ASSESSMENT OF THE ACTINIDE BURN PERFORMANCE OF A=2 TOROIDAL DEVICES

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Presented at the
International Workshop on Blanket and Fusion Concepts
for Transmutation of Actinides
San Diego, California

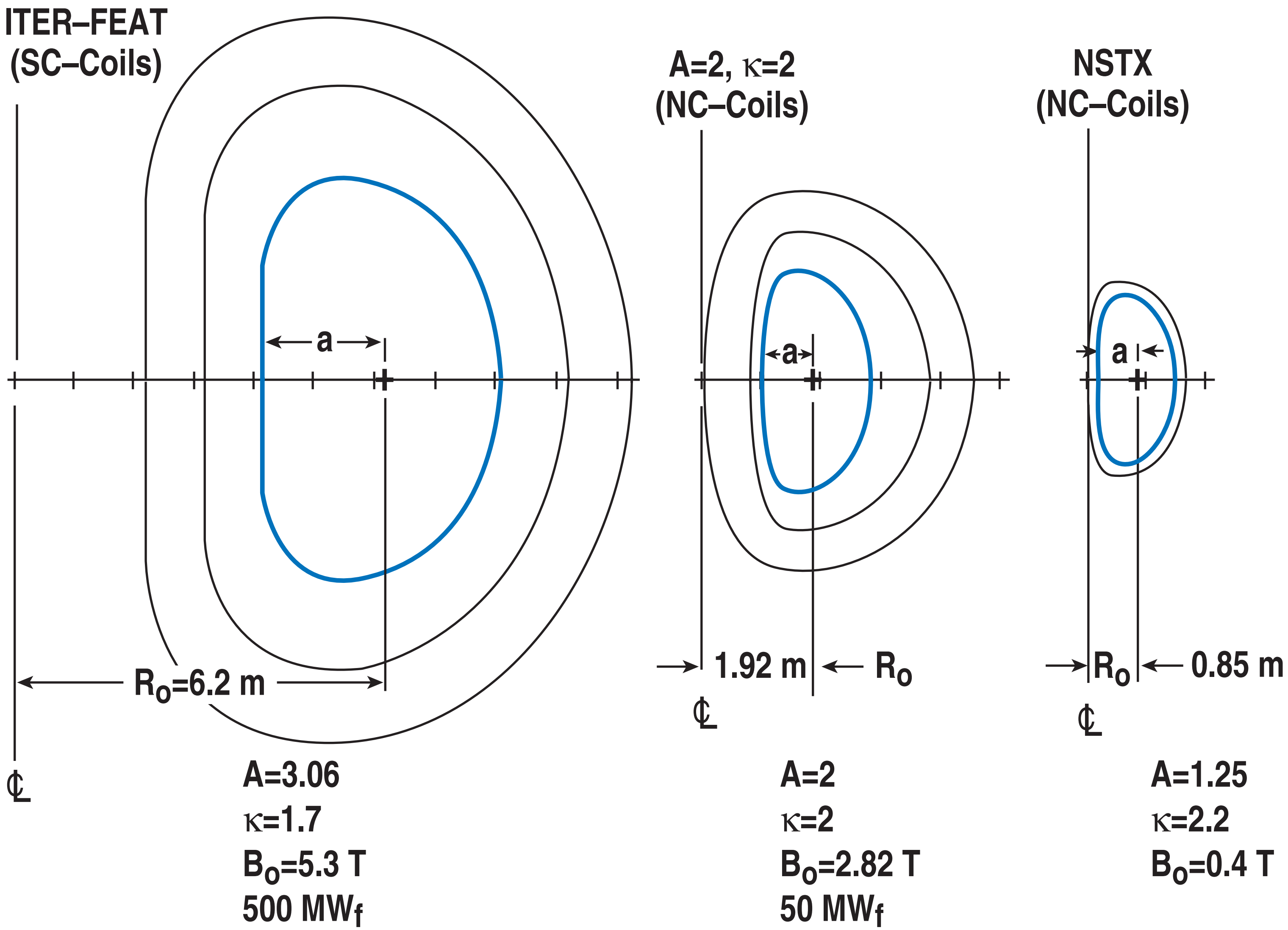
March 21–23, 2001

GENERAL ATOMICS

OUTLINE

- **Choice of Aspect Ratio, A (Optimum @ 2?)**
  - Resulted from the evaluation of NC and SC power and testing reactors as a function of A and elongation, κ
    - ★ MHD basis
    - ★ Systems study calculations
    - ★ Results leading to A=2
- **Actinide burn evaluation for NC, A=2, κ=2 and 3, fusion power = 50, 100, and 200 MW, and devices at different blanket energy multiplication, EM**
  - Major radius
  - Neutron wall loading
  - Re-circulating power
  - Net electrical power production
  - Capital cost
  - COE
  - Power density
  - Conversion rate
  - The value of conversion rate
  - Pure fusion designs
- **Conclusions**

TOROIDAL DEVICES WITH DIFFERENT ASPECT RATIOS ($A=R_O/a$)



GENERAL ATOMICS

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CHOICE OF ASPECT RATIO

- At recent IAEA meeting we presented a paper on “Toroidal Reactor Designs as a Function of Aspect Ratio and Elongation” [1]

- Do power reactors optimize at lower aspect ratio, A, as indicated by earlier systems studies?

