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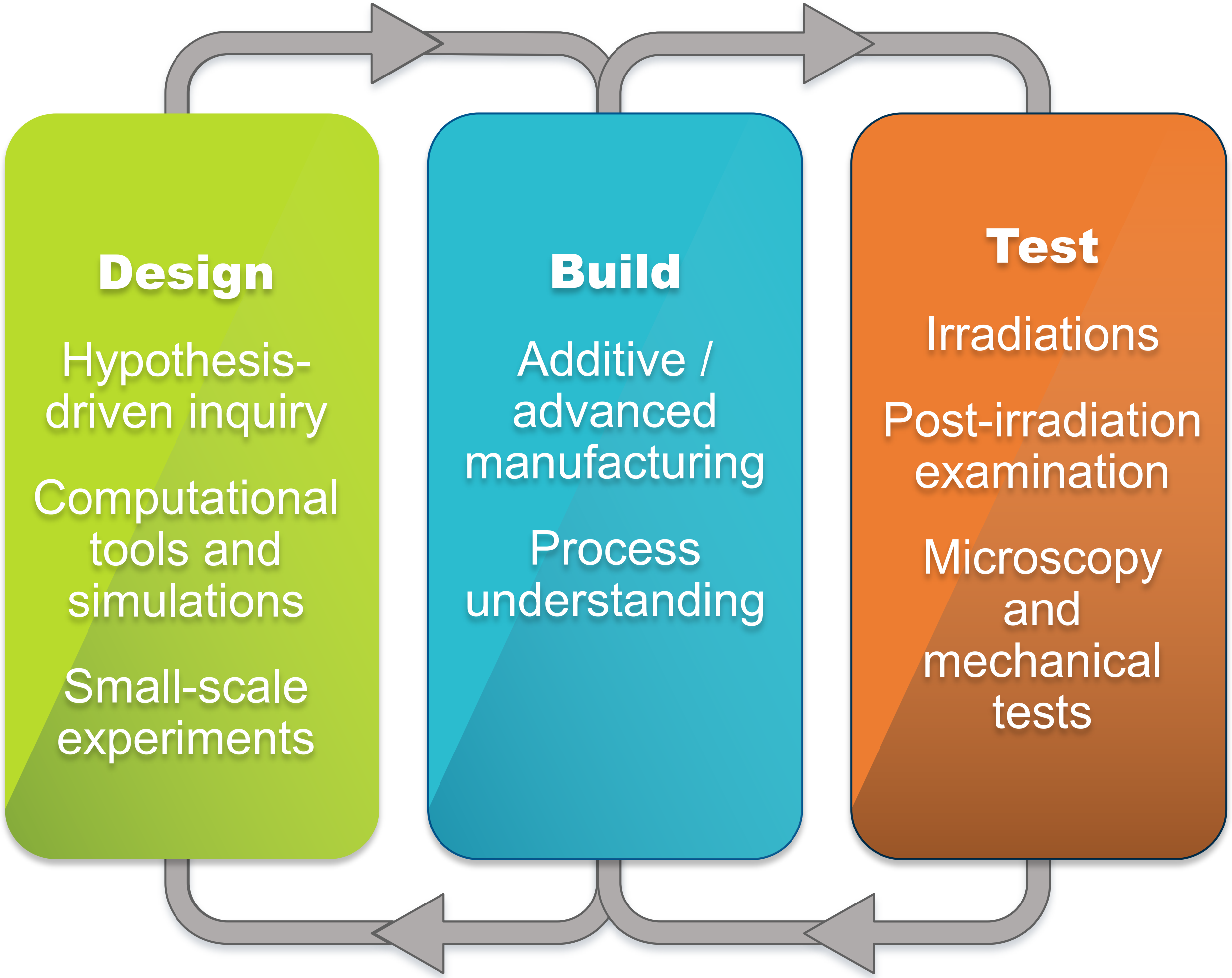
Radiation testing of AM materials

Andrea Jokisaari, TS Byun, Weiying Chen, Yiren Chen, Drew Johnson, Annabelle Le Coq, Kory Linton, Caleb Massey, Christian Petrie, Rongjie Song, Stephen Taller

