# The RFP Development Path

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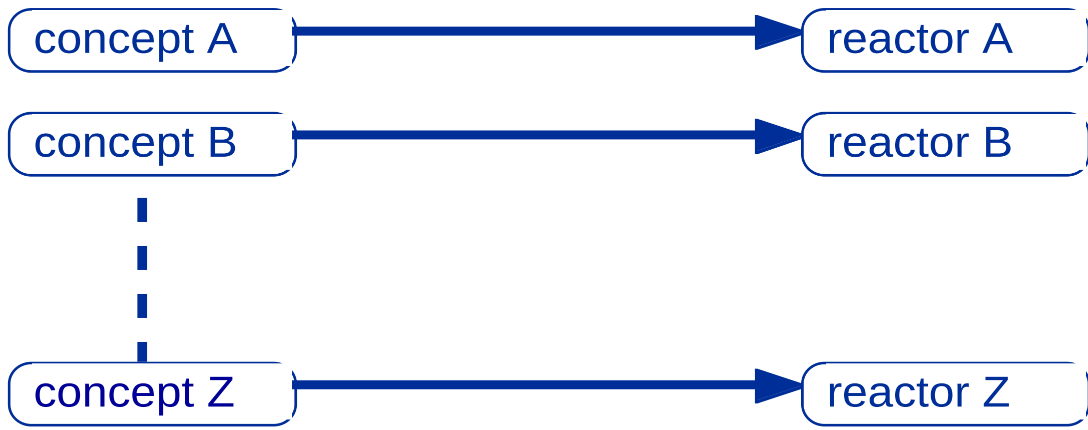
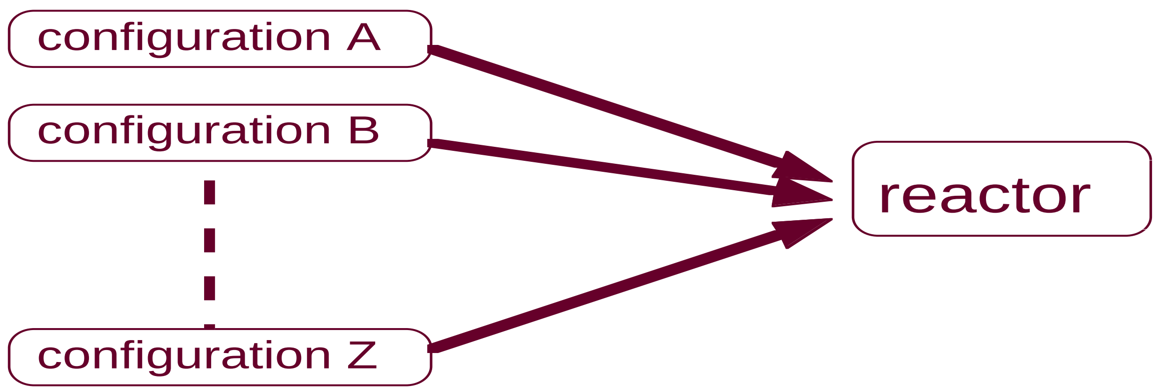
January, 2003