- We evaluated the superconducting coil (SC) and normal conducting coil (NC) power and testing reactors as a function of A from 1.2 to 6 and elongation κ = 1.5, 2 and 3

[1] C.P.C. Wong, J. Wesley, R.D. Stambaugh, E.T. Cheng, “Toroidal Reactor Designs as a Function of Aspect Ratio and Elongation,” Proc. 18th IAEA Fusion Energy Conference, October 4–10, 2000, Sorrento, Italy

MHD STABILITY BASIS

- We used the extended equilibria of $1.2 < A < 6$ and $\kappa = 1, 2,$ and 3
  - For the range of A from 1.2 to 3, R.L. Miller [1] found plasma equilibria that are stable to infinite-n ballooning and, with assumed wall stabilization to low-n kink modes at a bootstrap fraction of 99% for $\kappa = 1.5, 2,$ and 3
  - We parameterized these results to perform parametric investigations of A and κ variation with our systems model
  - For our calculations, we used a bootstrap fraction of 90% to determine β_N, β_T, and β_p and estimated the re-circulating power for normal and superconducting coil designs including neutral beam current drive

[1] R.L. Miller, *et al.*, "Stable Bootstrap-Current Drive Equilibrium for Low Aspect Ratio Tokamaks," Proc. ISPP-17 Workshop on Theory of Fusion Plasmas, August 26–31, 1996, Varenna

METHOD OF SYSTEMS CALCULATIONS

- **A systems study including physics, engineering, costings, and with necessary design constraints**
  - Starts with the inboard toroidal field (TF) coil radial build, Jc of central column, A, κ, plasma profiles, and δ_x (standoff distance between the coil and the plasma), β_N can be calculated
  - Bo, β_T, and β_p can be calculated with reactor geometry
  - n_{DT} and fusion power can be calculated
  - Electrical power and neutron wall loading (Γ_n) are determined iteratively
  - COE and capital cost can be estimated

The power reactor costing

★ ARIES systems code, based on 1992$

The test reactor costing

★ ITER-FDR design, based on 1999$

RESULTS OF SYSTEM STUDIES

- An intermediate-A NC design with high elongation could provide scientific and engineering data to support future SC or NC reactors development

  – COE of SC power reactor is lower than NC power reactors

  – NC and SC reactor designs have minimum COE towards lower A~2. Higher κ allows broader minimum

  – Captial cost of NC test reactors, for similar fusion power, is significantly lower than equivalent SC designs because of smaller inboard standoff distance

  – A NC test reactor at A~2 and κ~3 could produce 200 MW fusion power at 1.23 MW/m^2 average neutron wall loading at a total capital cost of ~$654M

  – This device could also be a toroidal device for early application of fusion neutrons and burn ~1270 kg of actinide per full power year

PARAMETERS OF INTEREST

- Therefore it would be interesting to investigate the estimated actinide burn rate of A=2 devices for κ=2 and 3 and for fusion power output at 50, 100, and 200 MW, represented by blanket energy multiplication values, EM [1]

- Lower elongation could indicate more ease in maintaining plasma stability

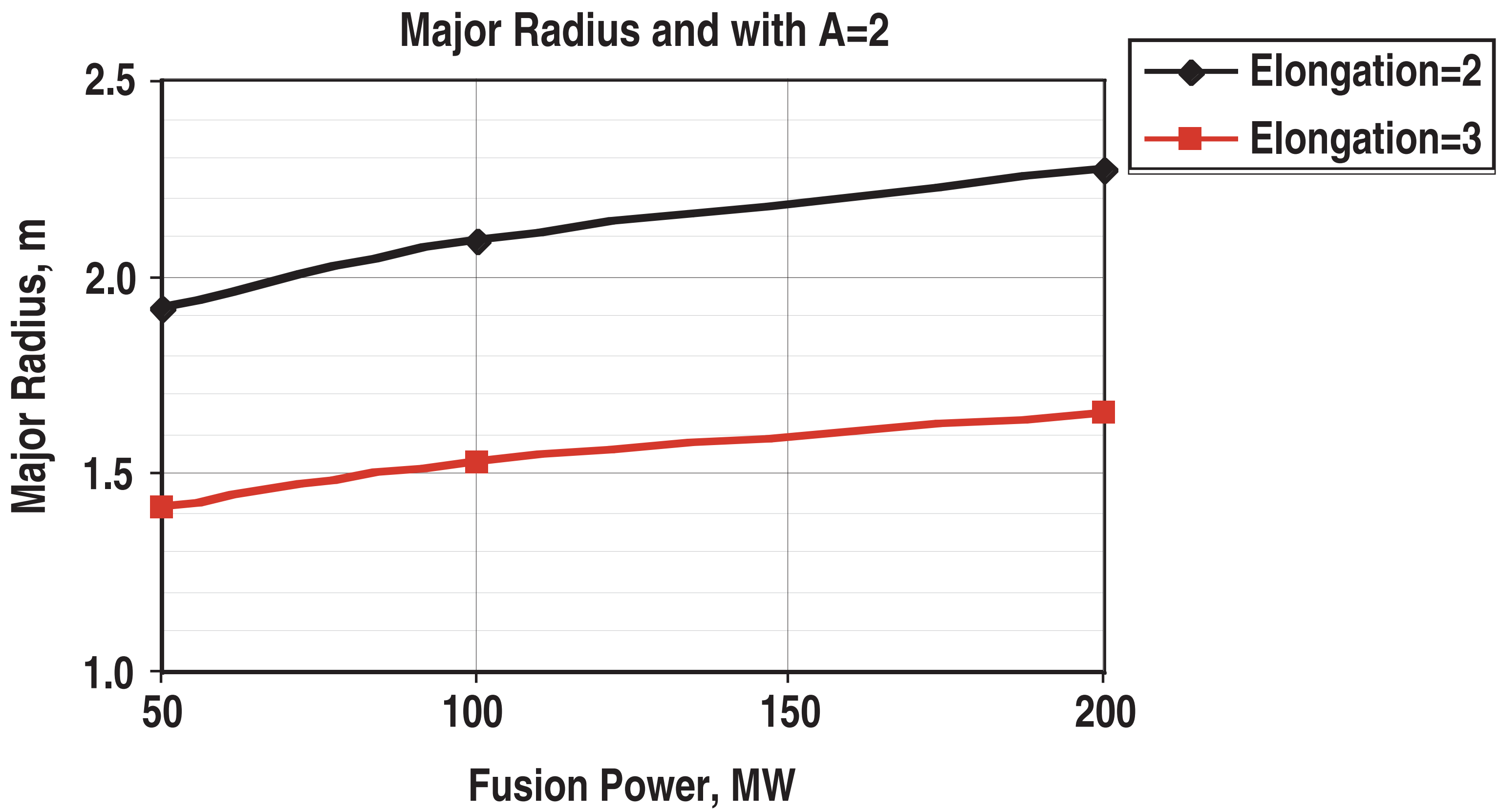
- The volumetric power density similar to LMFBR, from 300–600 MW/m^3 is used to indicate the credible regime of blanket thermal designs