AMMT program motivation for irradiated AM materials properties

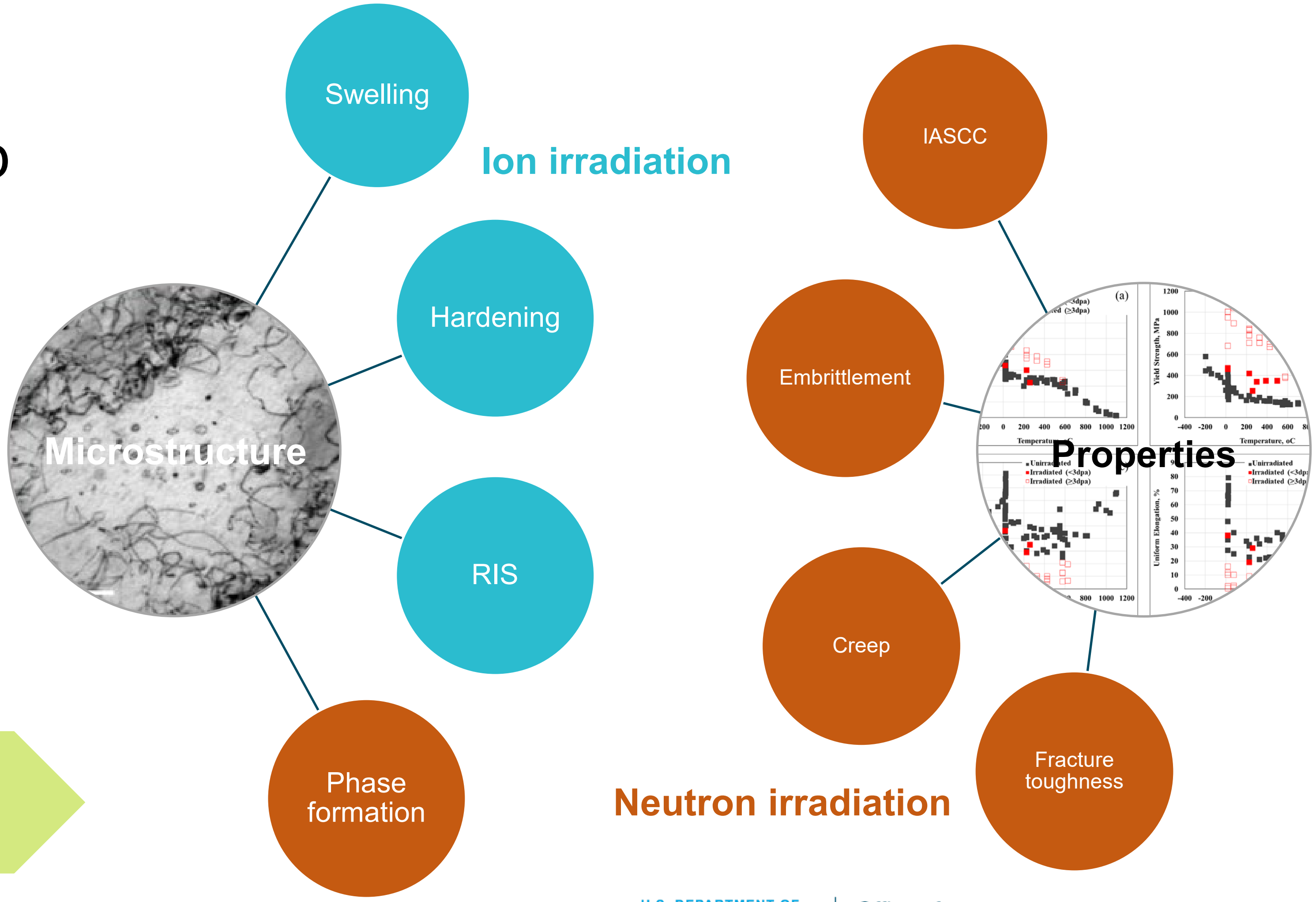
- AM is a new enabling technology
- New fabrication method means there is a large need for new data
- AMMT will provide new, valuable data for irradiation behavior of materials with engineering importance for nuclear reactors



