NCSX and MHH2 Reactor Assessments

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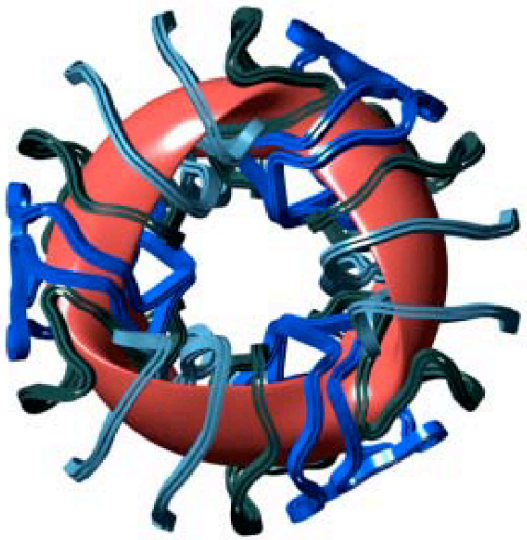
What's New Since Atlanta

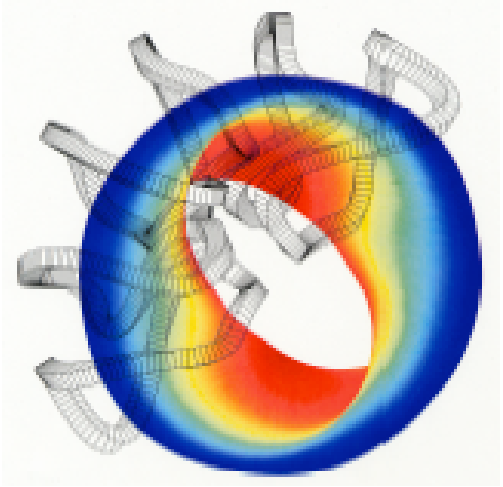
- Incorporated input from Atlanta meeting
- Improved parameters for Ku's NCSX-R configuration
- Analyzed Garabedian's MHH2-R configuration
- Initial look at extrapolating QPS to reactor size

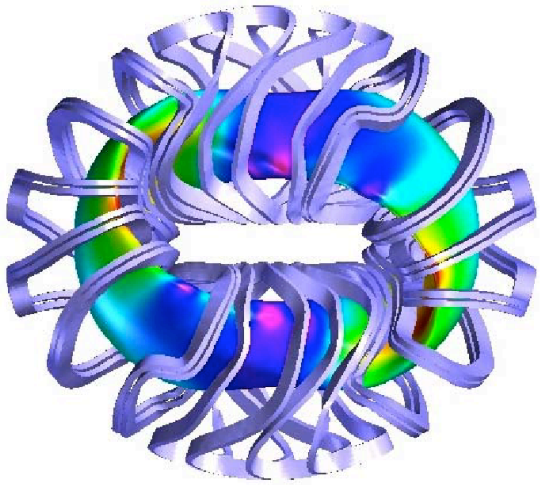
Topics

- Plasma and coil characterization
- Optimization assumptions, calculations
- NCSX-R, MHH2-R and QPS-r cases
- A case to explore engineering issues
- My questions
- Systems code input

Possible Reactor Configurations







- **NCSX-R**

quasi-axisymmetric

18 modular coils

ι_{ave} = 0.5, ι' = 0.6

- **MHH2-R**

quasi-axisymmetric

16 modular coils

ι_{ave} = 0.45, ι' = –0.22

- **QPS-r**

quasi-poloidal

20 modular coils

ι_{ave} = 0.3, ι' = 0.28

- **Except for MHH2-R, these configurations have been optimized for an experiment and *not* for a reactor!**

Configuration Characterization

	NCSX-R	MHH2-R	QPS-r
Plasma-coil aspect ratio $A_{\square} = \langle R \rangle / \square_{min}$	5.90	5.52	6.08
Min. coil-coil aspect ratio $A_{c\text{-}c} = \langle R \rangle / (c\text{-}c)_{min}$	10.1	13.3	10.1
B_0/B_{max} for R = 6.5 m, d = 0.3 m, k = 1	0.49	0.43	0.45
Plasma aspect ratio $A_p = \langle R \rangle / \langle a \rangle$	4.50	3.75	2.74
$\square$-particle loss (%)	30	30	25
$\langle \square_{limit} \rangle$ (%): infinite-n to finite-n modes	4.1 to 6	4 to 5?	2.5 to >5
Surface figure of merit $A_{\square}^2/A_p$	7.74	8.13	13.5

