Paths to Magnetic Fusion Energy

(nature ignores budget austerity)

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Strong science foundation supports accelerated path

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fusion pressure achieved
high energy confinement achieved (extended on ITER)
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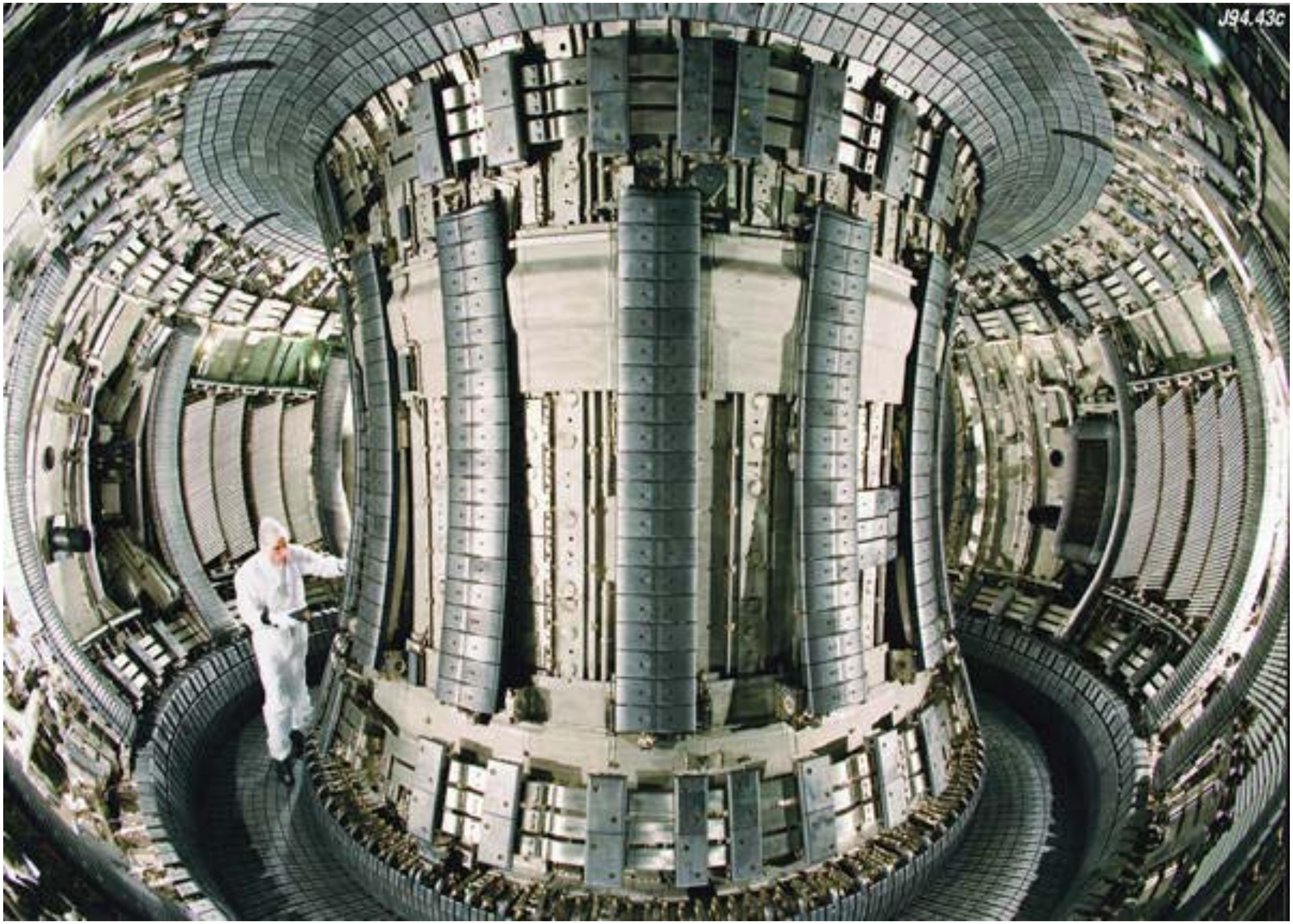
safely operated with tritium
large, complex fusion facilities operated successfully

A modern fusion machine



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Above obtained at short plasma time duration (seconds)