Using the right tool for the job

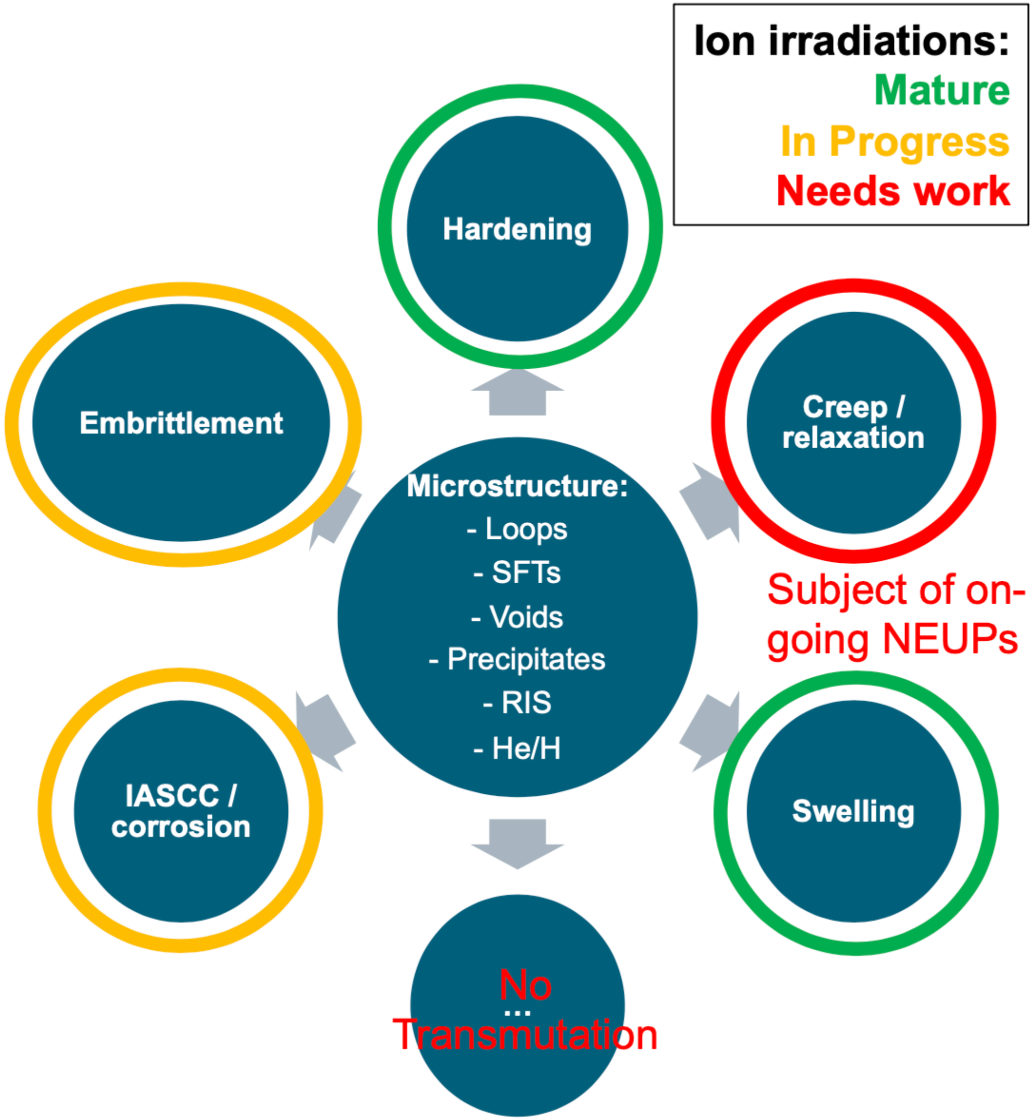
- AMMT uses its expertise to select the right tool for the job
  - High level conceptualization of radiation testing for design achievement
  - Timelines to obtain data (accelerated vs prototypical)

Data needs → PIE needs → Radiation type and facility



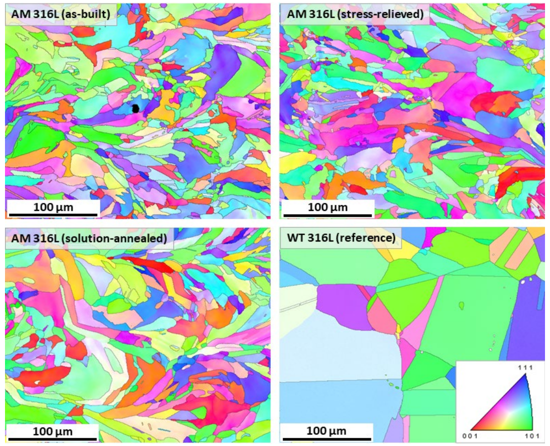
Using ion irradiations for screening and regulatory purposes

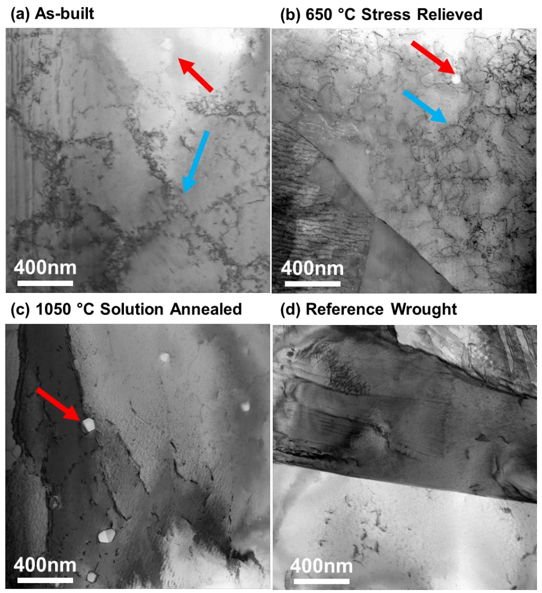
- Many advanced reactor designs aim for 100+ dpa
  - Materials test reactors will provide ~1-10 dpa/year
- Ion irradiations can:
  - Provide rapid screening of materials evolution
  - Link to prototypical neutron irradiation conditions by generating microstructure data
  - Modeling predicts microstructure evolution and links microstructure to properties to predict the effect of different irradiation conditions (temperature, fluence, energy)