Reactor Parameter Selection

- **Minimize reactor core cost**
  - **Cost ~ blanket/shield + coils + vacuum vessel**
  - **Cost ~ surface areas, approx. ~ R^2**

- **Minimize R for a reactor -- small d, large k**
  - **$\langle R \rangle \geq A_{\iota}(t_{so+fw+sh+cc} + d/2k^{1/2})$**
  - **Min. coil-coil dist. $R/A_{c\text{-}c} - k^{1/2}d - 2(csth) \geq 0$**
    - **$A_{\iota} = \langle R \rangle / \iota_{min}$, $d = (cw \times cd)^{1/2}$, $k = cw/cd$**
    - **$t_{so+fw+sh+cc} = t_{Laila} - 0.1\ m = 0.95 + 0.0624\ ln(p_{n,wall}/2)$, csth = 1 cm**

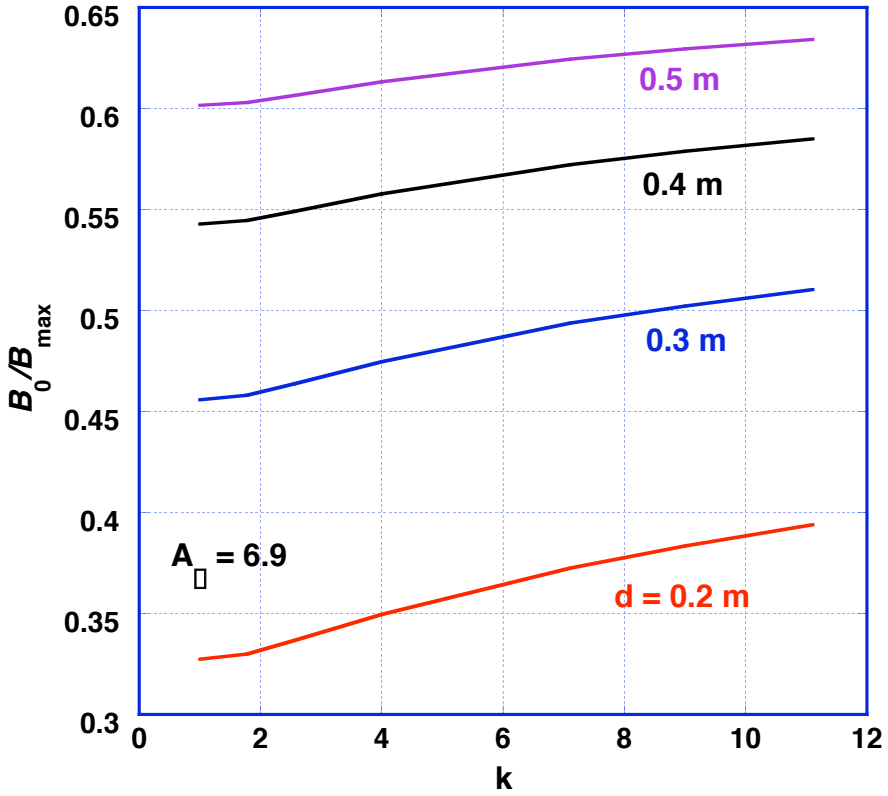
- **Maximize B_0 (minimizes ι)**
  - **$B_0(T) = 16\ B_0/B_{coil,max}(d,k)\ /(R/8.25)$ (for NCSX-R)**

