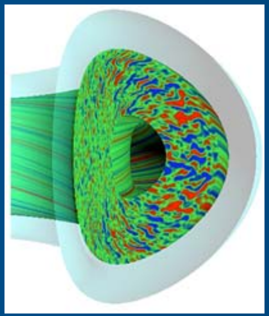
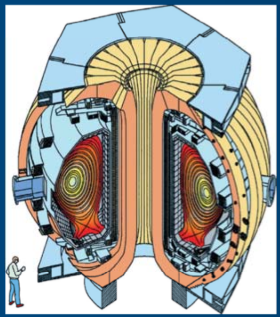
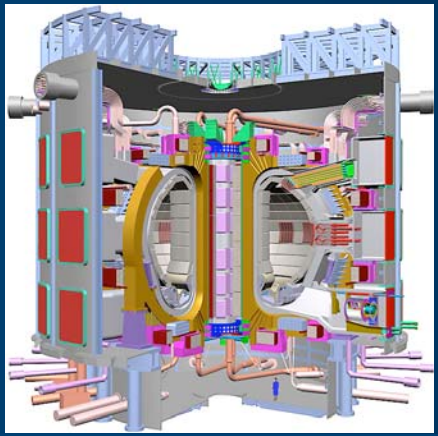
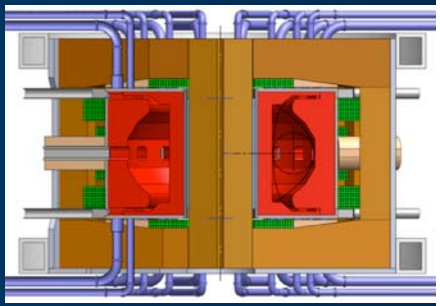
Overview of the Fusion Program at General Atomics

Fusion Power Associates Meeting

Washington, DC

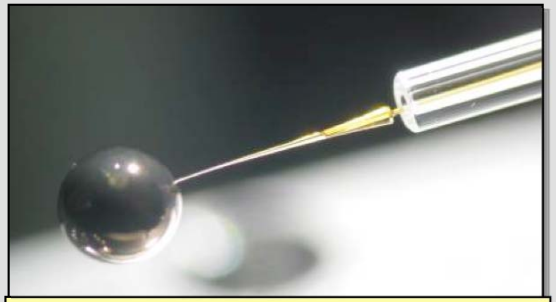
December 2, 2009

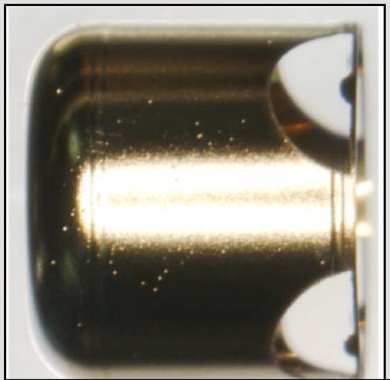
GENERAL ATOMICS

GA's target fabrication division designs, develops and produces targets as a partner in the ICF mission

NIF

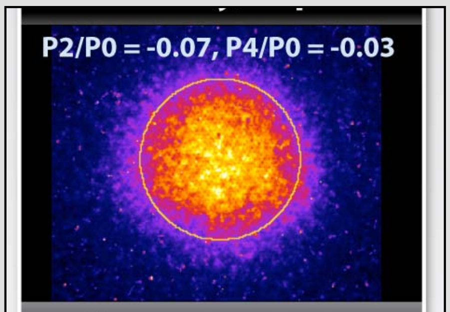


Be Capsule/Fill Tube



U hohlraum

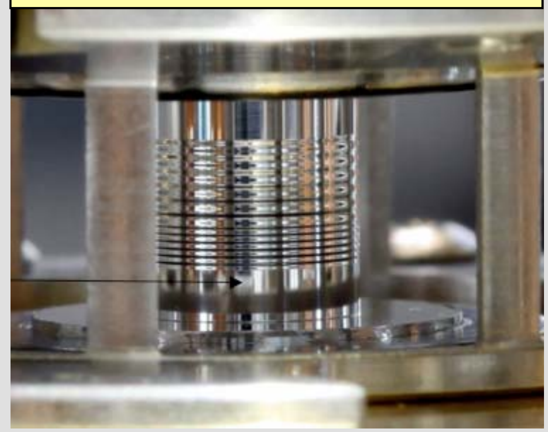
Assembled target

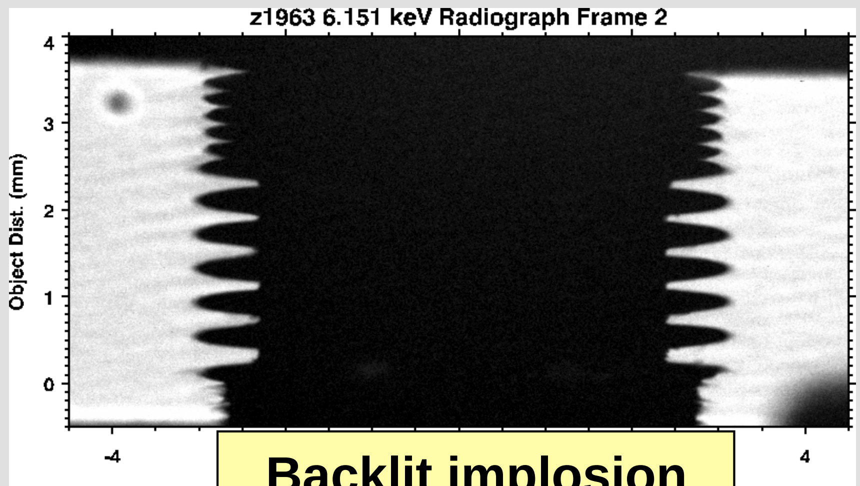


NIF implosions

Z

Magneto-RT target



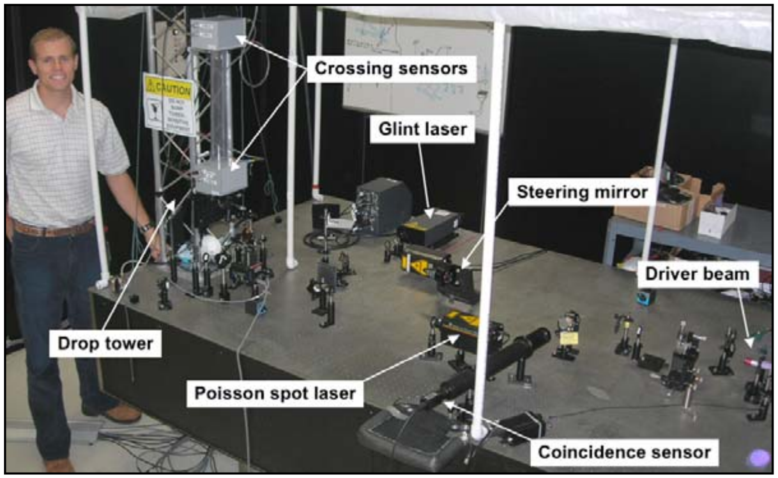


Backlit implosion

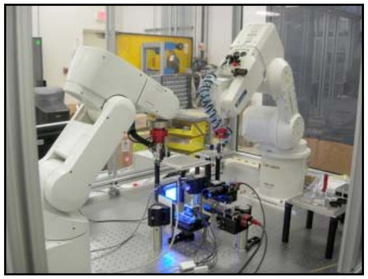
Targets have played a central role in success of NNSA facilities