# Reminder: Two views of non-tokamak research

*Each concept as a fusion reactor*




*each configuration building fusion science*

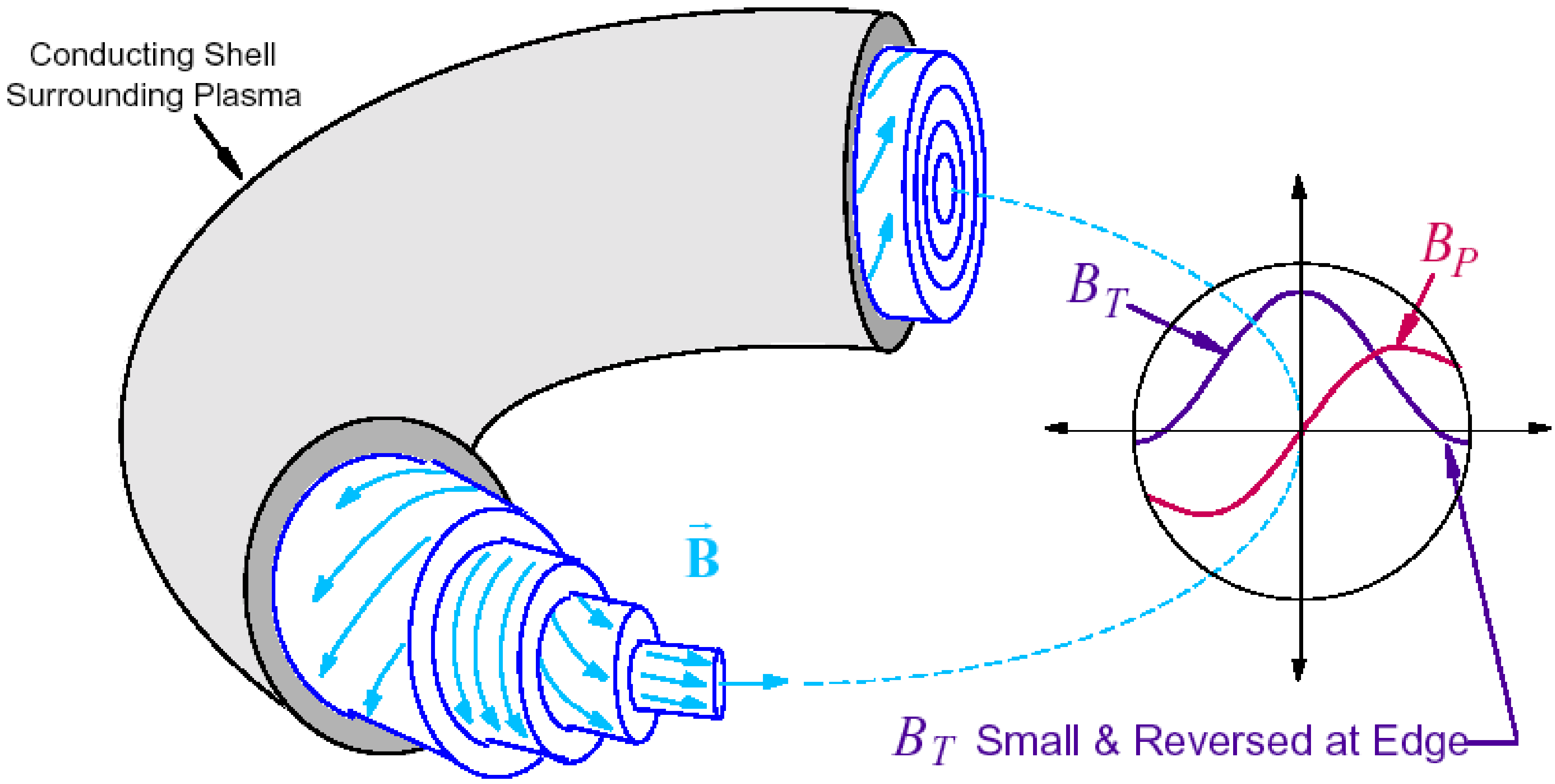



*Optimal: mixture of both approaches*

# Outline

- RFP features and status
- Steps in development plan
- Schedule and cost

# The RFP


Conducting Shell
Surrounding Plasma
$\vec{B}$
$B_T$
$B_P$
$B_T$ Small & Reversed at Edge

# Why the RFP as a fusion concept?

low magnetic field

$\Downarrow$

High beta

Very high engineering beta (low field at coils)

Normal (nonsuperconducting) coils, reduced shielding

High mass power density (compact)

