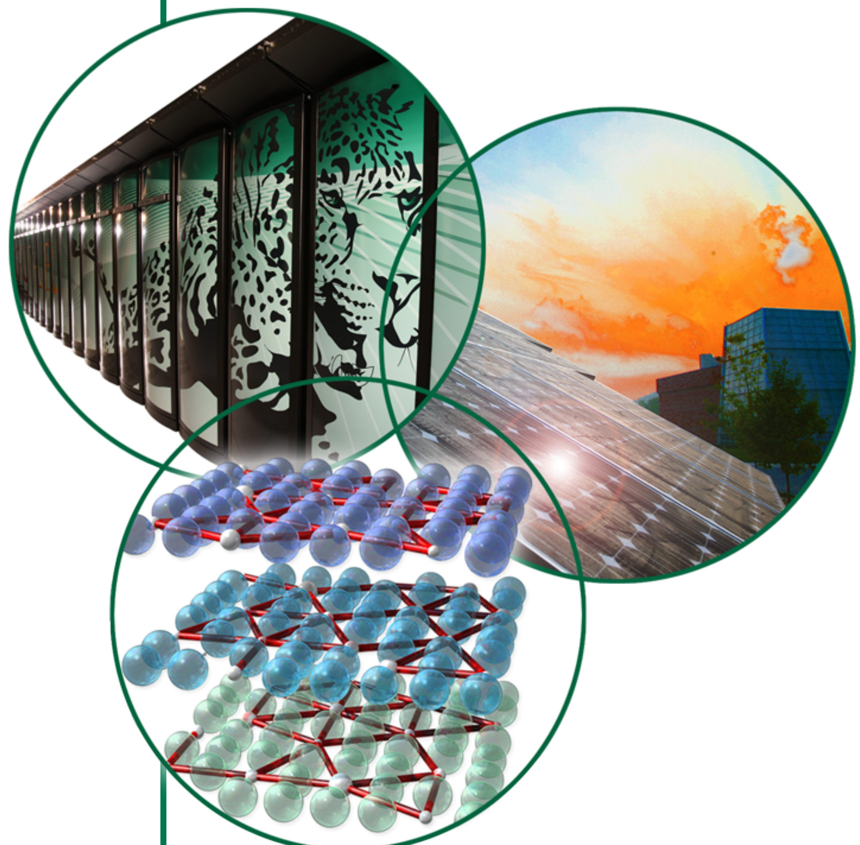
Multidisciplinary multi-physics simulation and analysis tool to support "Fusion Materials Science" research – Charge 3



Y-K.M. Peng

Fusion Energy Division
OAK RIDGE NATIONAL LABORATORY

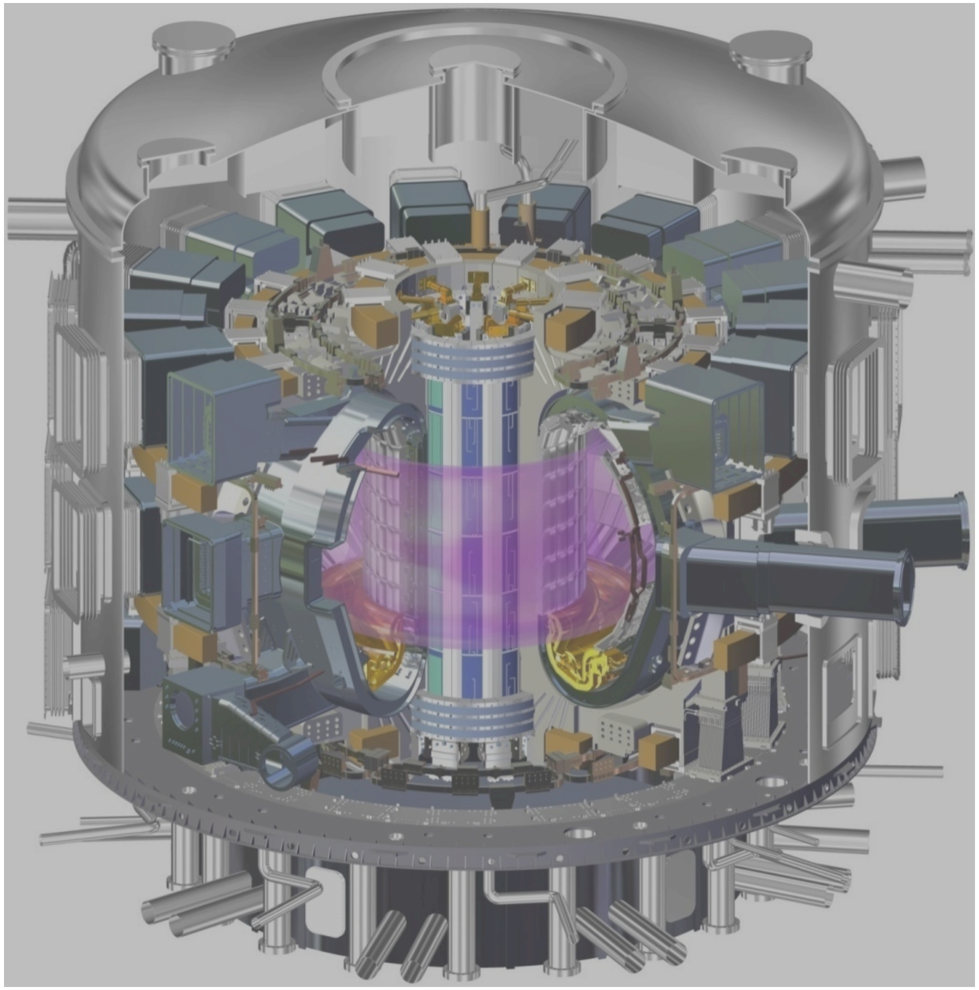
USBPO Webinar Input to
FESAC Panel on MFE Research Priorities