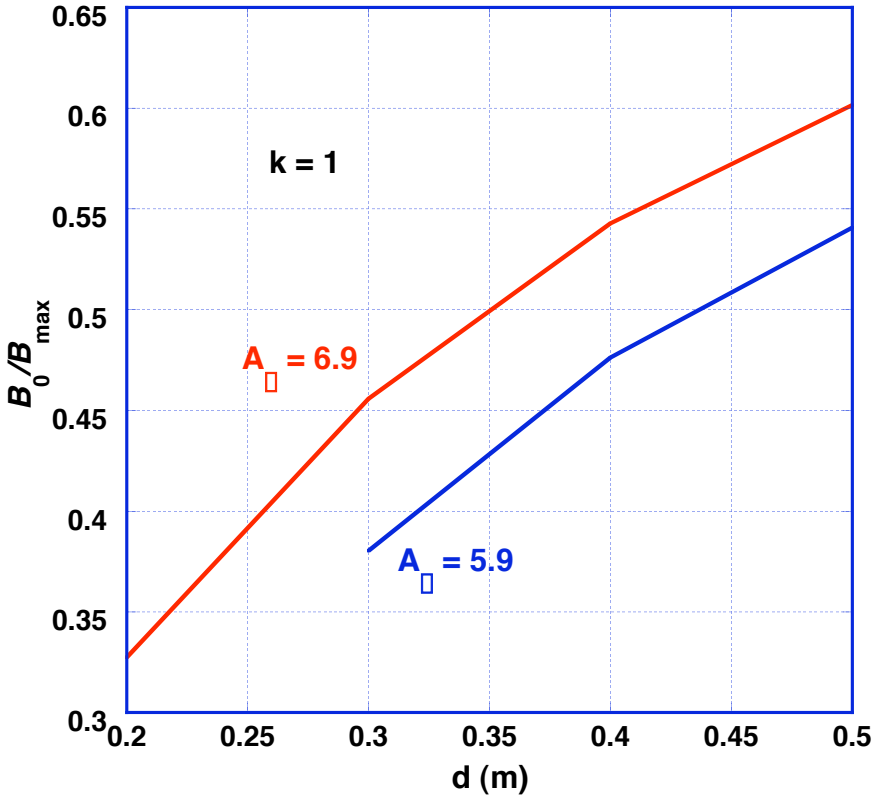
Check if Need to Increase R

- If $\beta > \beta_{limit}$: ($P_E \sim \beta^2 B_0^4 R^3$)
- If $j_{coil}(MA/m^2) = 13(B_0/5.3)(R/8.25)/d^2 > 330$ (or >110-135 for Nb_3Sn)
- Increase R by increasing d (increases B_0 & reduces k) but need to keep $B_{coil,max} < 16$ T
  - $B_{max} = (R/8.25)B_0 / \{B_0/B_{coil,max}(d,k)\}$

Maximum B_0 Determination

- B_0(T) = 16 B_0/B_{max}(d,k) /(R/8.25)
- B_0/B_{max}(d,k) from Ku (2/25/03 NCSX coil set)
- Normalize to B_0/B_{max}(d = 0.3 m, k =1) for each coil case and interpolate between d,k values





Physics Constraints

- **Beta limit**
  - Nominally set by linear infinite-*n* ballooning limit
  - However, limits for finite-*n* ballooning and external kink or vertical modes are more realistic
  - Use equilibrium beta limit instead?
- **Confinement multiplier H-ISS95**
  - H-ISS95 values up to 2.5 obtained in experiments
  - No deterioration seen at highest β values in experiments
  - Quasi-symmetry aiding rotation should help, so reasonable to assume H-ISS95 up to ~4?
- **Alpha particle losses: 10% loss vs 30% loss**
  - Small effect on parameters: β = 5% –> 4.4%, 16 T –> 15 T
  - *But*, factor of 3 reduction in high-energy flux to divertor
    - reduces blistering (a problem?)

NCSX-R Parameter Choices

Coil d	Coil k	R axis (m)	Max B axis	j (MA/m2)	c-c min	Wall load	Beta (%)	Cost factor
	1.00	6.39	5.18	252.87	0.41	4.27	9.04	0.59
	1.78	6.26	5.32	254.83	0.33	4.44	8.81	0.57
	2.56	6.19	5.49	260.05	0.27	4.54	8.42	0.56
	4.00	6.12	5.54	259.43	0.19	4.64	8.41	0.54
	7.11	6.06	6.21	287.83	0.05	4.74	6.80	0.53
0.2 m	8.41	6.04	6.35	293.59	0.00	4.76	6.52	0.53
	9.00	6.04	6.42	296.23	-0.02	4.77	6.41	0.53
0.227 m	6.84	6.09	6.89	249.07	-0.01	4.69	5.48	0.54
	1.00	6.53	6.44	205.55	0.38	4.09	5.67	0.62
	1.78	6.36	6.65	206.96	0.28	4.31	5.52	0.59
	2.56	6.28	6.85	210.36	0.20	4.42	5.31	0.57
	4.00	6.19	7.16	216.95	0.09	4.54	4.95	0.56
0.25 m	5.53	6.14	7.40	222.55	0.00	4.61	4.69	0.55
	7.11	6.11	7.64	228.57	-0.08	4.66	4.43	0.54
0.275 m	4.77	6.19	7.87	197.23	-0.01	4.54	4.09	0.56
	1.00	6.66	7.59	171.64	0.34	3.93	3.96	0.64
	1.78	6.46	7.86	172.45	0.22	4.18	3.86	0.61
	2.56	6.36	8.08	174.60	0.13	4.31	3.74	0.59
0.3 m	4.00	6.26	8.40	178.75	0.00	4.44	3.54	0.57
	7.11	6.16	8.88	186.01	-0.21	4.59	3.24	0.55
	1.00	6.92	9.14	120.88	0.27	3.64	2.57	0.70
	1.78	6.66	9.53	121.23	0.11	3.93	2.51	0.64
0.4 m	2.47	6.53	9.79	122.22	0.00	4.08	2.45	0.62
	2.56	6.53	9.81	122.31	-0.01	4.09	2.44	0.62