Efficient maintenance/disassembly

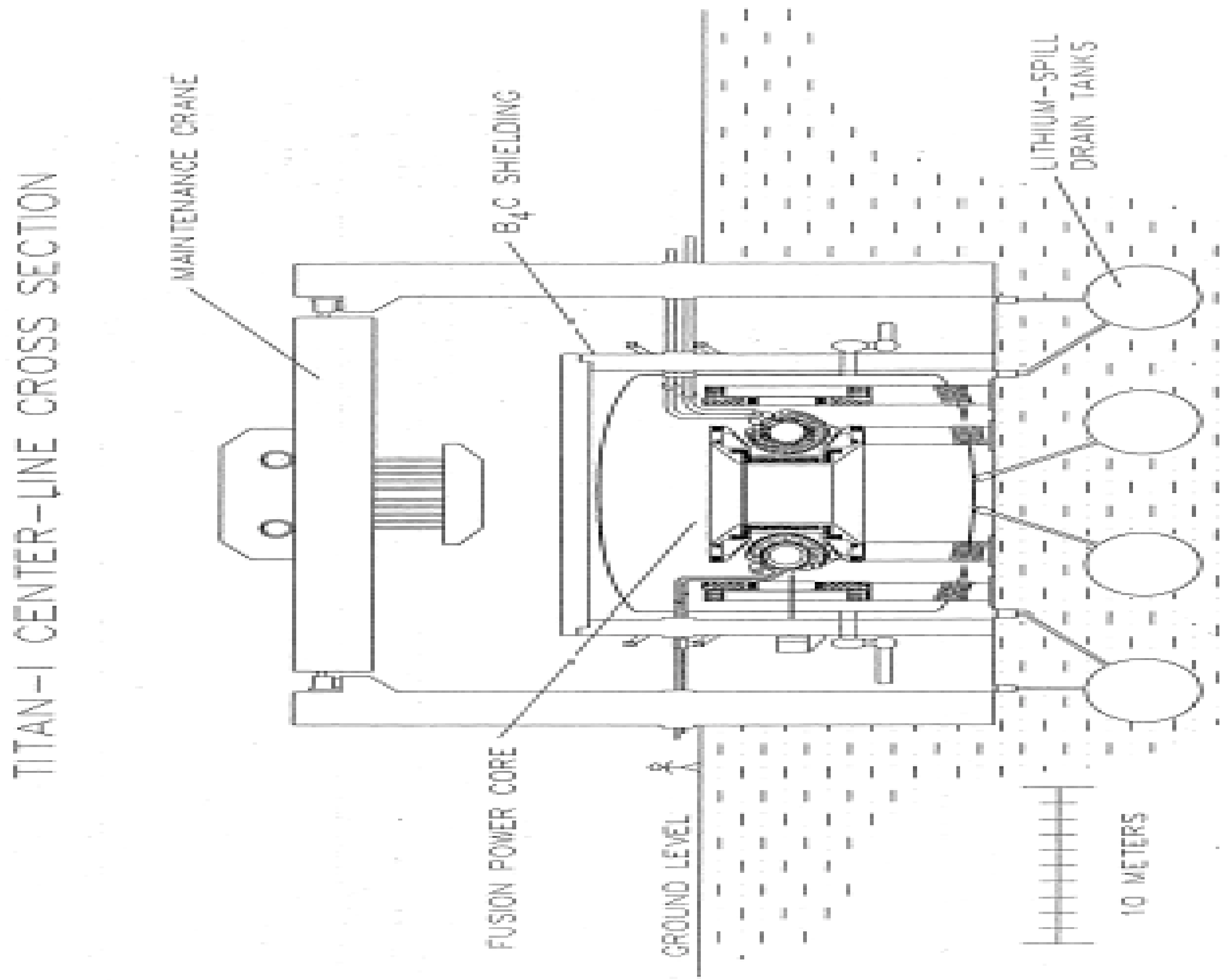
Possibly free choice of aspect ratio

# The TITAN RFP Reactor Design

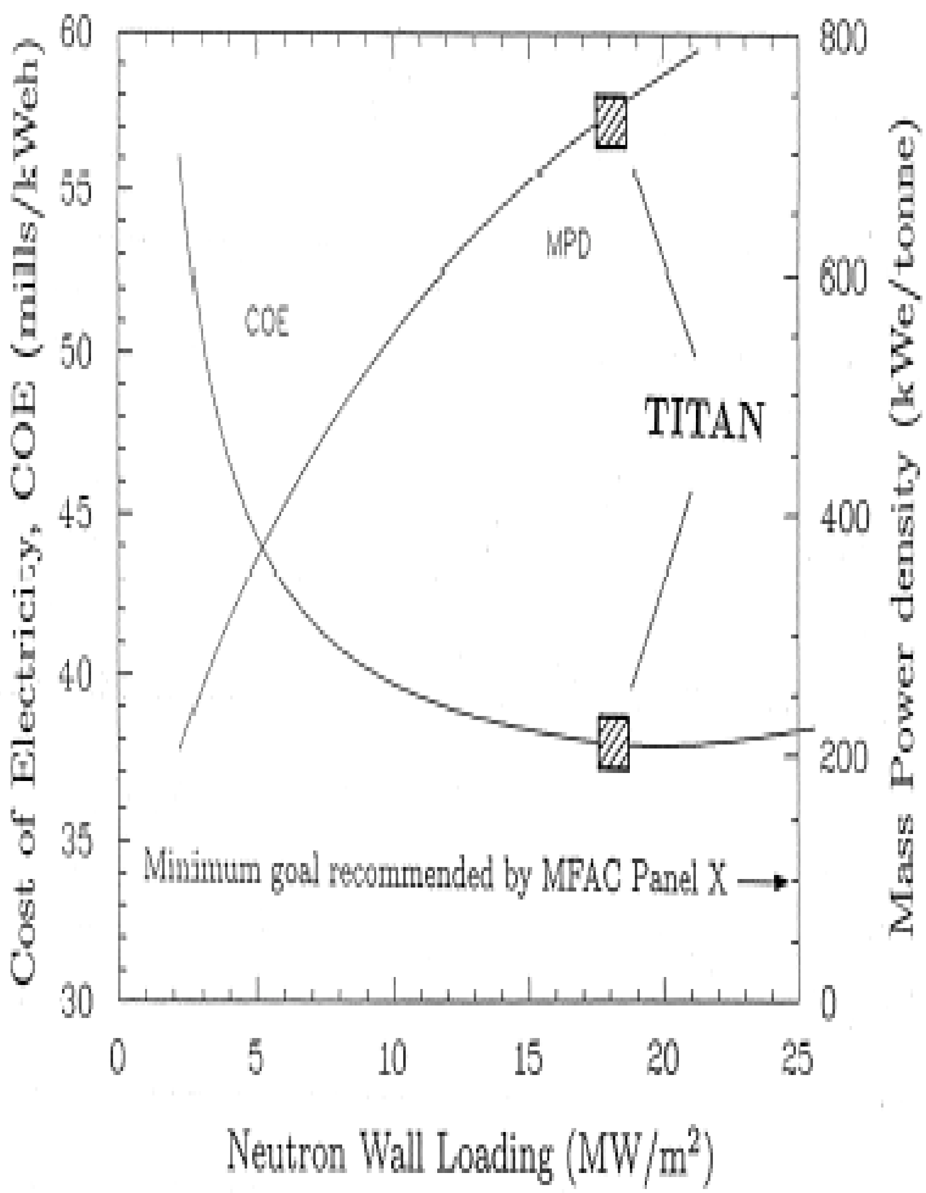
(Najmabadi, Conn et al., 1990)

- a = 0.6 m, R = 3.8m, I = 18 MA
- Integrated blanket/TF coil concept
- Mass power density ~ 400 - 800 kWe/tonne
- Neutron wall load ~ 5 - 20 $MW/m^2$
- Single piece maintenance (high availability)
- COE ~ 40 mill/kWh (FPC ~ 10% of total cost)