GA is a leading developer of rep-rated and IFE target supply processes and target related systems

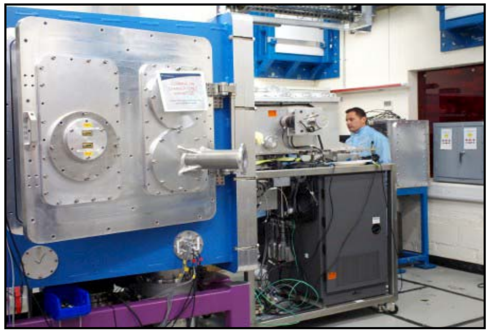
Making foam or fast ignition shells



Hit-on-fly demo for target tracking



Robotic assembly



Rapid insertion at Gemini

Inject targets (gas-gun or electromagnetic)

Electrically steer targets

Fill targets & layer in a cryogenic fluidized bed

GA Theory Program is Organized in Focus Areas to Support OFES Mission

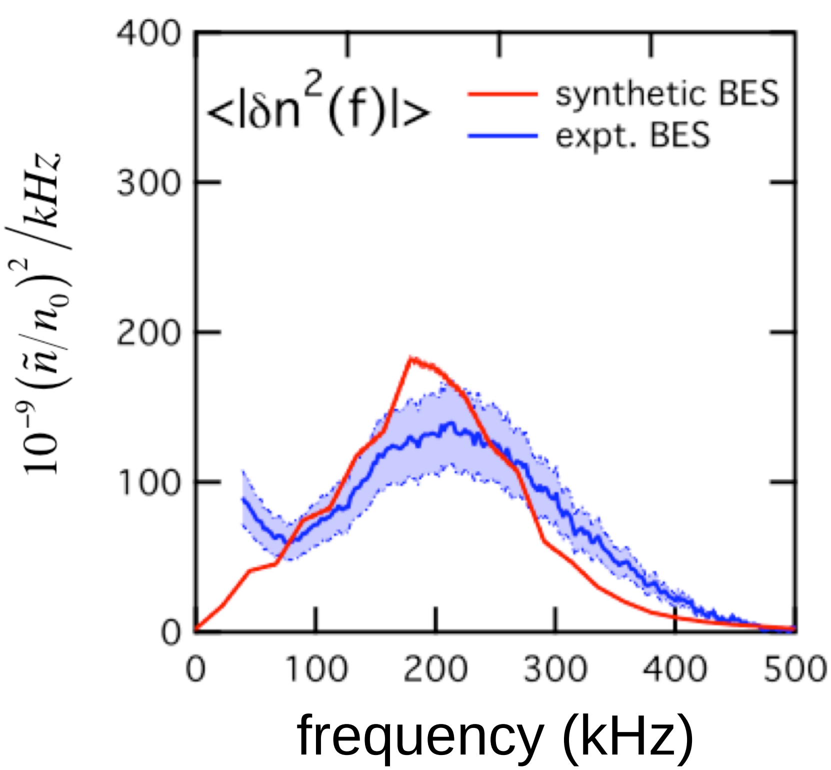
- **Turbulence and Transport**
  - Focus on understanding mechanisms for particle and heat transport in magnetically confined fusion plasmas
  - Develop extensive simulation capabilities for nonlinear interactions between magnetized charged particles and electromagnetic waves
- **Integrated Modeling**
  - Focus on self-consistent integration of various physical components
  - Enable experimental interpretation, model validation and next step design work

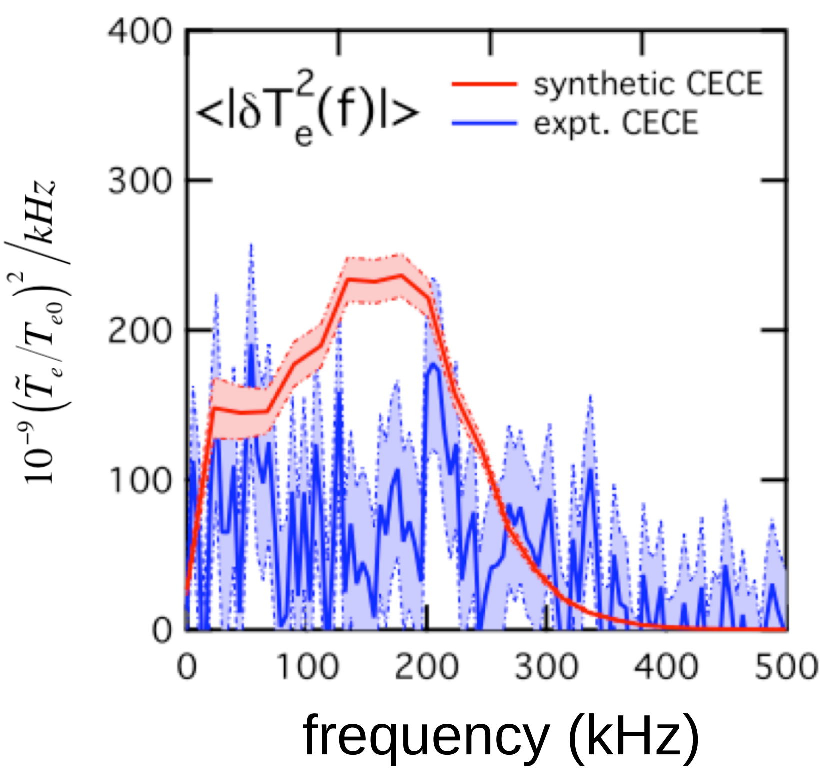
Strengths of GA Theory Program:

- Strong collaboration with experiments
- Leaders in numerical simulations using high performance computers
- Extensive international collaborations
- Strong post-doc program

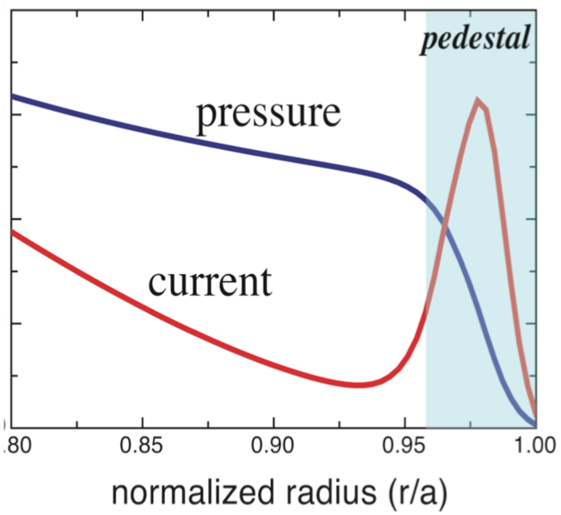
Transport Models (GLF23, TGLF) Derived From GYRO Allow Predictive Transport Simulations Inside H-mode Pedestal

