Neutron Testing: What are the Options for MFE?

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Rationale

- Existing materials testing facilities address property changes with irradiation (next VG):
  - **Physical**: density, microstructure, compatibility, bonding, welding, …
  - **Mechanical**: stress, strain, tensile strength, creep, fracture toughness, hardening, cracking, ductility, embrittlement, DBTT shift, …
  - **Dimensional**: swelling, elongation, …
  - **Electrical**: resistivity, conductivity, loss tangents, dielectric constant, …
  - **Thermal**: conductivity, expansion, …
  - **Damage**: dpa, transmutations (He, H, …), …

- In US, there is **only one 14 MeV materials irradiation facility** at Berkeley (several cm^3 test volume, $6x10^{12}$ n/s): http://www.nuc.berkeley.edu/fusion/neutron/rtns.html

- Fusion will continue utilizing **non-fusion facilities for material characterizations** using neutron, ion, and X-ray sources. Examples:
  - ORNL Spallation Neutron Source (SNS)
  - ORNL High Flux Isotopes Reactor (HFIR)
  - INL Advanced Test Reactor (ATR)
  - Los Alamos Neutron Science Center (LANSCE)
  - Small Angle Neutron Scattering Facility @ NIST
  - LANL Ion Beam Materials Lab
  - PNL EMSL Ion Beam Lab
  - ANL IVEM Tandem Facility
  - Advanced Photon Source (APS)
  - Electron Microscopy National User Center.

Neutron Irradiation

Ion Accelerators

Rationale (Cont.)

- Separate, single effect database can be established in labs (e.g., temperature and magnetic field effects).

- Fusion devices will not be licensed by NRC unless components are fully tested in relevant fusion environment to address multiple, synergistic effects (neutrons, charged particles, temperature, magnetic field, etc):
  - **Low-fluence** integral testing before building experimental devices (such as ITER) may not be essential. However, low-dose neutron effects on material properties should be established
  - **High-fluence** integral testing before building Demo is essential. Key Demo components (FW, blanket, and divertor) must be tested in relevant neutron environment.

- **ITER** will enable major advances for many fusion components, but it's not high fluence machine ⇒ Some of ITER's technology data are not power-plant-relevant.

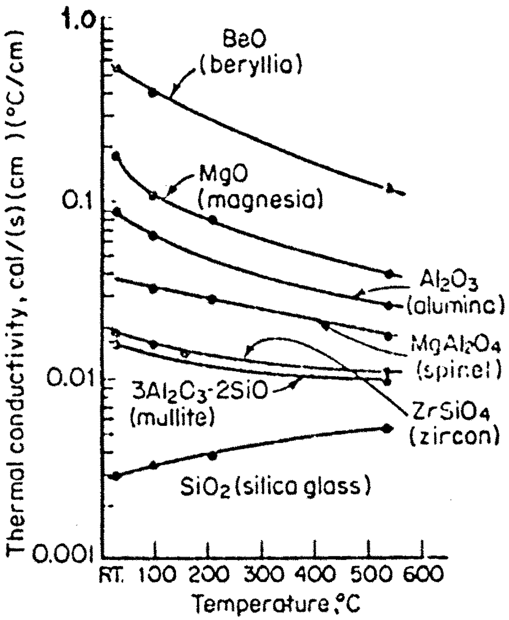
- Component certification mandates building CTF to test key components in harsh plasma and neutron environment.

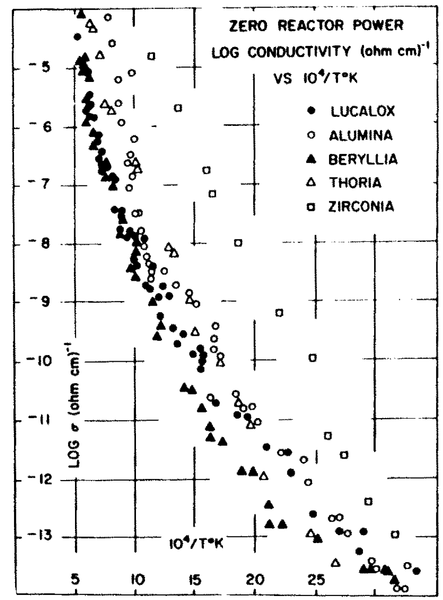
CTF is essential element of US fusion roadmap