# Single piece maintenance



# PARAMETRIC VARIATION OF TITAN-I DESIGN POINT



# The RFP Status

- 1999: recommended by FESAC as PoP program

- Now: intermediate between CE and PoP program

  (US experimental funding ~$5M/yr

  required PoP experimental funding ~ $8M/yr)

- Outside US: 1 PoP experiment (Italy)

  > 2 CE experiments

*Cost/schedule extrapolation to DEMO is speculative*

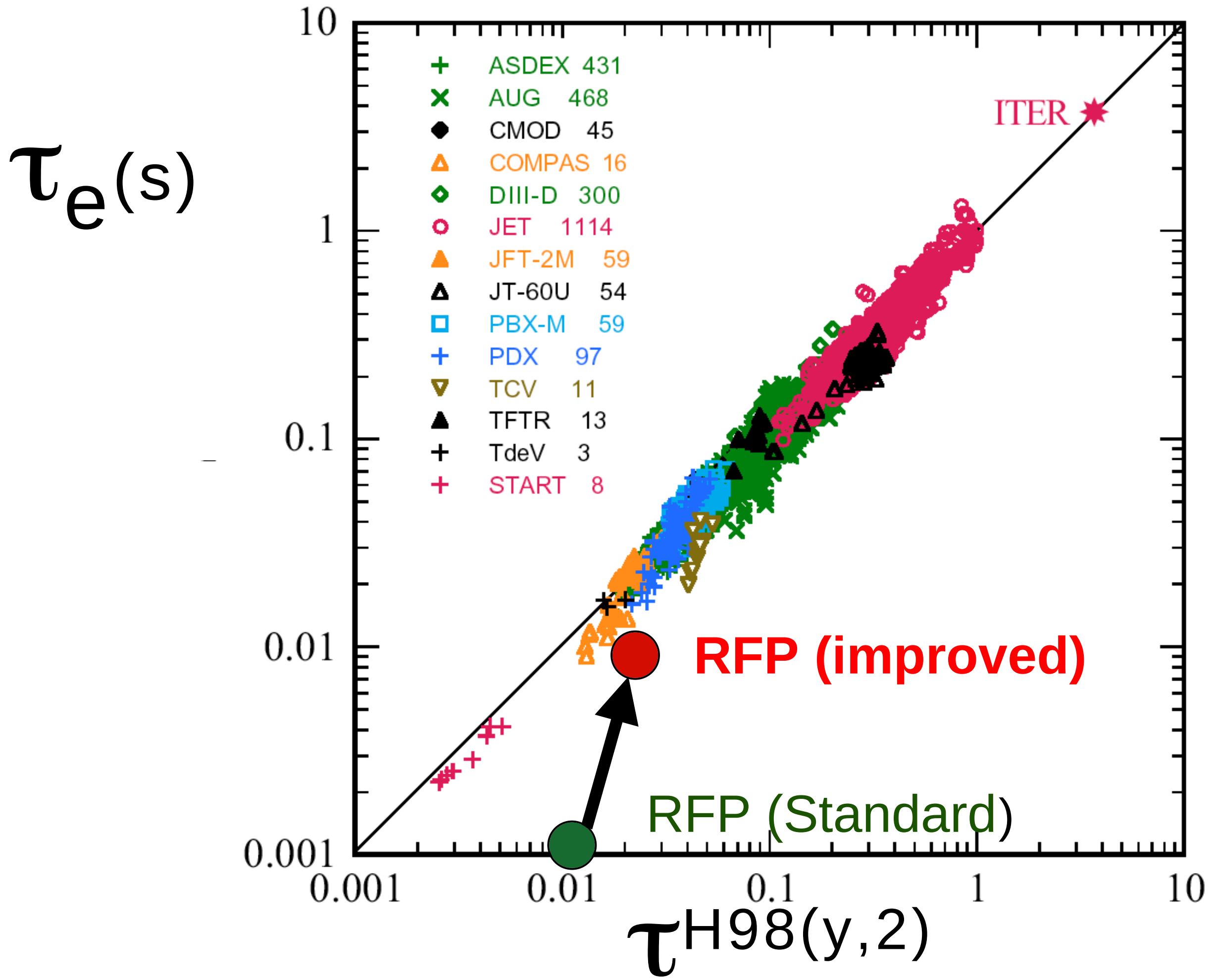
# Current RFP Physics Issues

| Issue | Status | Next |
|---|---|---|
| Confinement | Tokamak quality, achieved transiently | Discover ultimate confinement, sustain good confinement |
| beta | High beta achieved $\beta_{tot}$ ~ 15%, $\beta_{tor}$ > 100% | Discover ultimate limit |
| Current sustainment | Open issue | Test ac helicity injection, examine pulsed RFP scenrios |
| Resistive wall instability | Observed, external kink feedback achieved | Develop solution (rotation, feedback..) |

# RFP confinement comparable to tokamak

(at same I, n, P, size, shape)

*ELMy H-Mode*




With high beta and weak field

# Criteria to advance to next step

- Demonstrate sustained plasmas with

  confinement time = 10 ms

  beta = 15%

  T = 1 keV

- Develop understanding that physics is likely to scale favorably

# The Next Step

- Either more advanced PoP or Performance extension experiment

  I ~ 1 - 4 MA

  T ~ 2 - 10 keV

  duration ~ 0.1 - 5 sec

- Results from current program will determine

  resistive wall mode stabilization

  plasma shape, aspect ratio

  plasma heating and current drive

# The RFP Burning Plasma Experiment

Are results from a tokamak BPX transferable to an RFP?

| | | |
|---|---|---|
| **Alpha particle physics** | | |
| classical effects | } | basic physics transfers, |
| $\alpha$-generated instabilities | | geometric details differ, |
| instability effects on alphas | | maybe magnetic fluct. |

Burn control/integration: may differ

Fusion technology: mostly transfers

# Can we skip the RFP BPX step?

(assuming a prior tokamak BPX)

Probably not.

Note: to date, tokamak research has greatly accelerated non-tokamak research.

But, no step has ever been skipped

predictability in 20 years will be much improved, but the risk of skipping the BPX step is high

# The RFP materials program

Similar to the advanced tokamak materials program

- IFMIF: as for tokamak program
- CTF: can be an RFP or tokamak

# An RFP CTF

(Los Alamos, 1989)

