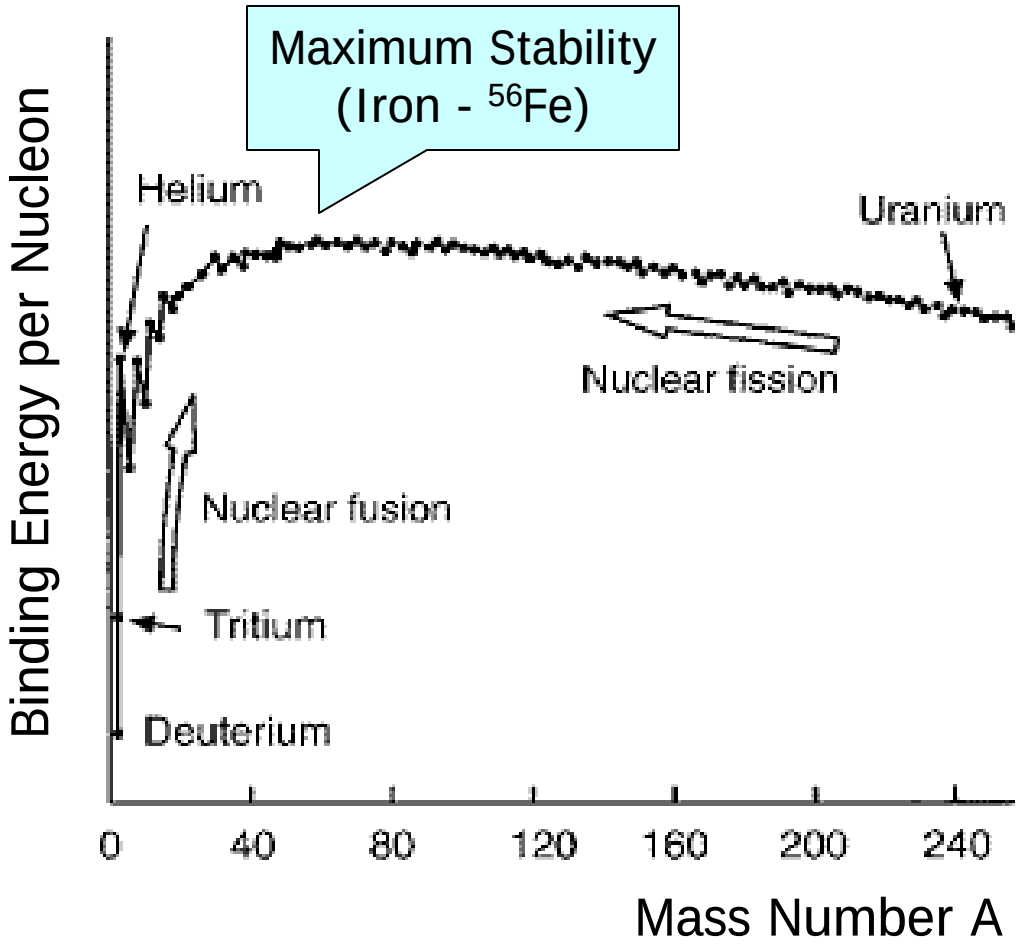
Nuclear Division
Hong Kong Institution of Engineers

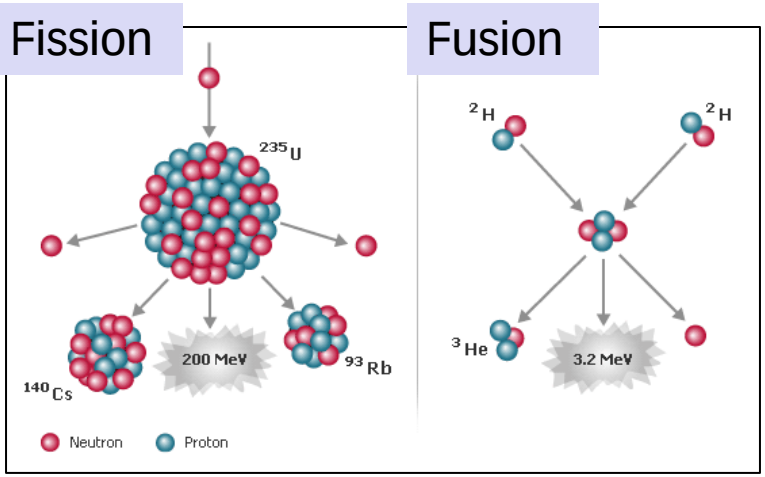
Technical Seminar

Filling the Gap of Nuclear Energy: Fission-Fusion Hybrid

Ir Dr. Herman Tsui

Two Forms of Nuclear Energy





http://encarta.msn.com

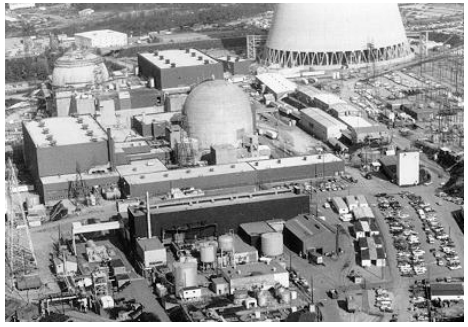
- Fission of 1 kg ^{235}U
  $\Rightarrow$ ~23x10^{6} kWh
- D-T fusion to 1 kg helium
  $\Rightarrow$ ~120x10^{6} kWh
- Combustion of 1 kg coal
  $\Rightarrow$ ~10 kWh