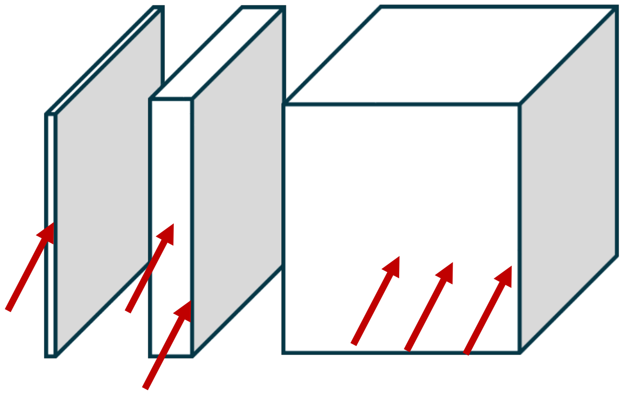
Providing data and science to aid with NRC licensing

- A new fabrication method means a lot of data is needed to understand process-structure-properties-performance links to support licensing applications to the NRC
  - Case-by-case basis
  - Materials information to support safety case
- Looking for equivalencies or major differences from conventionally made materials
  - Impact of microstructure
  - Build variability
  - Post-build heat treatments





Sampling Location



> *"The NRC licenses and regulates the Nation's civilian use of radioactive materials, to provide reasonable assurance of adequate protection of public health and safety, to promote the common defense and security, and to protect the environment."*

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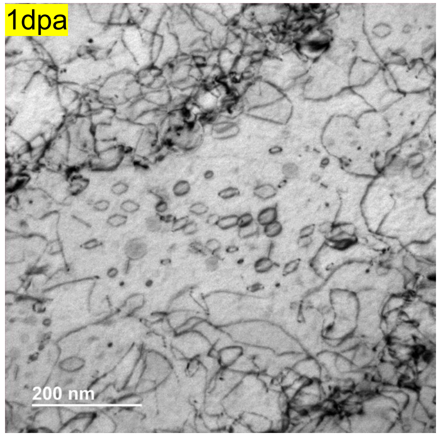
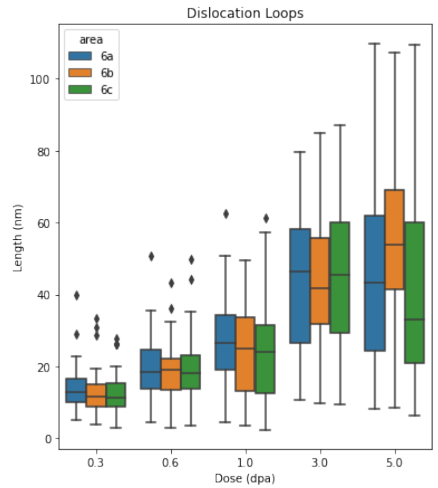
AMMT program strategy for irradiated AM materials properties

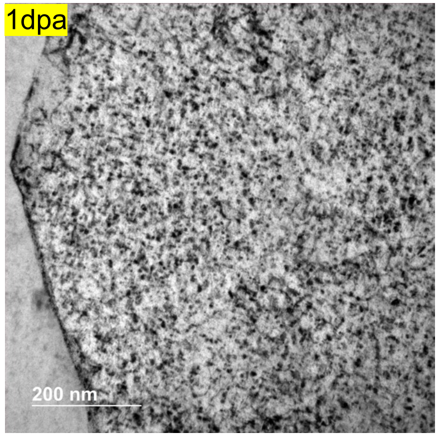
- Consistent test plan of to deliver data and science
- AMMT is also working on a framework to promote the regulatory acceptance of combined neutron irradiations, ion irradiations, and modeling
- **Looking for industry input on parameter spaces of interest**