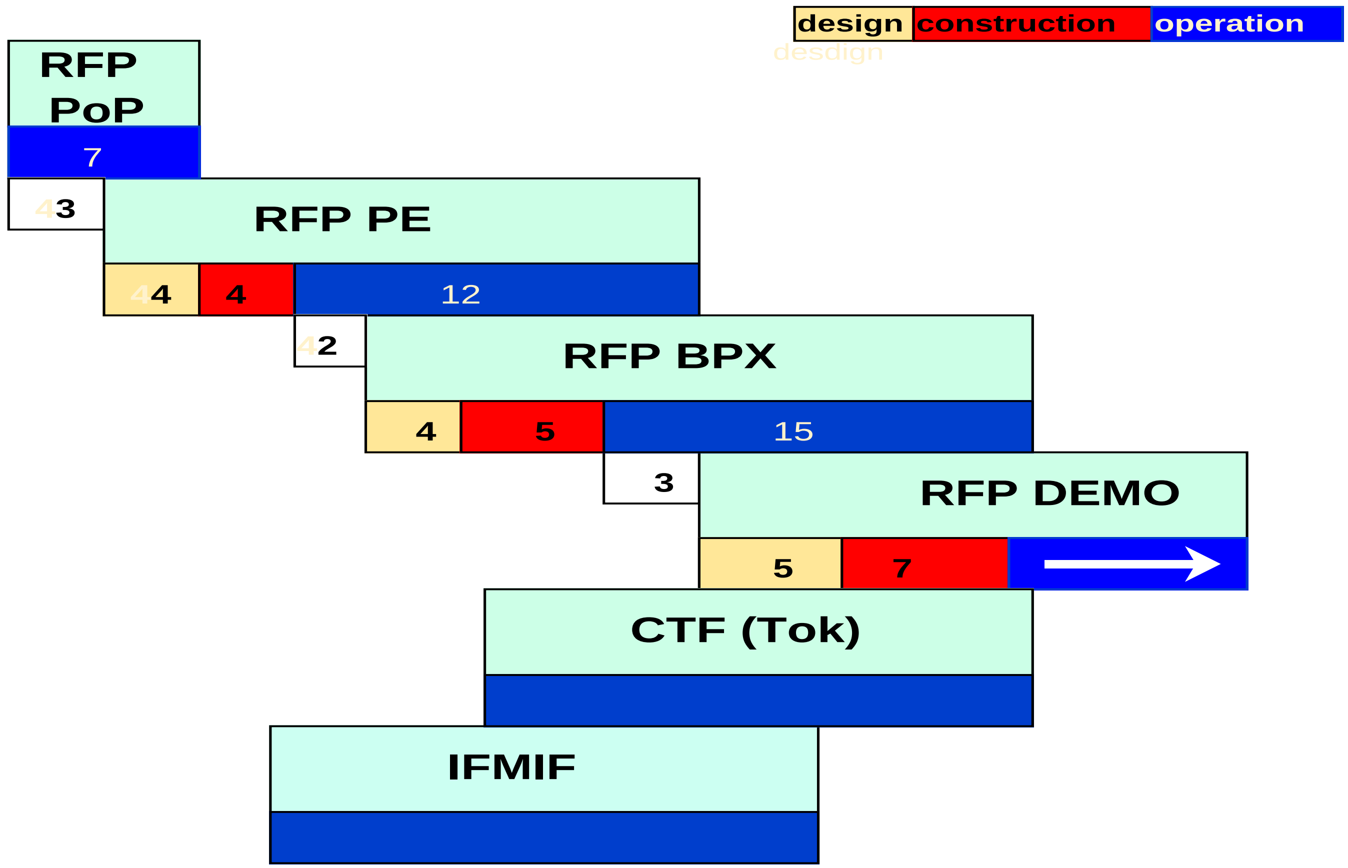
- Fusion power ~ 124 MW
- Fluence ~ 3.4 MW yr/m$^2$
- Neutron wall load ~ 5 MW/m$^2$
- a = 0.3 m, R = 1.8m, I = 10 MA
- Cost ~ $336 M 1988

# An RFP Development Schedule

Assume:

- An RFP BPX is needed
- IFMIF and a tokamak CTF proceeding separately
- Favorable scientific progress at each step
- small time lag between steps