http://www.euronuclear.org/info/encyclopedia/n/nuclearenergy.htm

Evolution of Fission Power Systems

Generation I

Early Prototype Reactors



- Shippingport
- Dresden,Fermi-I
- Magnox

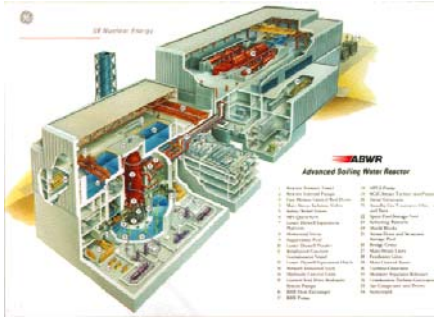
Generation II

Commercial Power Reactors

- LWR: PWR/BWR
- CANDU
- VVER/RBMK

Generation III

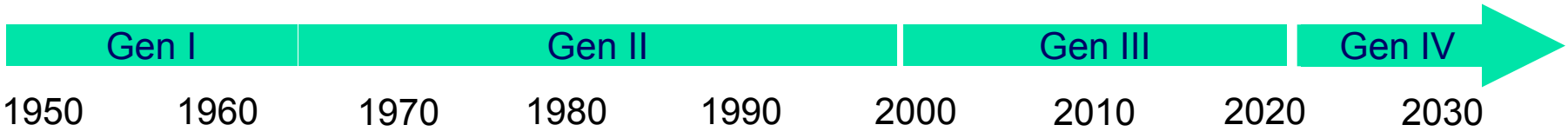
Advanced LWRs



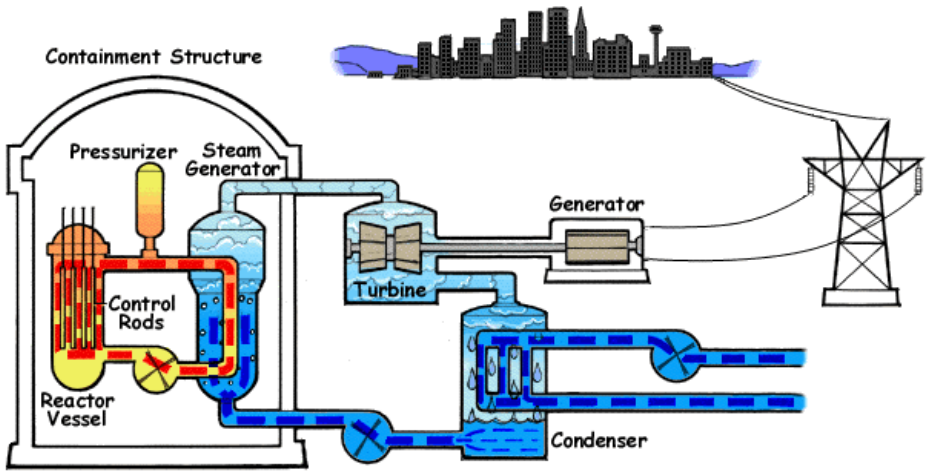
- System 80+
- EPR
- AP1000
- ABWR

Generation IV

- **Enhanced Safety**
- **Improved Economics**
- **Minimized Wastes**
- **Proliferation Resistance**



Fission Power

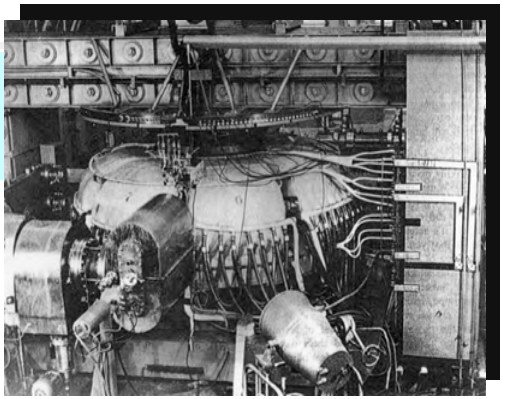


Mature technology but still faces three challenges:

- **Safety**: Possibility of reactor core meltdowns following emergency shutdowns
  (mitigated by Gen.III and Gen.IV reactors)
- **Sustainability**: Necessity to breed more radioactive fuel
  (mitigated by Gen.IV reactors)
- **Waste Management**: Accumulation of long lived nuclear waste requiring storage for as long as 100,000 years
  (mitigated by Gen.IV reactors)

Progress of Fusion Development

T3 Tokamak achieved the first high temperature (10^7 ^oC) plasma in 1968



1932 - 1958

- Fusion discovered
- Lawson criteria **($n\tau_E \sim 10^{21}$ s/m^3)**
  - ➔ Confinement or compression essential