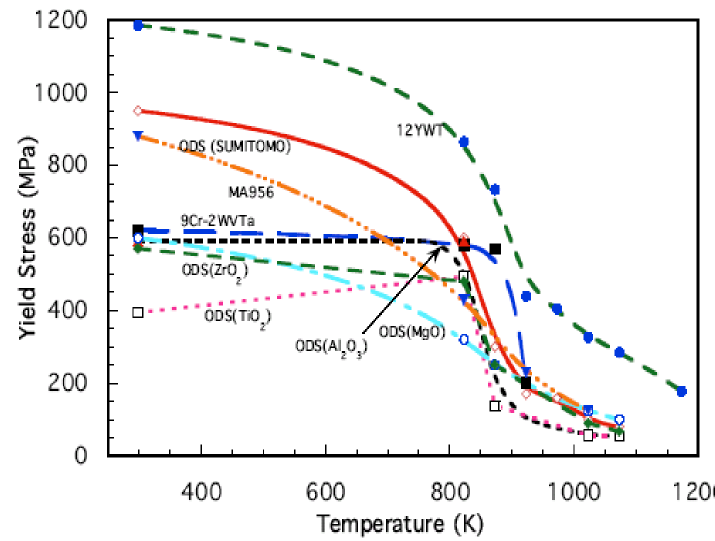
- **14 MeV integral experiments** support neutron testing mission.

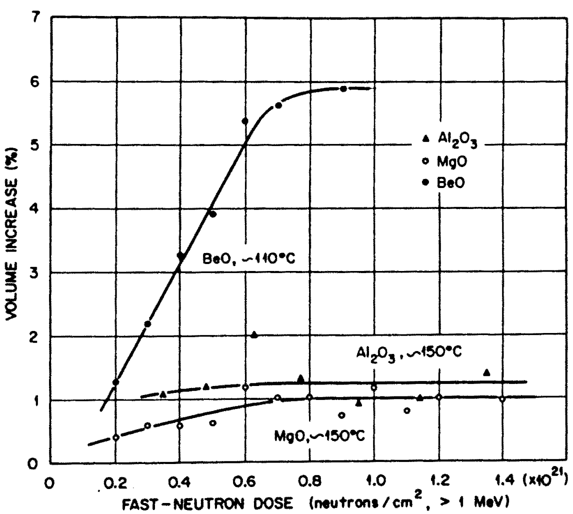
- Worldwide, several **14 MeV integral experiments** exist (in Japan, Europe, and Russia).

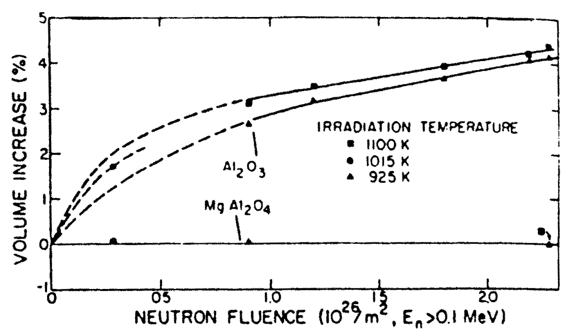
Examples: Degradation of Properties with Temperature & Neutron Irradiation

