Restructured US Tokamak Research and Synergistic EU Program Engagement

US Tokamak Research Program

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Overview: US Tokamak Research Has New Structure to Execute US Fusion Science & Technology Roadmap

- **US Tokamak Research Program addresses gaps in physics basis for conventional tokamak:**
  - Unites the national program to advance tokamaks by executing and closing gaps identified in the US Fusion Science & Technology Roadmap

- **Research program aligns with FESAC Long-Range Plan in executing Roadmap**
  - Five research focus areas: Sustaining Burning Plasmas, Exhaust Handling, PMI, Control of Damaging Transients, and Theory/Simulation/Modeling/VVUQ (TSMV)
  - Cross-cutting program matrix elements to ensure integration and exploitation of synergies

- **TR Management Council to provide strong program guidance and coordination**
  - Coordinates experimental work: DIII-D, international facility collaborations
  - Coordinates theory/simulation/VVUQ work: domestic integration, international collaboration

Why a New U.S. Tokamak Research Program Structure?

- **The Department of Energy has initiated a restructuring of U.S. Tokamak R&D, prioritizing *national mission delivery* over institution- or facility-centric programs**
- **New structure and program emphasizes coordinated, outcome-driven integration across experiments, theory, modeling, and data science**
- **The new Tokamak Research (TR) structure is designed to:**
  - Close critical physics and technology gaps identified in the **U.S. Fusion Science & Technology Roadmap**
  - Enable **extrapolable and extensible progress toward burning plasma and fusion pilot plant operation**
  - Align domestic and international research efforts under a **single, coherent execution framework**
- **This reorganization establishes:**
  - Clear **strategic ownership and accountability**
  - Strong **program-level coordination across projects and major topical areas**
  - A management model optimized for **integration, convergence, and timely decision-making**
  - **Cross-cutting coordination among domestic facilities and international partnerships**

US Tokamak Research Program Will Deliver US Fusion Roadmap in Context of Industry, Public, and International Partner Program Priorities

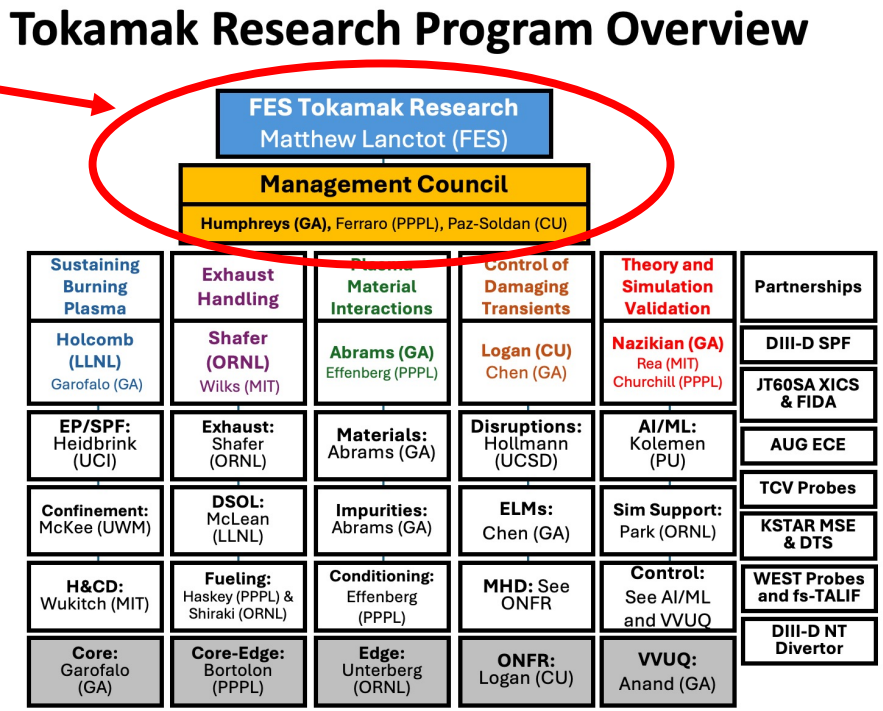
- **US Roadmap high-level tokamak priorities (further refinement underway):**
  - Core/edge confinement & integration
  - Divertor exhaust/operation
  - Plasma-Material Interaction
  - High priority to domestic/international facility partnerships and collaboration
  - Validated, uncertainty-quantified predictive capabilities
  - Stability and controllability solutions

