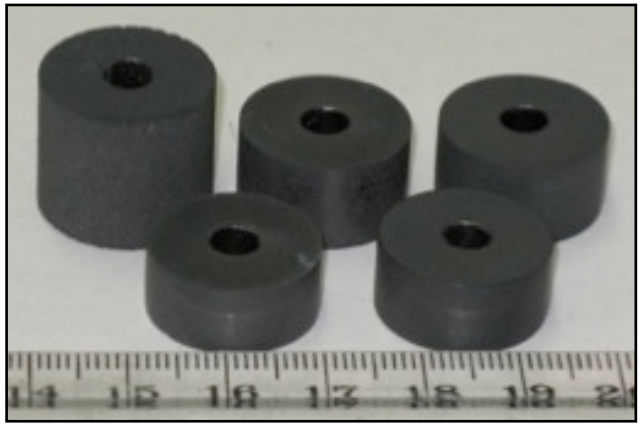


Hot press

UC kernels



Sintered pellets



SiC composite fuel cladding

Gel particles with carbon

Prototypes have been fabricated and samples prepared for irradiation

GA Fabrication Scale-up for SiC-SiC Cladding Tubes

Preform Equipment → CVI Coater → Polishing Equipment → Joining Equipment → Pre-Fueling Testing

Fiber Preforming

Full-size

SiC Coater

Up to ~1m *

Polishing

Up to ~1m

Hot Press

Full-size plugs
~24" rodlets

Full-size

NDE X-Ray Equipment

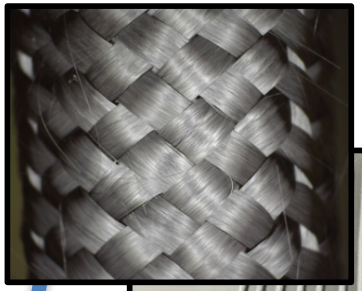
Up to ~1m

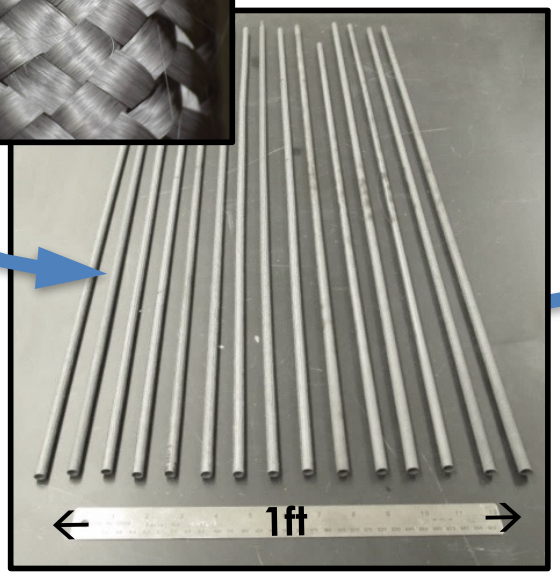
*250 part batches,
Size upgrade 2016-17

GA Has Invested in the Capabilities, Process Development, and Scale-up for Advanced Reactors