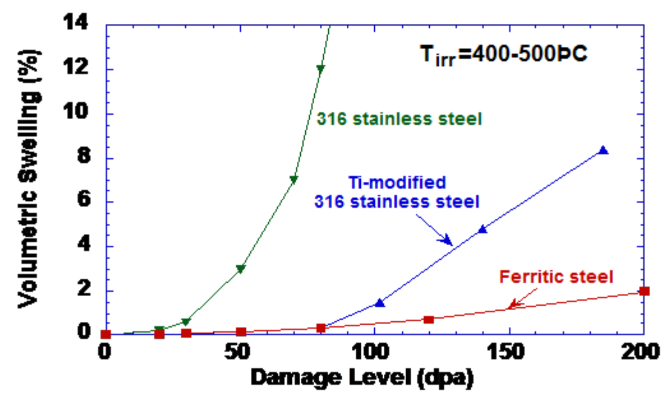












Existing Material Characterization Facilities Offer Limited Irradiation Volumes

THE UNIVERSITY of WISCONSIN MADISON

FESAC 2007 Report

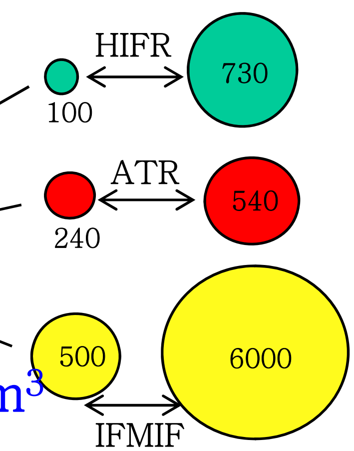
Table 3.d.8-1. Summary of the proposed IFMIF and Existing Ion and Neutron Irradiation Facility Parameters (He/dpa values are for ferritic steel; maximum 4 year irradiation assumed for the fission reactor max doses). The number of irradiation positions for ATR and HFIR are listed under the comments column.

	Facility (DOE funding agency)	Irrad. Temp. (K)	Max dose (dpa)	appm He/dpa ratio	Irrad. volume	Comments
LANL	LANL Ion Beam Materials Lab (BES)	80-1370	>100	Wide range	~1 μm depth by 3 mm diam	0.2-20 MeV ions; simultaneous dual beam; NRA, RBS, PIXE, ERDA
PNL	PNNL EMSL Ion Beam Lab (BER)	130-1300	>100	0	~1 μm depth by 3 mm diam	0.2-10 MeV ions; single beam; NRA, RBS, ERDA
ANL	ANL IVEM Tandem facility (BES)	15-1200	>100	0	~1 μm depth by 3 mm diam	In-situ TEM observation capability; single ion beam
ORNL	HFIR (BES)	330-1800	~70(T) ~20(RB)	0.2	50x1.6cm diam 50x4.3cm diam	T: target region(37); RB: RB position(8)
INL	ATR (NE)	370-1300	30 30	0.2	120x1.6cm diam 120x7.6cm diam	A, H positions(30); EFT position(1)
	IFMIF	520-1300	200 80	10	500 cm^3 (H) 6 liter (M)	H: high flux module; M: medium flux mod.

Operating budget for ORNL facilities exceeds $50M/y

Irradiation Volumes (cm^3)

LANL, PNL, ANL: 10^{-5}



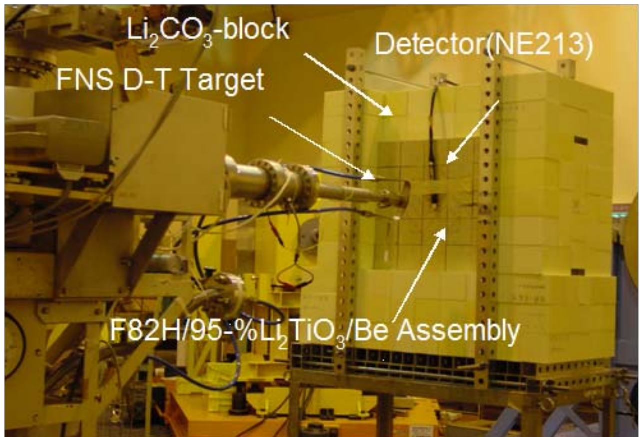
Could IFMIF test thin blanket modules?

Typical volume of blanket module exceeds $2x10^6$ cm^3

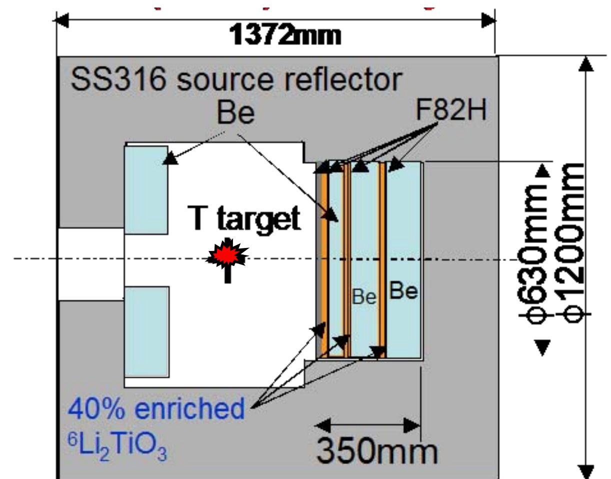
Existing 14 MeV Integral Experiments Could NOT Certify Mockups for CTF