- **Selected (additional) synergistic industry priorities:**
  - Effective actuators for power plant applications
  - Radiation-hard, “control-grade,” reactor-applicable sensors

- **Selected synergistic US Public and International Partner priorities:**
  - Demonstrations of [extrapolable/extensible] sustained burning plasma core performance
  - Demonstrations of operational stability/controllability for reactor-grade disruptivity/off-normality
  - Operational demonstrations of certifiable AI/ML [and other synthesis] control

US Tokamak Research Program is Architected in Matrix of Major Topical Areas Each Coordinating Focused Project Areas

- **Leadership team coordinates Council functions and high-level research with strong FES oversight**
- **Major Topical Area Programs are Managed by Research Coordinators**
  - MTA composed of Sub-Topical Areas
  - MTA program rolls up STA goals
- **Sub-Topical Area PI's run projects:**
  - Each STA project goals/metrics/deliverables
  - Strong PI model: high project control authority and research management



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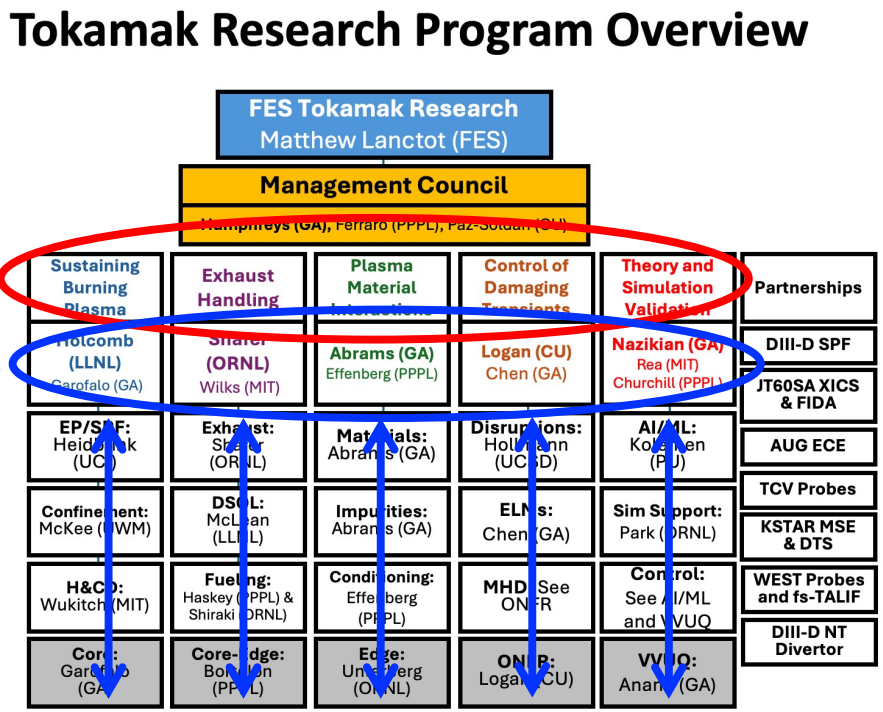

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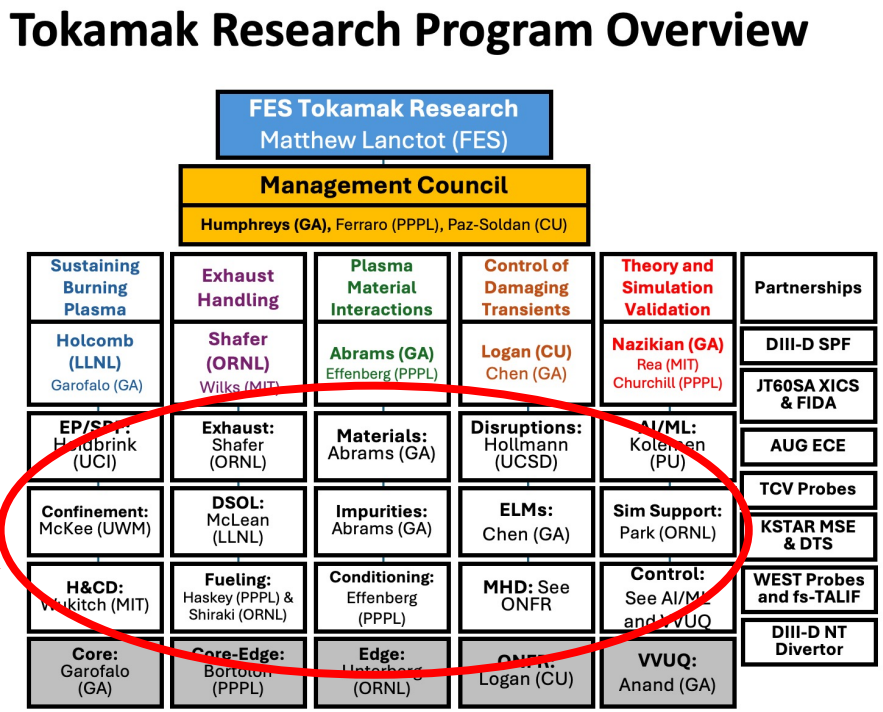

