ORNL Portable Diagnostic Package for Evaluating Mirror Performance

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INFUSE Project Overview

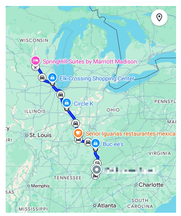
- Realta Fusion is sponsoring research at the University of Wisconsin-Madison's Wisconsin HTS Axisymmetric Mirror (WHAM) experiment to evaluate the path to a fusion power-producing mirror reactor.
- Realta Fusion and ORNL devised a plan to measure electron temperature (T_e) and density (n_e):
  - establish scaling with input power, mirror ratio, and other experimentally controllable parameters.
- The capability team and ready-hardware developed by ORNL provide independently validated data analysis and allow Realta Fusion to dedicate resources to device operation and optimization.
- The total estimated value of this CRADA was $250k (DOE contribution $200k; Realta in-kind contribution $50k) over a 12 month period of performance.

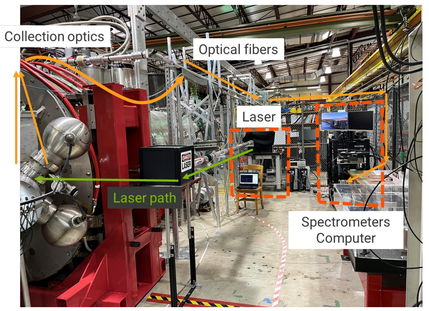
- This work was supported under the U.S. D.O.E. contract DE-AC05-00OR22725.

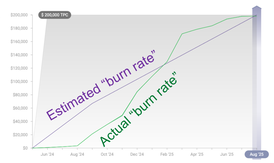
Application of the PDP to WHAM [1]

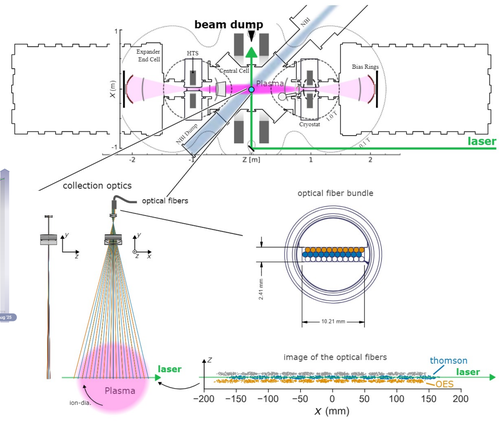
TABLE I. Summary of Visits and Key Activities

Visit	Project month	Activity Summary
–	PM1	Discussion and planning.
1	PM2 2024.09	Transport of PDP spectroscopy system from ORNL to WHAM and installation on device, integrated with WHAM timing. **First OES measurements from WHAM plasmas were achieved.**
2	PM3	Transport of PDP laser system from ORNL to WHAM and installation in machine area. **OES analysis automated for routine operation.**
3	PM4	Laser beam line enclosures established and laser-safety approval petitioned. TS laser integrated with WHAM timing.
4	PM5 2024.12	Open-beam laser operation approved, collection optics aligned, and stray light assessed.
5	PM6	Stray light improvements implemented and TS attempt on plasma (unsuccessful).
–	PM7	No visit due to scheduling conflicts.
6	PM8 2025.03	Stray light and timing improvements implemented. **TS attempt on plasma successful**; two experimental conditions measured as reported here.

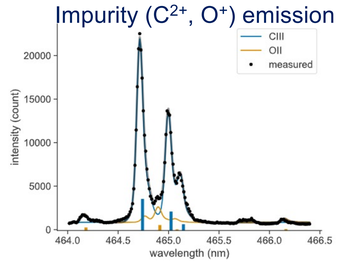




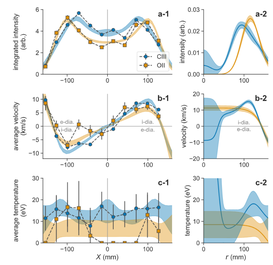




Impurity (C^{2+}, O^{+}) emission line

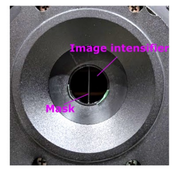


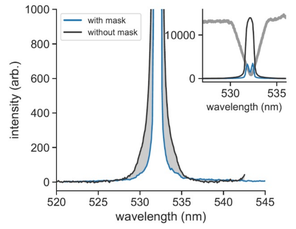
Radial distribution

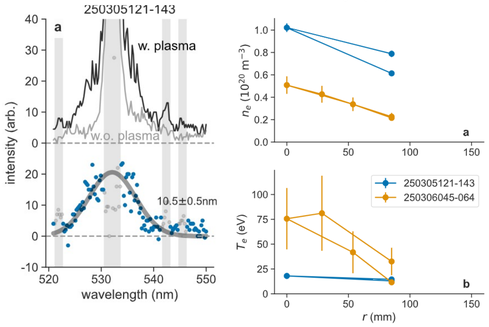


Main Results

- OES measurements of impurity ion flow and T_i made in WHAM.
- TS measurements of electron T_e and n_e demonstrated in test discharges.