- Reasons:
  - Single-effect experiments
  - Weak neutron source:
    - Few n's reach back of mockup
    - Long irradiation time for fluence related testing
- Examples of 14 MeV single-effect experiments for neutronics validation:
  - Cross section data validation
  - T production rate for ceramic and liquid breeders
  - Nuclear heating distribution
  - Shielding:
    - Layering of shielding blocks and cooling channels
    - W blocks
    - Streaming through ducts
- Worldwide D-T plasma-based facilities (with weak neutron source and low flux):
  - Fusion Neutron Source (FNS) @ JAEA, Japan: http://fnshp.tokai-sc.jaea.go.jp/english/index_e.html
  - Frascati Neutron Generator (FNG) @ ENEA, Italy: http://www.fusione.enea.it/LABS/FNG/detail_en.html
  - TUD neutron generator at Dresden Technical University in Germany: http://www.fzd.de/db/Cms?pNid=321
  - ??? in Russia.
- These experiments are not designed to study multiple effects (e.g., neutrons, heating, and magnetic field).
- Strong neutron source is desirable to shorten time required to conduct experiments.

FNS @ JAEA, Japan
(D-T Source)



Single Breeder Layer Assembly (50 x 50 x 30 cm)
-F82H/Li_2TiO_3(^6Li:95%)/Be assembly
surrounded by Li_2CO_3 and B_4C blocks



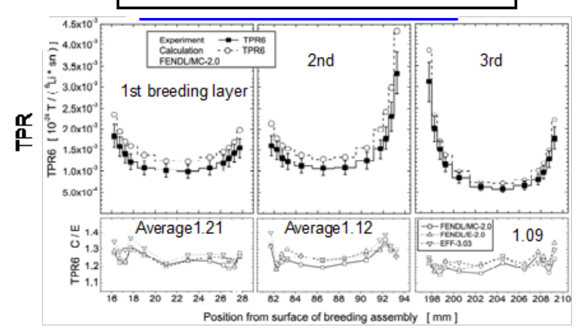
Three Breeder Layer Assembly

0.35 x 0.63 m
Mockup

Weak Neutron Source →

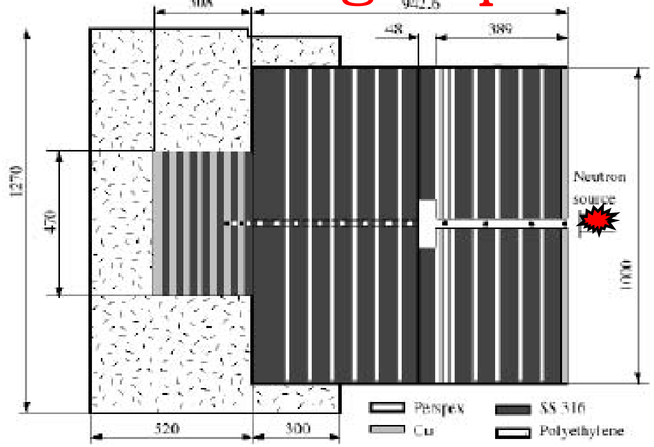
D-T neutron conditions
Neutron : 1.5 x 10^{11} n/sec/mA
Irradiated time: 10 ~ 20 h