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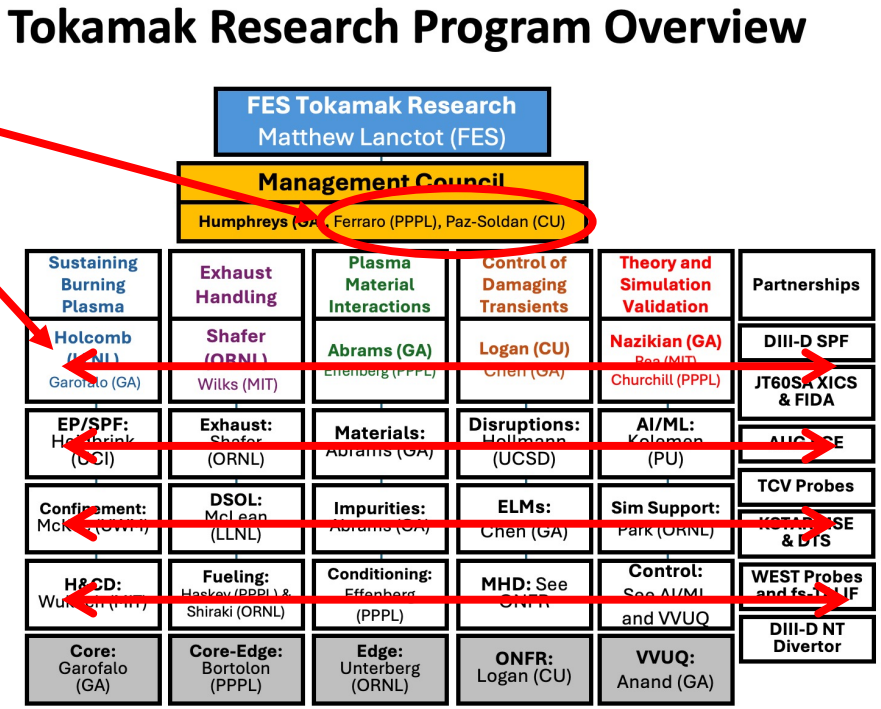
- **Cross-cutting integration and coordination by Vice-Chairs:**
  - Experimental Vice-Chair: C. Paz-Soldan
  - Theory/Sim/VVUQ Vice-Chair: N. Ferraro

- **Worldwide Facility/Project Partnerships:**
  - Short-pulse experiments: DIII-D, TCV, AUG
  - Long-pulse devices: WEST, KSTAR, JT-60SA



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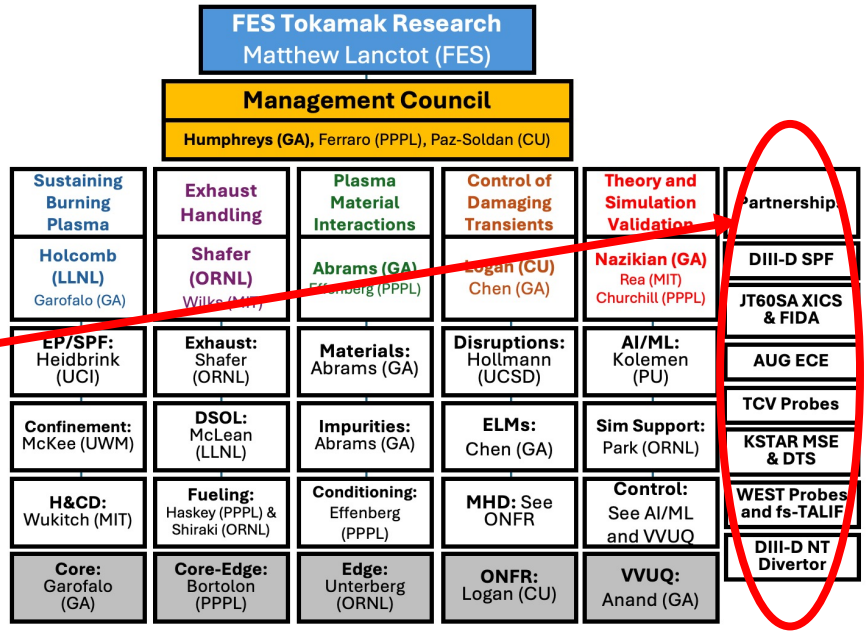
Tokamak Research Program Overview



