FIRE Status and Plans

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for the National FIRE Study Team

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http://fire.pppl.gov

Accomplishments FY 2002

- **Snowmass** – Physics and engineering design assumptions validated.

  There are no outstanding engineering-feasibility issues to prevent the successful design and fabrication of any of the three options.

  There is confidence that ITER and FIRE will achieve burning plasma performance in H–mode based on an extensive experimental database.

Issues and opportunities identified for further work.

- **FESAC**

  ITER and FIRE are each attractive options for the study of burning plasma science. Each could serve as the primary burning plasma facility, although they lead to different fusion energy development paths.

  Because additional steps are needed for the approval of construction of ITER or FIRE, a strategy that allows for the possibility of either burning plasma option is appropriate.

  We should proceed to a physics validation review, as planned, and be prepared to initiate a conceptual design by the time of the U.S. decision on participation in ITER construction.

- **NRC BPAC**

FIRE Responses to NSO PAC and Snowmass

- **NSO PAC 4 Recommendation 14:** FIRE should propose a fusion development path ….., and a brief summary of advantages and disadvantages of a multi-machine vs. a single-step to demo development strategy.

  The FIRE plan and strategy has been derived from considerations of the development path. An analysis identifying resources and schedule for FIRE-Based Development Path has been presented at FESAC DevPath and APS-DPP.

- **Snowmass Recommended**

  faster rep rate – added a second cooling tube for 3x faster rep rate

  more shots (fusion energy) to exploit AT – insulator SBIR, new configuration

  longer AT pulses: Operating regime of ARIES-like advanced tokamak regimes ($\beta_N \approx 4$, bootstrap fraction ≈ 80%) in FIRE have been extended to ≈ 5 current profile relaxation times (essentially steady-state). Reported at IAEA and APS-DPP.

  NTM stabilization – ECCD is being evaluated for AT (6T), LHCD for 10T

  Lower exhaust power density on divertor plate - radiative modes to optimize power distribution, double null reduces elms.

The Range of Energetically Accessible Non-Inductive AT Modes has been Determined using a 0-D Systems Analysis.

- Plasma Heating and Current Drive provided by LHCD and FWCD with $\eta \approx 0.24$ A/W-m^2 and bootstrap $f_{BS} \approx \beta_N q_{cly} (R/a)^{1/2} C_{bs} n(0)/\langle n \rangle$
- Confinement assumed to scale as a multiplier on ITER98(y,2)
- Exhaust power distribution optimized by adding impurities in both the core (Be, Ar) plasma and divertor (Ne) subject to:

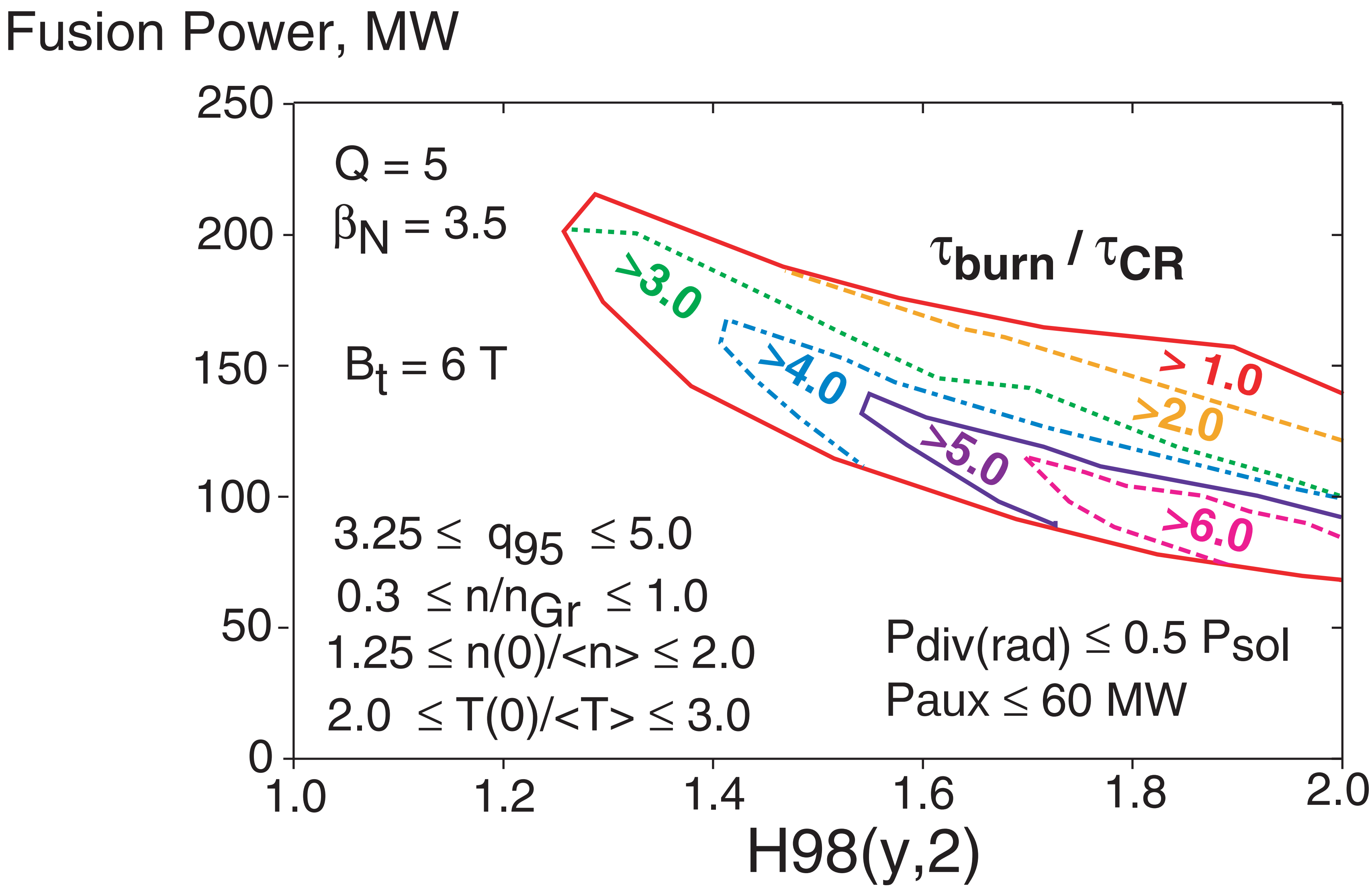
  P_{FW} (rad) $\leq$ 1 MWm^{-2}, including a peaking factor of 2
  P_{div}(part) < 28 MW, P_{div} (rad) < 0.5-0.7 P_{sol}, P_{div} (rad) < 8MWm^2

- Resistive and Nuclear Heating of the TF coils/Nuclear heat of Vac Vess limit

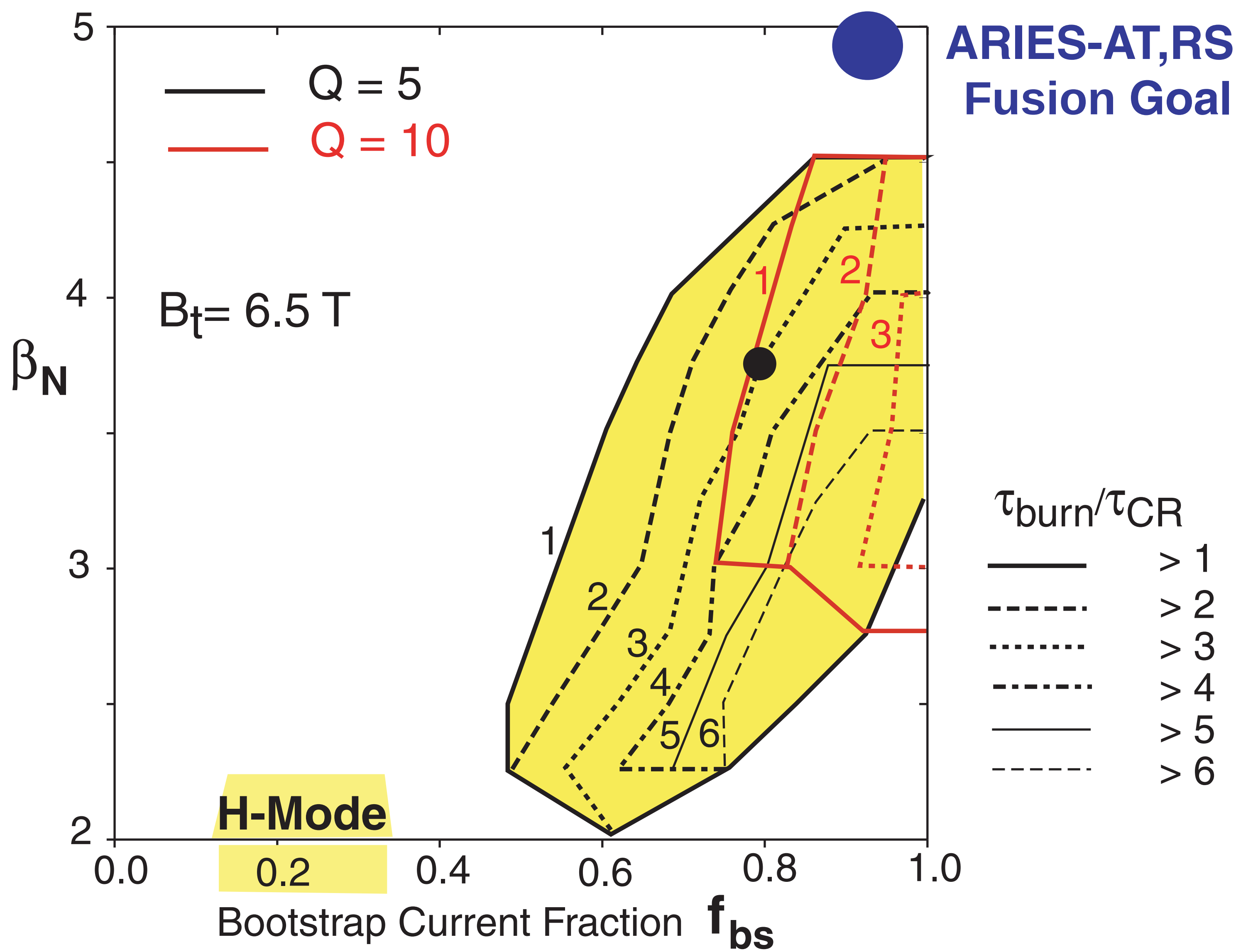
  P_{fusion} x Burn duration $\leq$ 4 GJ/pulse