1958

- **Fusion declassified**
- international collaboration & Many labs created

1968 - 1990

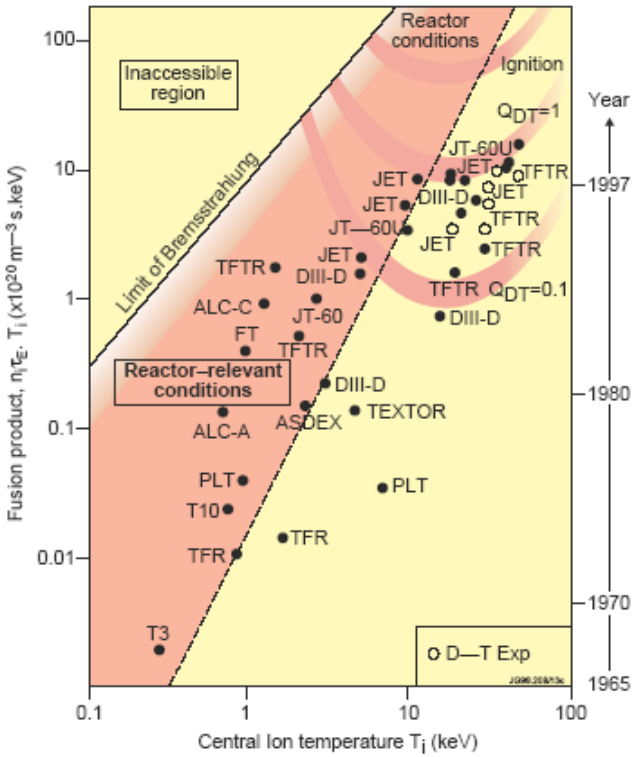
- **Tokamak breakthrough**; global stability

1990 – 2000+

- Scaling laws
- **Fusion for real**
  - ➔ >10MW; 5x10^{18} neutrons; duration >>minutes