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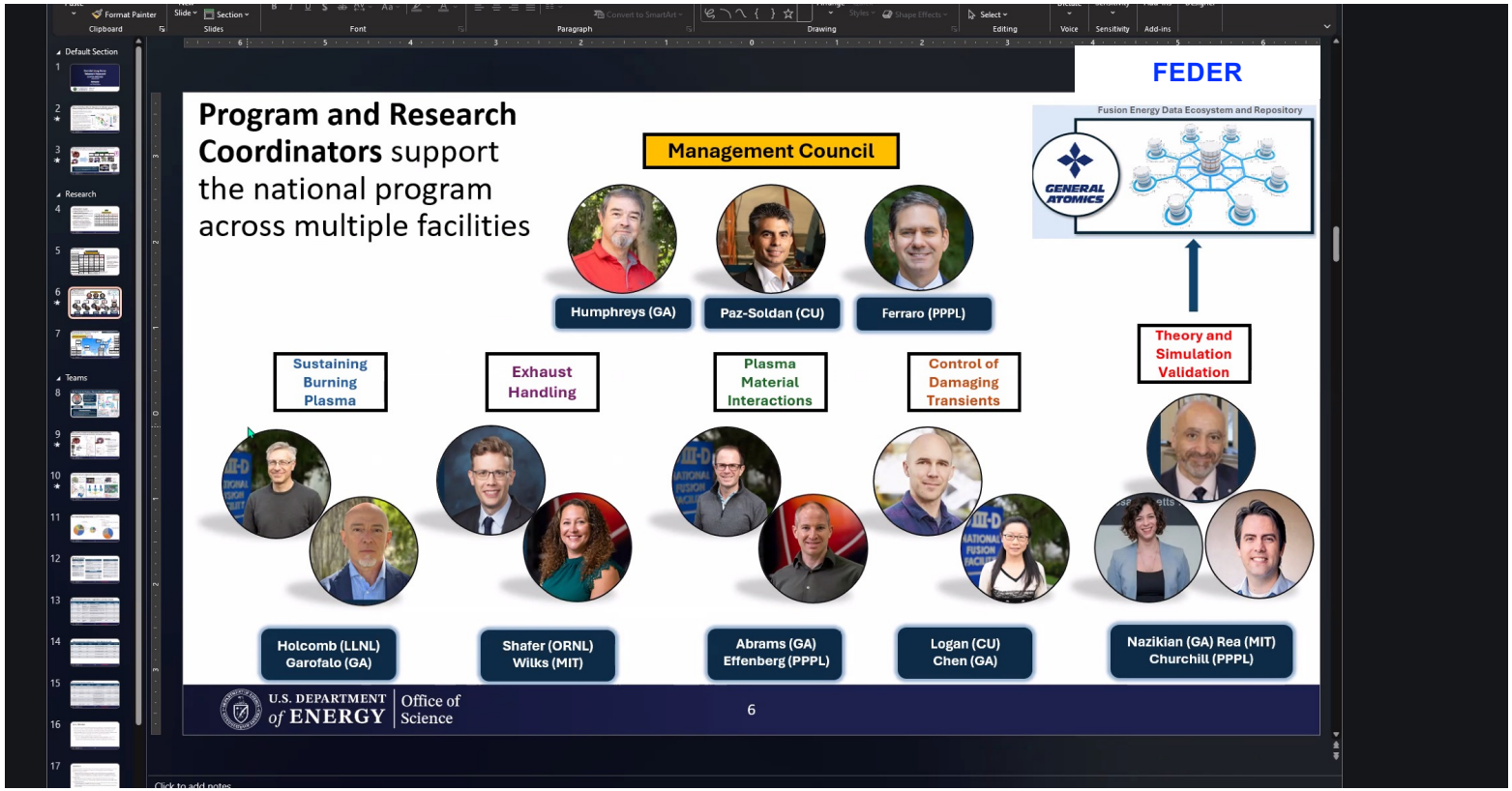
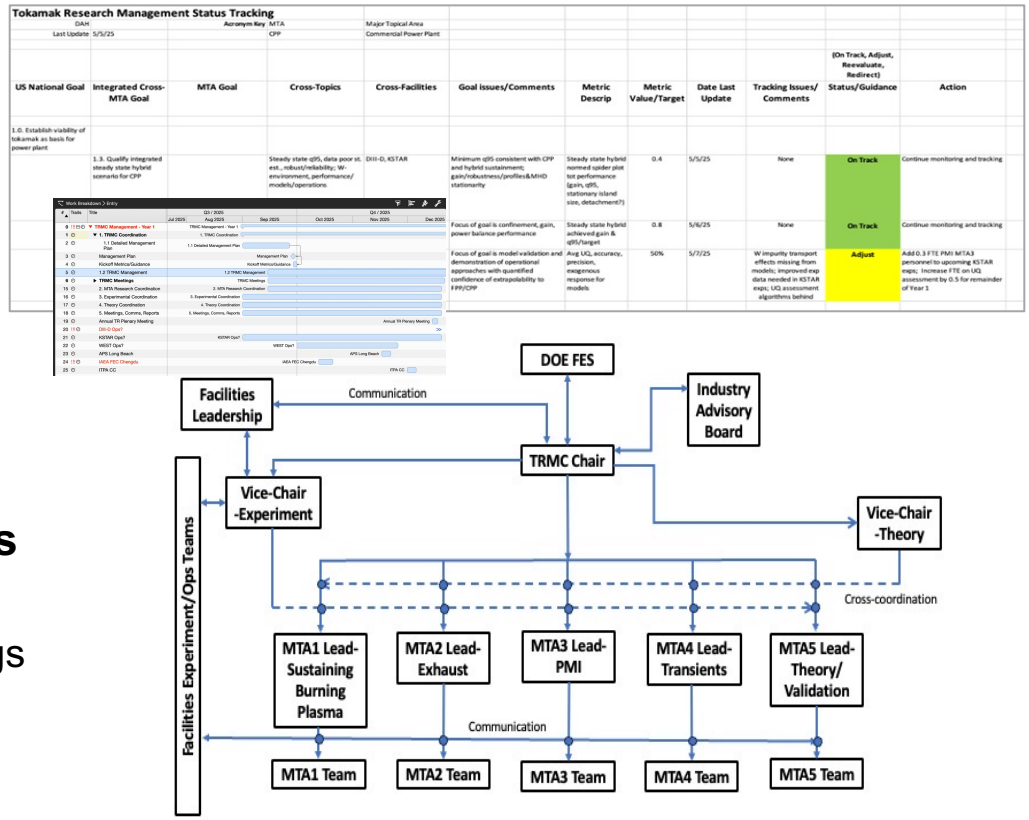


