Status of ARIES Compact Stellarator Reactor Parameters

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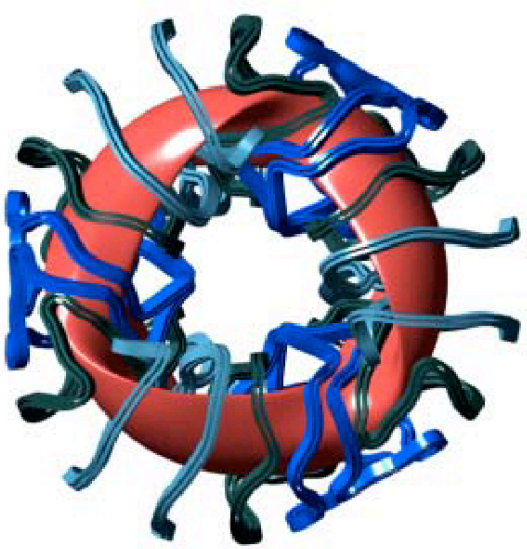
ornl

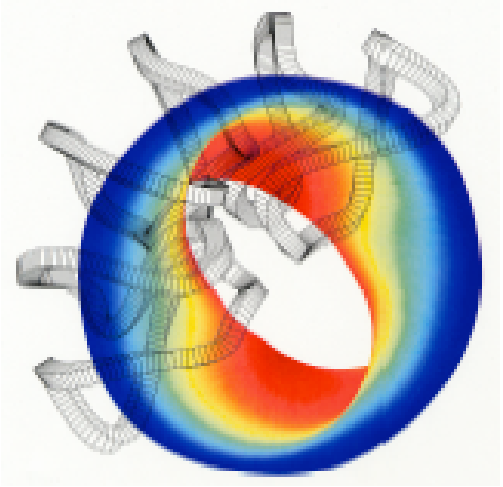
UT-BATTELLE

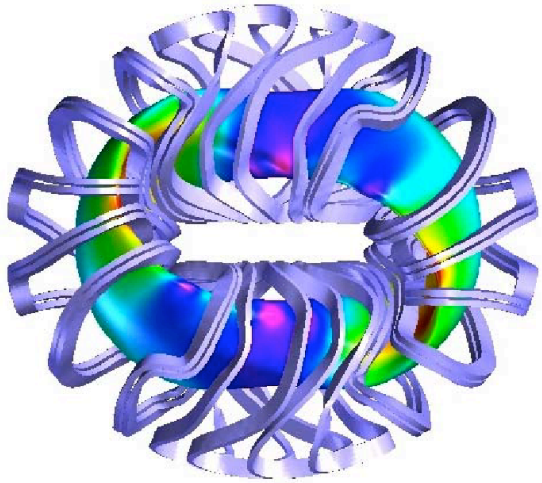
Topics

- Plasma and coil characterization
- Optimization assumptions, calculations
- NCSX-R, MHH2-R and QPS-r cases
- Choices

Possible Reactor Configurations







- **NCSX-R**

quasi-axisymmetric

18 modular coils

$\langle\beta\rangle_{ave}$ = 0.5, $\beta(0)$ = 0.6

- **MHH2-R**

quasi-axisymmetric

16 modular coils

$\langle\beta\rangle_{ave}$ = 0.45, $\beta(0)$ = –0.22

- **QPS-r**

quasi-poloidal

20 modular coils

$\langle\beta\rangle_{ave}$ = 0.3, $\beta(0)$ = 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

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. $R/A_{c\text{-}c} - k^{1/2}d - 2(csth) \geq 0$**
    - **$A_{\iota} = \langle R \rangle/\iota_{min}$, $d = (cw \times cd)^{1/2}$, $k = cw/cd$**
    - **$t_{so+fw+sh+cc} = 0.95 + 0.0624\, ln(p_{n,wall}/2)$, csth = 1 cm**