[1] EM is defined as the energy multiplication over the energy of 14 MeV neutrons, and the actinide burn rate conversion is assumed to be: 1000 kg burn/year at 3 GWth

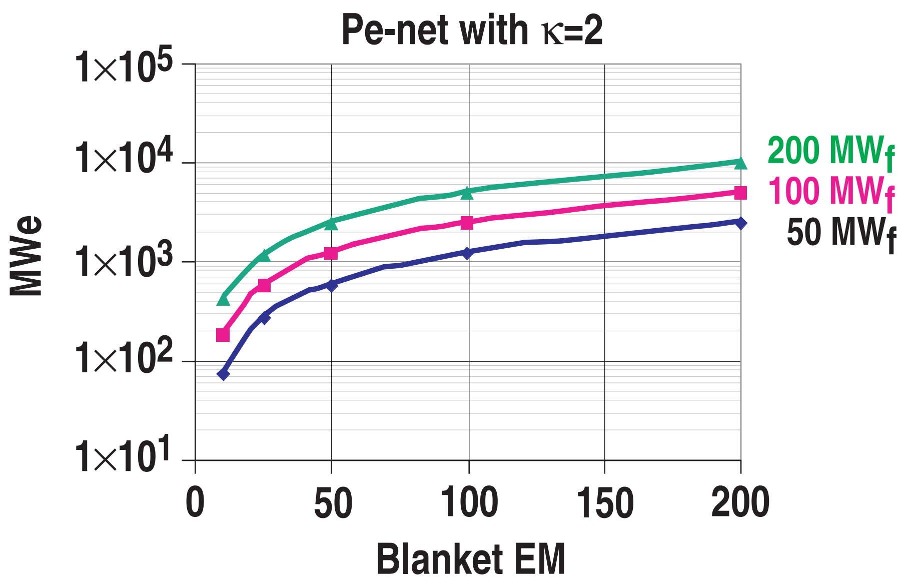
INPUT PARAMETERS FOR NORMAL CONDUCTING, A=2 ACTINIDE BURN DEVICES

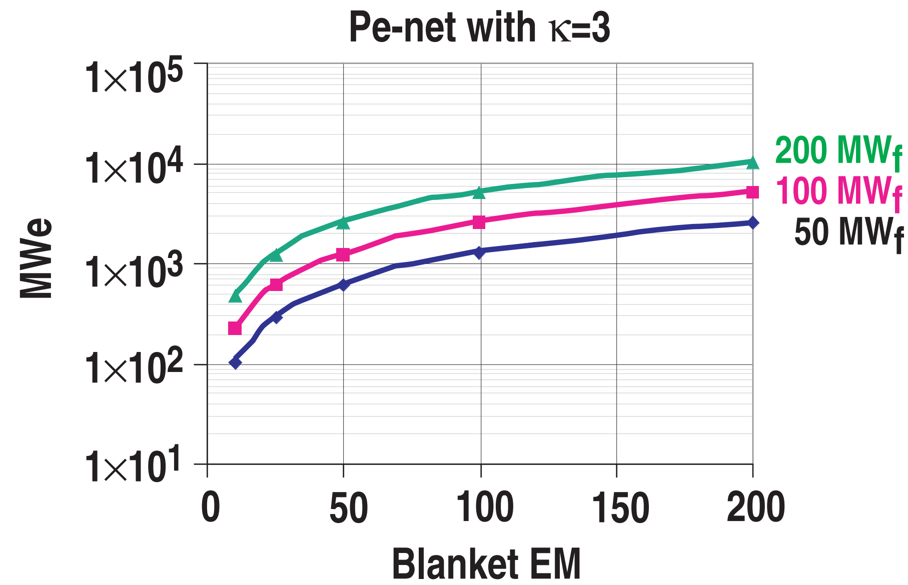
TF central column, Jc, MA/m^2	15.4
Number of TF coils	12
Outboard TF coil leg thickness, m	0.7
Inboard shield thickness, m	0.1
Outboard blanket thickness, m	0.8
Outboard shield thickness, m	0.2
Coil water coolant volume fraction	0.15
Coil water T_{in}/T_{out} (°C/°C)	30/50
Central column taper	1.5
Thermal conversion efficiency, %	33
Material fluence limit, MW · y/m^2	15