August 7, 2012

Multidisciplinary multi-physics (MDMP) simulation & analysis tool

- The need, in support fusion materials science research
  - Clarify benefit-cost-risk among options of internals, configuration, mission, performance
  - Inform research choices based on leverage
  - Can become tool needed to integrate research, FNSF designs, and eventually operation scenarios
- Help introduce a “fighting chance” for this research in ITER era

Fusion internals interact strongly and form option sets due to compatibility and safety



ITER, 500 MW

Examples:

A) Hot divertor surface with H_2O-cooled steel wall components (ITER)

1. W surface divertors
2. Be first wall
3. Water-cooled steel shield-blocks
4. Several TBM's each of ~1m^2 area

B) All-W PFC's (EU)

1. Surface T = 750C – 1000C
2. High pressure He cooling
3. Solid or Li-Pb liquid breeder blankets
4. High power conversion efficiency

C) Large flowing liquid Li PFC's (US)

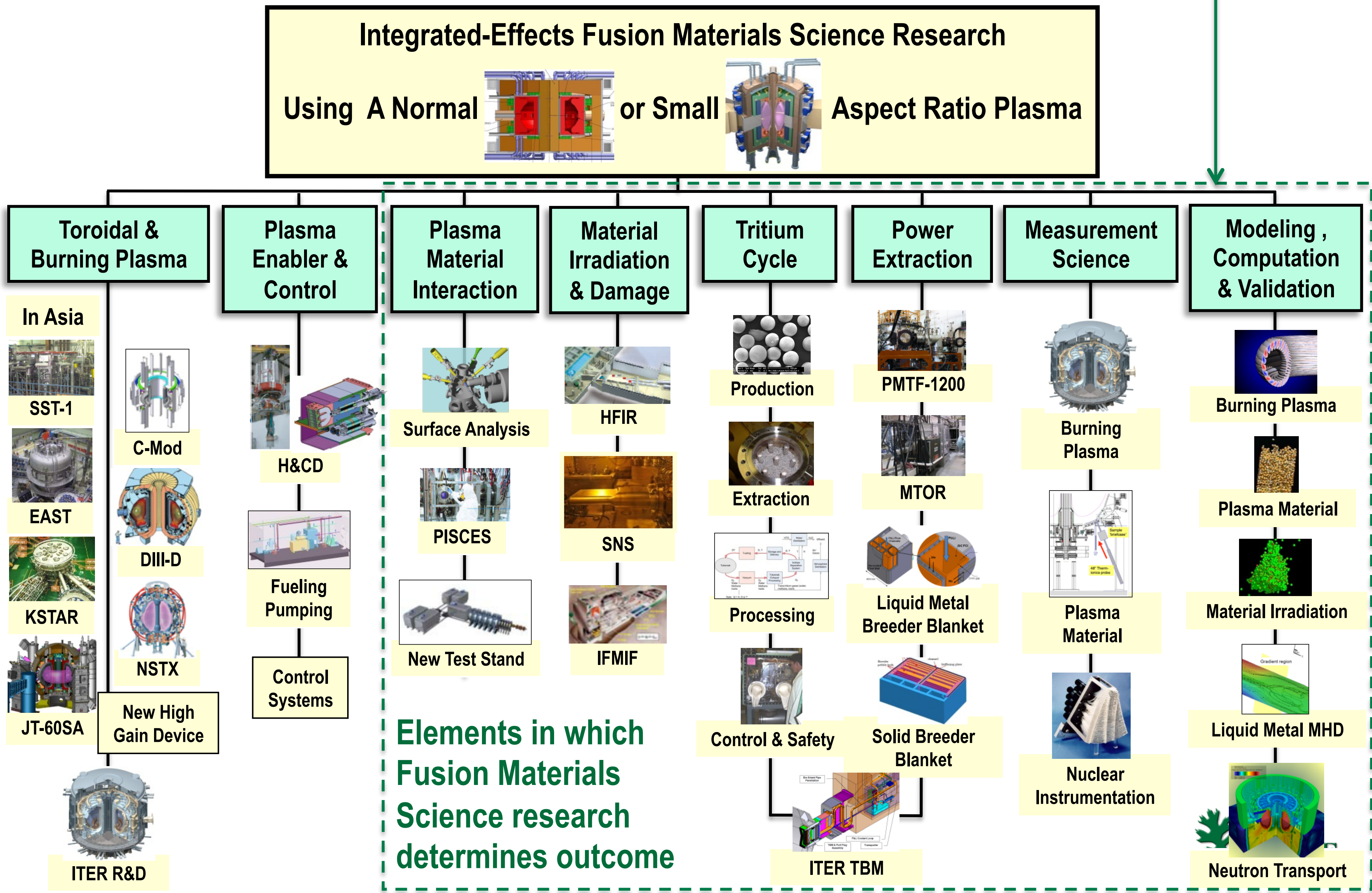
1. Surface T = 450C+, inlet T ~ 200C
2. He cooled internals
3. Avoid solid surface material damages
4. Need to remove Li-LiT on solid surfaces