MHH2-R Parameter Choices

Coil d	Coil k	R axis (m)	Max B axis	j (MA/m2)	c-c min	Wall load	Beta (%)	Cost factor
	1.00	5.93	4.85	152.49	0.18	4.32	9.68	0.75
	1.78	5.92	4.89	153.53	0.09	4.33	9.55	0.75
0.25 m	2.56	5.84	5.05	156.06	0.02	4.46	9.17	0.73
	4.00	5.58	5.44	160.95	-0.10	4.86	8.44	0.67
	1.00	6.07	5.70	127.33	0.14	4.13	6.77	0.79
0.3 m	1.78	6.03	5.77	127.93	0.03	4.18	6.69	0.77
	2.56	5.76	6.11	129.53	-0.07	4.58	6.38	0.71
	1.00	6.20	6.20	104.02	0.10	3.94	5.54	0.82
0.35 m	1.61	6.17	6.26	104.36	0.00	3.99	5.49	0.81
	1.78	6.13	6.30	104.43	-0.02	4.04	5.46	0.80
	2.56	5.84	6.68	105.53	-0.14	4.45	5.22	0.73
	1.00	6.48	6.69	89.68	0.07	3.62	4.47	0.90
0.4 m	1.31	6.34	6.84	89.81	0.00	3.78	4.41	0.86
	1.78	6.07	7.16	89.94	-0.10	4.13	4.30	0.79