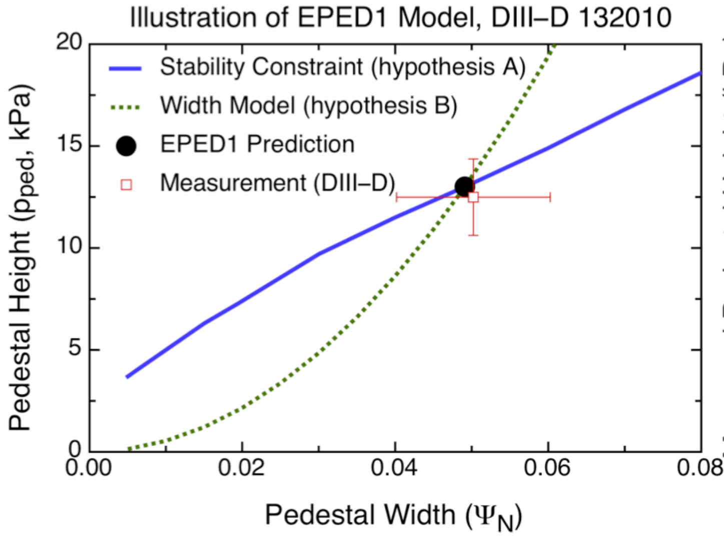
- **Newly developed synthetic diagnostic algorithms have been applied to massively parallel GYRO simulations of a DIII-D discharge to allow for direct comparisons with upgraded beam emission spectroscopy (BES, left) and new correlation electron cyclotron emission radiometry (CECE right) diagnostics**
  - Simulations used > 3000 processor-hours on `jaguar` CRAY XT4 machine at NCCS

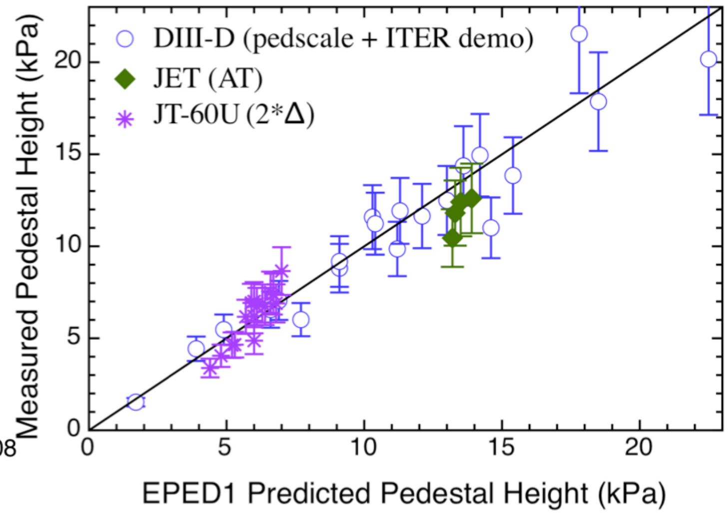




New Predictive Physics Model (EPED1) for the Pedestal Developed and Tested







- **Formation of an edge barrier or "pedestal" allows high performance operation in tokamaks [left]**
  - Predicting pedestal height key to optimization of the tokamak
- **New EPED1 model combines two constraints to predict height and width of the pedestal**
  - Peeling-ballooning stability constraint calculated with the ELITE code [solid line]
  - Simple model of kinetic ballooning mode transport constraint [dashed line]
- **EPED1 highly successful in initial tests, including predictions made before a dedicated DIII-D experiment**
  - Predicted/Measured pedestal height = 1.02 ±0.13 (21 DIII-D, 16 JT-60U, 4 JET)

DIII-D is an International Research Program

Active Collaborations 2008-2009

US Labs
- **LANL** (Los Alamos, NM)
- **LBNL** (Berkeley, CA)
- **LLNL** (Livermore, CA)
- **ORNL** (Oak Ridge, TN)
- **PPPL** (Princeton, NJ)
- **SNL** (Sandia, NM)

Industries
- **ALITRON** (CA)
- **AWE Comm** (Germany)
- **Calabasas Creek** (CA)
- **CompX** (Del Mar, CA)
- **CPI** (Palo Alto, CA)
- **Digital Finetec** (Ventura, CA)
- **DRS** (Dallas, TX)
- **DTI** (Bedford, MA)
- **FAR-TECH, Inc.** (San Diego, CA)
- **GA** (San Diego, CA)
- **Lodestar** (Boulder, CO)
- **NOVA Photonics** (Princeton, NJ)
- **SAIC** (La Jolla, CA)
- **Spinner** (Germany)
- **Tech-X** (Boulder, CO)
- **Thermacore** (Lancaster, PA)
- **TSI Research** (Solana Beach, CA)

US Universities
- **Auburn** (Auburn, Alabama)
- **Colorado School of Mines** (Golden, CO)
- **Columbia** (New York, NY)
- **Georgia Tech** (Atlanta, GA)
- **Hampton** (Hampton, VA)
- **Lehigh** (Bethlehem, PA)
- **Maryland** (College Park, MD)
- **Mesa College** (San Diego, CA)
- **MIT** (Cambridge, MA)
- **New York U.** (New York, NY)
- **Palomar** (San Marcos, CA)
- **Purdue U.** (W. Lafayette, IN)
- **SDSU** (San Diego, CA)
- **Texas** (Austin, TX)
- **UCB** (Berkeley, CA)
- **UC Davis** (Davis, CA)
- **UCI** (Irvine, CA)
- **UCLA** (Los Angeles, CA)
- **UCSD** (San Diego, CA)
- **U. Arizona** (Tucson, AZ)
- **U. New Mexico** (Albuquerque, NM)
- **U. Oklahoma** (Tulsa, OK)
- **U. Rochester** (NY)
- **U. Utah** (Salt Lake City, UT)
- **U. Washington** (Seattle, WA)
- **U. Wisconsin** (Madison, WI)

Europe
- **CEA** (Cadarache, France)
- **CFN-IST** (Lisbon, Portugal)
- **Chalmers U.** (Göteberg, Sweden)
- **CIEMAT** (Madrid, Spain)
- **Consorzia RFX** (Padua, Italy)
- **CRPP** (Lausanne, Switzerland)
- **EFDA** (Belgium)
- **FOM** (Utrecht, The Netherlands)
- **Frascati** (Frascati, Lazio, Italy)
- **FZ-Jülich** (Germany)
- **Helsinki U.** (Helsinki, Finland)
- **IFP-CNdR** (Italy)
- **IPP** (Greifswald, Germany)
- **IST** (Lisbon, Portugal)
- **ITER** (Cadarache, France)
- **JET-EFDA** (Culham, United Kingdom)
- **Kharkov IPT** (Ukraine)
- **Max Planck** (Garching, Germany)
- **U. Dusseldorf** (Germany)
- **UKAEA** (Culham, United Kingdom)
- **U. Naples** (Italy)
- **U. Rome** (Italy)
- **U. Strathclyde** (Glasgow, Scotland)