# An RFP Development Schedule




$\Rightarrow$*37 years to an RFP Demo*

with major fusion science advances along the way

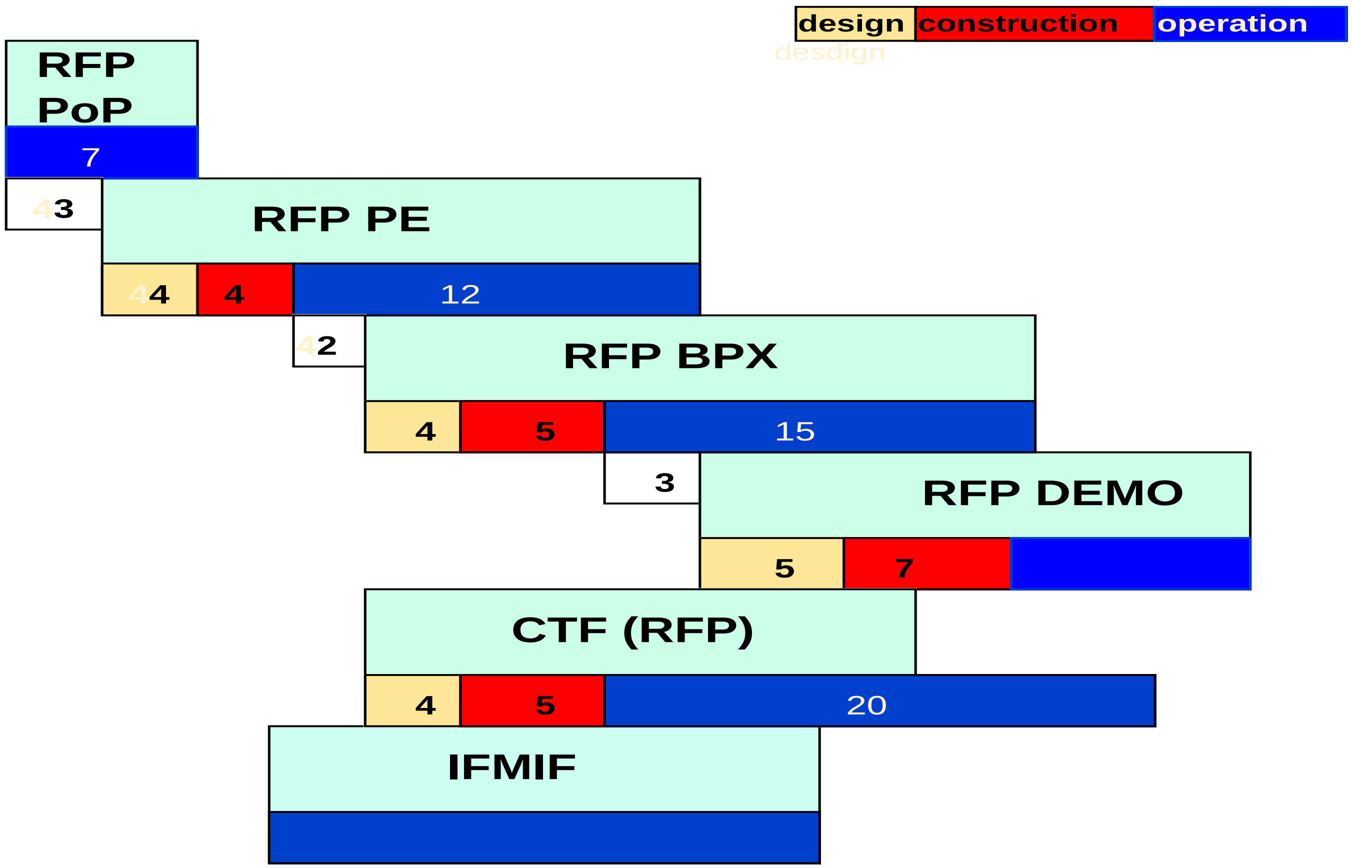
# Costs

(i.e., informed guesses for the purpose of discussion)

In addition to tokamak program costs:

| | |
|---|---|
| PoP experiment | $0.06B |
| PE experiment construction | $0.2 |
| PE experiment operation | $0.6 |
| BPX construction | $1 (0.3 FPC only) |
| BPX operation | $1.5 |
| underlying RFP research | $0.15 |
| | $3.5B (2.8B) |
| | $87M/yr (70M/yr) |

# Plan with an RFP CTF




CTF begins simultaneous with BPX - increased risk

# Approach #2 to development paths

Describe plan also via science issues

Example

issue: determine transport vs $B_T$

how: integrated studies in

tokamak, ST, RFP, spheromak, FRC

strong $B_T$ → weak $B_T$

# Summary

An RFP DEMO is possible in ~35 years

- Assuming successful, timely physics
- For modest additional cost