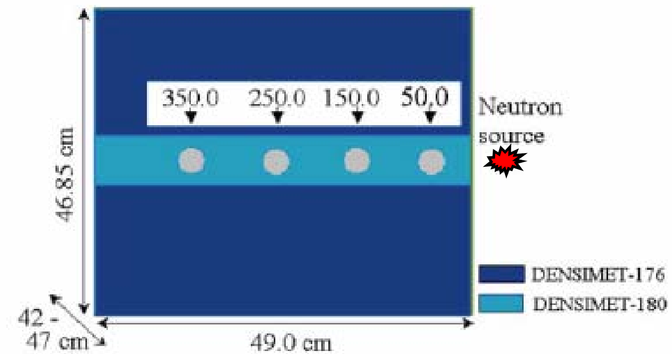
0.5 x 0.5 x 0.3 m
Mockup



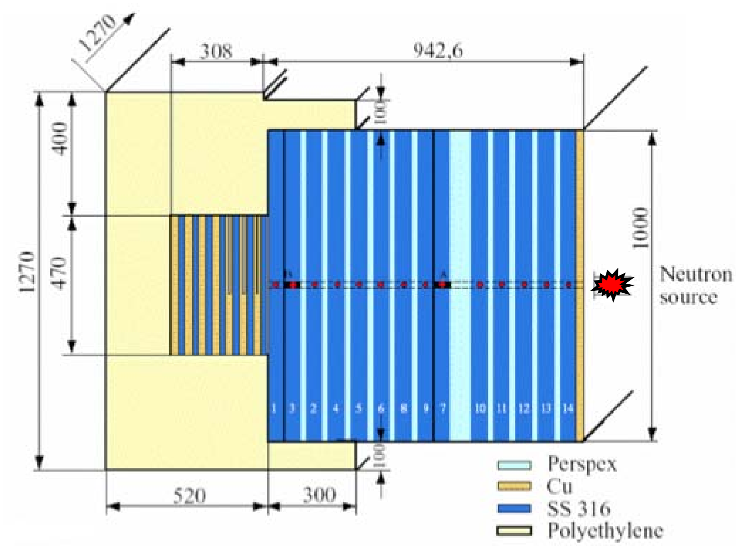
FNG @ ENEA, Italy
(D-T Source)

Streaming Experiment





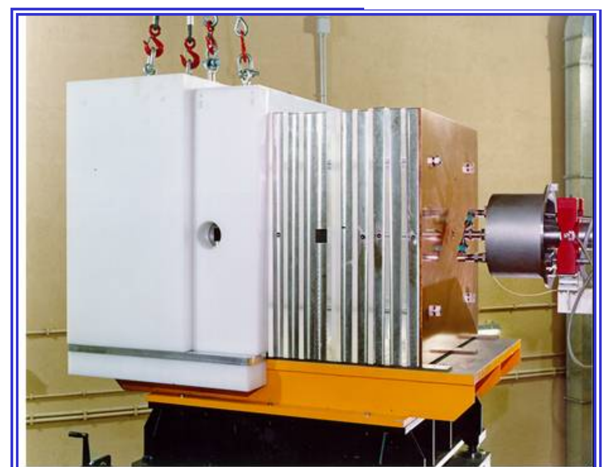
Tungsten Experiment



Bulk Shielding Experiment

1 x 1 m Mockup

Facility



Weak Neutron

Integral Testing in CTF is Essential to Qualify Components for Demo

- Multiple, synergistic effects can only be tested in fusion devices like CTF. Neutronics-related examples include:
  - Surface and volumetric heating
  - Volumetric heating gradient that influences MHD effect
  - Realistic n/γ heating ratio
  - He/dpa ratio.

- CTF key features:
  - Fusion relevant environment
  - Fluence machine, unlike ITER
  - Large blanket testing volumes (> 0.5 m^3)
  - Could test various blanket concepts simultaneously or consecutively
  - Could operate in phases with different NWLs > 1 MW/m^2
  - Low tech "bulk blanket with Be" to breed most of T (TBR > 0.8). Does CTF need to breed **all** T needed for plasma operation? **5.56 kg/ 100 MWy P_f**
  - Designing CTF, nuclear activity plays important role as it drives

Integral Testing in CTF is Essential to Qualify Components for Demo (Cont.)

