Comparison of Accelerator Technologies for Use in ADSS,

MOOBN3, PAC2011

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1. Introduction

ADS systems offer several interesting advantages in comparison to critical reactors:

- ADS provides greater flexibility for the composition and placement of fissile, fertile, or fission product waste within the core, and require less enrichment of fissile content;
- The core can be operated with a reactivity keff that cannot reach criticality by any failure mode.
- When the beam is shut off fission ceases in the core;
- Coupling the fast neutron spectrum of the spallation drive to fast core neutronics offers a basis for more complete burning of long-lived actinides.
- ADS designs can have sufficient thermal mass that meltdown cannot occur from radioactive heat after fission is stopped.

Challenges of Accelerator and ADS System Performance

- Capable of delivering CW >10 MW power
- Target, window, and interface to core
- Fuel composition, neutronics, power level
- Availability of >80%
- Trips < 2500 per year for finite duration
- RAMI
- ES&H

Range of Parameters for ADS

	Transmutation Demonstration	Industrial Scale Transmutation	Industrial Scale Power Generation with Energy Storage	Industrial Scale Power Generation without Energy Storage
Beam Power	1-2 MW	10-75 MW	10-75 MW	10-75 MW
Beam Energy	0.5-3 GeV	1-2 GeV	1-2 GeV	1-2 GeV
Beam Time Structure	CW/pulsed (?)	CW	CW	CW
Beam trips (t < 1 sec)	N/A	< 25000/year	<25000/year	<25000/year
Beam trips (1 < t < 10 sec)	< 2500/year	< 2500/year	<2500/year	<2500/year
Beam trips (10 s < t < 5 min)	< 2500/year	< 2500/year	< 2500/year	< 250/year
Beam trips (t > 5 min)	< 50/year	< 50/year	< 50/year	< 3/year
Availability	> 50%	> 70%	> 80%	> 85%

Fermilab

(Courtesy, S. Henderson, SC White paper [1])

2. Case Study of Nuclear Core [4]

- The primary focus of this study will be the merit of a multi-beam target system, which allows for multiple spallation sources into the target/blanket assembly to ensure reliability and technology readiness.
- To ameliorate the effects of sudden accelerator beam interruption.
- To control power output level
- To allow for fast start of useful program