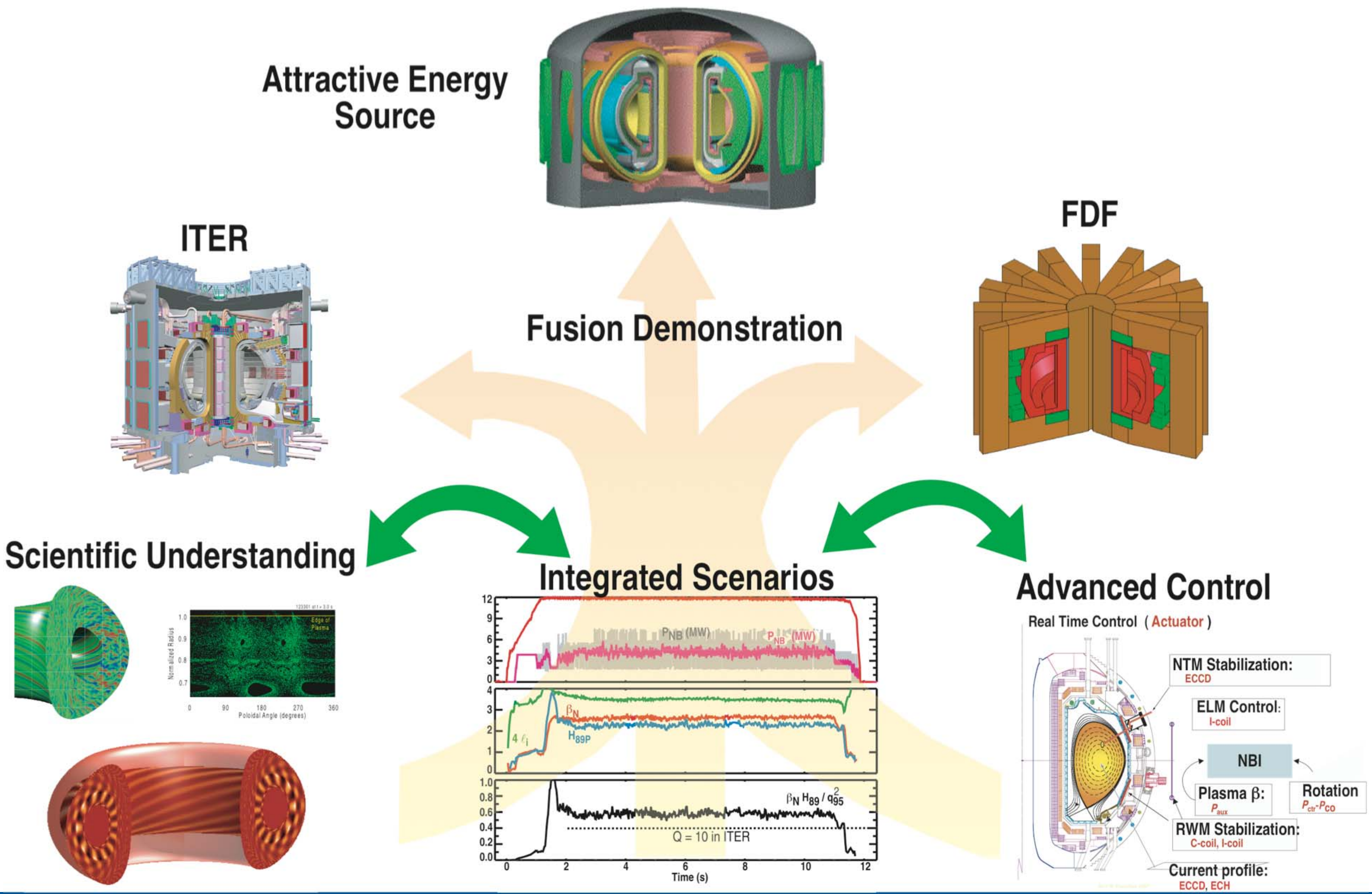
Japan
- **JAEA** (Naka, Ibaraki-ken, Japan)
- **NIFS** (Toki, Gifu-ken, Japan)
- **Tsukuba U.** (Tsukuba, Japan)

Russia
- **Ioffe** (St. Petersburg)
- **Keldysh** (Udmurtia, Moscow)
- **Kurchatov** (Moscow)
- **Moscow State** (Moscow)
- **St. Petersburg State Poly** (St. Petersburg)
- **TRINITI** (Troitsk)
- **Inst. of Applied Physics** (Nizhny Novgorod)

Other International
- **Australia National U.** (Canberra, AU)
- **ASIPP** (Hefei, China)
- **IPR** (Gandhinager, India)
- **NFRI** (Daejeon, S. Korea)
- **Nat. Nucl. Ctr** (Kurchatov City, Kazakhstan)
- **Pohang U.** (S. Korea)
- **Seoul Nat. U.** (S. Korea)
- **SWIP** (Chengdu, China)
- **U. Toronto** (Toronto, Canada)

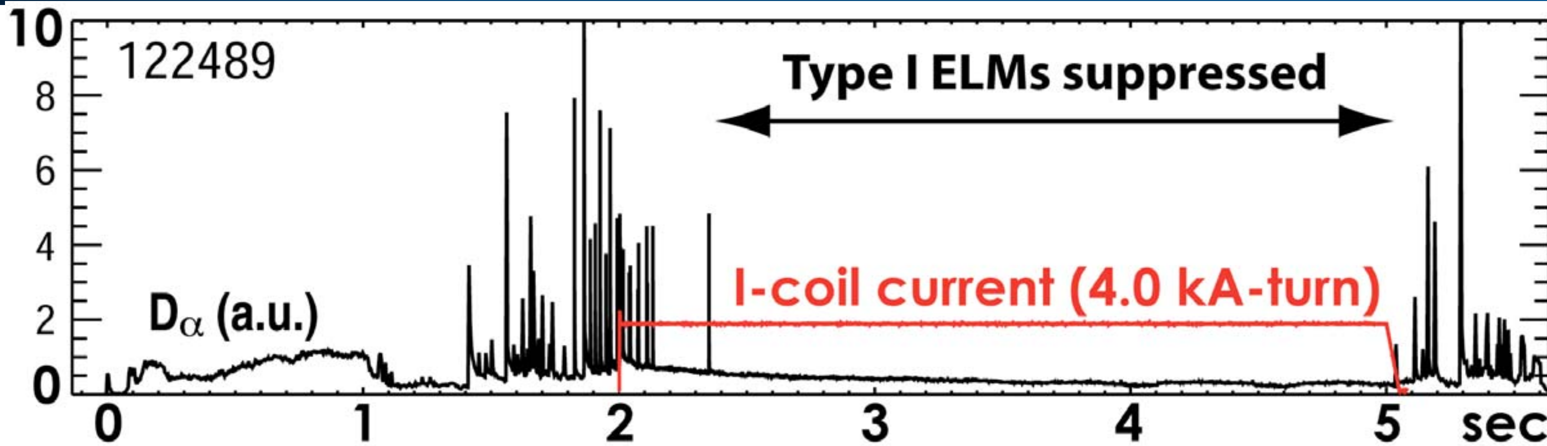
- **100 institutions worldwide**
- **430 scientific authors (2008 IAEA)**
  - GA: 120
  - Collab: 310
- **Students, post docs, and faculty from 53 universities**
  - 18 PhD students
  - 18 Post Docs