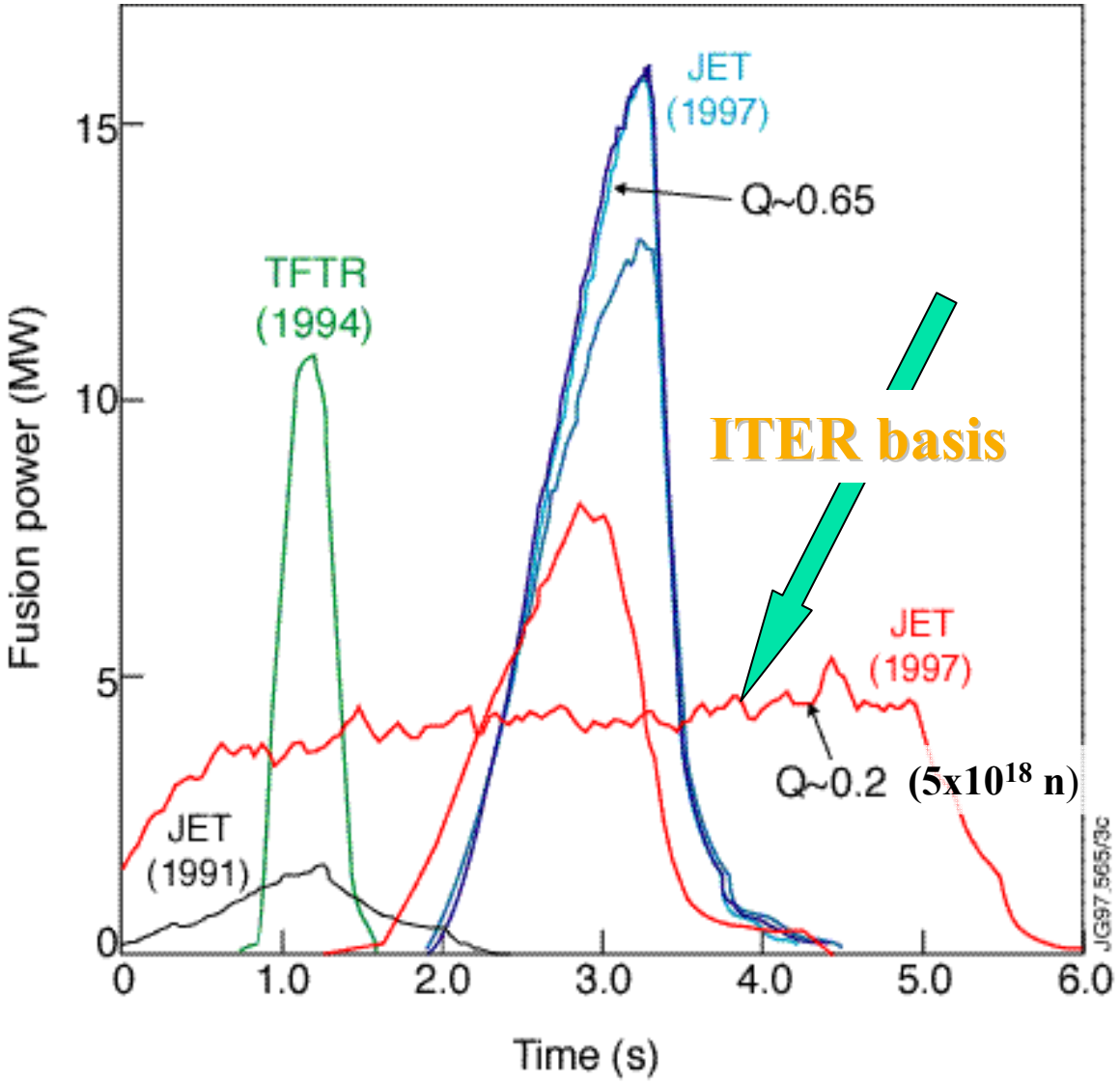
2000 to present

- Start of a new era ➔ **ITER, DEMO …**

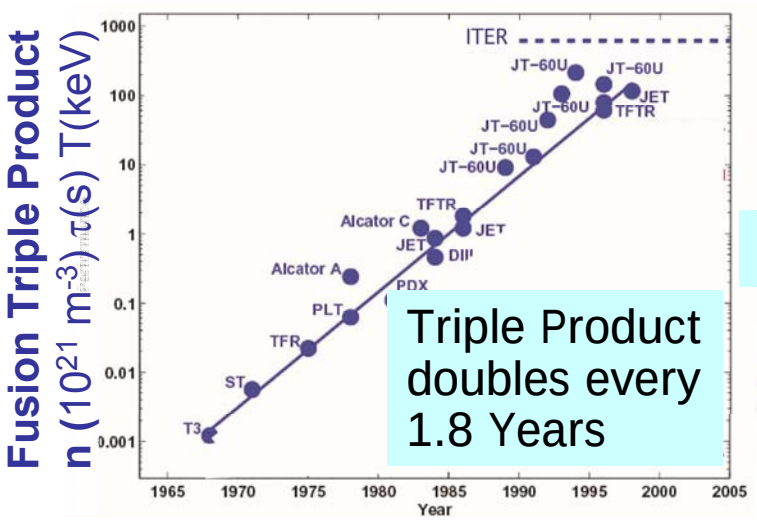


Modified from J Jacquinot, Geneva FEC 2008

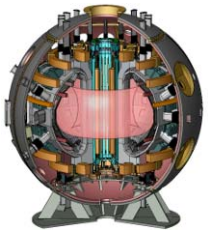
Fusion for Real:
TFTR & JET



Fusion Power Development



Triple Product doubles every 1.8 Years



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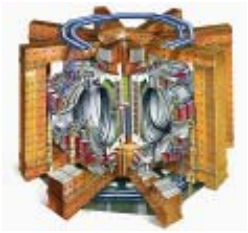
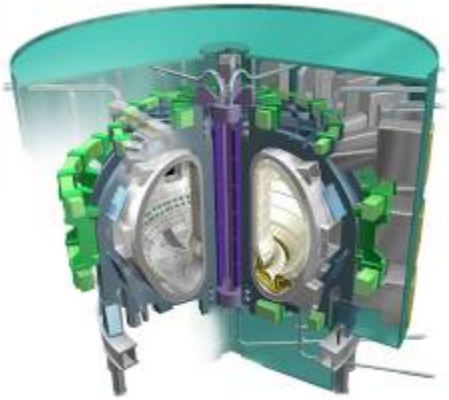