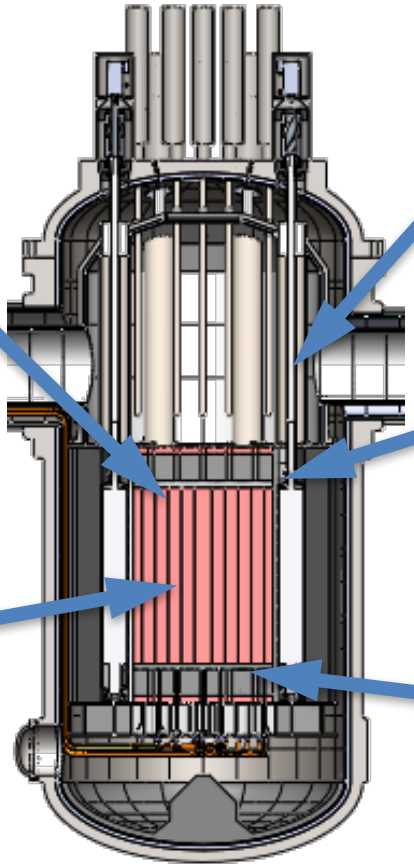
Fuel pellet fabrication

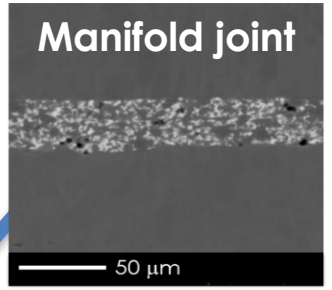
Cladding fabrication

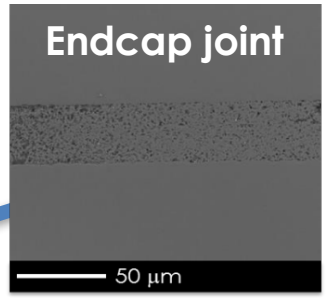




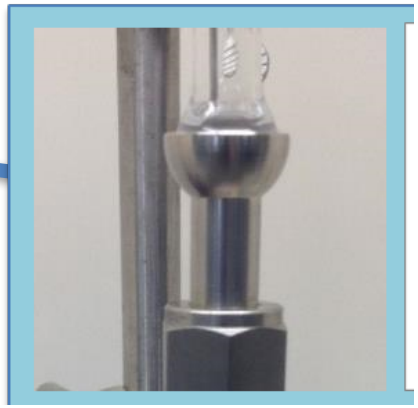
Cladding scale-up







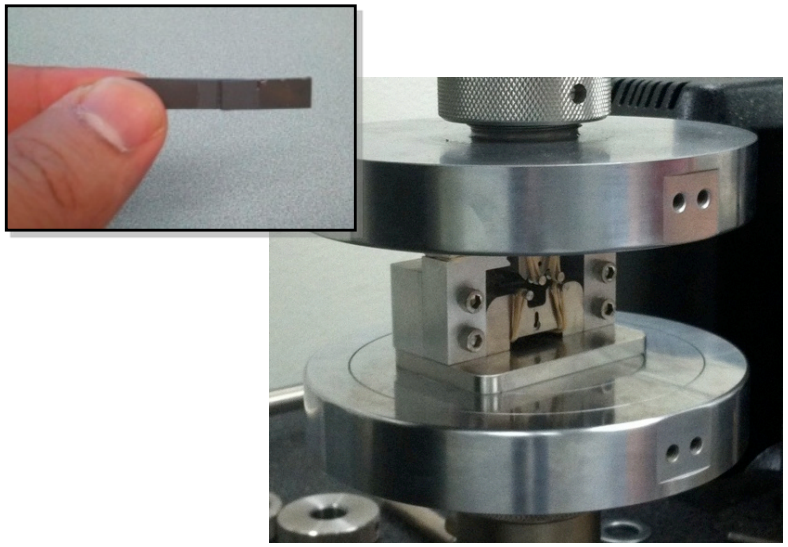
SiC joint methods adapted to address different core components