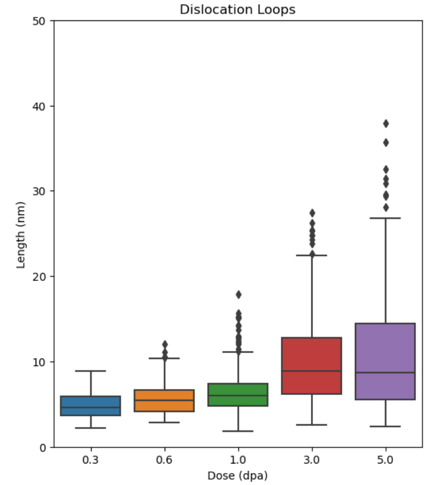
AM316H
600ºC





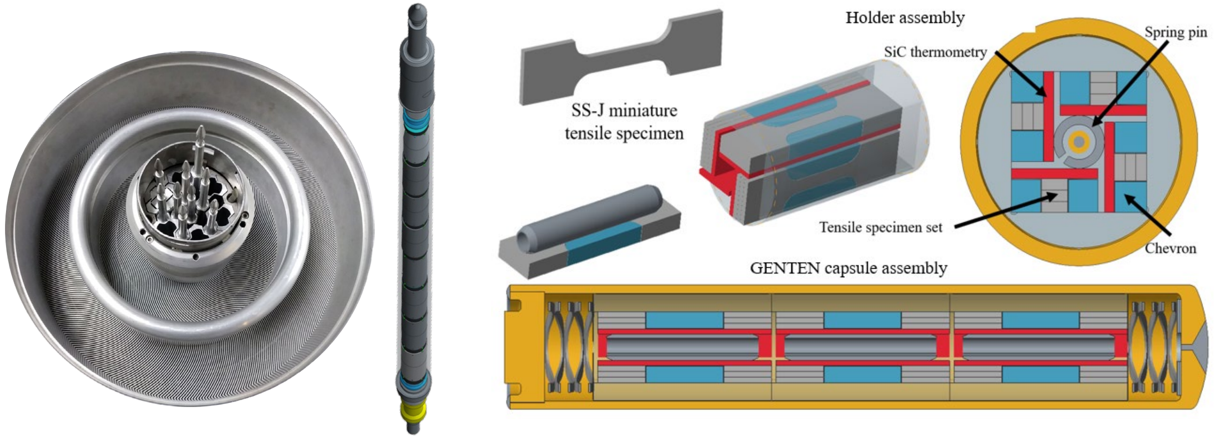
AM316H
300ºC



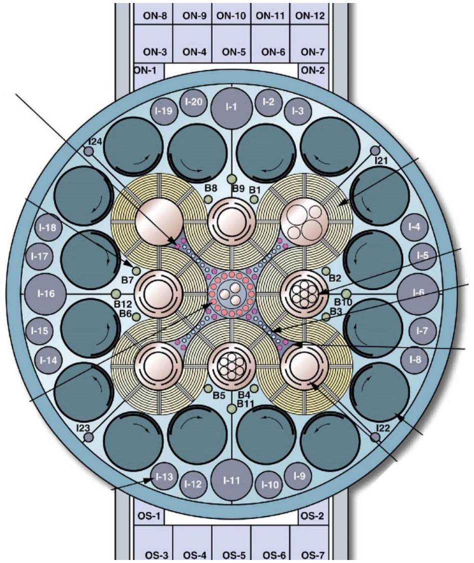


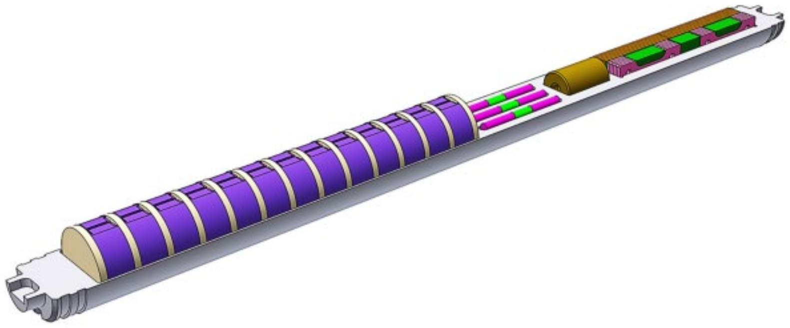
Neutron irradiation test plan development for AM316H

- Two-level testing strategy
  - HFIR@ORNL will provide baseline engineering information to higher doses
  - ATR@INL will provide novel advanced PIE for new reactor technologies
  - Leveraging standard capsule designs to make neutron irradiations faster and cheaper
- **Looking for industry input on parameter spaces of interest**



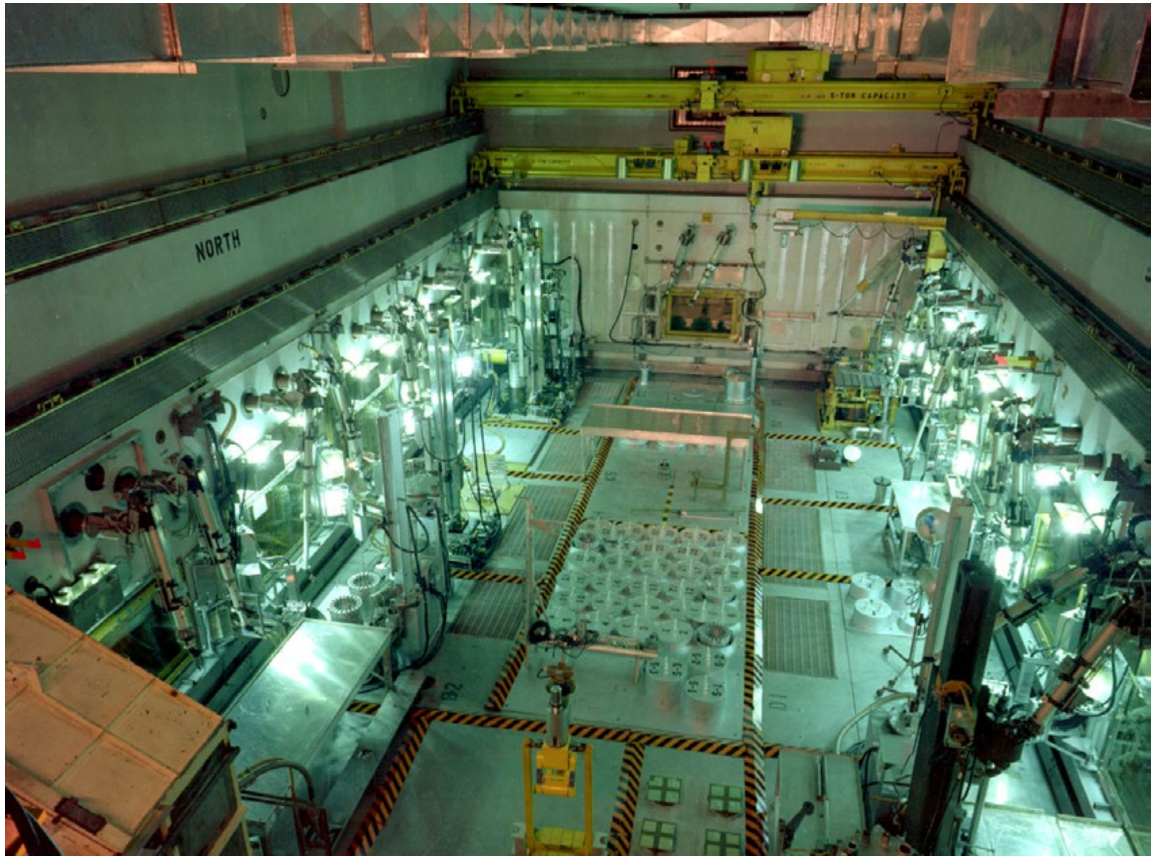
P. A. Champlin et al., ORNL/TM-2019/1310, Oak Ridge National Laboratory, Oak Ridge, TN, 2019.