USTR Will Follow Strong Program/Project Management Approach

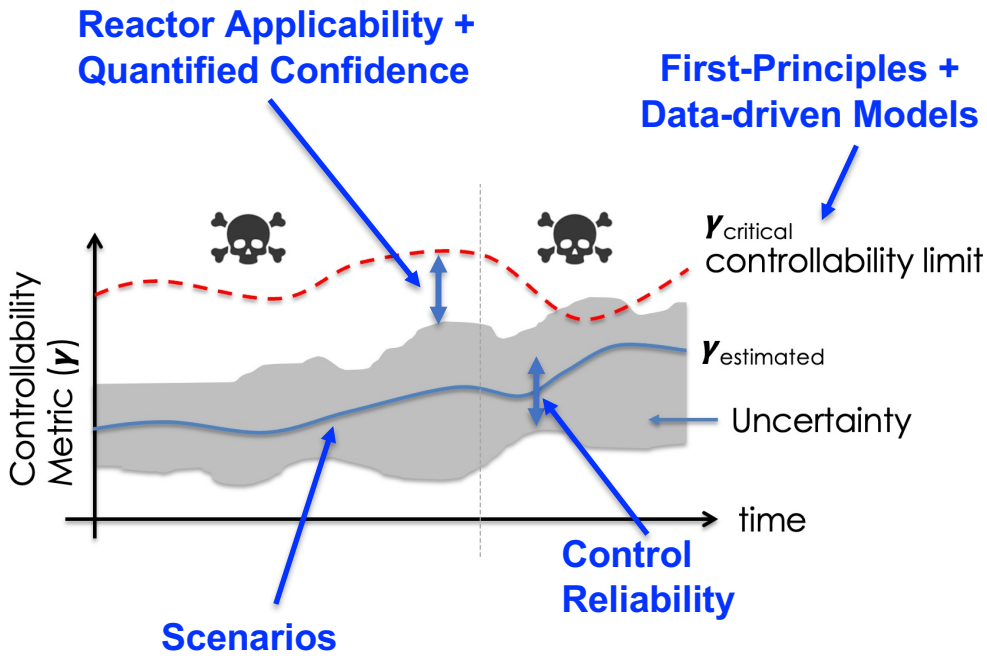
- **Vertical and matrixed project planning and management**
  - PI-level Goals/Metrics/Deliverables
  - Roll-up to Major Topical Areas
    → Roll-up to TR Strategic level
  - Cross-cutting integration by effective matrix project manager Vice-Chairs