New superconducting facilities overseas will extend to long duration

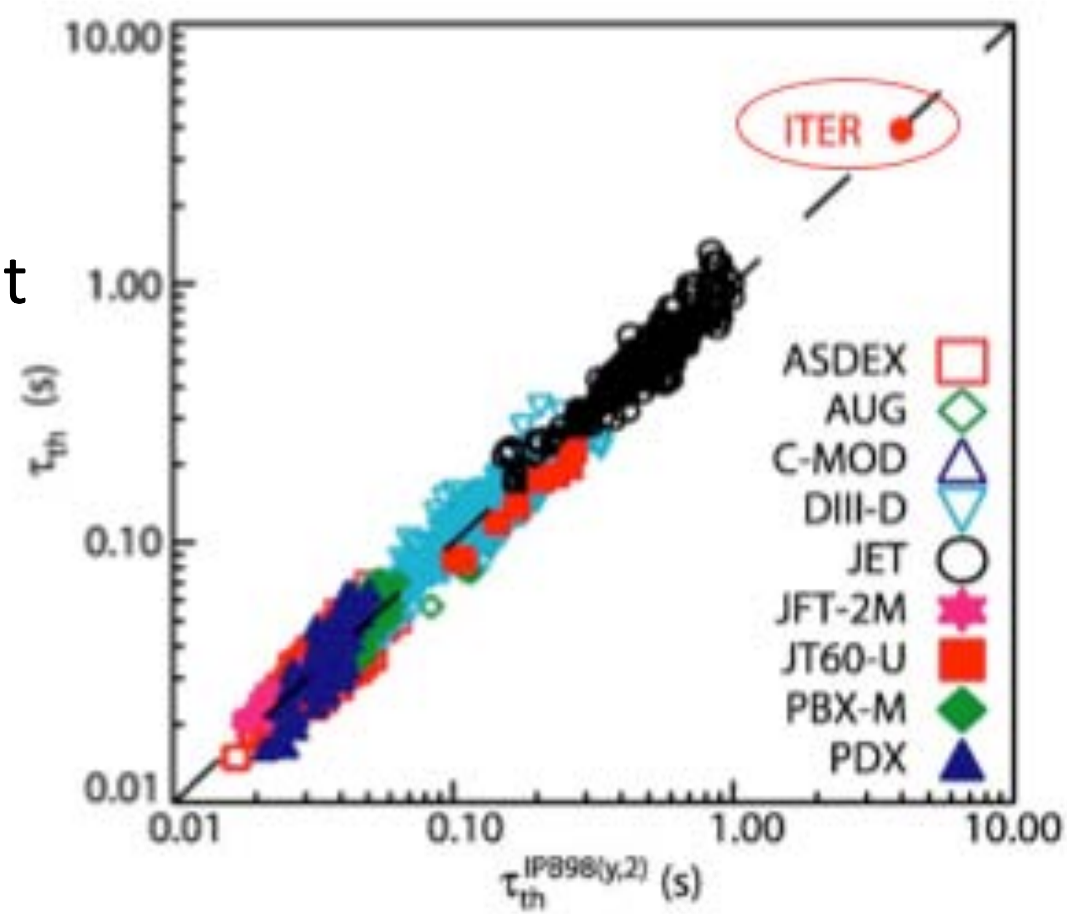
Remaining challenges

- The plasma
  - Burning plasmas (ITER)
  - High performance, steady-state
- The plasma-material interface
  - a combined plasma/material science problem
- The material structure
  - withstanding neutron flux
  - using neutrons to breed and produce heat
  - (fusion nuclear science)

and integrating all the above into one system

There is scientific optimism that ITER will achieve its spectacular goals

Energy confinement time



Thus, remaining fusion problems should be solved *in parallel* with ITER

Demonstration power plant in 25 years

- a common conclusion, internationally
  (see Workshop on *MFE Roadmapping in the ITER Era*, Sept, 2011)

- An aggressive, but reasonable goal
  (*not* a “Manhattan project”)

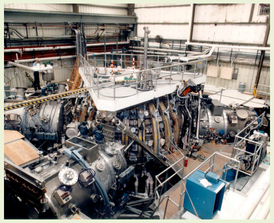
- Requires strong research program complementary to ITER

- Common view of research challenges

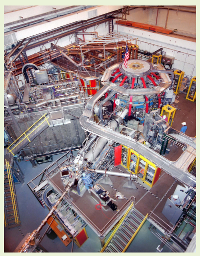
- Differences in detail in the path to DEMO