D) Water-cooled solid breeder blankets (JN)

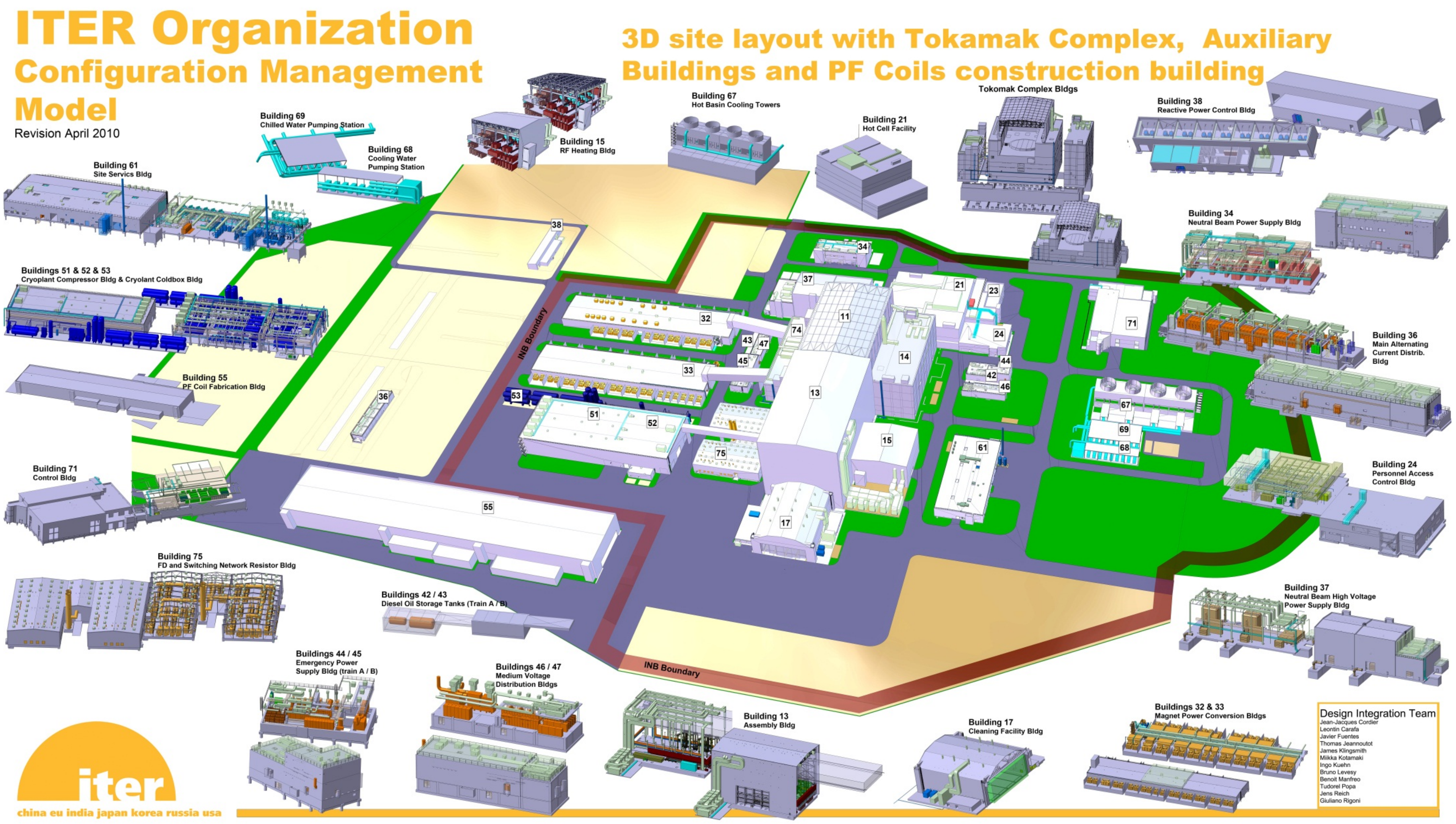
1. Super critical steam ~300C, He-cooled solid breeder
2. Extend LWR materials and technologies
3. Standard power conversion efficiency