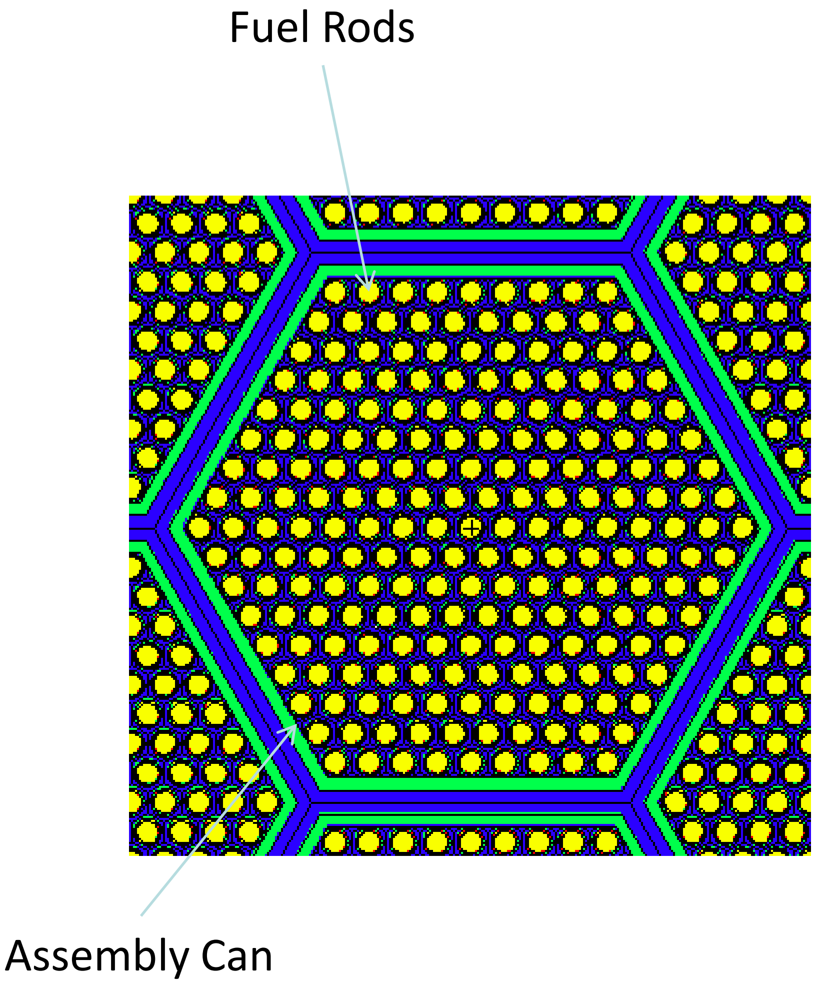
Detail of Fuel Element

Fuel Assembly

- **217 Fuel Rods – OD = 0.9 cm.**
- **Fuel; Thorium Oxide/Plutonium Oxide (84.5%/15.5%)**
- **Clad HT9 Ferritic Stainless Steel (Thickness = 0.0625 cm.)**
- **Helium bond between fuel and clad**
- **Fuel rod Pitch/diameter = 1.2**
- **Assembly Pitch = 17.5 cm.**