JT60-SA
Supra conductors
SS operation

JET ~ 80 m³
D/T ~16 MW$_{th}$

\+ **many other facilities**

ITER: 2019 - 2040

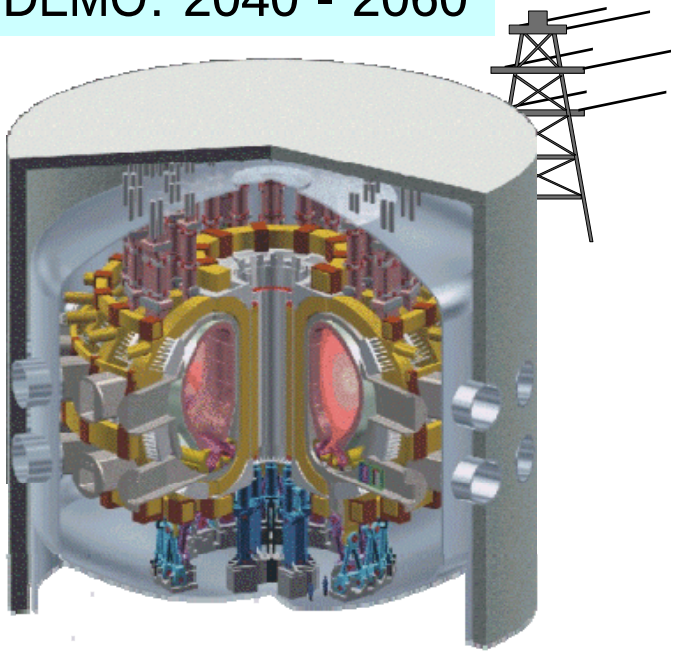


800 m³

~ 500 MW$_{th}$

Q = P$_{fusion}$/P$_{heat}$ = 10

DEMO: 2040 - 2060



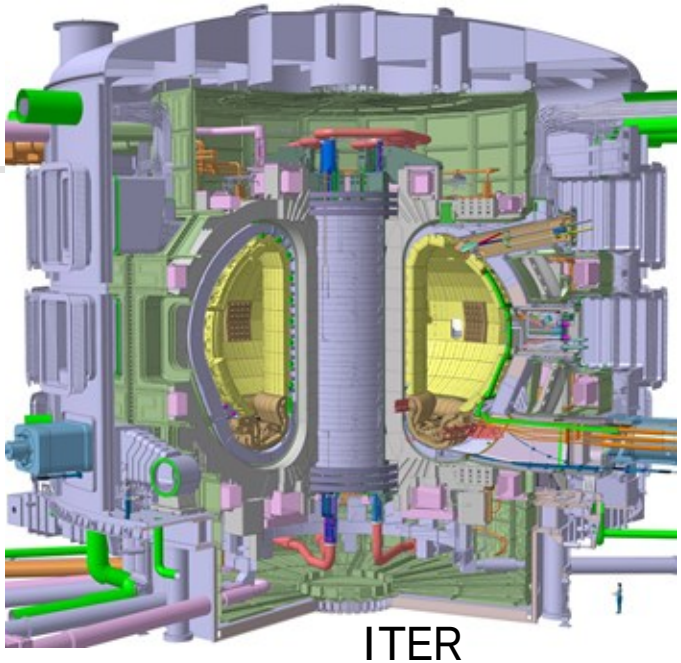
~ 1000 - 3500 m³

~ 2000 - 4000 MW$_{th}$

Q ~ 30

Modified from J Jacquinot, Geneva FEC 2008

Fusion Power Advantages


ITER

- Practically inexhaustible fuel resource (D or Li).
- Wastes much easier managed, much less problematic than actinides and long-lived fission products.
- Inherently safe - with no criticality risks. Contains minimal (100-1000g) fuel or radioactive inventory at any instant. Negligible after heat.
- No major proliferation concern - fusion has no fissile fuel cycle and no involvement with any actinides, hence inspections are technically easy. Breakout threat minimized by zero inventory.

Nuclear Power Development
A Possible Roadmap

- **Near term** - deploying improved LWRs, developing advanced fast burner reactors to fission the long half-life transuranics (TRU) in the spent nuclear fuel discharged from LWRs, and further development of improved thermal reactors
- **Intermediate term** - developing and deploying breeder reactors that can better utilize the uranium fuel resource and developing fusion physics and technology
- **Longer term** - developing and deploying fusion power reactors.

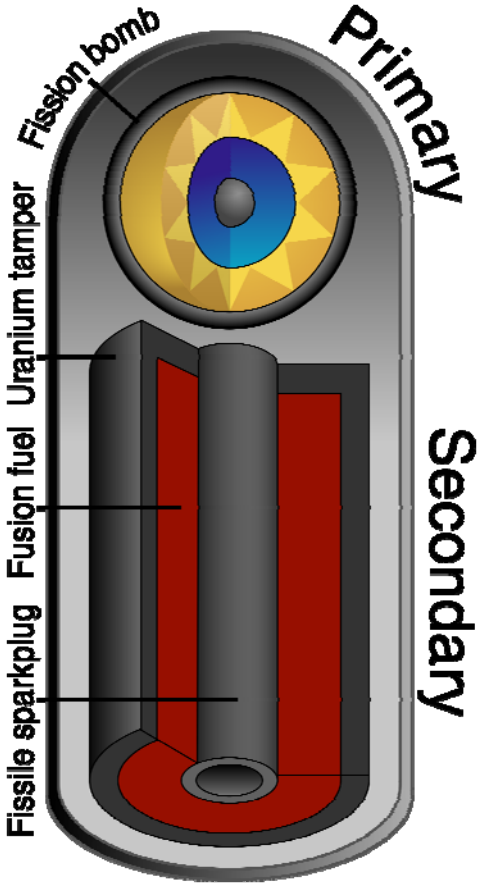
Fission-Fusion Hybrid
Advantages

Fission is energy rich and neutron poor...
Fusion is energy poor and neutron rich.