WE ARE INVESTIGATING RELATIVELY SMALL TOROIDAL DEVICES



ELECTRICAL POWER OUTPUT IS NOT SENSITIVE TO ELONGATION





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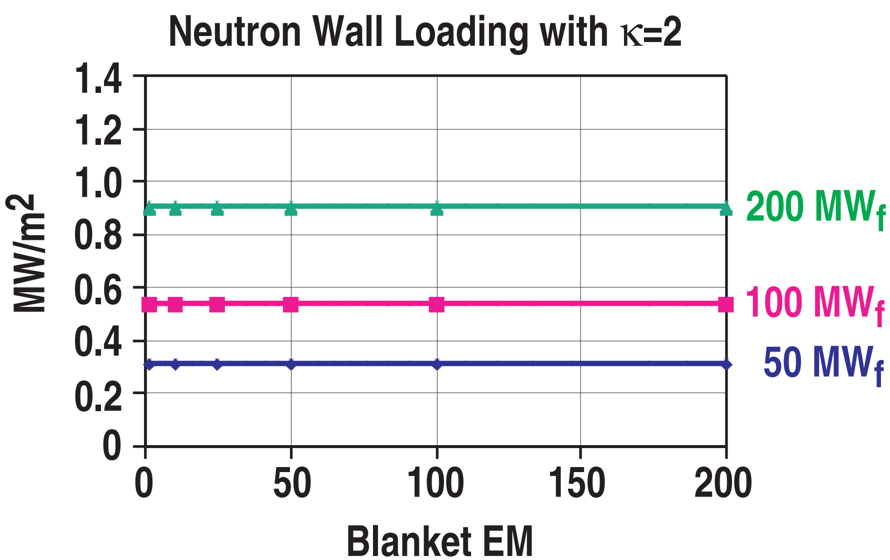
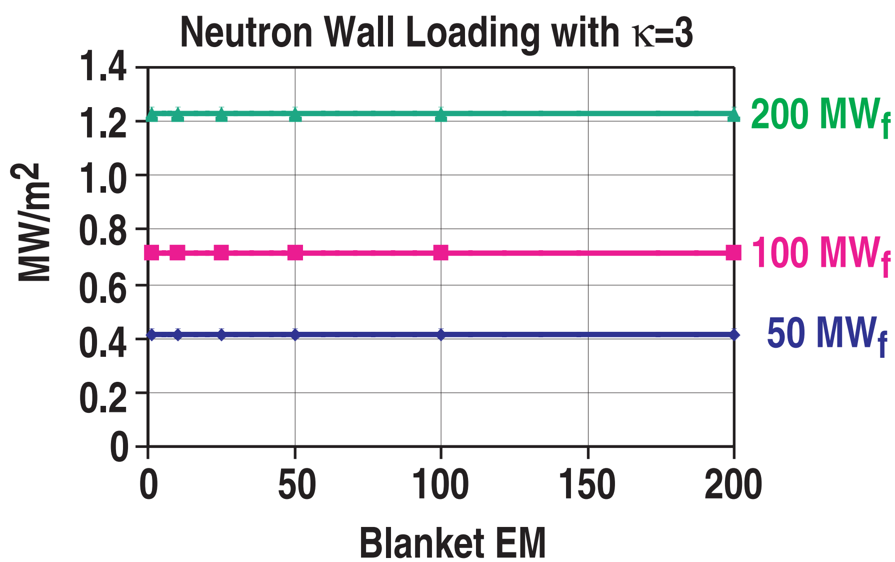
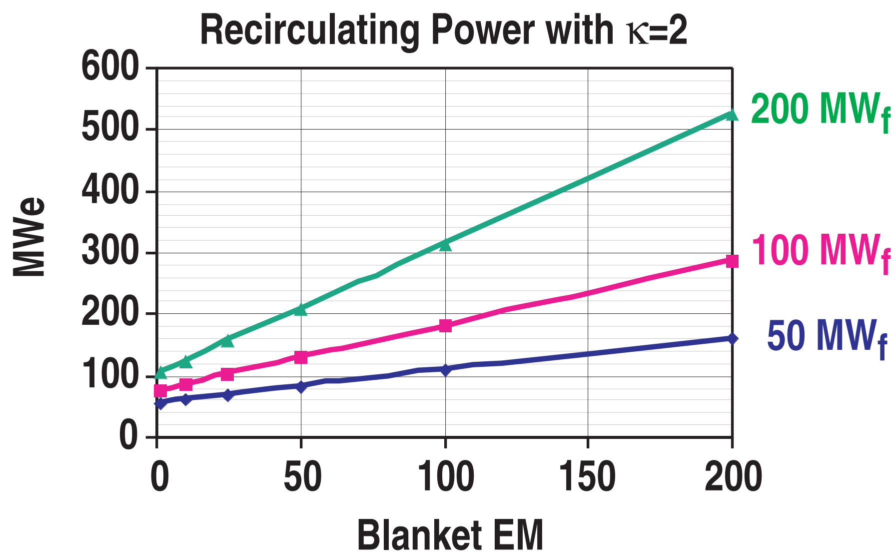
GENERAL ATOMICS