A US roadmap to fusion energy

DIII-D



NSTX

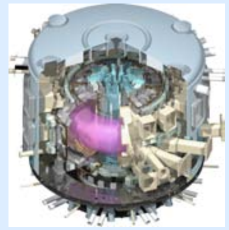


CMOD

Plasma confinement research program

present

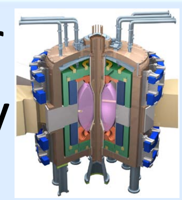
ITER



<u>Base Research Program</u>

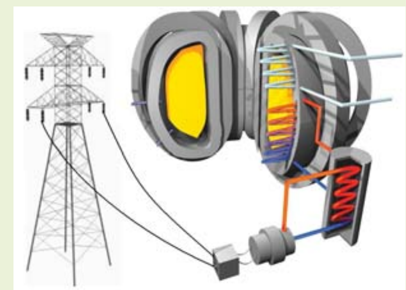
Plasma confinement
Materials science/engineering

Fusion Nuclear Science Facility



2020 – 2035
The ITER Era

Demonstration Power Plant

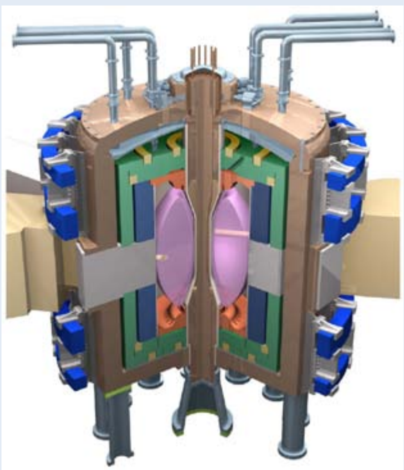


~ 2035
The fusion era

Options for the Fusion Nuclear Science Facility (FNSF)

mission: fill in gaps in ITER and existing programs to enable DEMO

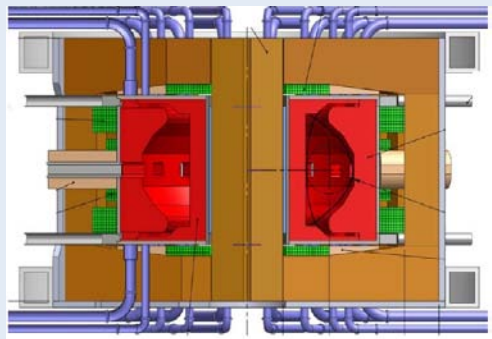
FNSF – ST (spherical tokamak)



Objectives

- high neutron flux for long times
- test/validate materials
- breed tritium
- produce heat

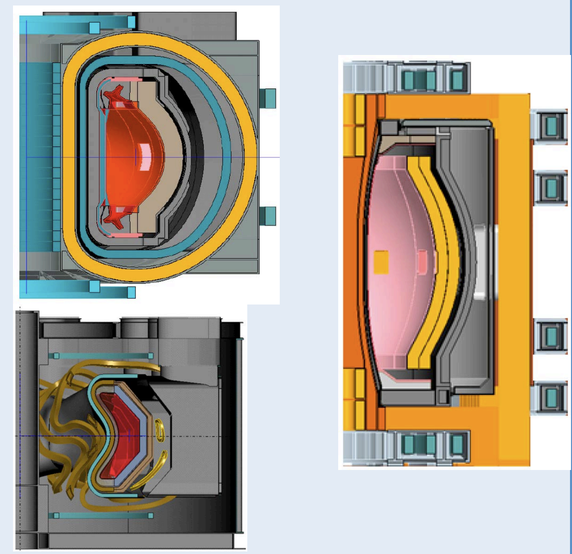
FNSF – AT (advanced tokamak)



Add

- DEMO-class high performance plasma

FNSF – PP (pilot plant)