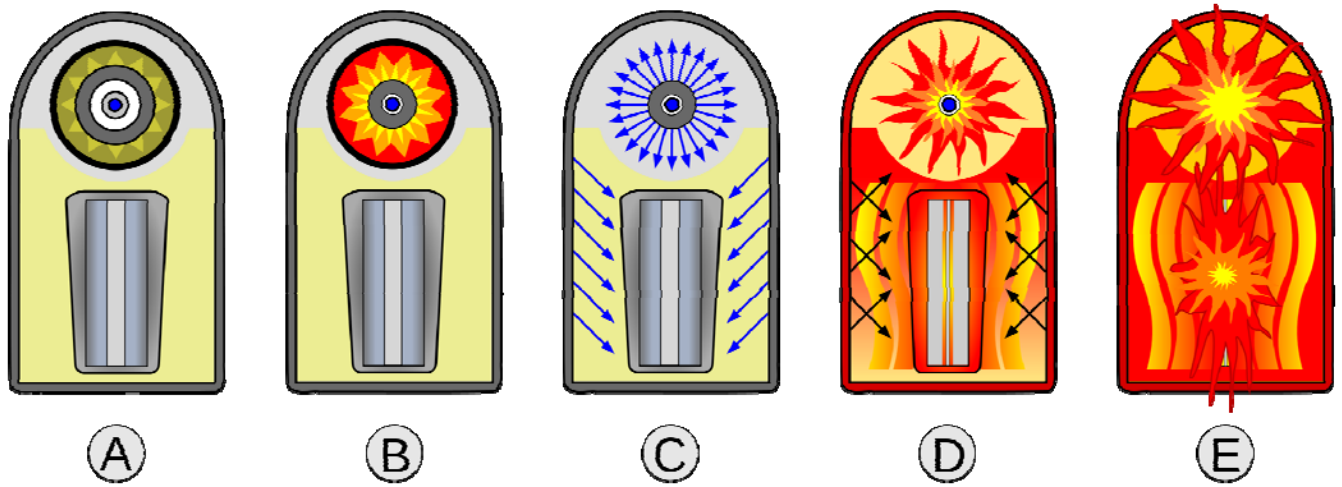
A perfect match!

- Low Q fusion core + Sub-critical fission blanket
  easily achievable plasma-related parameters
- Neutrons from fusion core drive reactions in blanket
  - generate fission power
  - breed fissile fuel
- Good passive and inherent safety performances (sub-critical)
  large design margin because of subcritical features
- Avoidance of nuclear proliferation
- Benefit both fusion and fission
  fill in the gap, support fusion, solve fission spent fuel issue

A Fission-Fusion Hybrid Device



http://en.wikipedia.org/wiki/Thermonuclear_weapon



A. Primary (fission bomb) at top, secondary (fusion fuel) at bottom, all suspended in polystyrene foam.

B. High-explosive fires in primary, compressing plutonium core into supercriticality and ignite fission reaction.

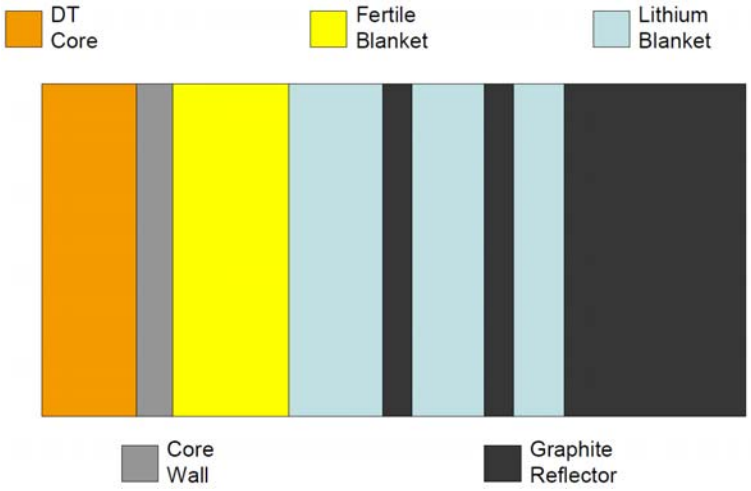
C. Fission in primary emits X-rays which are scattered along the inside of the casing, irradiating the polystyrene foam.

D. Polystyrene foam becomes plasma, compressing secondary, and plutonium sparkplug begins to fission, supplying heat.

E. Compressed and heated, lithium-6 deuteride fuel produces tritium and begins fusion reaction. The neutron flux causes the U238 tamper to fission. A fireball is starting to form.

Fission-Fusion Hybrid Reactor

Addressing waste and proliferation problems



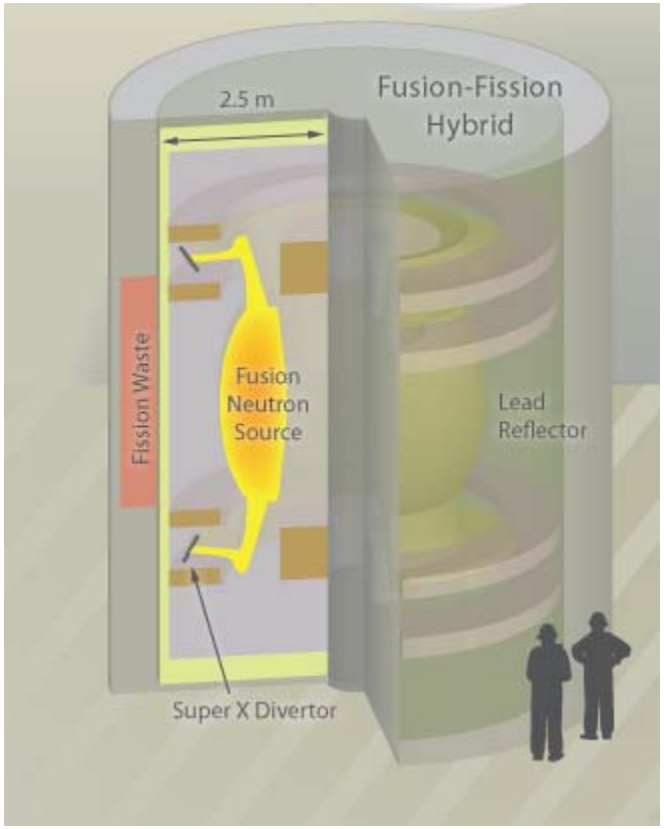
http://www.psfc.mit.edu/~g/spp/Presentations/Freidberg-Fission-Fusion%20Hybrid%20rev1.ppt