- Parameter space scanned for power balance over:
  $3.5 \leq q_{95} \leq 5$, $0.3 \leq n/n_{Gr} \leq 1.0$, $1.25 \leq n(0)/\langle n \rangle \leq 2.0$, $2.0 \leq T(0)/\langle T \rangle \leq 3$
  $1\% \leq f_{Be} \leq 3\%$, $0\% \leq f_{Ar} < 0.4\%$, $2.5 \leq \beta_N < 4.5$, for Q = 5, 10
  to determine the required H(y,2) and allowed τ_{burn}/τ_{CR}

FIRE can Access High-β AT Modes under Quasi-Steady-State Conditions



AT Modes with $\beta_N \approx 4$, $f_{bs} \approx 85\%$ Sustained for 2 - 4 τ_{CR} are Energetically Accessible in FIRE



FIRE Engineering Status and Tasks

- **Toroidal Field Magnet** (LN, wedged BeCu inner leg, OFHC outer leg, plates)
  - 30% reserve beyond normal design allowables. Judged to be the most conservative BP design in Snowmass assessment.
  - improving TF cool down to increase repetition rate by ~ 3
  - SBIR program to develop improved TF insulation to extend lifetime.
- **Poloidal Field Magnet** (LN, segmented solenoid, OFHC)
  - modification to accommodate change 2m to 2.14m major radius, 6.5 MA to 7.7 MA and larger AT range while maintaining 30% reserve.
  - previously all OFHC, now CuCrZr being evaluated for one coil pair.
- **Vacuum Vessel** (double shell 306L stainless steel, shielding interspace**)**
  - modification for changes above, and reanalysis of nuclear heating effects and disruption loads.
  - should FIRE consider low activation ferritic steels for the vacuum vessel?
- **Plasma Facing Components**(W-rod divertor targets, Be coated tiles first wall)
  - extend testing of W brush concept with improved Cu backing plates
  - modification to accommodate geometry change, extend UEDGE calcs
  - extend pulse length capability of divertor/first wall – radiation and cooling
  - disruption analysis – thermal and electromagnetic analysis

- **Plasma Heating and Current Drive**
  - ICRF (20 MW, 80 – 120 MHz, 4 in-port single strap launchers)
    - evaluate and develop design for double strap launchers
  - LHCD (20MW, 4.6 – 5.6 GHz), 2 multi-grill launchers
    - evaluating CD efficiency in collaboration with MIT
  - ECCD in AT modes at ~ 6T (TBD MW, ~170 GHz)
    - physics evaluation
- **Plasma Fueling and Pumping**
  - HFS launch pellet injection – modeling needed, base program strength
- **Neutronics and Shielding**
  - reanalysis of modified geometry, using 1 -D
  - streaming analysis for design of generic integrated port and diagnostic
- **Fast Response Plasma Position Control and RWM Stabilization**
  - continued physics and machine integration analysis - Columbia/DIII-D
  - feasibility study of a generic RWM coil integrated with port plug
- **High-Strength High-Conductivity Cu alloys for Magnets**
  - test and qualify materials under a range of neutron irradiation.
- **Remote Handling**
  - develop and test fasteners and techniques for to ensure that components inside the vacuum vessel are remotely maintainable.