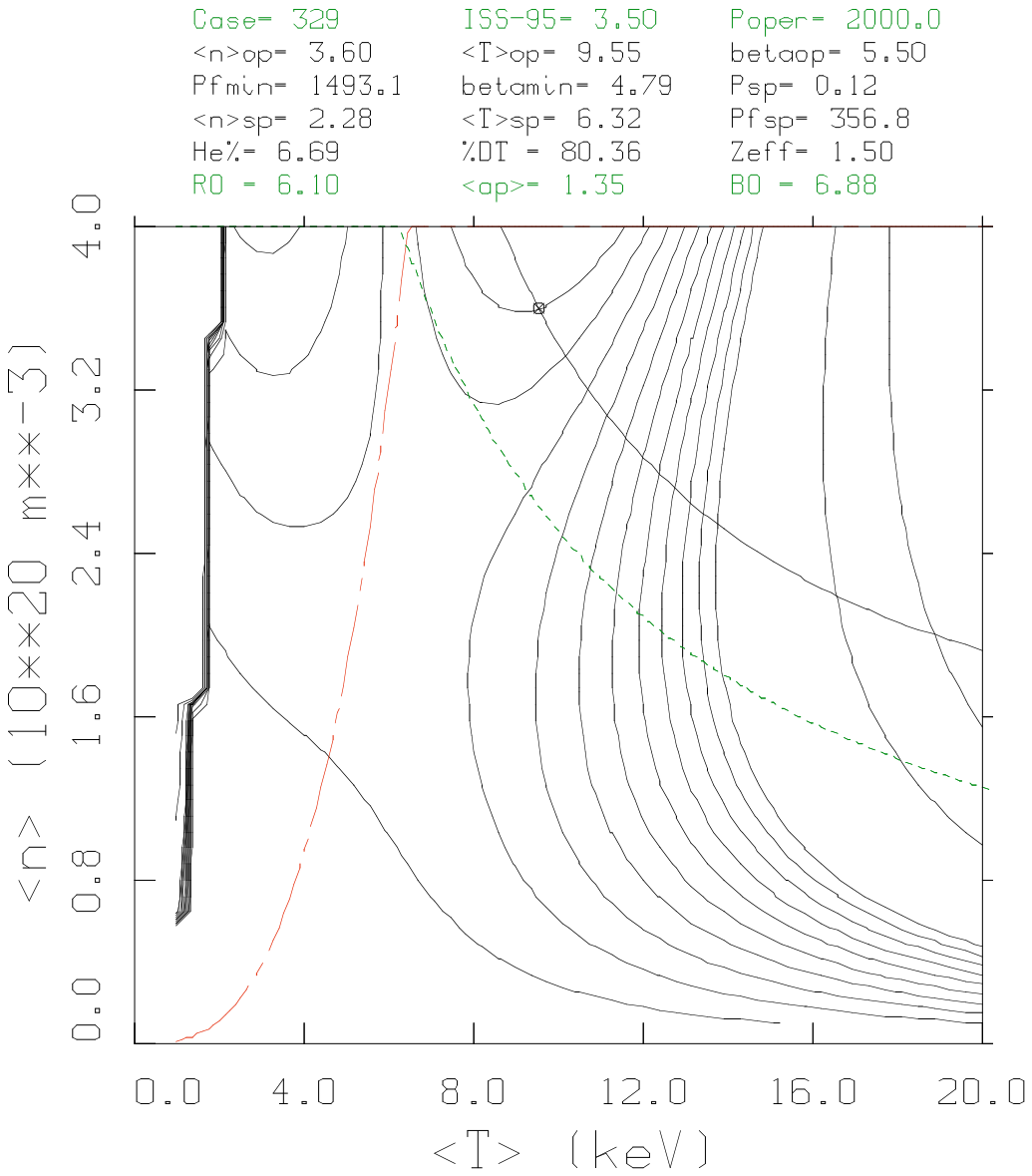
QPS-r Parameter Choices

	coil k	R axis (m)	Max B axis	j (MA/m2)	c-c min	Wall load	Beta	Cost factor
	1.00	6.53	4.41	144.78	0.37	3.57	7.41	1.25
	1.78	6.52	4.44	145.78	0.29	3.58	7.31	1.24
	2.56	6.43	4.58	148.17	0.21	3.69	7.02	1.21
	4.00	6.15	4.94	152.81	0.09	4.02	6.46	1.11
0.25 m	5.53	6.10	5.11	156.76	-0.01	4.10	6.11	1.08
	7.11	6.06	5.28	161.00	-0.09	4.15	5.77	1.07
	1.00	6.68	5.18	120.90	0.34	3.41	5.19	1.30
	1.78	6.64	5.24	121.47	0.23	3.46	5.12	1.29
	2.56	6.34	5.55	122.99	0.12	3.79	4.88	1.17
0.3 m	4.00	6.38	5.65	125.91	0.01	3.74	4.67	1.19
	7.11	6.11	6.13	131.02	-0.22	4.07	4.22	1.09
	1.00	6.84	5.63	98.76	0.30	3.26	4.24	1.36
	1.61	6.79	5.68	99.09	0.21	3.30	4.20	1.35
	1.78	6.75	5.72	99.15	0.18	3.34	4.18	1.33
	2.56	6.56	5.95	100.20	0.07	3.54	4.04	1.26
0.35 m	4.00	6.30	6.32	102.22	-0.10	3.83	3.80	1.16
	1.00	7.14	6.07	85.14	0.28	2.99	3.42	1.49
	1.31	6.99	6.21	85.27	0.21	3.12	3.37	1.42
	1.78	6.68	6.50	85.39	0.11	3.41	3.29	1.30
0.4 m	2.56	6.53	6.71	86.15	-0.02	3.57	3.19	1.25
	4.00	6.38	6.98	87.52	-0.19	3.74	3.06	1.19
	1.00	7.29	6.75	61.88	0.20	2.87	2.68	1.55
0.5 m	1.78	6.91	7.14	62.04	-0.01	3.19	2.60	1.39
	2.56	6.72	7.38	62.40	-0.16	3.37	2.53	1.32

Configuration Comparisons

	NCSX-R	MHH2-R	QPS-r
Average major radius (m)	6.09	6.17	6.38
Average magnetic field on axis (T)	6.89	6.26	5.65
Volume-average beta (%)	5.50	5.44	4.67
ISS-95 confinement multiplier	3.50	3.40	3.65

NCSX-R Reference Case



Questions

- **Beta limit = 4%, 5%, 6%? Use equilibrium limit instead of linear infinite-n ballooning?**
- **Maximum H-ISS95 = 4 OK? typically ~3.5**
- **B_{max} on coils = 16 T? Prefer less?**
  lower B_{max} is an option at larger R
- **1 cm coil side case thickness OK?**
- **High-T superconductor or Nb_3Sn?**
  Nb_3Sn is an option for MHH2-R
- **Divertor geometry?? -- affects everything!**
- **Devote effort to reactor configuration optimization?**

Systems Code Input

- Have information on blanket/shield costing
- Need Bromberg's input for coil costing
- Need to develop analytic expression for $B_{max}(d,k)/B_0$
- Need to decide how to treat the divertor issue

Summary

- **Improved reactor parameters for 2 cases**
  - **Ku's 8/1 coil configuration**
  - **Garabedian's MHH2 configuration**
- **Facts in hand to choose a case for *exploring engineering issues* but *not* a final candidate**
- **Started on systems code input**