Add

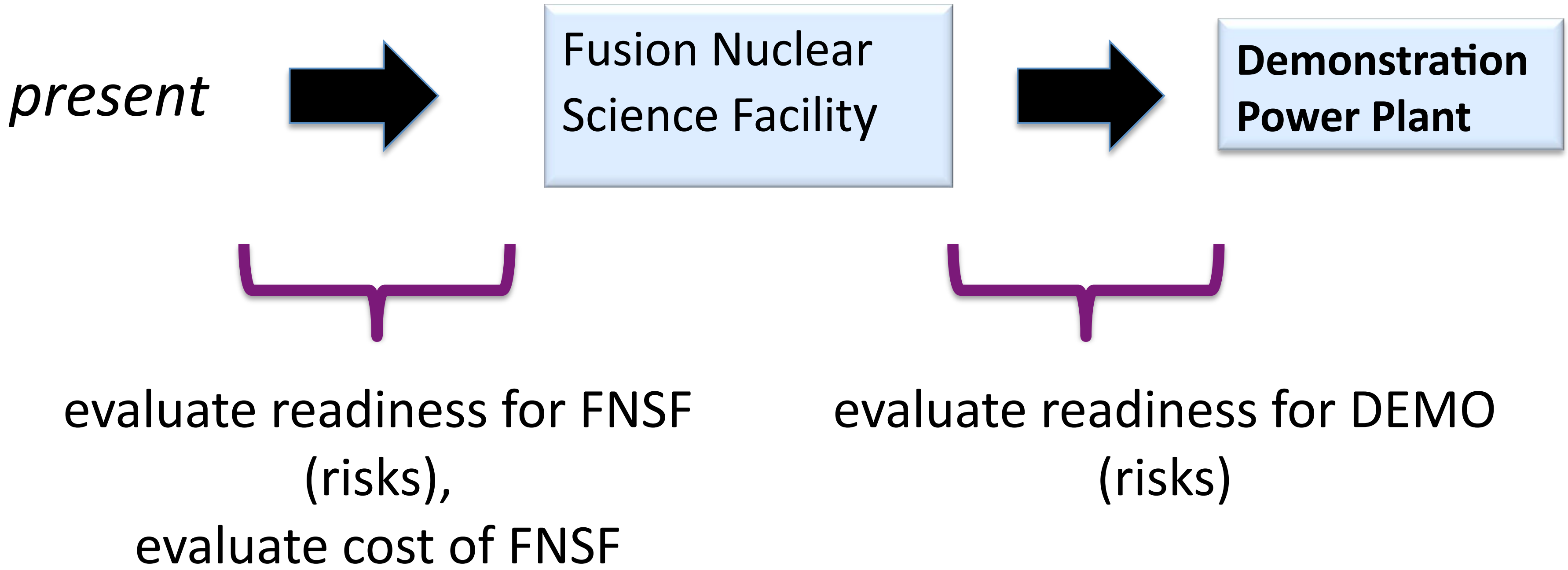
- net electricity generation
- high system efficiency
- reactor maintenance schemes

Essential to assess range of options

- To understand tradeoffs and determine wisest choice (tradeoffs in risk, benefit, cost, time not obvious)
- To justify choice
- Planning in other nations vary from skipping FNSF to FNSF-ST to pilot plant

Range of available options is a strength

Evaluate tradeoffs at two steps for each FNSF option



More (less) risk at the first step → less (more) risk at the second step

Demo Goals

From Starlite (1997) and FESAC (2007):

1. Net electric output > 75% of commercial
2. Availability >50%; ≤ 1 unscheduled shutdown per year including disruptions. Full remote maintenance of the power core.
3. Closed tritium fuel cycle.
4. High level of public and worker safety, low environmental impact, compatible with day-to-day public activity.
5. Competitive cost of electricity.

Beginnings of evaluation of readiness for DEMO for two FNSF options
(FNSF-PP and FNSF-AT)

Score on 0 – 10 scale for each technical category

10: FNSF option fully satisfies DEMO prerequisite

0: FNSF contributes nothing to DEMO readiness, DEMO relies on accompanying research program

	Pilot Plant	FNSF-AT
Plasma Configuration		
Burning Plasma	6 – 8 (AT) 9 – 10 (ST, CS)	6 - 8
Steady-state operation	8	6? 8?
Divertor performance	8 – 10	8 – 10
Disruption avoidance	9 – 10	6 – 7? 9 – 10?
Control Technology		
Diagnostics and control systems		
Heating, current drive and fueling		
Superconducting coils	9-10 (AT, CS)	0
In-Vessel Systems and Tritium		
Divertor Targets and First Wall Components	8 – 10	8 – 10
First wall/blanket materials	7 – 8	6 - 7
Vacuum Vessel	7 – 8	7 - 8
Tritium processing	8	8
Tritium self-sufficiency	9 – 10	9 - 10
Plant Integration		
High Availability data & experience	7 – 8	3 - 4
High Availability overall demonstration	9 – 10	4
Remote handling	9 – 10	4
Electricity generation	9 – 10	2 - 3
Power plant licensing		
General Requirements- Demo minus 1 lead facility must…		
Use power core and plant subsystems representative of those in a commercial plant.	**9-10**	**2-3** (fails on magnets, machine configuration, maintenance, and many plant sub-systems)
Achieve tritium self-sufficiency.	**9-10**	**9-10**