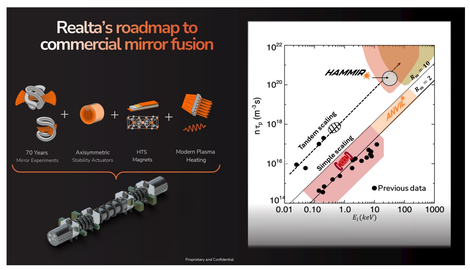


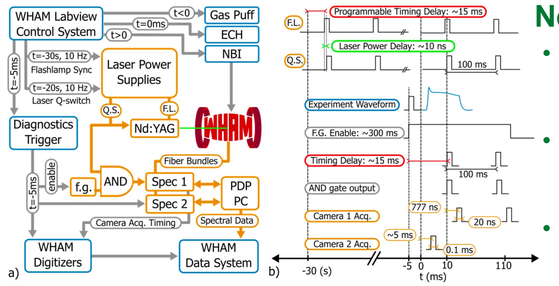




Realta Fusion's path to fusion energy via improvements in mirror-confinement [2]

- Magnetic mirror confinement concepts for fusion were proposed decades ago.
- The evolution of technology and physics understanding in the intervening time will be applied in the WHAM device, and a more rapid path to fusion energy will be enabled.





Next Steps

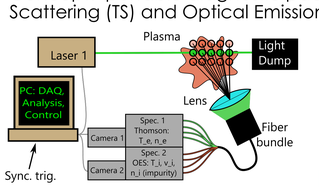
- Realta Fusion has contracted ORNL to continue to support the utilization of the PDP on WHAM.
- The TS system is being upgraded to increase system reliability and enable "single shot" capability.
- Collaboration on the design of the TS and OES diagnostics for Anvil.

A Portable Diagnostic Package (PDP) for measurement of TS and OES spectra [3,4,5]

ARPA-E Tina: Fusion Diagnostics Objectives

1. Realize diagnostic systems that can be transported to and shared among different experiments: (cost savings)
2. Enable high-quality measurements of plasma and fusion parameters on fusion-concept-exploration experiments supported by ARPA-E: (validation of performance and identification of potential issues)
3. Leverage expertise of the entire fusion R&D community to advance potentially transformative fusion-concept development, and to build "diagnostic resource teams" for a potential future expansion of this type of fusion R&D program: (developing a public-private partnership)

Concept: portable diagnostic package (PDP) for Thomson Scattering (TS) and Optical Emission Spectroscopy (OES)

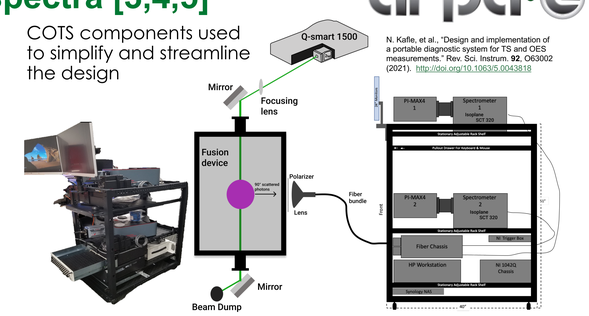


- Public validation of ARPA-E funded "transformational" private fusion concepts
- Collaborative development team:
  - ORNL: T.M. Biewer, D. Elliott, N. Kafle
  - UTK: Z. Zhang, Z. He
- Leverage distributed ORNL team to synchronize with 3 private companies:
  - Princeton Fusion, CTFusion, Helion Energy

Metric	Solicited	Proposed
"readiness to first measurement"	<9 months	<6 months
"minimum time interval between devices"	"days or a few weeks"	~4-5 days
Spatial & temporal	Single point	Multi-point, 10 Hz

Param.	Diagnostic method	Range and resolution	Spatial / temporal resolutions	spatial points
T_e	TS	5 - 1000 (eV)	~10 ns	~10
n_e	TS	>10^{19} (m^{-3})	~10 ns	~10
T_i	OES	5 - 1000 (eV)	~>2 ns (photon limited)	~10
n_i	OES	Impurity	~>2 ns (photon limited)	~10
v_i	OES	~>10 (km/s)	~>2 ns (photon limited)	~10

COTS components used to simplify and streamline the design



N. Kafle, et al., "Design and implementation of a portable diagnostic system for TS and OES measurements." Rev. Sci. Instrum. **92**. 063002 (2021). http://doi.org/10.1063/5.0043818

References

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2. Endrizzi, D., J. K. Anderson, M. Brown, J. Egedal, B. Geiger, R. W. Harvey, M. Ialovega, et al. 2023. "Physics Basis for the Wisconsin HTS Axisymmetric Mirror (WHAM)." Journal of Plasma Physics **89** (5): 975890501.
3. Z. He, et al., Rev. Sci. Instrum. **93**, 113526 (2022).
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5. N. Kafle, et al., Rev. Sci Instrum. **93**, 113506 (2022).