These options drive differing requisite research and FNSF

Fusion Materials Science underpins fusion nuclear science research and FNSF

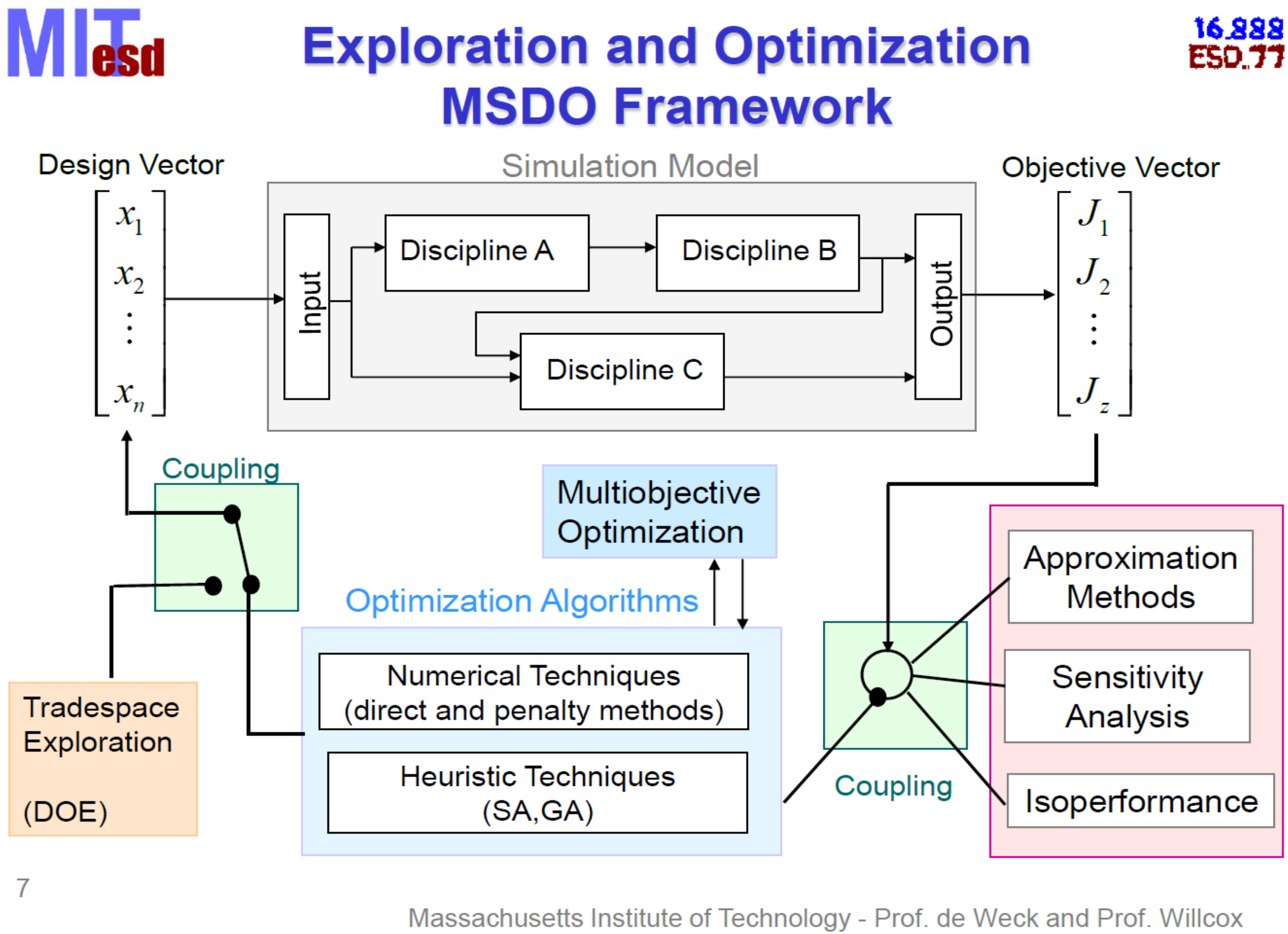


Fusion internals option further determines