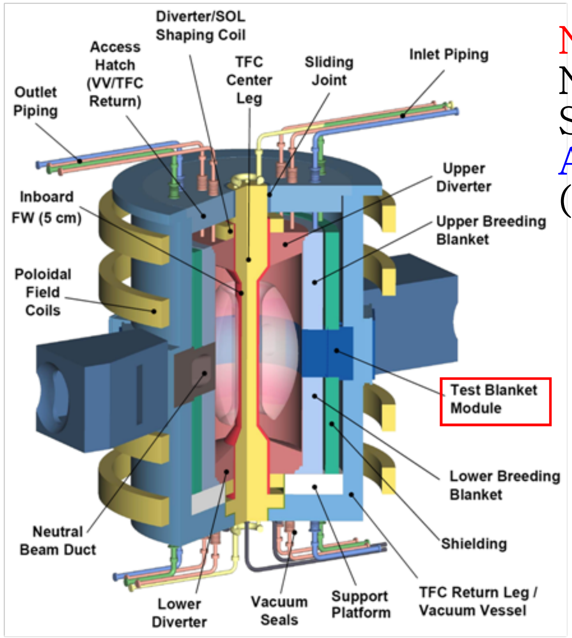
- Besides blanket testing, CTF could test and provide info on:
  - Divertor
  - Tritium processing system
  - Power management
  - System integration
  - Remote maintenance.

- Few recent **CTF designs** have been developed in US and UK based on ST and tokamak concepts. Common feature is **Cu TF magnets** (non-cryogenic).

- **STs can operate with P_f < 150 MW**, consuming less T than tokamaks. Weak ST features include:
  - High recirculating power
  - High heat flux at divertor
  - Accessibility.

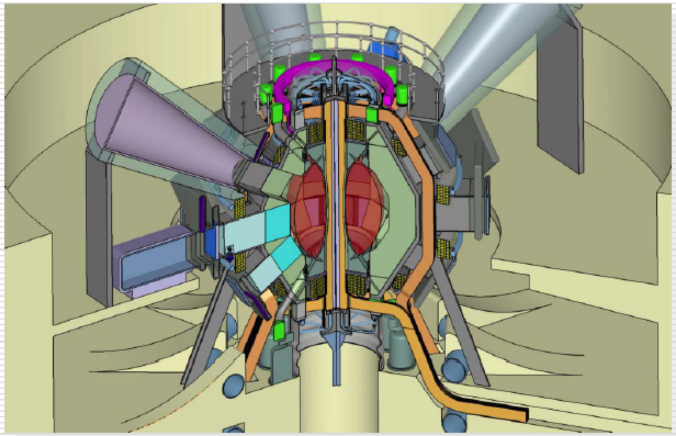
- **Not designed yet**: Tokamak CTF with S/C magnets. Any interest?

Integral Testing in CTF is Essential to Qualify Blankets for Demo (Cont.)

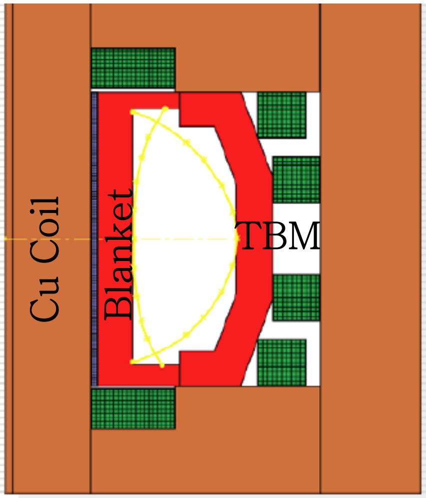


NCT
Nuclear Component Testing Facility
ST with Cu magnet
A=1.5, R=1.14 m, P_f=135 MW
(M. Peng, ORNL)

CTF
ST with Cu magnet
A=1.6, R=0.85 m, P_f=35 MW
(Culham, EU)



FDF
Fusion Development Facility
Tokamak with Cu magnet
A=3.5, R=2.5 m, P_f=300−400 M
(R. Stambaugh, GA)