- **TR Management structure provides key coordinating interfaces:**
  - Experimental facilities leadership/orgs
  - Theory institutions leadership/orgs
  - Stakeholder Advisory Board (strong participation by Industry)



Guiding Principles for Research Will Ensure Focused Convergence to Gap Closure for Fusion Pilot Plants and Tokamak Power Plants

- **Extrapolability & Extensibility** to burning plasmas
- **Reactor-relevance** and operational capability: constraints/conditions
- **Multi-facility** experimental/multi-effort modeling synergies
- **Quantified uncertainty**, accuracy, precision, performance (VVUQ required throughout)
- **Optimized combinations** of first-principles-based and data-driven modeling
- **Demonstrated achievable workflows** for machine learning applications



Understanding+Control enables Extensibility
= effective application without full understanding

Experimental Facility Research Coordination is a Key Cross-Cutting Responsibility of the Tokamak Research Management Council

- **Tokamak Research Program takes on coordination of DIII-D research**
  - Experimental research planning and coordination, runtime allocation
  - Research Coordinators (MTA level) are have principal role in coordinating/delivering experimental research in their MTA's
  - Vice-chair cross-cutting coordination of DIII-D and international collaboration activities maximizes synergies and worldwide effectiveness of experimental research

- **Experimental opportunities in any given year will be dynamic, requiring agile coordination:**
  - TR-collaborating devices will field new upgrades, go offline for extended maintenance
  - Dynamic team engagement and adjustment of resources will be essential

- **International facility collaborations and partnerships essential to advancement of tokamaks:**
  - Unique machine environments, complementary to DIII-D
  - Long Pulse SC devices continue to provide unique abilities to qualify scenario, operational solutions for extrapolability/extensibility…

Cross-Cutting Theory/Simulation/Modeling/VVUQ Research Coordination is Essential to Success of USTR Program

- **Ensure cross-program integration of theory/simulation/modeling/VVUQ support**
  - STA's that focus on Whole Device Modeling, scenario/experimental simulation
  - Predict-first, simulation-driven design for experiments and analysis
  - Operational trajectories and control design
  - VVUQ as input and output of all research

- **Ensure optimized, focused application of data science:**
  - Integrated, optimized first-principles + data-driven models
  - Universal incorporation of VVUQ process and standards throughout research activities

- **Explicit integration of FEDER, data-management infrastructure:**
  - High-efficiency federated data curation/marshalling + application of data science & AI/ML tools
  - Collaboration and integration with international partners in data science space

Summary and Conclusions

- **Restructured US Tokamak Research program will close gaps and execute the US Fusion Science & Technology Roadmap with quantitative progress demonstrated in 4-5 years**