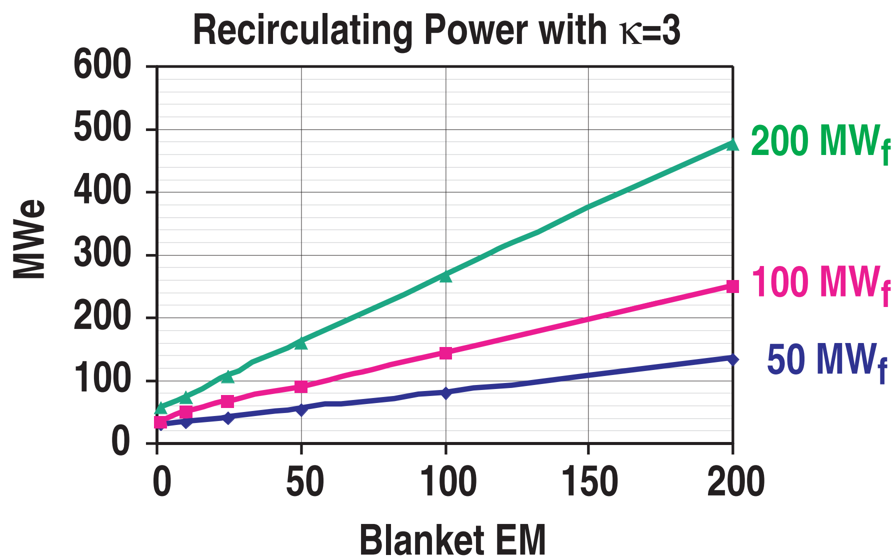
HIGHER ELONGATION LEADS TO HIGHER AVERAGE NEUTRON WALL LOADING





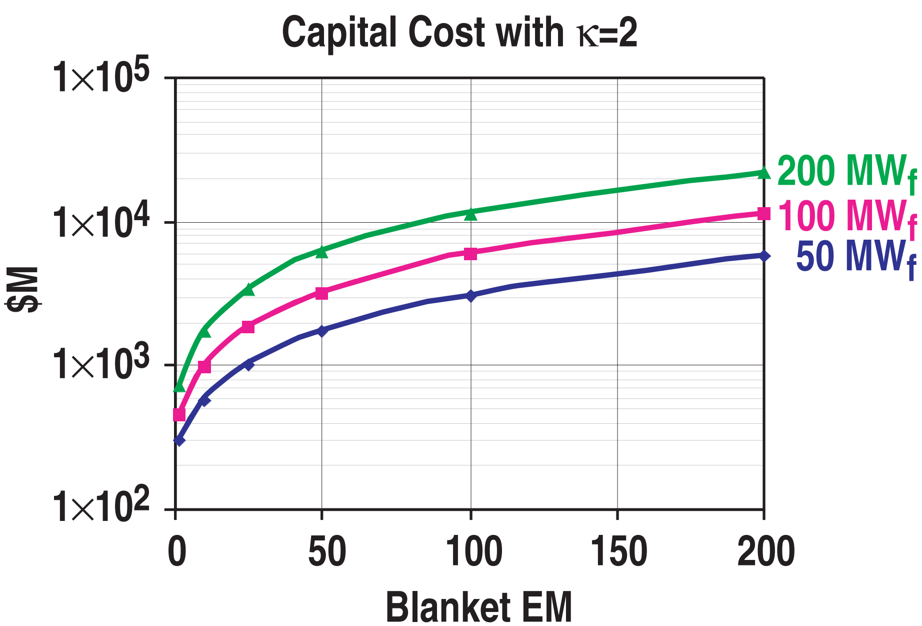
HIGHER ELONGATION LEADS TO LOWER RECIRCULATING POWER

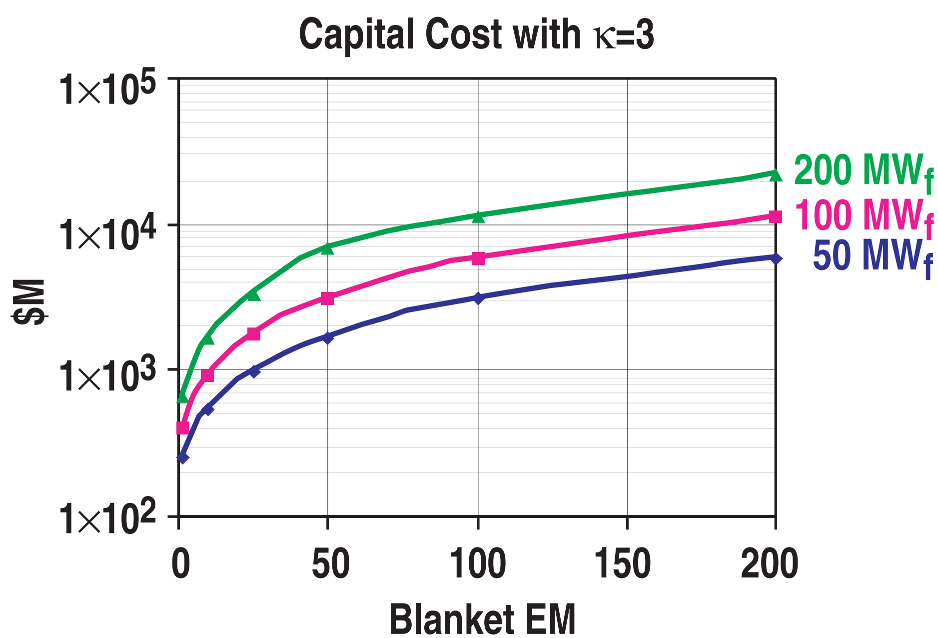




GENERAL ATOMICS

DEVICE CAPITAL COST* IS NOT SENSITIVE TO ELONGATION