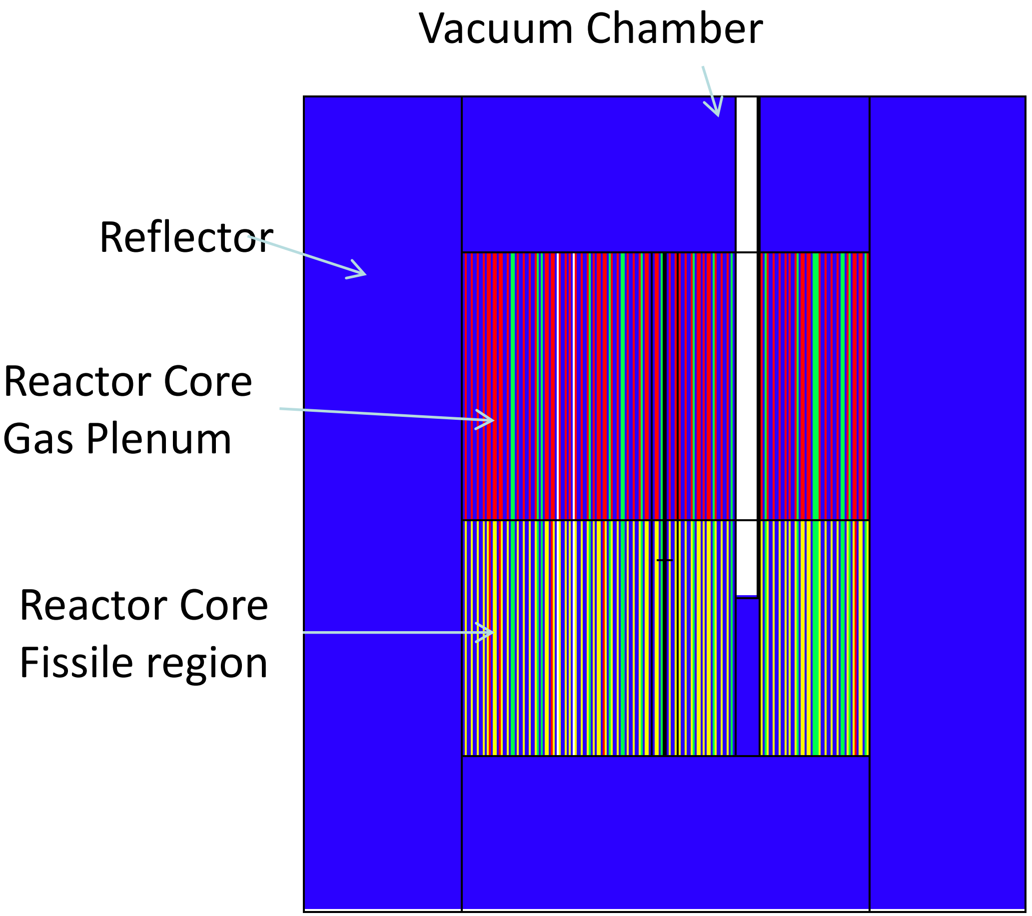
Similar to GE S-PRISM fast reactor

Code used: MCNPX



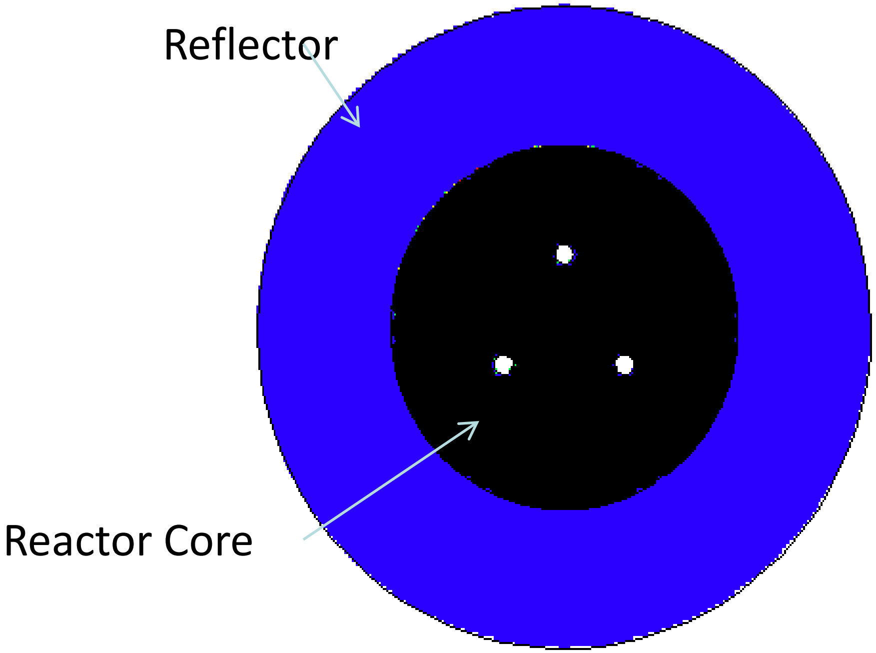
Longitudinal Section Through Target – Reactor Assembly

Reactor Core 195 Fuel Elements
Lead Reflector and Coolant
Overall Height = 520 cm.
Overall Diameter = 460 cm.
Core Diameter = 260 cm.
Vacuum Tube Diameter = 15.0 cm.
Window material – Inconel 718.
Active Core Height = 150 cm.
Fission Gas Plenum Height = 170 cm.



Section Through Target-Reactor Assembly for Three Beam Configuration

- Overall Diameter = 460 cm.
- Core Diameter = 260 cm.
- Beam Footprint = 14 cm



Performance Parameters

Figures of merit studied are:

- The thermal stress induced in the ceramic fuel used in the thorium reactor following a sudden proton beam interruption from full power.
- Variation of ke with time as the reactor operates and consumes the fissile material (Pu), and breeds in additional fissile material (U233). If the value of ke becomes equal to a safe limit, external control will have to be imposed on the blanket. Alternatively a lower initial value of ke can be used.
- Variation of the required accelerator beam power to maintain a constant thermal power output from the reactor.
- Window dpa, and gas production (H and He)

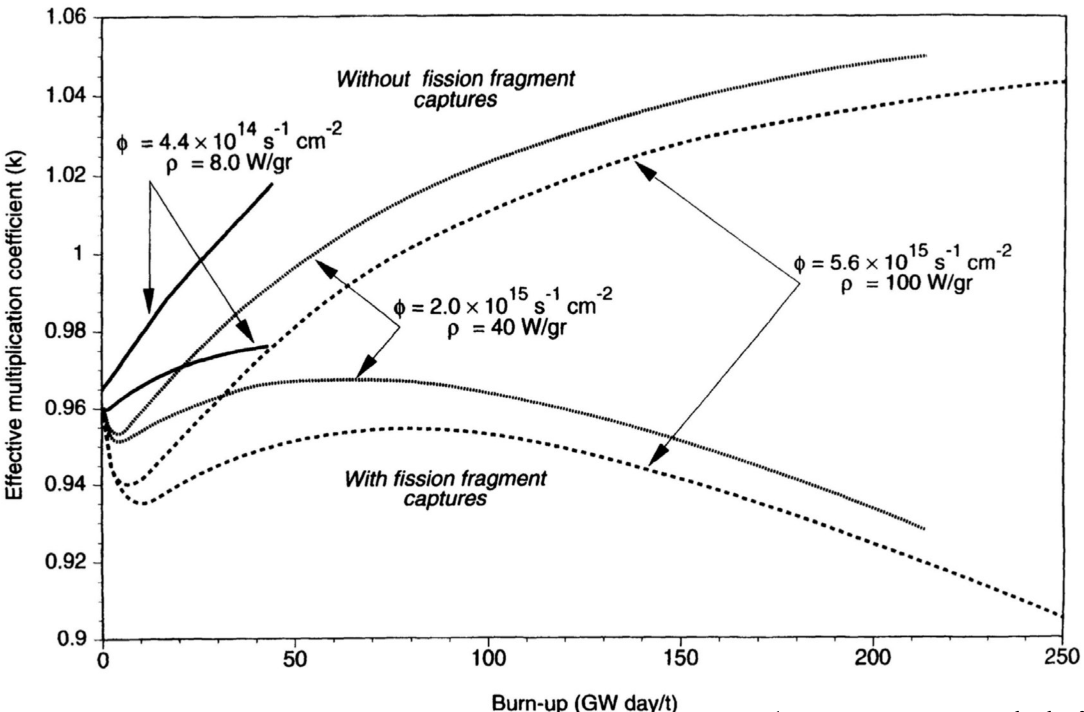
Fractional Change in Energy Deposited as Function of Radius [4]