Physics Tasks – Base Program

- AT Mode Analysis (Advanced Tokamak Systems Code and TSC)
  - Configuration (high beta, high bootstrap)
  - Exhaust Power Handling
- Current Drive Optimization
  - Four Strap ICRH launcher
  - Refine LHCD calculations
- Experimental Proposals on C-Mod and DIII-D
  - High triangularity and double null effects on confinement, elms, etc
  - Steady state High beta high bootstrap ARIES-like AT modes
- MHD Stability
  - NTM Control
  - RWM Stabilization
- Diagnostics
  - High frequency magnetic diagnostics in high neutron flux
  - AT diagnostics [e.g., J(r), E(r)] , NB or other technique?, spatial res.
  - fluctuation/transport diagnostics

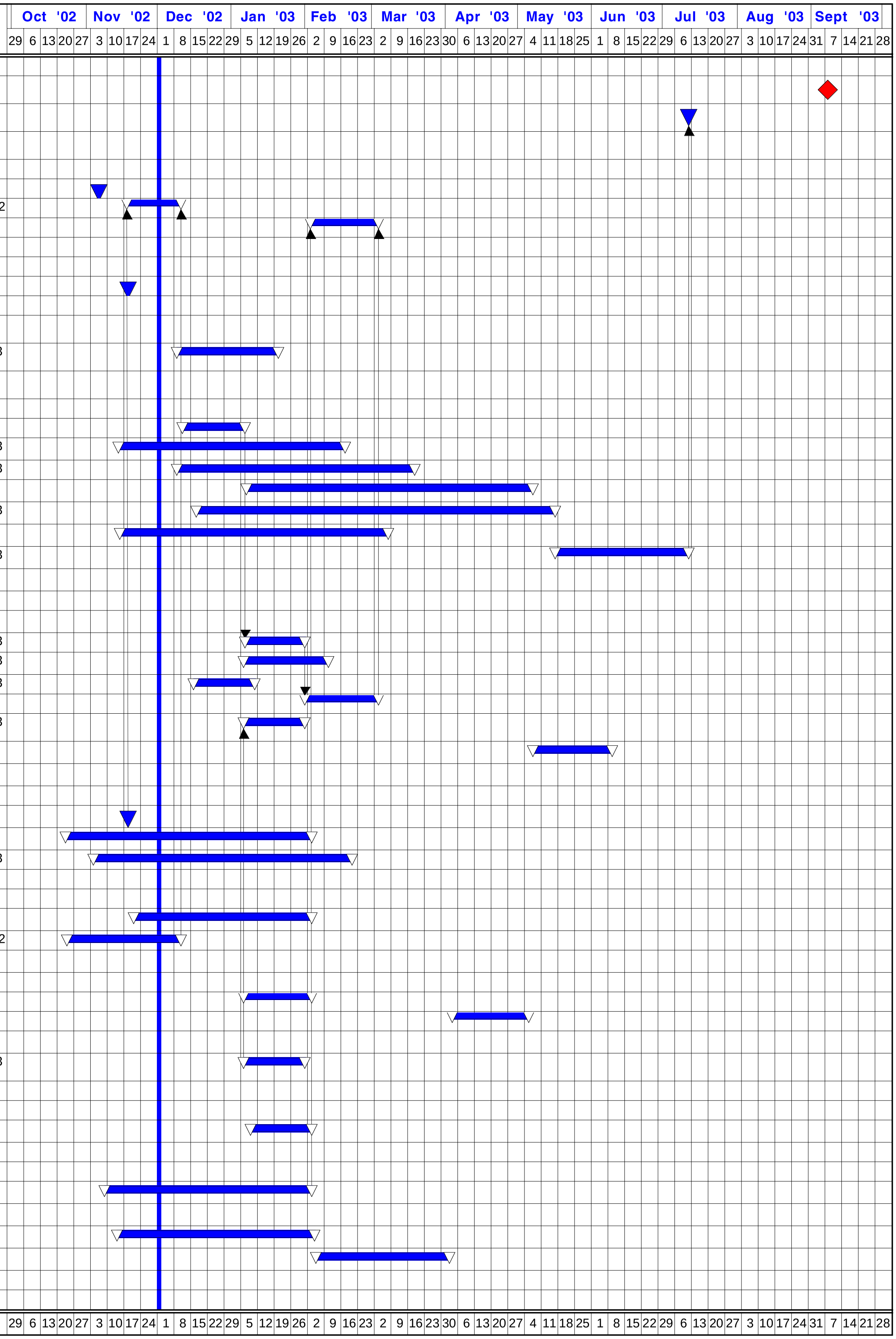
FIRE Overview Schedule (FY 2003)