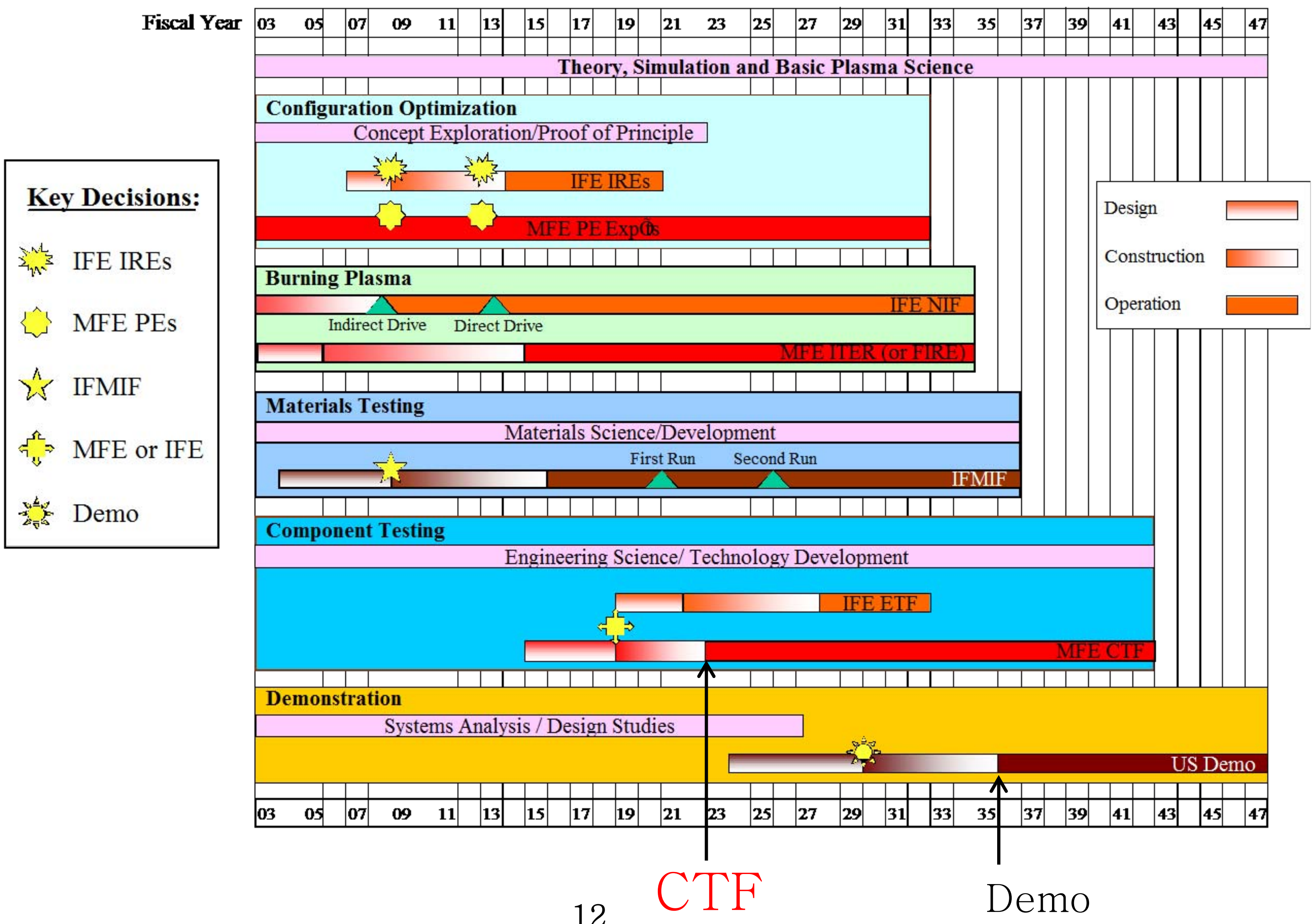
5.56 kg/ 100 MWy P_f

CTF is Essential Element of Proposed US Roadmap

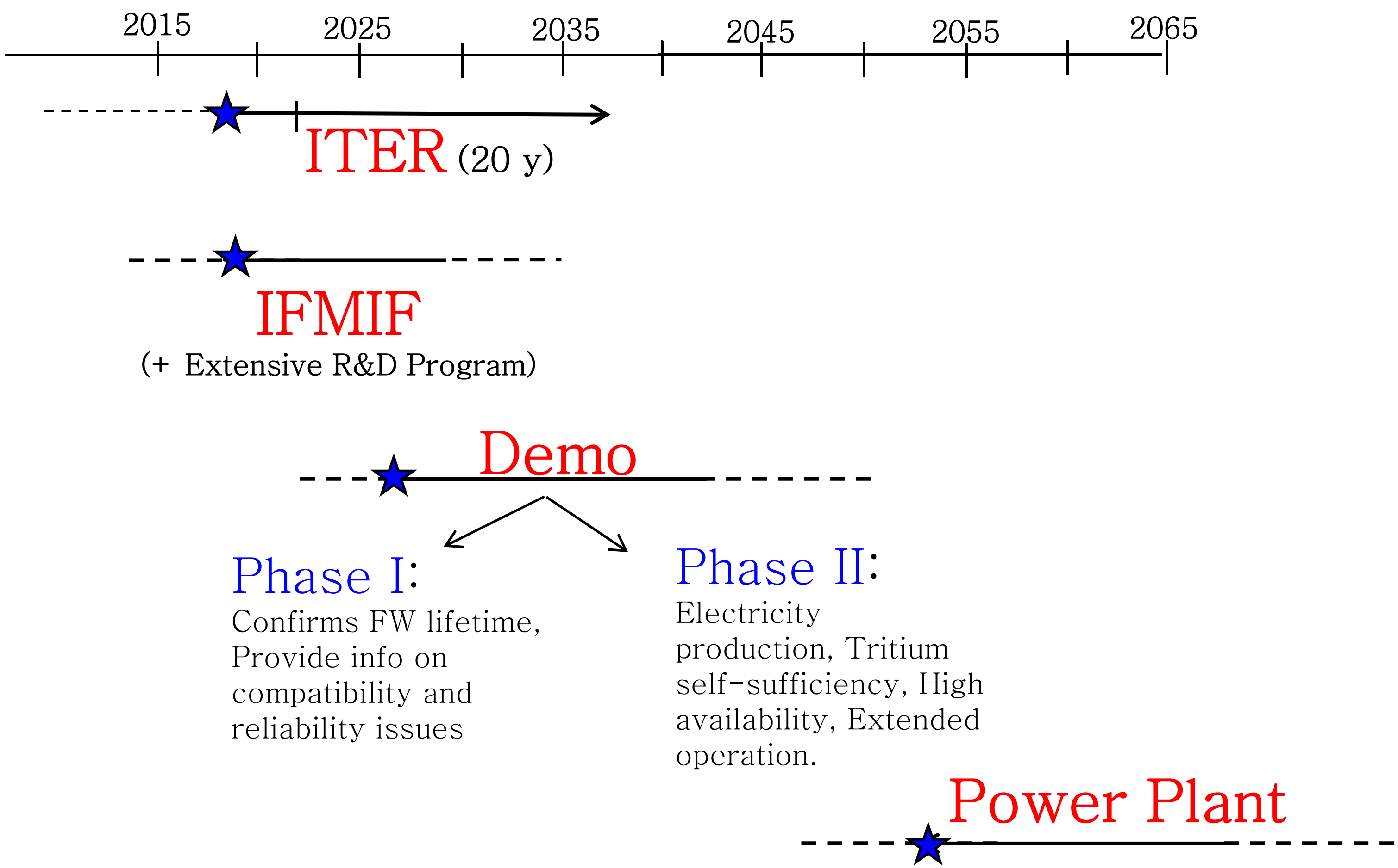
FESAC 35 Year Fusion Development Plan for MFE and IFE

http://fire.pppl.gov/fesac_dev_path_wksp.htm

(not officially endorsed by DOE)



EU Roadmap
(Fast Track; No CTF)



★ Operation

US Options for Neutron Testing

Option I:

- **Build** all facilities in US (construction in series or overlap): :
  Integral Experiment → CTF → Demo → Power Plant
  (Integral Experiment: with relatively inexpensive, 14 MeV intense neutron source)

Option II:

- **Survey** worldwide integral facilities to identify needed experiments (with 14 MeV n source) before building CTF
- **Collaborate** with e.g., J, EU, etc to:
  - Conduct experiments at existing facilities (e.g., FNS in Japan and FNG in Italy) with stronger, multiple neutron sources
  - Modify existing experiments to address multiple effects, if feasible.
- **Build** remaining facilities in US:
  CTF → Demo → Power Plant