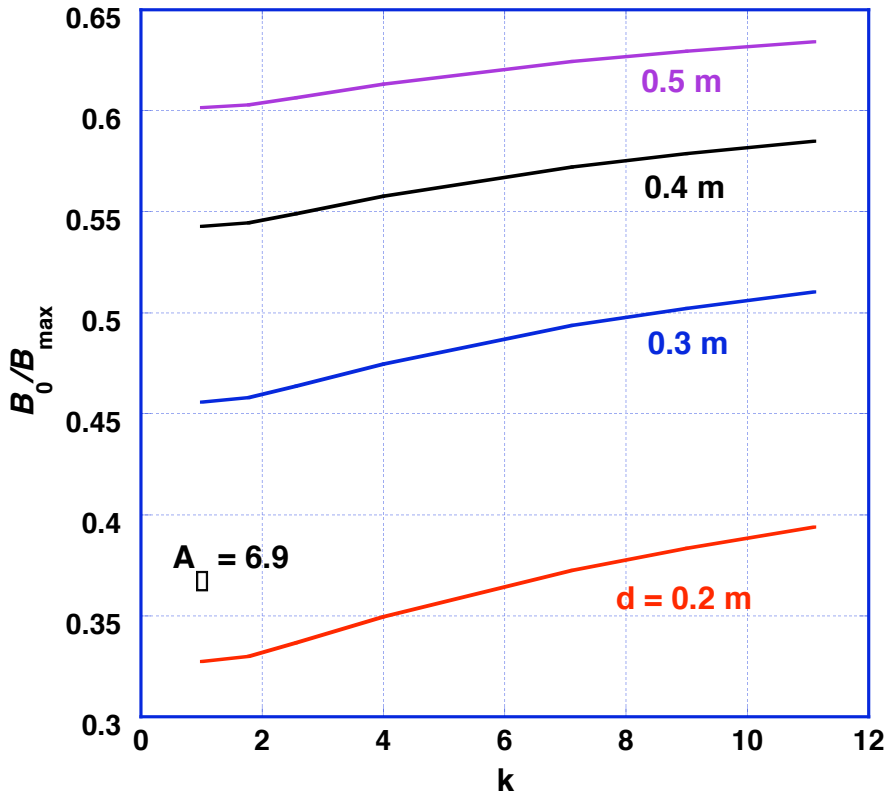
- **Maximize B_0 (minimizes ι)**
  - **B_0(T) = 16 $B_0/B_{coil,max}(d,k)$ /(R/8.25) (for NCSX-R)**

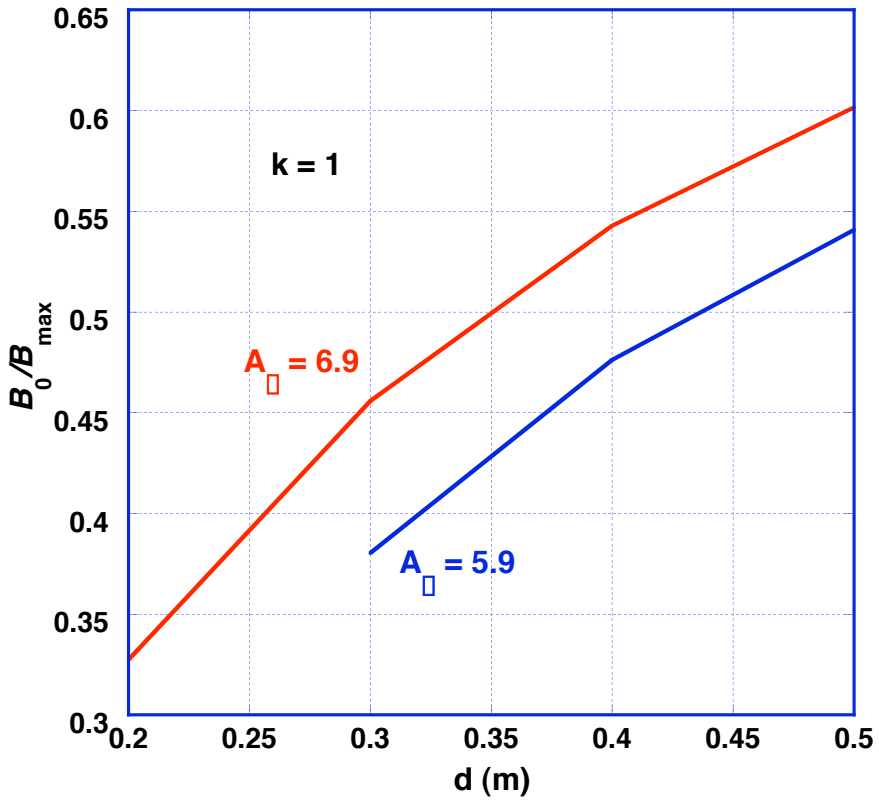
Check if Need to Increase R

- If $\beta > \beta_{limit}$: ($P_E \sim \beta^2 B_0^4 R^3$)
- If $j_{coil}(\mathrm{MA/m^2}) = 13(B_0/5.3)(R/8.25)/d^2 > 330$ (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?)