* Not including fission related costs

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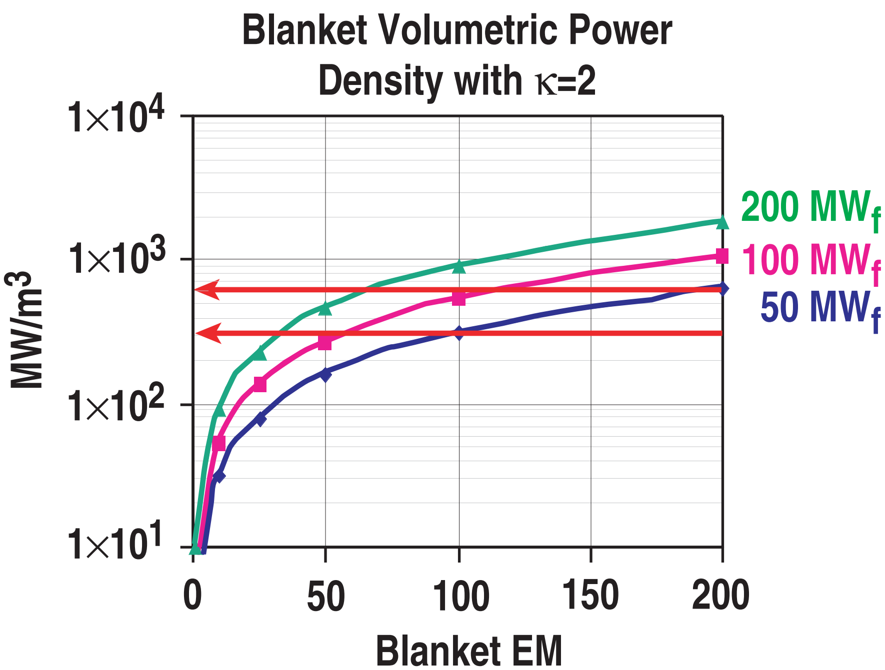
GENERAL ATOMICS

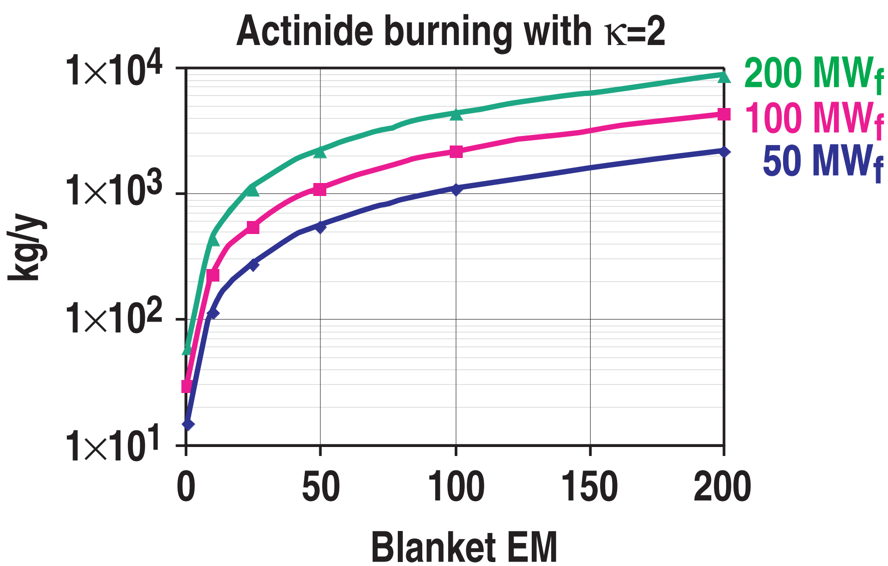
BLANKET POWER DENSITY CAN BE USED TO DEFINE OPERATION RANGE OF BLANKET EM

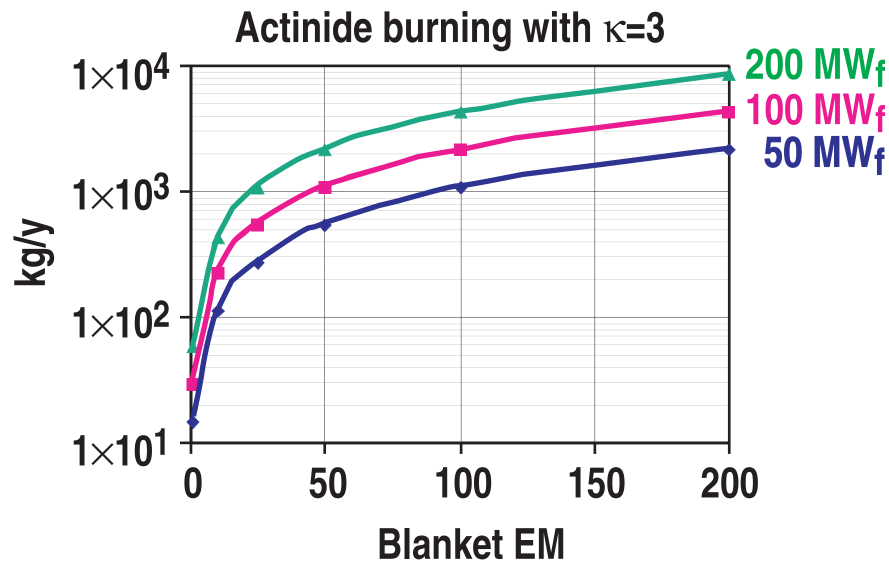
(LMFBR Q‴ RANGE: 300–600 MW/m^3)