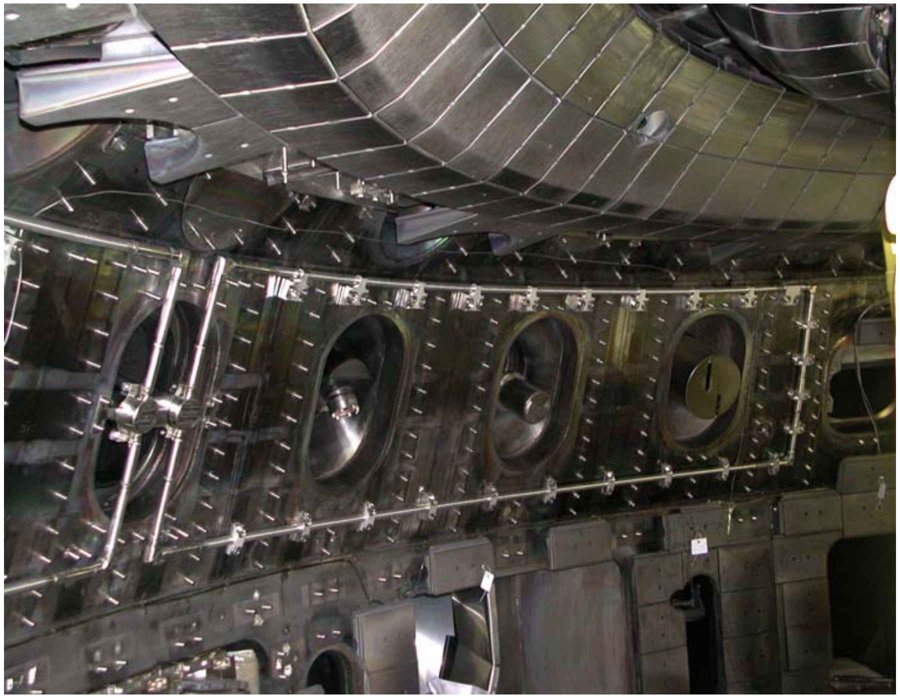
DIII-D Mission: Establish the Scientific Basis for the Optimization of The Tokamak Approach to Fusion Energy Production

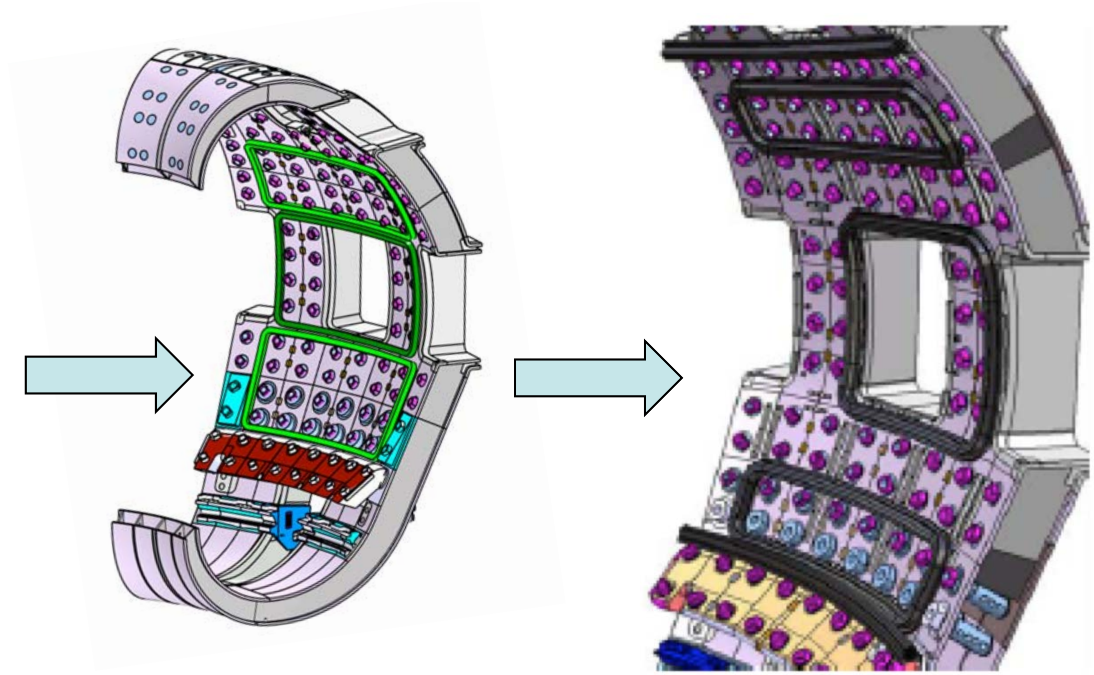


GENERAL ATOMICS

ELM-Suppression Using the DIII-D Internal Coils Has Led to the Design of Internal Coils for ITER

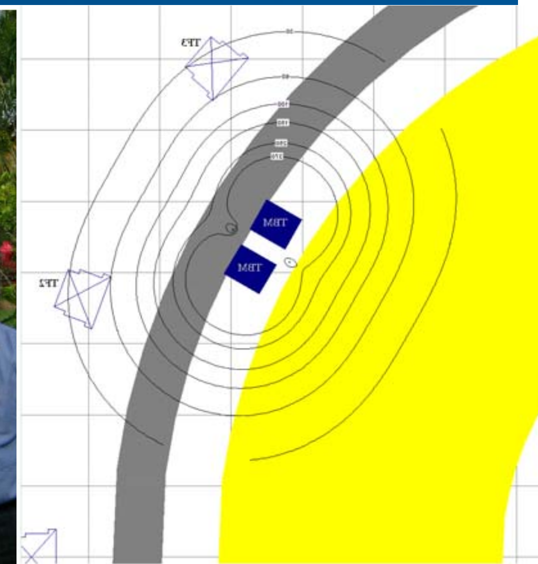


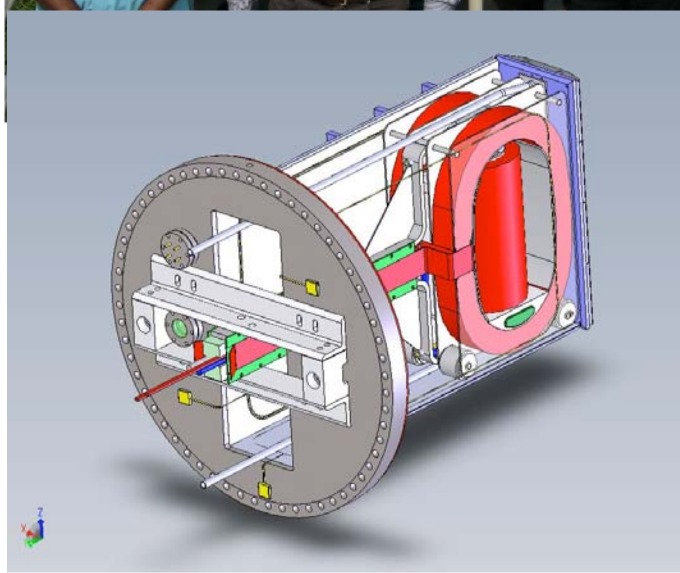




An International Team Recently Carried Out Experiments on DIII-D Simulating ITER-TBM Error Fields