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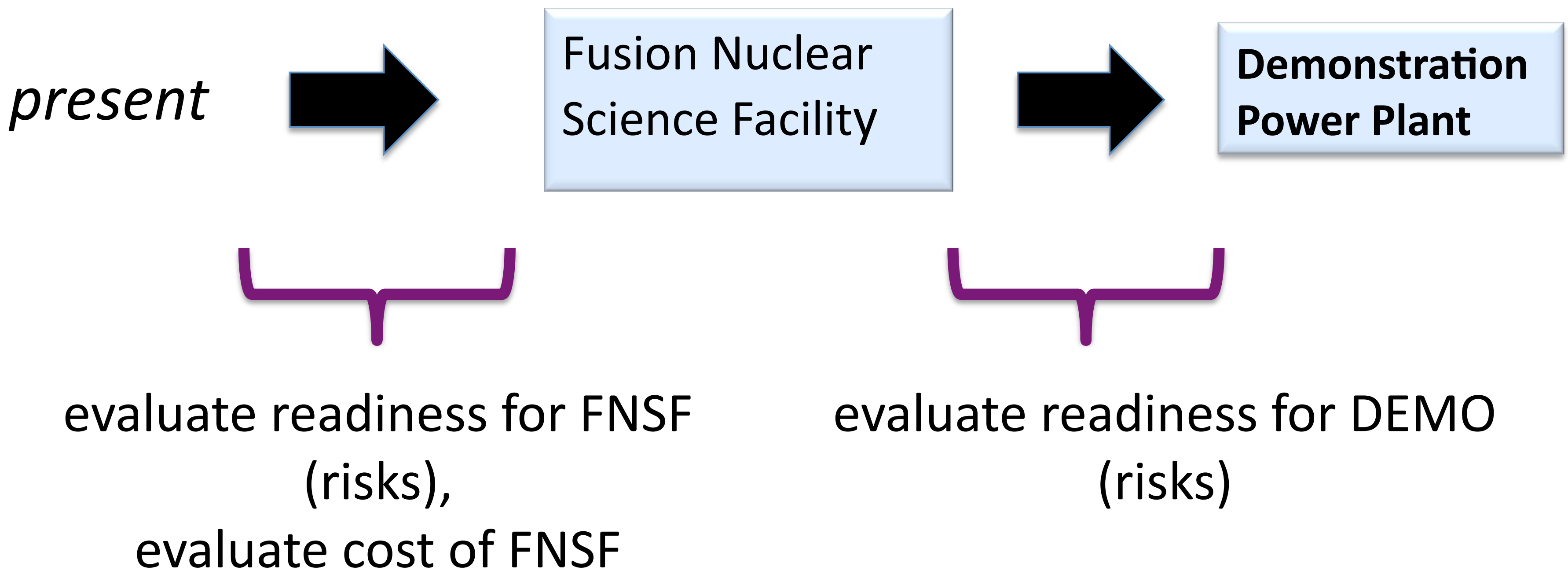

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Evaluation of readiness for FNSF
(just beginning)

Score FNSF options on scale 0 – 3 for each technical category

3: Could be ready in ≤ 10 years by continuing existing programs, with focus

2: Could be ready in ≤ 10 years with larger (but < $50M/yr) program

1: Could be ready in ≤ 20 years with larger (but < $50M/yr) program

0: Could not be ready in < 20 years

Work in progress….

	Pilot Plant	FNSF - AT
Plasma Configuration		
Burning Plasma	1	1
Steady-state operation		
Divertor performance	1 - 2	1 - 2
Disruption avoidance		
Control Technology		
Diagnostics and control systems	2	2 - 3
Heating, current drive and fueling		
Magnets	3	3
In-Vessel Systems and Tritium		
Power handling	2	3
Vacuum Vessel & Blanket	1	1
Tritium processing & self-sufficiency	2	2
Plant Integration		
High Availability & Remote handling	2	2
Electricity generation	2-3	3
Power plant licensing	3	3

Both FNSF options have similar readiness

In summary,

- A powerful knowledge/data base justifies an accelerated program

- Above path delivers fusion in a time scale that matters

  with a cost that is affordable
  (~ 0.1% of annual US energy expenditure)

  with an aggressive program
  (but not a "Manhattan Project")

- We should now optimize the path, build the case
  (through a national "next-step options and roadmapping" activity)