GENERAL ATOMICS

ACTINIDE BURN RATE CAN BE DESIGNED TO THE RANGE OF 1000 – 3000 kg/Y WITH A=2, AND ELONGATION = 2 OR 3 DEVICES





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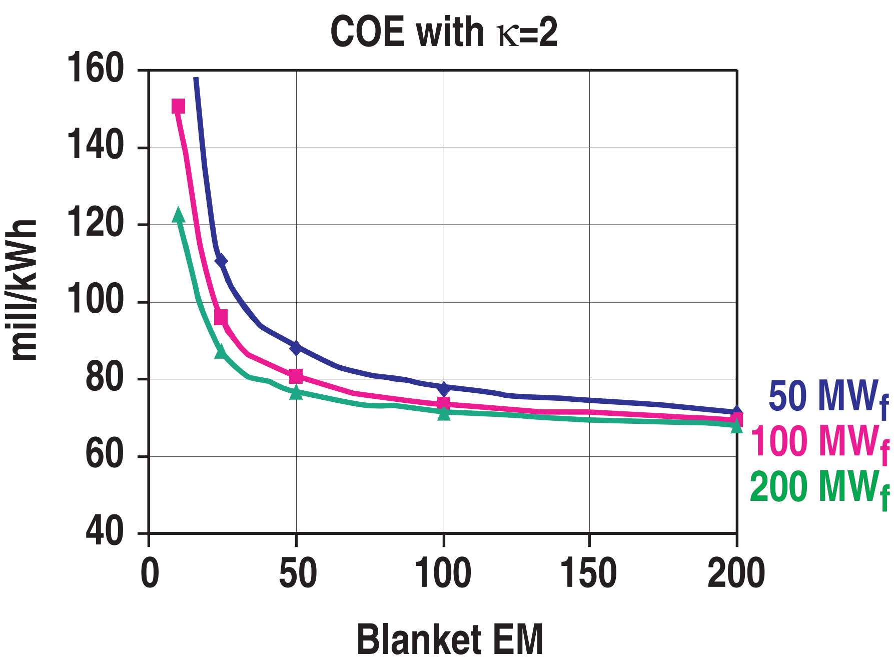
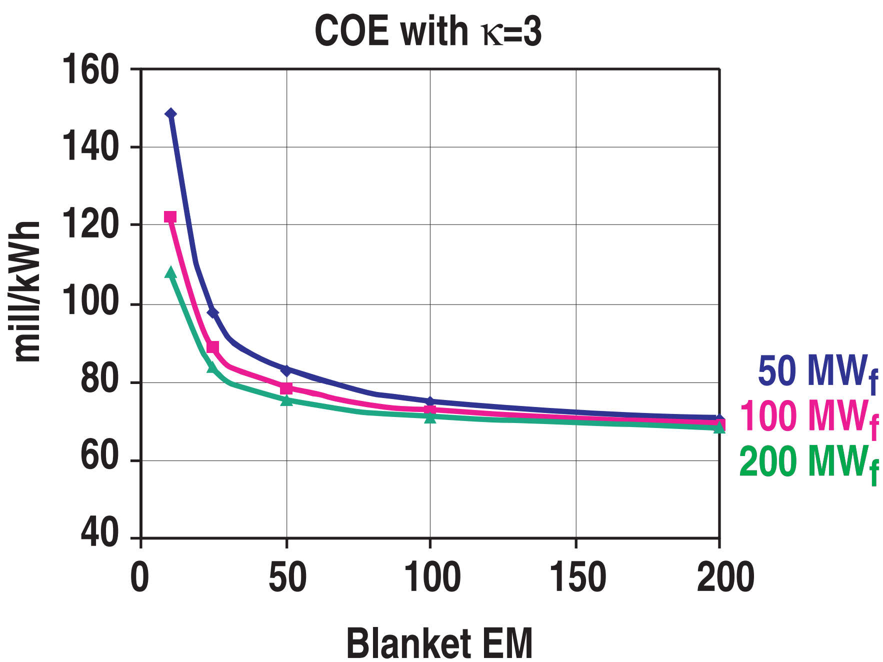
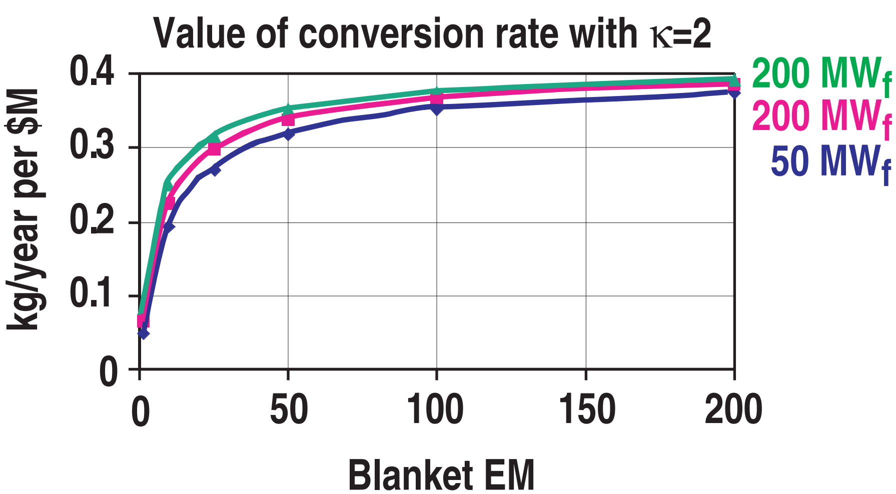
GENERAL ATOMICS