the support systems of the entire facility – ITER example

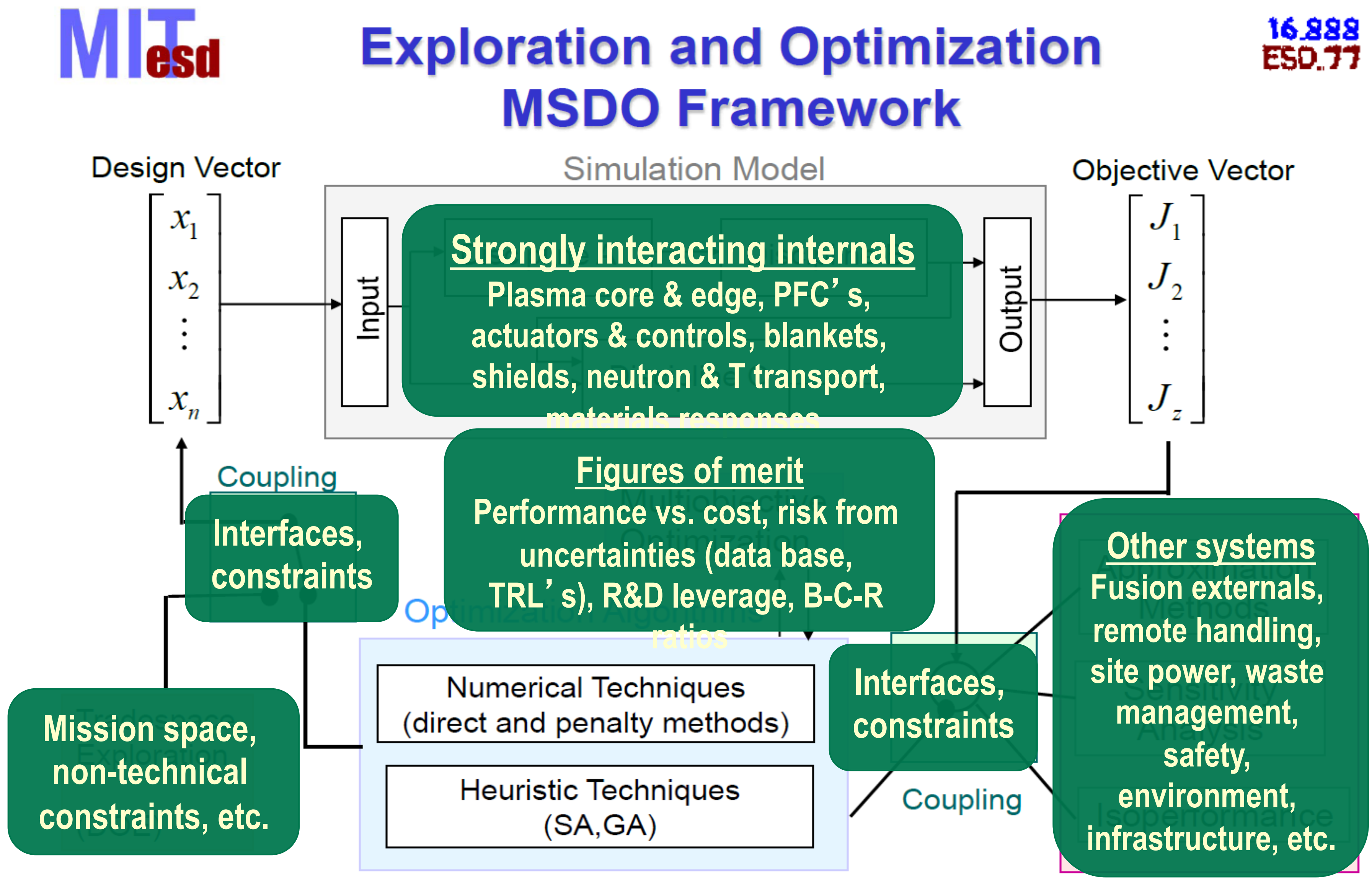


Need to estimate relative benefit-cost-risk of different internals options and the associated requisite research