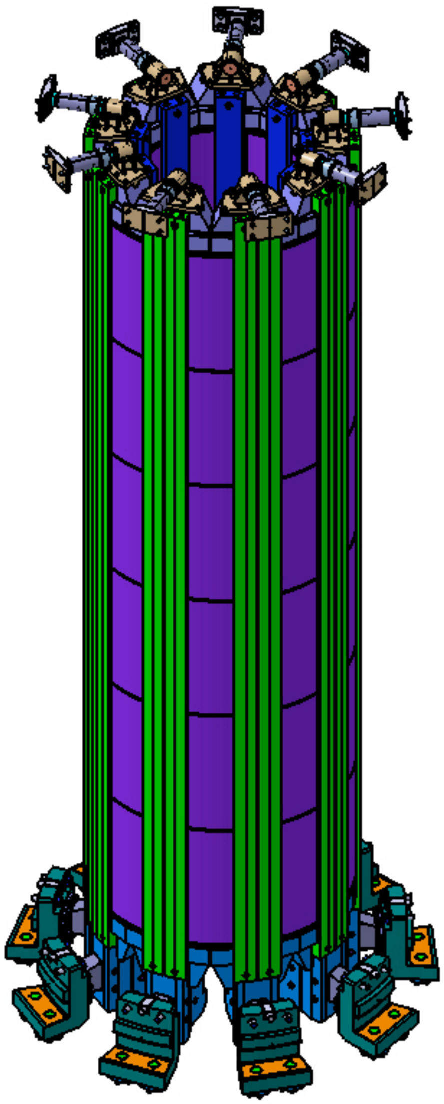
Michael Schaffer	USA
Joseph Snipes	IO
Charles Greenfield	USA
Valery Chuyanov	IO
Alberto Loarte	IO
Naouki Oyama	Japan
Kouji Shinohara	Japan
Hogun Jhang	S Korea
Kwang-Il You	S Korea
Xiang Gao	China
Songlin Liu	China
Yanjing Chen	China
Guoyao Zheng	China
Gabriella Saibene	Europe
Peter de Vries	Europe
Tuomas Tala	Europe
Filomena Nave	Europe
Anti Salmi	Europe
Oliver Schmitz	Europe
Marcin Jakubowski	Europe
Ruth Laengner	Europe
Henning Stoschus	Europe
R. Srinivasan	India
R. Narayanan	India
Punit Gohil	USA
Don Spong	USA
David Gates	USA
Jong-Kyu Park	USA
Gerrit Kramer	USA





GA Seeks to Apply its Experience with the ITER CS Model Coil to the ITER Central Solenoid

CS Model Coil
Inner Solenoid

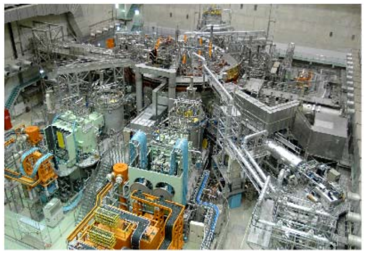


CS

GA is the World Leader in ECH Transmission Lines and Components in the 100 GHz Range

JAPAN:

JT-60U: 4 lines

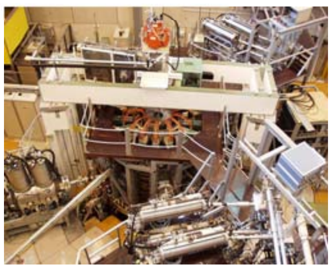


LHD: 2 + lines

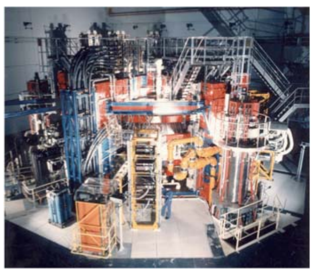
Gamma-10: 1

TRIAM-1M: 1

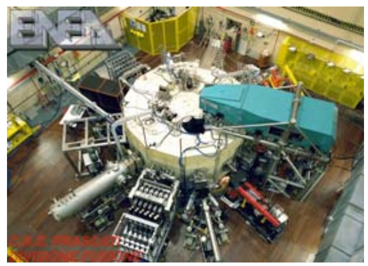
EUROPE:



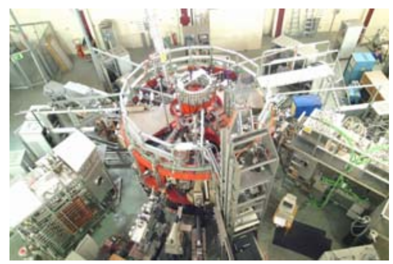
TCV: 9



Tore Supra: 6

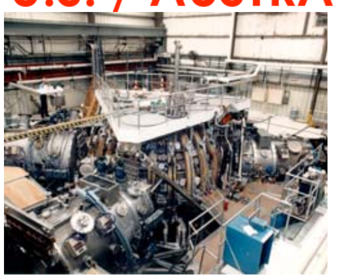


FTU: 4



TJ-II: 1

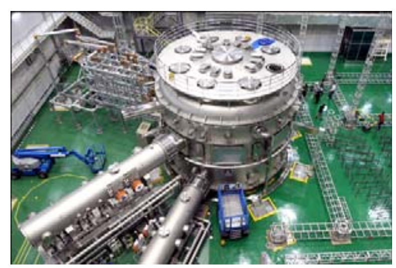
U.S. / AUSTRALIA / KOREA:



DIII-D: 6

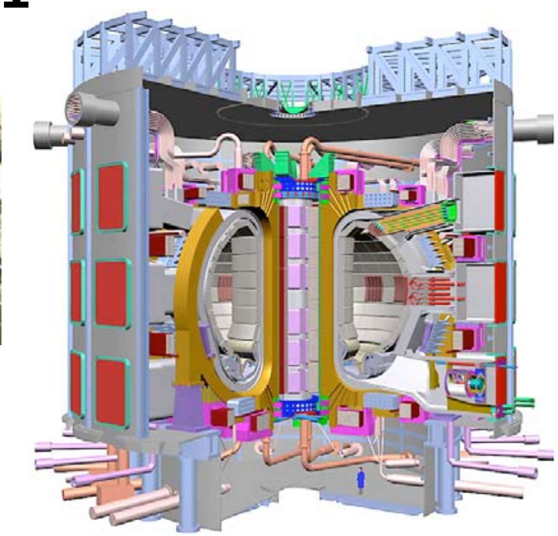
Haystack: 4

H-1NF: 1



KSTAR: 1

GA has delivered 42 lines / 3 km total

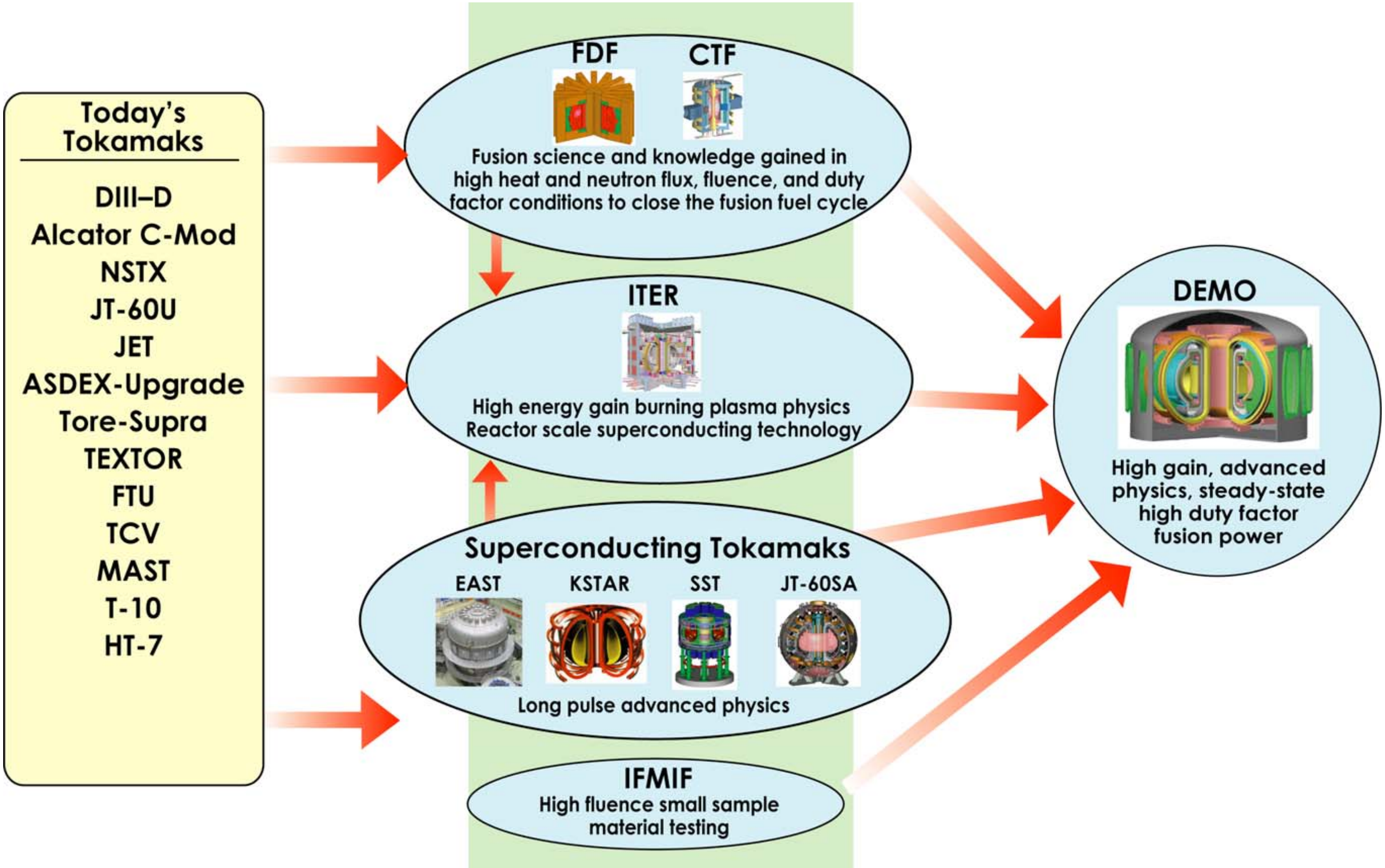


ITER: 56 lines 4 km total

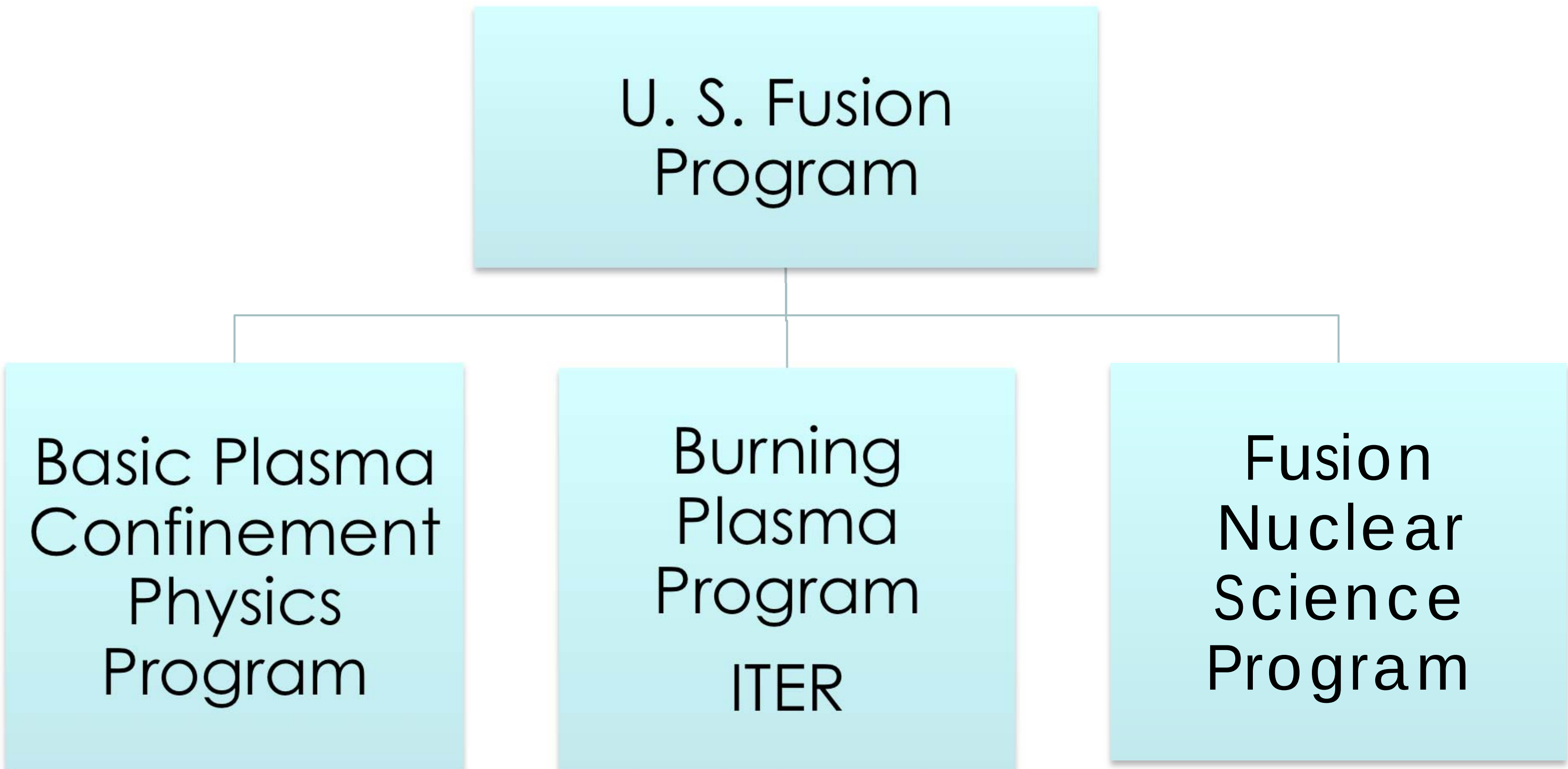
The Fusion Development Facility Mission: Show Fusion Can Produce Energy and its own Fuel

- **FDF will:**
  - Produce significant **fusion power** (100-300 MW)
  - Demonstrate **fusion fuel self-sufficiency**
  - Show fusion can produce high grade **process heat and electricity**
  - Provide a materials irradiation facility to develop low activation, high strength, high temperature, radiation resistant **materials**.
  - Enable research on **high performance, steady-state, burning** plasmas for Demo.
  - Obtain first data on fusion system operation, fuel management, reliability, availability, and maintainability to guide future fusion energy development.
- **By operating** steady-state **with**
  - Modest energy gain ($Q<7$)
  - Continuous operation for 30% of a year in 2 weeks periods
  - High neutron fluence (3-6 MW-yr/m^2)