- Hybride consists of
  - below break-even fusion core
  - sub-critical fission blanket
- Fusion core provides neutrons to
  - drive fission reactions in the blanket
  - convert fertile materials to fissile fuel (Th-232 / U-238) → (U-233 / Pu-239)
  - Transmute long lived radioactive byproducts in the hybrid blanket
- Hybrid-enabled fuel cycle:
  - 5 hybrids to support ~ 100 LWRs (vs 1 fission breeder to 1 fission reactor)
- Hybrid operates with currently achievable fusion parameters:

  need Q = 2 ~ 5 instead of Q > 30 for full scale fusion reactor

Fission-Fusion Hybrid Operation
Destruct Waste & Produce Fissile Fuel

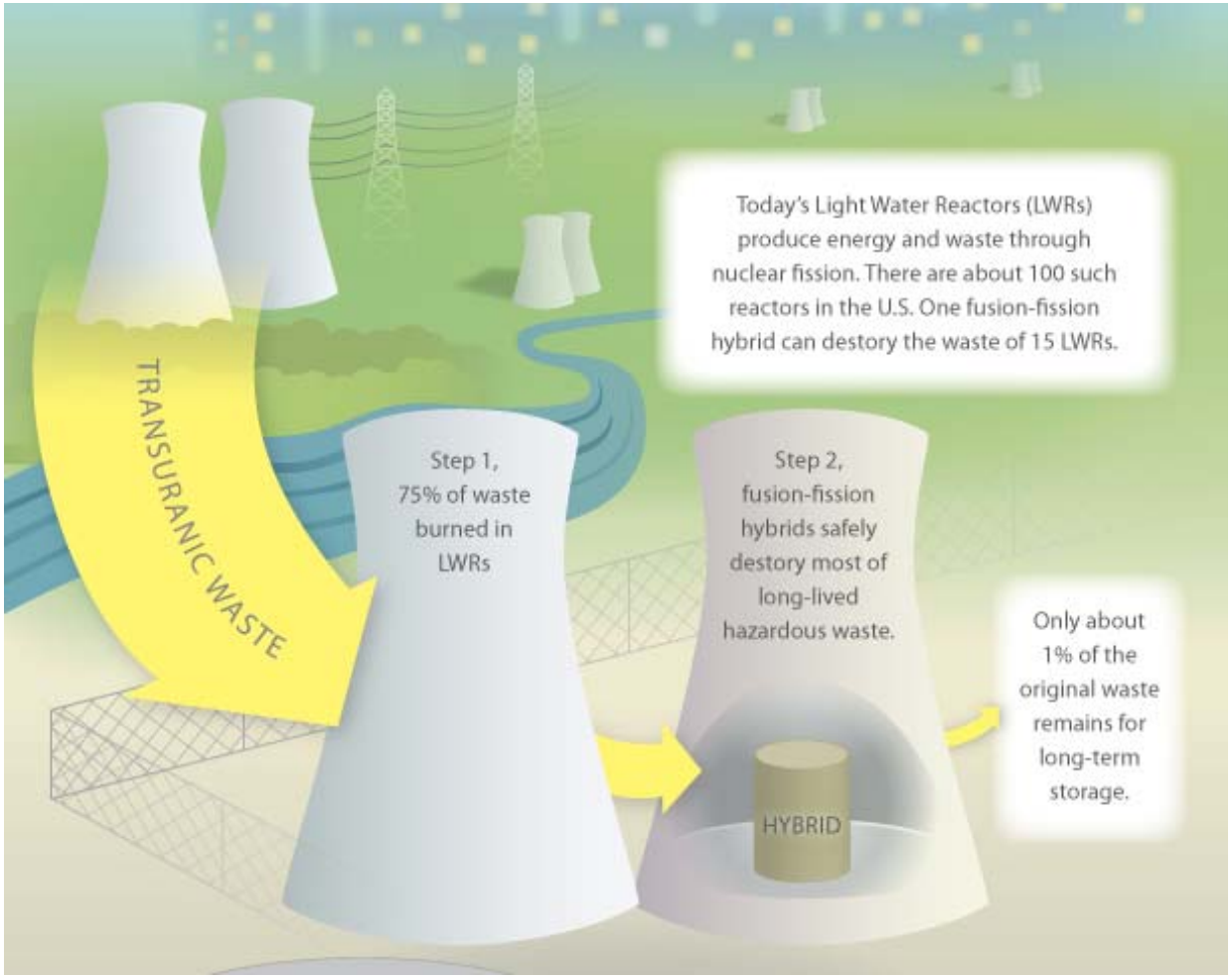
- One 200 MWe-equivalent (i.e. 500 MWt) tokamak fusion core
- Surround with a thorium-lithium blanket – produces about 5,500 kg of U-233 plus 20 kg of tritium per year
- Separate the U-233 and combine it with U-238 to form fissile fuel for LWR
  - Sufficient to power two 800 MWe LWRs
  - Power gain = 8!
- Burn the resulting Pu and actinides in an onsite 300 MWe fast reactor.