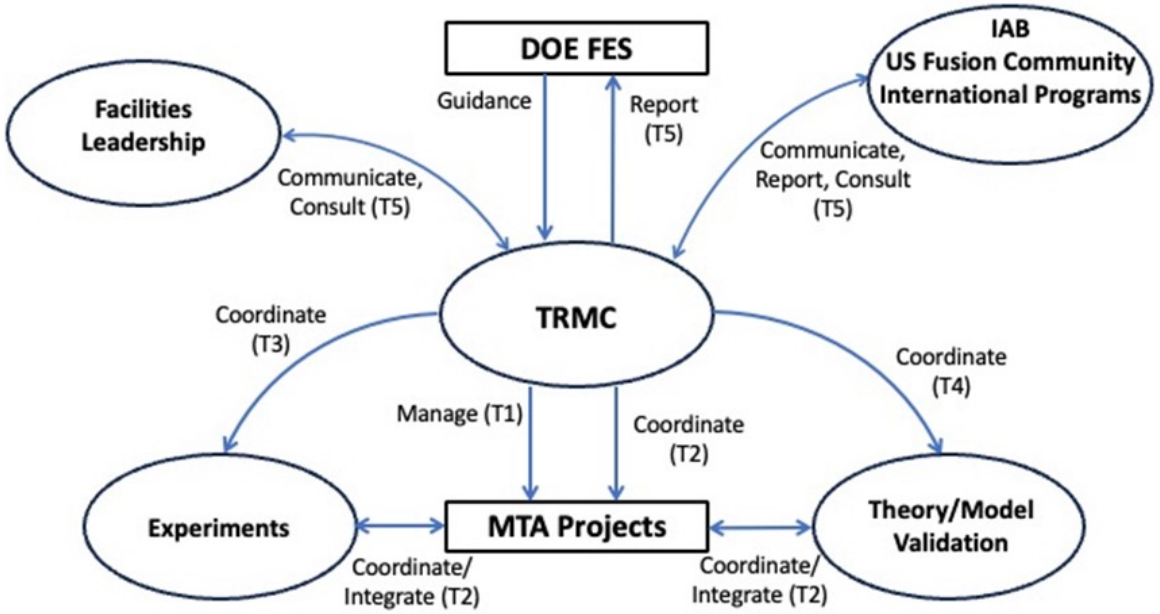
- **Program applies strong project management, coordination, and integration to accelerate establishment of tokamak power plant viability**
  - Clear, focused project goals with quantitative metrics for effective guidance, facilitation, convergence
  - Principles guiding research toward pilot/power plant extrapolability/extensibility
  - Optimized use of first-principles physics understanding and data-driven solutions

- **Highly-integrated experimental/theory/simulation/VVUQ activities**
  - Program cross-cutting matrix process to maximize synergies
  - Theory/simulation/VVUQ and data management resources leverage other supporting US programs (e.g. FEDER)

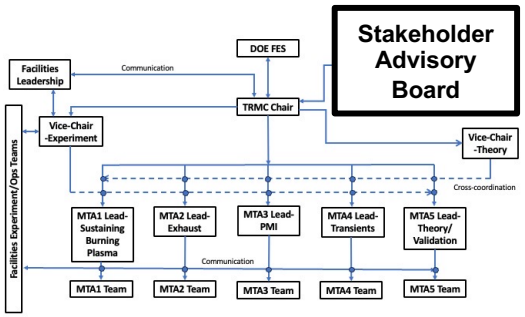
- **Cross-program integration of Experimental Facilities and Theory/simulation/VVUQ teams**
  - Strong integration of DIII-D, domestic institutions, with international device teams and partners

ADDITIONAL SLIDES

Tokamak Research Program Management Council Functions Through Effective Team Communication and Coordination with DOE Guidance

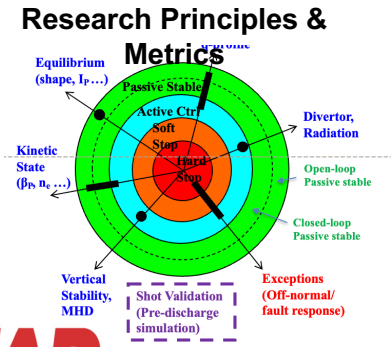


Modern Agile, Metric-Driven Project Management Combined with Strong Integrated Research Vision will Deliver on the Tokamak Fusion Roadmap



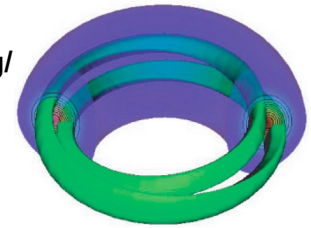
DIII-D NATIONAL FUSION FACILITY

Multi-facility Experimental Coordination



Uniting the National Tokamak Research Program to Advance Rapidly through the US Roadmap to Fusion

Theory/Modeling/ Simulation/ DataScience



KSTAR

WEST