Current irradiation capabilities summary

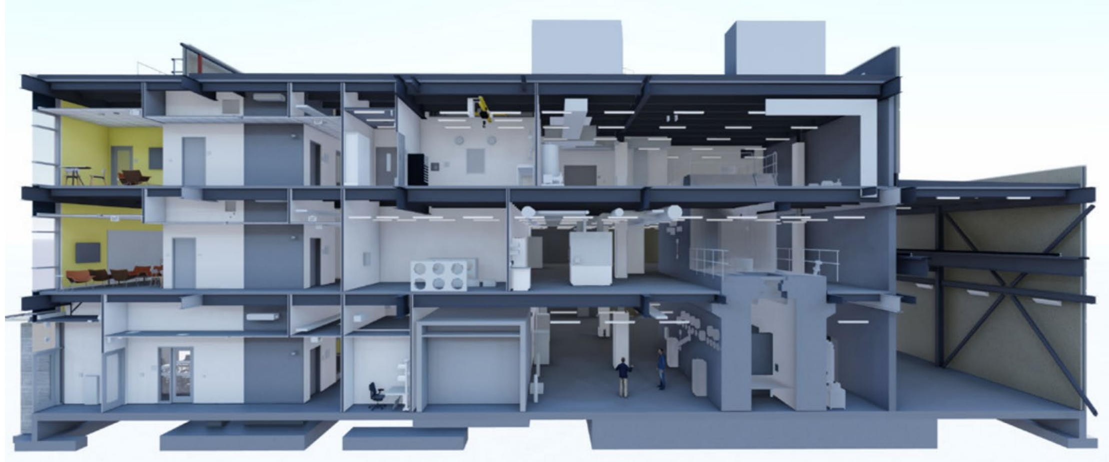
- Mechanical specimens
  - INL (ISHA):
    - SSJ tensile bars (16mm x 4mm x 0.5–1mm) - max 48 specimens per capsule
    - Round compact-tension - max 13 specimens per capsule
    - Bend bars - max 24 specimens per capsule
    - TEM specimens (3mm diameter)
  - ORNL (Rabbit):
    - SSJ tensile bars (16mm x 4mm x .5mm-0.75mm) – max 36 specimens per capsule
    - Bend Bars (14.8 mm x 3 mm x 4.5 mm) – 6 specimens per capsule
    - Pressurized tubes
- Irradiation temperature: 200 – 1200°C
- Post-irradiation examination (PIE)
  - Elevated testing up to 800°C
  - Uniaxial tensile testing
  - Microstructural characterization
  - Hardness testing
  - Fracture toughness
  - 3- and 4-point bend
  - …