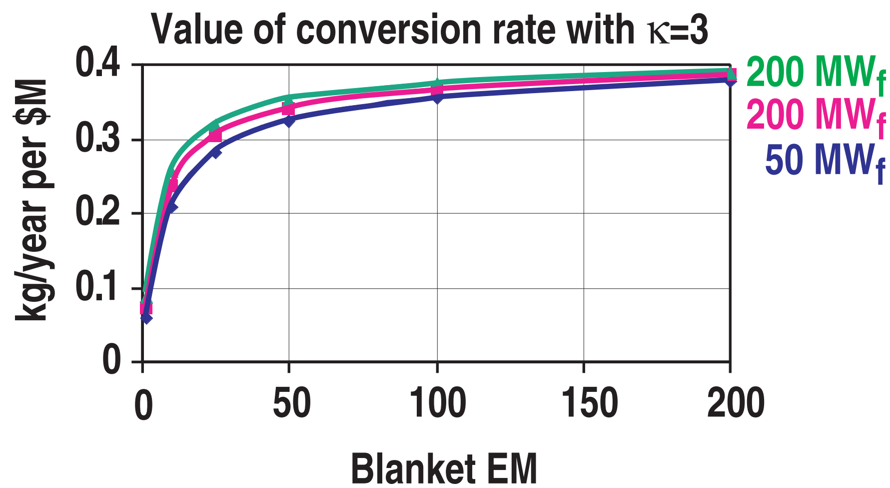
- COE converges at higher blanket EM and levels for EM > 100
- COE is lower at higher elongation and higher power output





THE VALUE OF ACTINIDE BURN RATE, (kg/YEAR PER $M CAPITAL COST) LEVELS OFF FOR BLANKET M>100 TO ABOUT 0.38 kg/YEAR PER $M





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GENERAL ATOMICS

A LOW FUSION POWER 50 MW TOROIDAL DEVICE AT A=2 and κ=2 COULD BE TURNED INTO A VERY EFFICIENT ACTINIDE BURNER

Actinide burn rate kg/year

- (Conversion factor @ 1000 kg burn/year at 3 GWth and including the estimated impact from availability, normalized to 75% at Γn = 4 MW/m^2)

	κ = 2		κ = 3	
P_{fusion}/Q'''	300 MW/m^3	600 MW/m^3	300 MW/m^3	600 MW/m^3
50 MW	1000 (M=100)	2000 (M=200)	750 (M=70)	1400 (M=155)
100 MW	1200 (M=51.5)	2500 (M=1300)	1000 (M=45)	1800 (M=80)
200 MW	1400 (M=30)	3000 (M=65)	1000 (M=20)	2000 (M=70)

SELECTED DESIGN PARAMETERS FOR NORMAL CONDUCTING COIL, A=2 PURE FUSION DEVICES

	1	2	3	4	5	6
κ	2	2	2	3	3	3
P_{fusion}, MW	50	100	200	50	100	200
R_o, m	1.92	2.09	2.274	1.42	1.53	1.66
Bootstrap Fraction	0.9	0.9	0.9	0.9	0.9	0.9
n shape factor	0.25	0.25	0.25	0.25	0.25	0.25
T shape factor	0.25	0.25	0.25	0.25	0.25	0.25
R_{coil}, m	0.812	0.895	0.987	0.558	0.615	0.678
B_o, T	2.82	3.15	3.52	1.81	2.03	2.28
β_N	5.4	5.4	5.4	6.65	6.65	6.65
β_T, %	10.8	10.8	10.8	33.2	33.2	33.2
Triagnularity	0.4	0.4	0.4	0.4	0.4	0.4
I_p, MA	5.38	6.54	7.95	6.39	7.77	9.44
n_i, $10^{20}/m^3$	0.66	0.824	1.03	0.836	1.06	1.33
q@95% flux surface	6.3	6.3	6.3	5	5	5
n_e/n_{GW}	0.37	0.45	0.544	0.213	0.26	0.314
Plasma volume, m^3	72.6	92.45	118.2	45	56.2	70.6
FW area, m^2	122	143.6	169.4	92	107	124.8
NB CD power, MW	0.3	0.5	0.83	0.33	0.56	0.93
Power recirculating, MW	55.64	76.13	105.4	28.67	39.7	56.1
Blanket EM	1.1	1.1	1.1	1.1	1.1	1.1
Ave, Γ_n, MW/m^2	0.31	0.53	0.9	0.41	0.71	1.23
Capital cost, \$M	300	449	718	256	396	654

CONCLUSIONS

- We have investigated relatively small toroidal devices with major radius from 1.5 to 2.27 m
- Higher elongation leads to higher average neutron wall loading and lower re-circulating power
- Capital cost is not sensitive to elongation
- Actinide burn rate can be designed to the range of 1000–3000 kg/year with A=2, and elongation = 2 or 3 devices
- COE is lower at higher elongation and higher blanket EM and power output
- COE converges and levels at blanket EM > 100 to ~75 mil/kWh
- The value of actinide rate, (kg/year per $M capital cost) also levels off for blanket EM > 100
- A 50 MW toroidal device at $\kappa = 2$ could be a very efficient antinide burner, provided the physics is validated by experiments