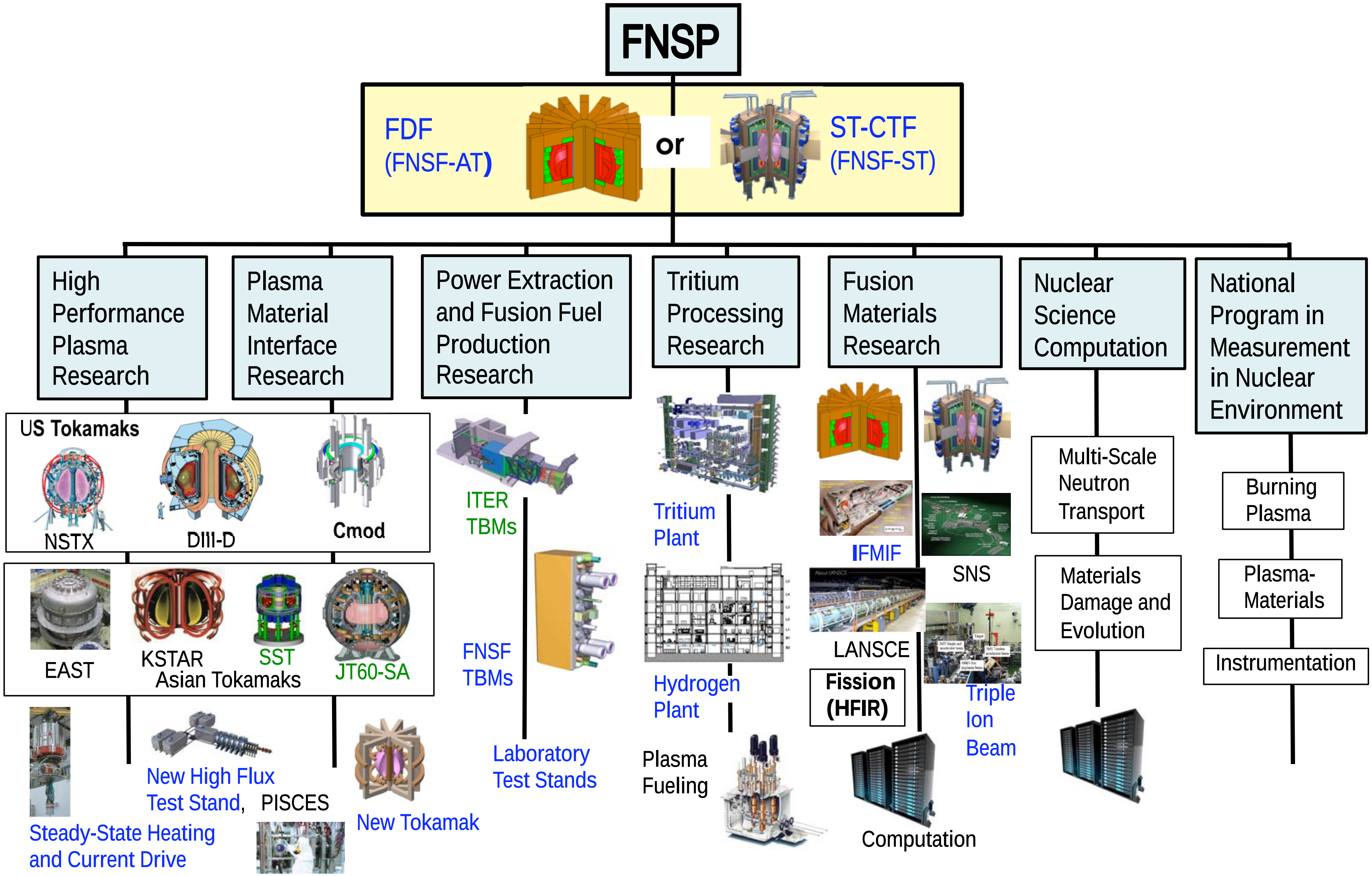
A Fusion Nuclear Science Facility, ITER, Superconducting Tokamaks, and a Materials Test Facility Enable DEMO



Fusion Nuclear Science Needs to Become as Strong as the Other Two Existing Legs of the US Fusion Program

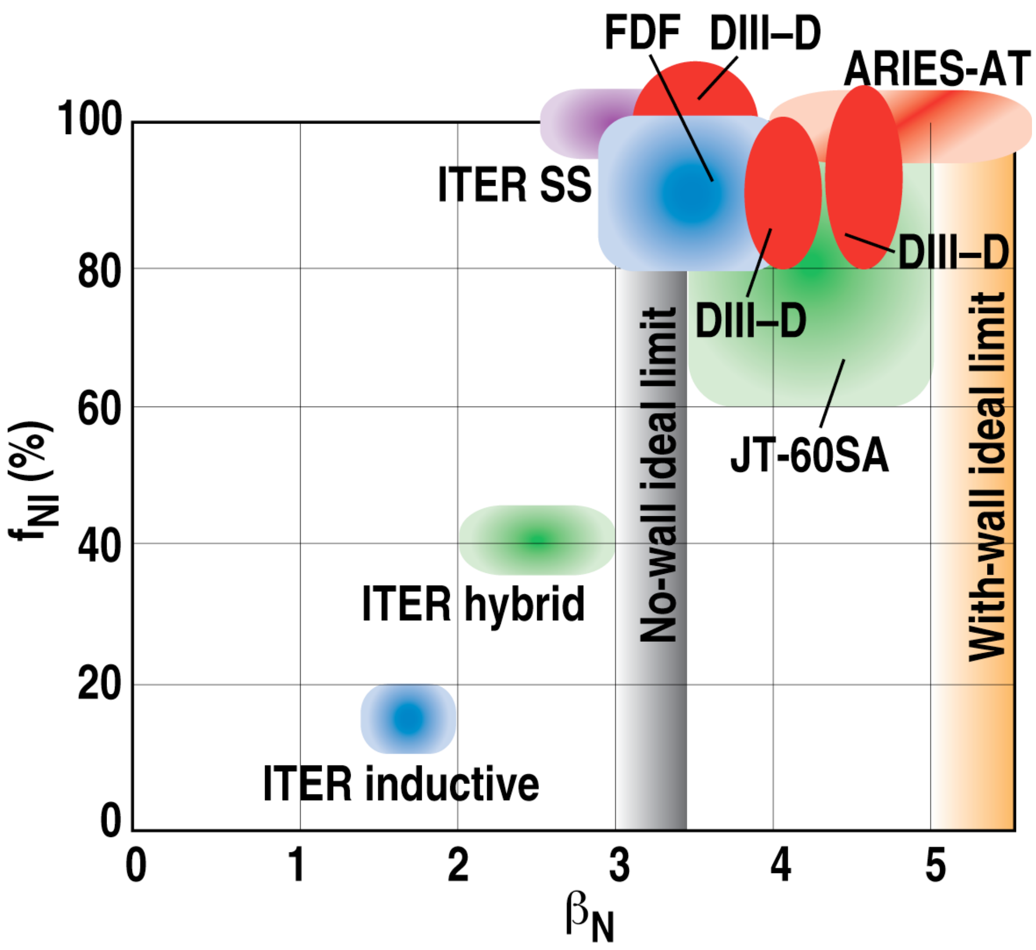


Fusion Nuclear Science Program (FNSP): The Scientific Basis for Fusion Energy Applications



DIII-D and Other Tokamaks Can Solidify the Physics Basis for the FNSF in 2–3 Years

- Required stability values already achieved in 100% non-inductive plasmas in DIII-D (extend pulse length)
- RWM stabilization by rotation
- NTMs already stabilized
- ELMs gone - stochastic edge field
- ELMs gone - QH mode operation
- Confinement quality required already obtained in long pulse DIII-D plasmas
- Bootstrap fractions already achieved
- Far off-axis LHCD in H-mode
- Pumped, high triangularity plasma
- DIII-D plasma control system
- Power exhaust more challenging than DIII-D and comparable to ITER
- Main challenge is PFC tritium retention



Green = already achieved, Blue = near term, Red = main challenge

It is Time for Fusion

- **We are ready to make the transition**

  from fusion's preparatory era
  (research with hydrogen and deuterium plasmas)

  to fusion's nuclear science era
  (research with burning DT plasmas)