	Activity Name	Start Date	Finish Date
1	FIRE-AT: IAEA/ITPA	10/14/02	10/23/02
2	FIRE Eng Mtg	11/7/02	11/8/02
3	FIRE-AT: DevPath APS	11/11/02	11/15/02
4	VLT PAC	12/4/02	12/5/02
5	FIRE Update Drwgs	12/2/02	1/15/03
6	NSO/FIRE PAC	2/11/03	2/12/03
7	FIRE Eng Meeting	3/20/03	3/21/03
8	FIRE Physics Workshop	4/7/03	4/10/03
9			
10	FIRE Engineering Documentation Update	10/1/02	7/12/03
11			
12	FIRE Physics Documentation	10/1/02	8/11/03
13			
14	**FIRE Physics Validation Review**	9/10/03	

2002: Oct, Nov, Dec — 2003: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sept

FIRE Task Schedule FY 2003

	Activity Name	Start Date	Finish Date
1			
2	PVR	9/8/03	
3	Issue Report	7/11/03	
4			
5	INTEGRATION		
6	Establish Radial builds	11/6/02	
7	Initial Elevation	.1/18/02	12/10/02
8	Final Elevation	2/3/03	3/3/03
9			
10	KESSEL		
11	Plasma Surface	.1/18/02	
12	Flexability		
13	TSC Disruptions (2.14)		
14	PF Flexability	12/9/02	1/20/03
15			
16	PFC'S		
17	Divertor support	.2/11/02	1/6/03
18	Plasma Equilibrium	.1/14/02	2/17/03
19	Edge Modeling	12/9/02	3/18/03
20	Disruption Forces	1/7/03	5/7/03
21	Divertor Design	.2/17/02	5/16/03
22	Heat Flux Test	.1/15/02	3/7/03
23	Report	5/16/03	7/11/03
24			
25	VV		
26	Disruption Anal. (2.0)		
27	Divertor Support	1/6/03	1/31/03
28	Full Disruption Anal.	1/6/03	2/10/03
29	Port Geometry	.2/16/02	1/10/03
30	VV Model	1/31/03	3/3/03
31	Diagnostic integration	1/6/03	1/31/03
32	Port Plug Design	5/7/03	6/9/03
33			
34	TF		
35	PF/TF Elevation	.1/18/02	
36	Evaluate Edge Cooling	.0/23/02	2/3/03
37	TF Terminals	11/4/02	2/20/03
38			
39	PF		
40	PF Flexability Studies	.1/21/02	2/3/03
41	CS Design	.0/24/02	12/10/02
42			
43	DIAGNOSTICS		
44	Inboard Requirements	1/6/03	2/3/03
45	Plug Concept	4/3/03	5/5/03
46	Magnetic Diag. Design		
47	Diagnosic integration	1/6/03	1/31/03
48			
49	LH		
50	Antenna Configuration	1/9/03	2/3/03
51			
52	NEUTRONICS		
53	Model 2.14 m machine	11/8/02	2/3/03
54	One-D analysis		
55	For Diagnostics	.1/14/02	2/4/03
56	For Insulation	2/5/03	4/2/03
57			
58	REMOTE MAINENANCE		



Critical for FIRE to Incorporate Recommended Changes and modify cross-section drawings early in the fiscal year.

Critical Items of Broad Interest (FIRE, ITER, ARIES)

- Plasma Facing Components (Divertor and First Wall)
  - high power density
  - long pulse capability
  - low tritium retention
  - elm erosion
  - disruption survivability
  - maintainability
- Vacuum Vessel (blanket modules and shielding port plugs)
  - low activation ?
  - nuclear heating ---- blanket module test assemblies
  - disruptions
  - integrate with closely coupled control and stabilization coils
  - integration with diagnostics
- Plasma Heating, Current Drive and Fueling
  - development/design of ICRF, LHCD systems for BP scenarios
  - interface with fusion environment (esp. launchers)
- Diagnostics Development and Design Integration
  - new diagnostics for J(r), E(r), fluctuations, alpha particles
  - integration with fusion environment(eg radiation induced conductivity)

Summary

- Actions underway to respond to Snowmass and NSO PAC recommendations.

- Details of FIRE configuration are being updated in early FY 2003 to serve as basis for the Physics Validation Review.

- PFCs, First Wall and Vacuum vessel are critical items for FIRE (& BPs).

- Some reallocation of resources within FIRE are needed.