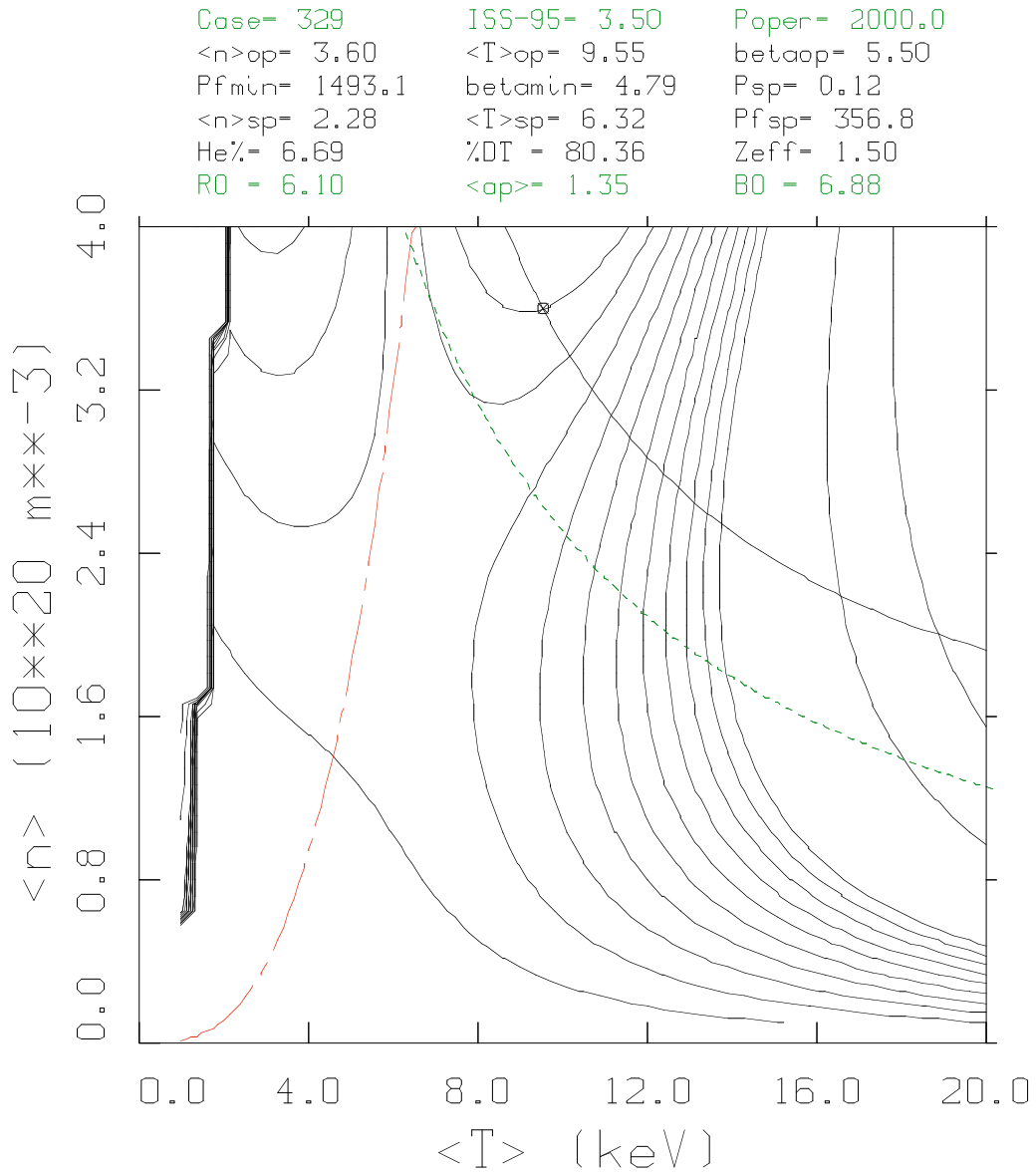
NCSX-R Parameter Selection

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

Configuration Comparisons

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

An NCSX-R Reference Case



Choices

- **Beta limit = 4%, 5%, 6%? Use equilibrium limit instead of linear infinite-*n* ballooning**
- **Maximum H-ISS95 = 4 typically ~3.5**
- **B_{max} on coils = 16 T**
  lower B_{max} is an option at larger R
- **1 cm coil side case thickness**
- **High-T superconductor, Nb_3Sn, NbTi**
- **Impurity radiation to reduce power to divertor**
- **Divertor geometry -- affects everything!**

Summary

- **Improved reactor parameters for 2 cases**
  - **Ku's NCSX coil configuration**
  - Garabedian's MHH2 configuration
- **Facts in hand to choose a case for *exploring engineering issues* but *not* a final candidate**