MDMP simulation & analysis methodology has been successfully applied in aerospace & started for LWR's



This methodology applies to fusion systems and the associated R&D



How does this tool support fusion materials science research?

- Goal: help quantify uncertain benefit-cost-risk for differing internals option sets and the associated research
  - Cover options of mission, configuration, performance, cost, research choices, impact due to uncertainties (risks)
  - Inform critical decisions
  - A vehicle to develop in-kind collaboration with SC, NE, NNSA
- Start soon to benefit early, from simple to complex, point model to detailed modeling, and link to available advanced simulation codes
- Work with practitioners of plasma dynamics & control and materials science research, and also other interested within DOE

How could this possibly be realized within the constraints of Charge 3?

To introduce a "fighting chance" while addressing Charge 3

Fusion materials science research in ITER era ($M/yr)	2015-2019 (preparation)	2020-2029 (research program & project)	2030-2039 (integrated research)
I. MDMP tool	1-2 (part of III)	5 (part of IV)	3 (part of IV)
II. Other DOE in-kind, equivalent	1	~10% of III + IV	~10% of III + IV
III. Fusion materials science research	10 (requisite)	50 (internals)	50 (integrated testing)
IV. FNSF	1-2 (metrics, mission and options)	50 (facilities)	50 (operations)
V. Fusion plasma dynamics and control in-kind	Guidance to MDMP tool development	5 (plasma dynamics and control design)	10 (plasma dynamics and control operation)
VI. International in-kind, equivalent	Possibly, 1	80 (45% of VIII)	83 (45% of VIII)
VII. Total DOE (II + III + IV + V)	12-13	115	120
VIII. Total level of effort equivalent (VI + VII)	13-14	195	203

- **Assume readiness to start FNSF (integrated research) in mid-2020's**
- **Multiple internals options drive FNSF modularization and research flexibility (measure, discover, understand, improve, re-measure).**
- **Constrained fund likely leads to "adjacent possible" FNSF options**

Multidisciplinary multi-physics (MDMP) simulation & analysis tool has high leverage

- Supports fusion materials science research
  - Clarifies benefit-cost-risk among options of internals, configuration, mission, performance
  - Informs research choices based leverage
  - Can become tool needed to integrate research, FNSF designs, and eventually operation scenarios
- Helps introduce a “fighting chance” for this research in ITER era
- Has broader potential applications
  - Can retool for other fusion energy systems / facilities
  - With early progress, can inform ITER operation and upgrade choices

Backup

CASL vision: Create a virtual reactor (VR) for predictive simulation of LWRs

Leverage

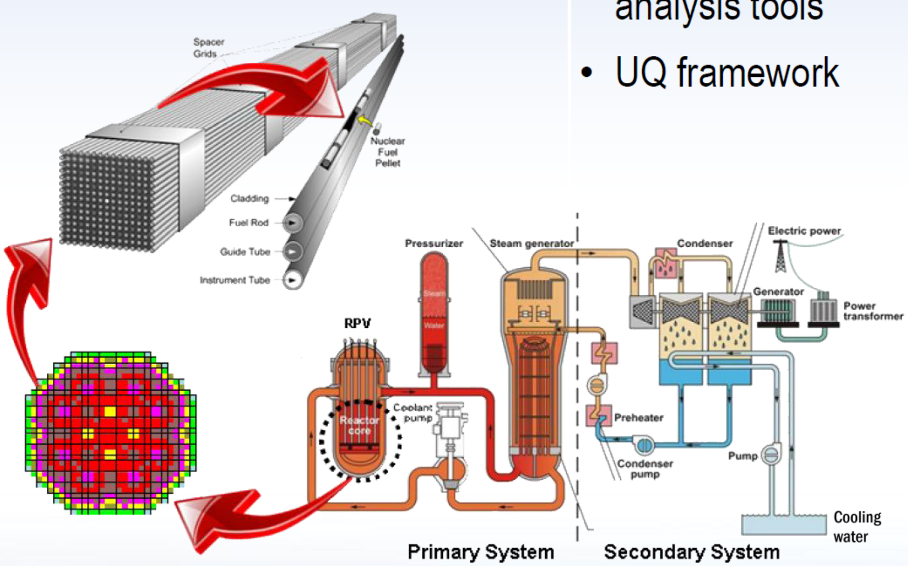
- Current state-of-the-art neutronics, thermal-fluid, structural, and fuel performance applications
- Existing systems and safety analysis simulation tools