HFEF hot cell

INL Future Rad Mechanical Testing

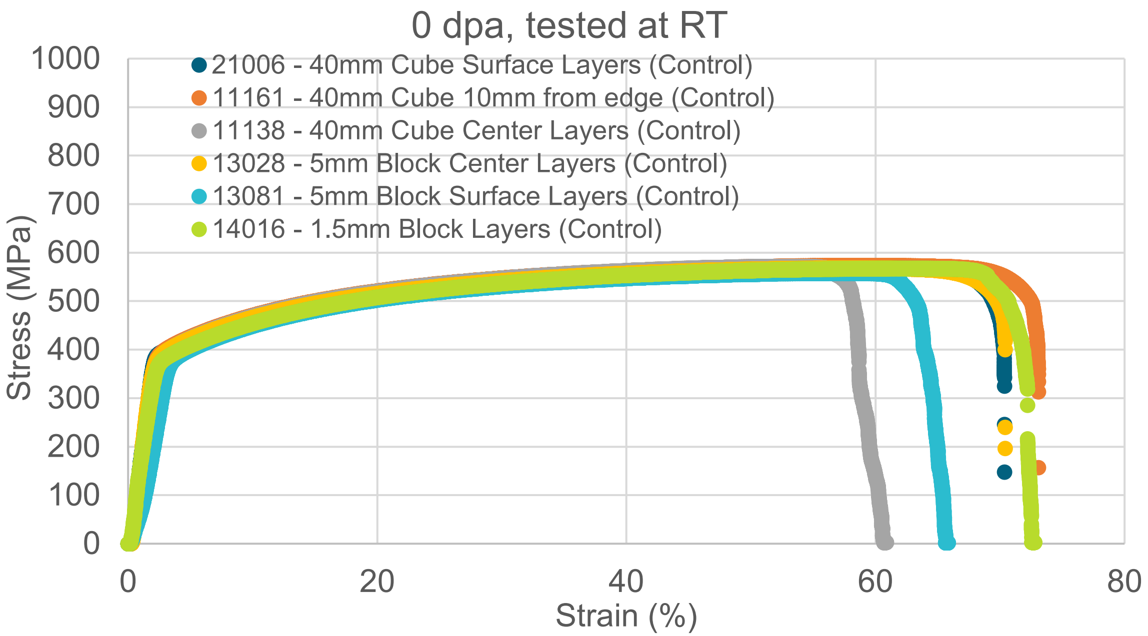
- SPL facility opening start of FY26
- Max testing temperature 1200°C
- Creep testing
- Creep crack growth
- Fatigue
- Automated Charpy impact testing
- Additional capacity for tensile compression testing
- Nanoindentation and micromechanical testing