http://www.psfc.mit.edu/~g/spp/Presentations/Freidberg-Fission-Fusion%20Hybrid%20rev1.ppt

- Store short lived radioactive byproducts on site
- Transmute long lived radioactive byproducts in the hybrid blanket

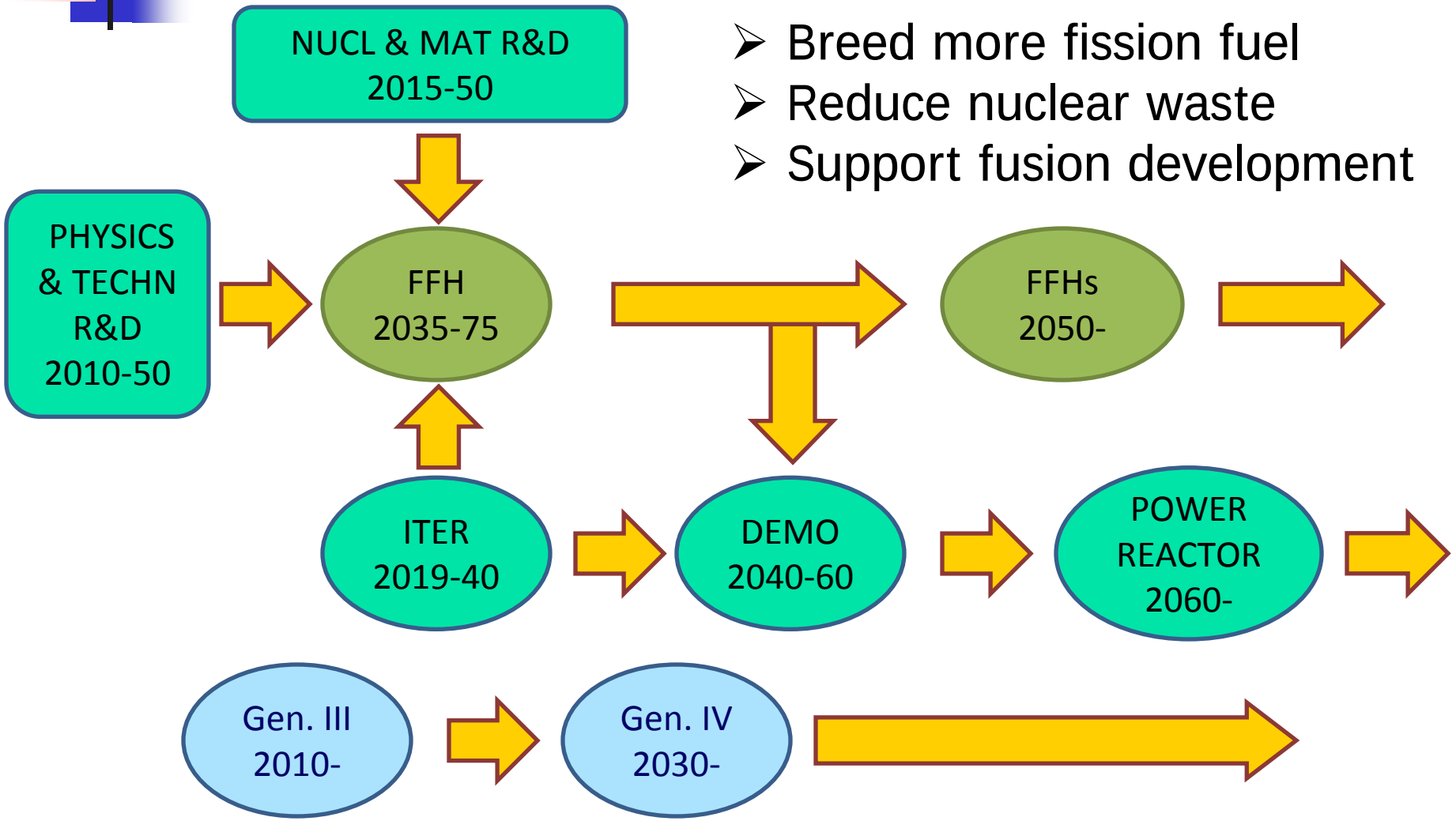
Fission-Fusion Hybrid Fuel Cycle



http://www.frc.gatech.edu/Policy/epri.ppt#312,50,FUSION POWER DEVELOPMENT WITH A DUAL FUSION-FISSION HYBRID PATH

- Step 1 - 75% of waste burned in fission reactors while producing energy
- Step 2 - Hybrid safely destroy most of long-lived hazardous waste
- 1% of the original waste remains for long terms storage

Possible Role of Hybrid in Nuclear Power Development



- Breed more fission fuel
- Reduce nuclear waste
- Support fusion development

Thank You

Q&A