Develop

- New requirements-driven physical models
- Efficient, tightly coupled multiscale/multiphysics algorithms and software with quantifiable accuracy
- Improved systems and safety analysis tools
- UQ framework

Deliver

- Toolkit for predictive simulation of physical nuclear reactors
- Architected for platform portability ranging from desktops to DOE's leadership-class and advanced architecture systems (large user base)
- Validation basis against 60% of existing U.S. reactor fleet (PWRs), using data from TVA reactors
- Base M&S LWR capability

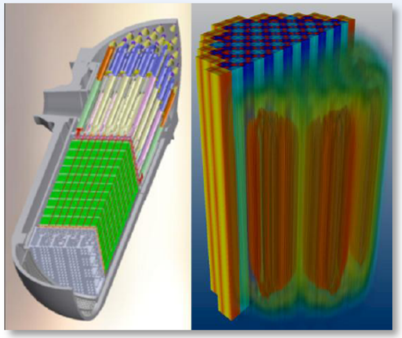


CASL mission: Develop and apply the VR to address 3 critical performance goals for nuclear power

1. **Reduce capital and operating costs per unit energy by:**
   - Power uprates
   - Lifetime extension

2. **Reduce nuclear waste** volume generated by enabling higher fuel burnups

3. **Enhance nuclear safety** by enabling high-fidelity predictive capability for component and system performance from beginning of life through failure



“Multiphysics Integrator” simulates reactor core

Virtual Environment for Reactor Analysis (VERA)

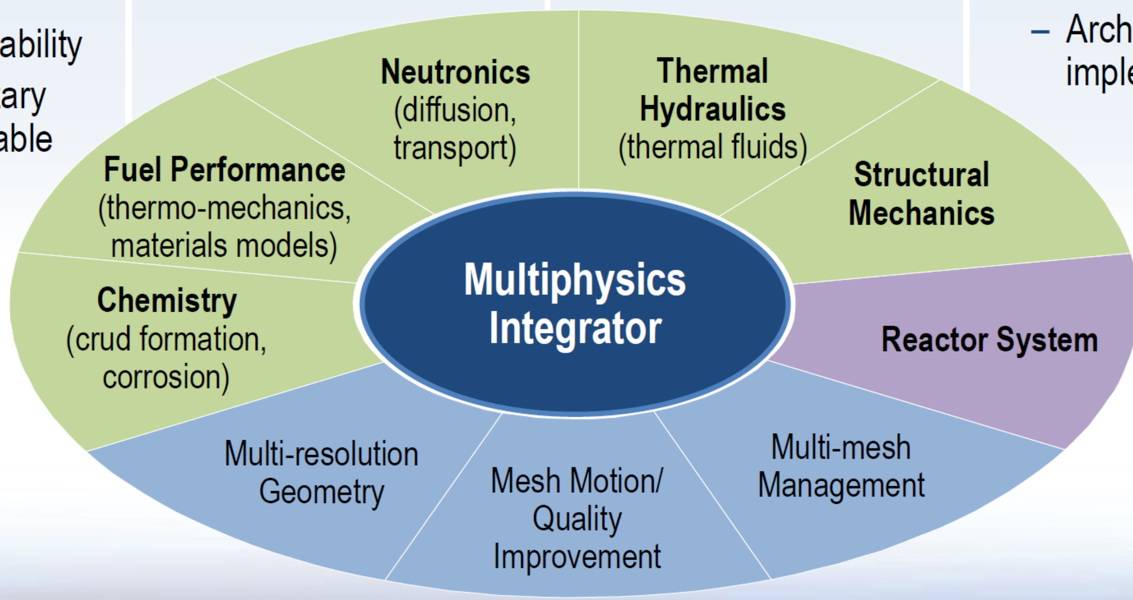
A code system for scalable simulation of nuclear reactor core behavior

- Flexible coupling of physics components
- Toolkit of components
  - Not a single executable
  - Both legacy and new capability
  - Both proprietary and distributable

- Attention to usability
- Rigorous software processes
- Fundamental focus on V&V and UQ