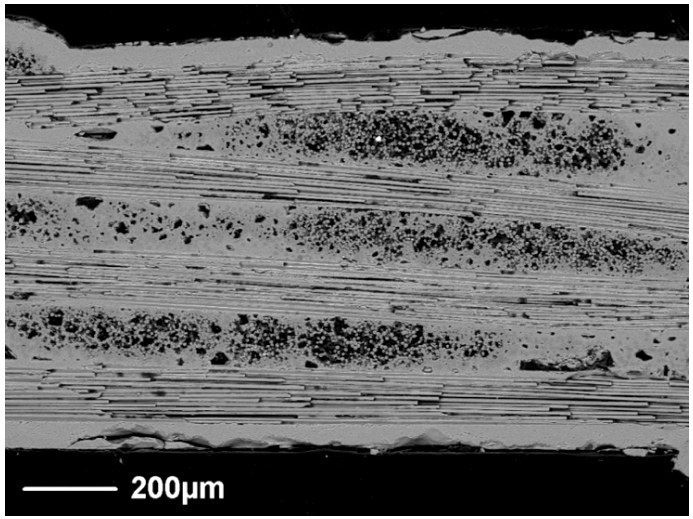


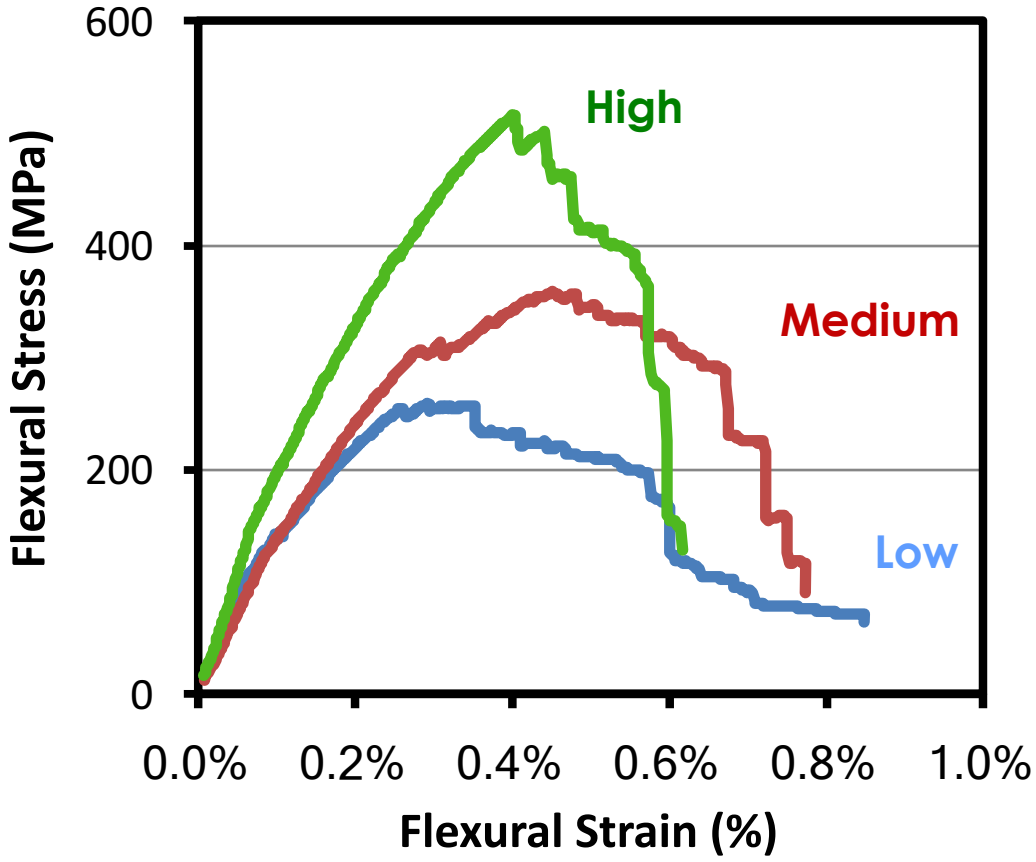
Mechanical ball-socket joint developed for venting meets EM² needs

GA Composites Show Pseudo-Ductile Behavior Under Mechanical Loads

- **Flexural strength increases significantly with density**

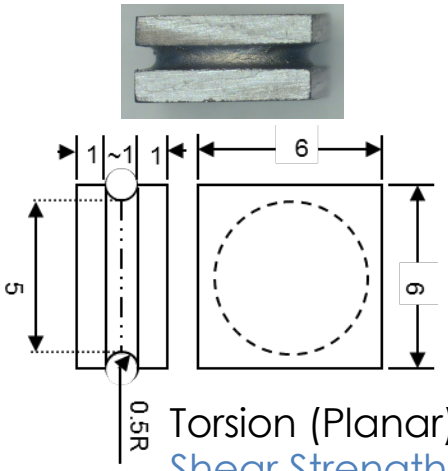






SiC Ceramic Joint Geometry Has Been Studied and Optimized

- **Planar geometries provide intrinsic properties but aren't applications specific**
- **Surface area and features at interface depend on material performance, processing behavior and application requirements**
- **Joint material must be considered in conjunction with the joint geometry**
  - Joining techniques must be applied to cylindrical geometries
  - Cylindrical joints must be characterized in reliable and meaningful ways