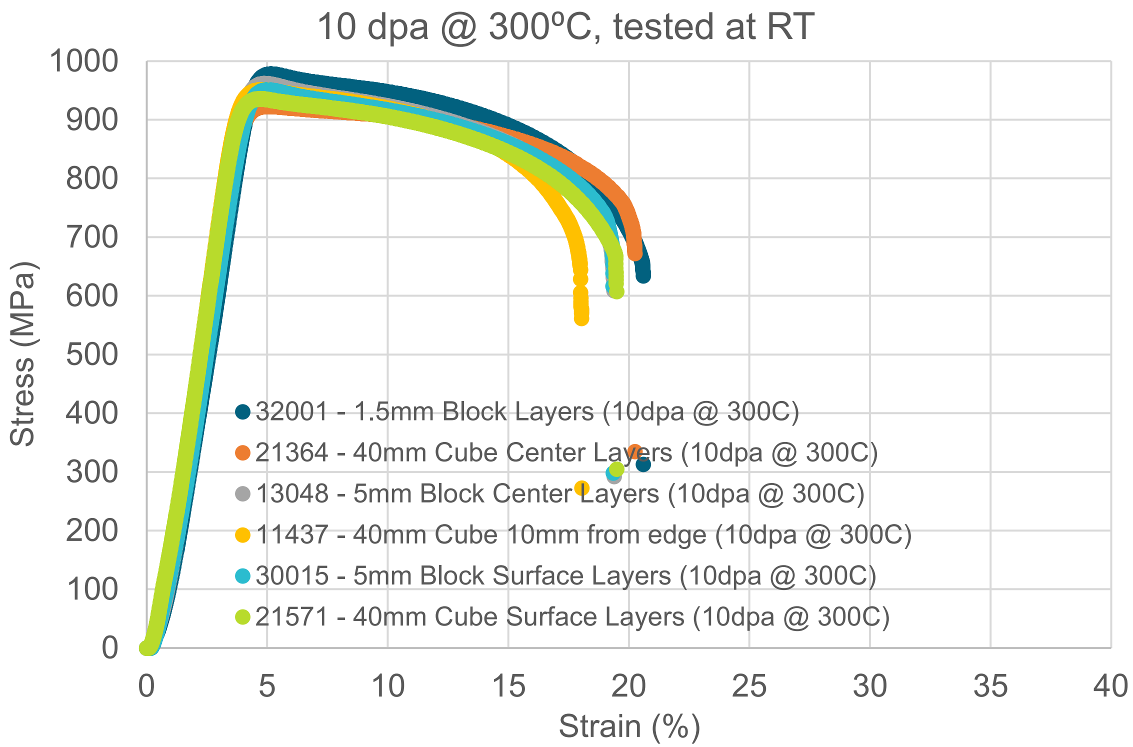


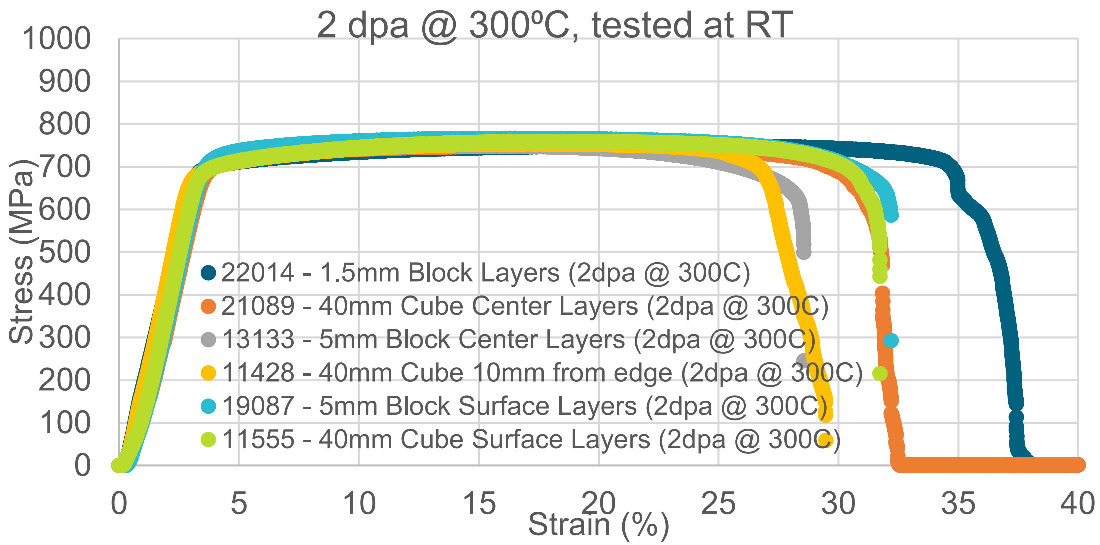
Delivering data and insights for AM316L and AM718

	FY	Capsule ID	Irr. Temp. (°C) Target/Measured	Dose (dpa)	Specimen/alloy
Initial Microstructure	2020	GTCR01	300/250	0.2	36 SS-J2 (AM 316L in as-built, stress-relieved, and solution-annealed conditions and WT 316L)
		GTCR02	300/376	2	36 SS-J2 (AM 316L in as-built, stress-relieved, and solution-annealed conditions and WT 316L)
		GTCR03	300/277	10	36 SS-J2 (AM 316L in as-built, stress-relieved, and solution-annealed conditions and WT 316L)
		GTCR04	600/673	0.2	36 SS-J2 (AM 316L in as-built, stress-relieved, and solution-annealed conditions and WT 316L)
		GTCR05	600/600	2	36 SS-J2 (AM 316L in as-built, stress-relieved, and solution-annealed conditions and WT 316L)
		GTCR06	600/550	10	36 SS-J2 (AM 316L in as-built, stress-relieved, and solution-annealed conditions and WT 316L)
Sampling Location	2021 - 2022	GTCR07	300/292	2	24 SS-J3 (AM 316L in stress-relieved condition, sampling from six build locations of 1.5 mm and 5 mm thick plates and 40 mm cube)
		GTCR08	600/494	2	24 SS-J3 (AM 316L in stress-relieved condition, sampling from six build locations of 1.5 mm and 5 mm thick plates and 40 mm cube)
		GTCR09	300/269	10	24 SS-J3 (AM 316L in stress-relieved condition, sampling from six build locations of 1.5 mm and 5 mm thick plates and 40 mm cube)
		GTCR10	600/511	10	24 SS-J3 (AM 316L in stress-relieved condition, sampling from six build locations of 1.5 mm and 5 mm thick plates and 40 mm cube)
Initial Microstructure		GTCR11	300/305	2	24 SS-J2 (WT IN 718 in standard, one solution-annealed, and two age-hardened conditions, AM IN 718) and 8 SS-J3 (AM 316L in stress-relieved condition, six build locations)
		GTCR12	600/553	2	24 SS-J2 (WT IN 718 in standard, one solution-annealed, and two age-hardened conditions, AM IN 718) and 8 SS-J3 (AM 316L in stress-relieved condition, six build locations)
		GTCR13	300/318	10	24 SS-J2 (WT IN 718 in standard, one solution-annealed, and two age-hardened conditions, AM IN 718) and 8 SS-J3 (AM 316L in stress-relieved condition, six build locations)
		GTCR14	600/578	10	24 SS-J2 (WT IN 718 in standard, one solution-annealed, and two age-hardened conditions, AM IN 718) and 8 SS-J3 (AM 316L in stress-relieved condition, six build locations)

Case study: delivering data and insights for AM316L







- Test strain rate of 5×10^{-4} s^{-1} (displacement rate = 0.15 mm/min)
- Strength increased and ductility decreased with irradiation dose
- All specimens showed prompt necking at yield at 10 dpa
- Effect of AM build thickness and location is not evident

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