- Development guided by relevant challenge problems
- Broad applicability

- Scalable from high-end workstation to existing and future HPC platforms
  - Diversity of models, approximations, algorithms
  - Architecture-aware implementations

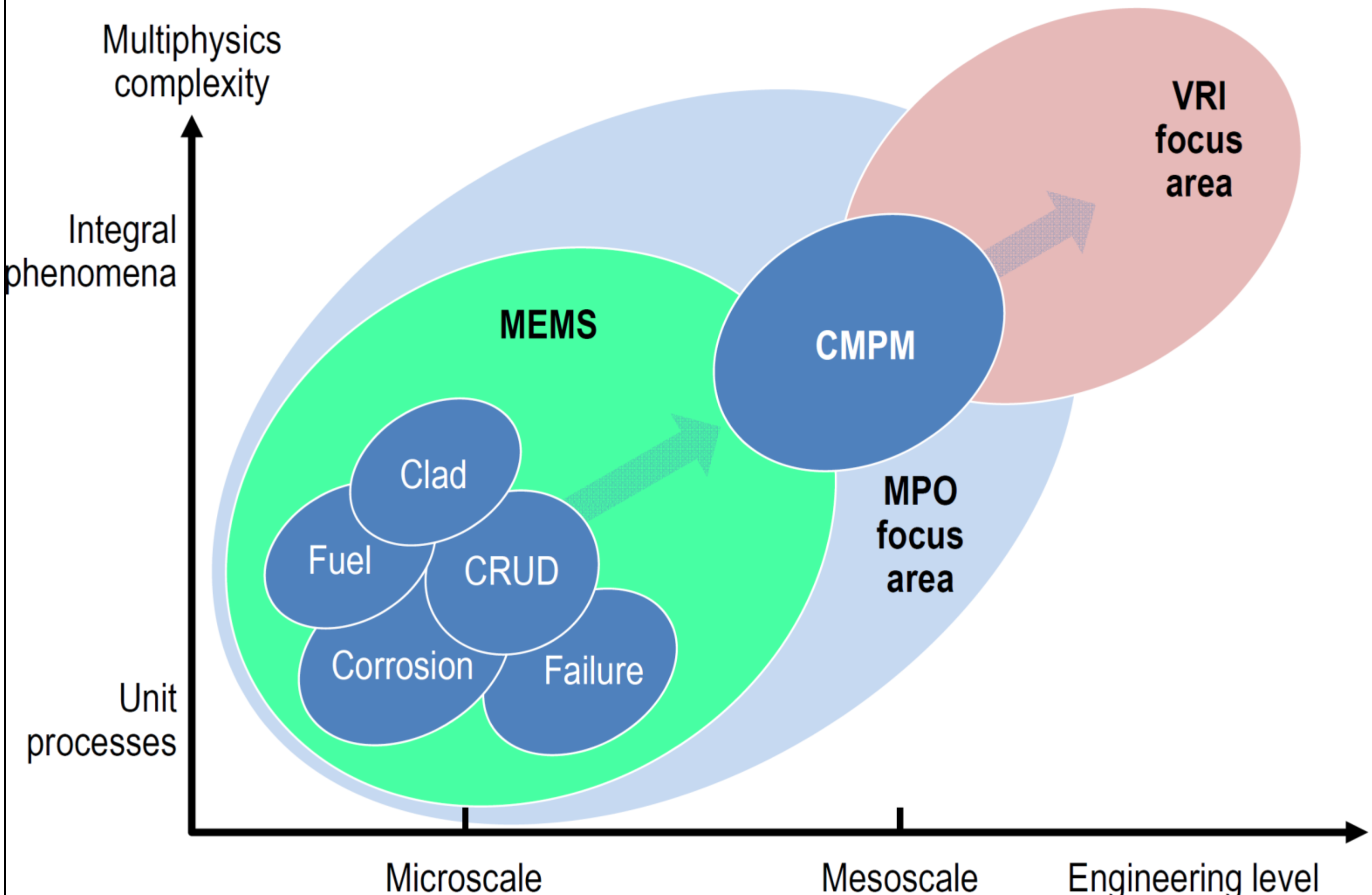


CASL

OAK RIDGE National Laboratory

Nuclear materials science underpins LWR performance

MPO science innovation is micro-meso coupling in both complexity of physical phenomena and modeling and simulation capability



Project	
1	CMPM
2	Microstructure evolution: Fuel
3	Microstructure evolution: Clad
4	Corrosion of clad/internals
5	CRUD deposition
6	Failure modes

CASL

Example of FNSF internals modularity & flexibility to address options, with low support-structure lifetime-dpa