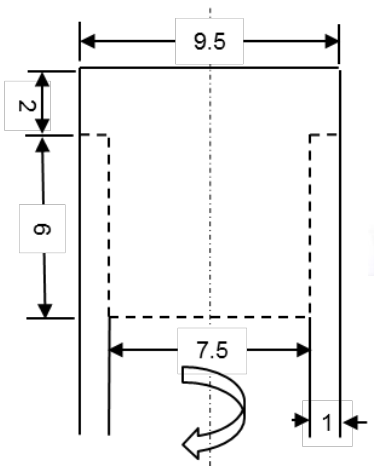


Torsion (Planar)
Shear Strength

Butted scarf

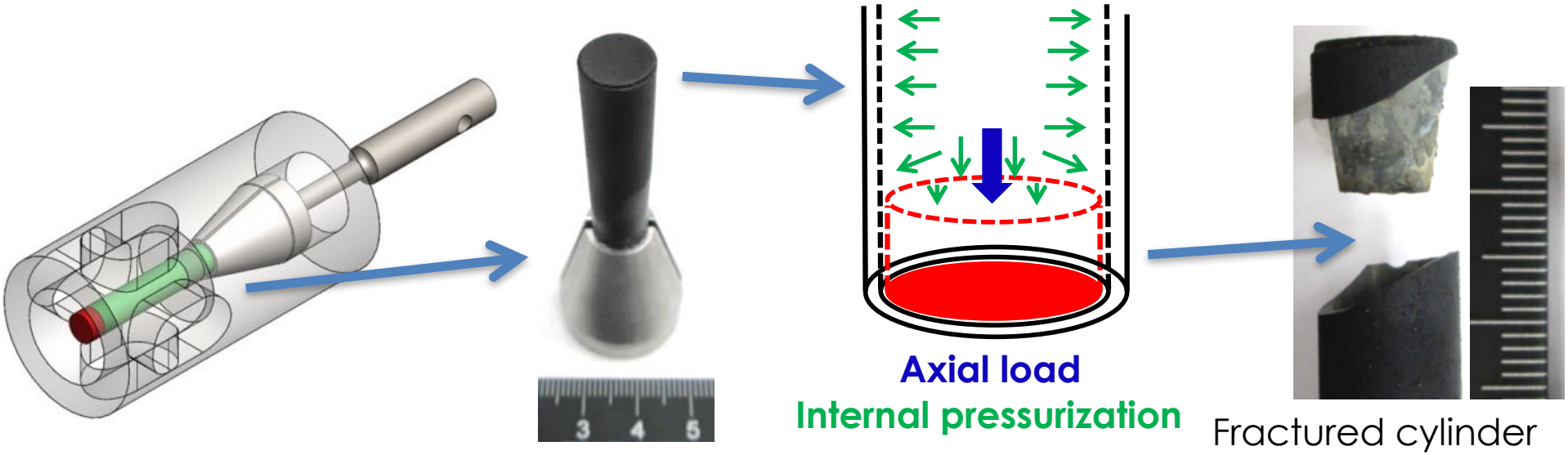
Scarf

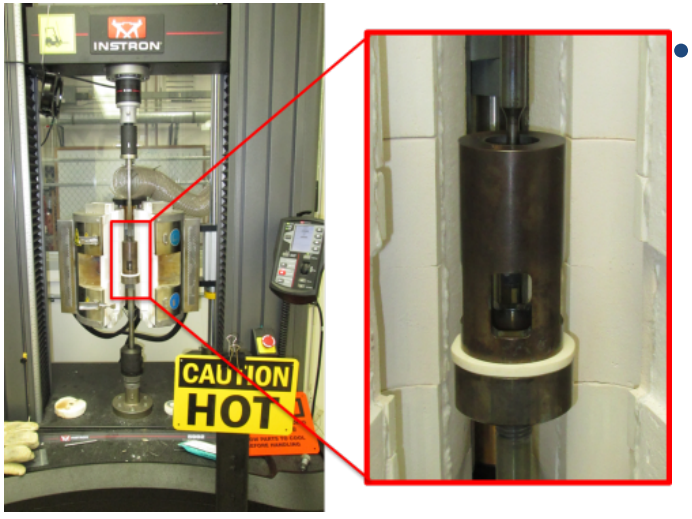
Butted lap



Tube/Endplug (Cylindrical)
Burst Strength

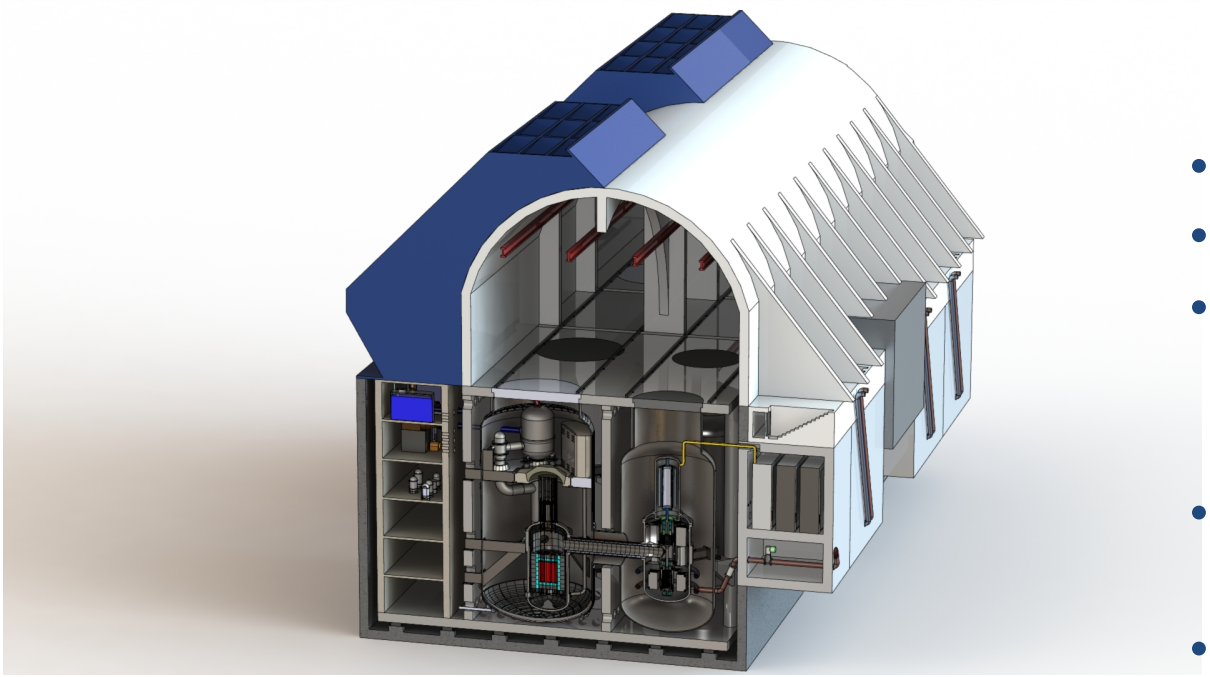
Methods Were Developed to Assess Mechanical Performance of Joined Cylindrical Components





- **Testing of joint-endplug-tube assembly**
  - **Hydrostatic burst testing**
    - Simulates internal pressurization of fuel rod
    - Complex set up, difficult to implement at high temp.
  - **Enplug Pushout testing**
    - Uniaxially loads endplug on internal surface
    - ASTM test standard being developed

EM^2 Is a Compact Fast Gas Reactor Optimized for the 21st Century Grid



- **Levelized power cost 40% less than advanced light water reactor (ALWR)**
- **53% net efficiency**
- **30-year refueling**
- **Burns low-enriched uranium, converted MOX, Th, depleted U**
- **Waste stream is 80% less than ALWR**
- **No need for water cooling**
- **Rapid load following**

Status

- Commercial plant concept design, safety analysis, cost estimate defined
- Fuel irradiation program has been initiated with Halden
- Current work focused on prototype design and design code update

GA is Drawing From Industry, Academia and National Labs to Meet the Technological Challenges

- **University of South Carolina**
  - Customized tube mechanical testing, AE, DIC
- **Massachusetts Institute of Technology**
  - Irradiation, corrosion, quench, and mechanical testing
- **Univ. California-Berkeley, Oxford**
  - Micro- and Nano-scale mechanical characterization
- **Oak Ridge National Laboratory**
  - Irradiation testing of SiC-SiC and joints
- **San Diego State University**
  - Ceramic sintering and consolidation
- **University of California-San Diego**
  - Structural characterization of SiC-SiC
- **Oregon State University**
  - Micro-scale modeling of SiC-SiC composites
- **Brookhaven National Laboratory**
  - 3-D x-ray tomography of SiC
- **Manchester University**
  - Micro- and Nano-scale characterization at temperature
- **University of Illinois at Urbana-Champaign**
  - Micro-scale thermal characterization of SiC-SiC