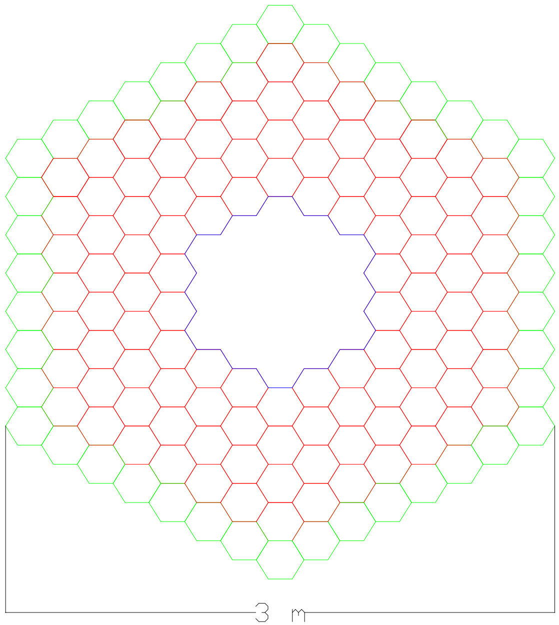
Radial position (cm)	One beam	Three beams	Six beams
8.75		-0.00809	-0.00096
26.25		0.123296	0.052654
43.75	1.0	0.293227	0.139641
61.25	1.0		
78.75	1.0	0.417357	0.216461
96.25	1.0	0.388490	0.188398
113.75	1.0	0.368829	0.163476
131.25	1.0	0.339910	0.150387

Fission products shadow neutrons, varying Keff over time

As fission proceeds, fission products absorb neutrons
→ neutron gain varies strongly within core and through fuel burnup.

Single coaxial drive beam (Rubbia):



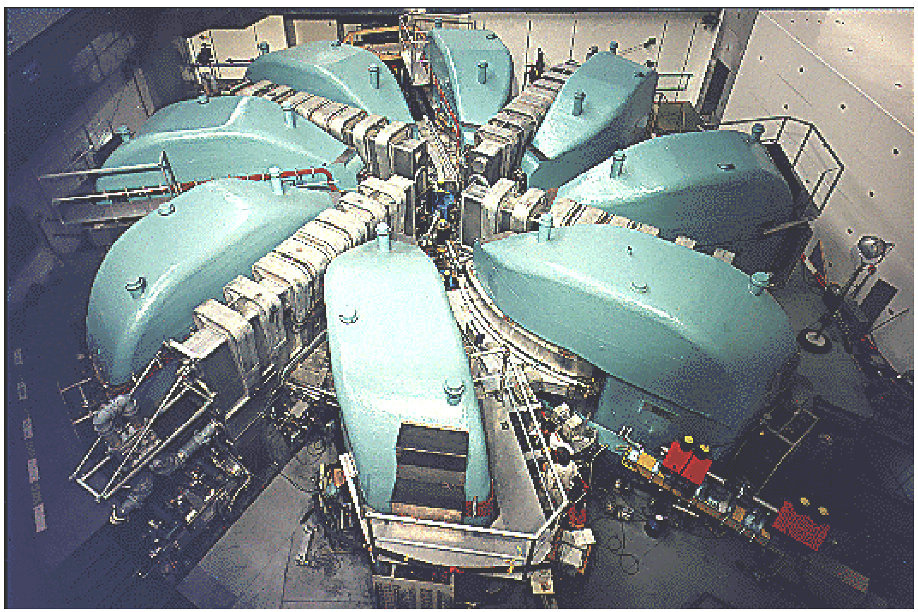


(From Rubbia)

3. IC-Based ADS Facility [3,6]

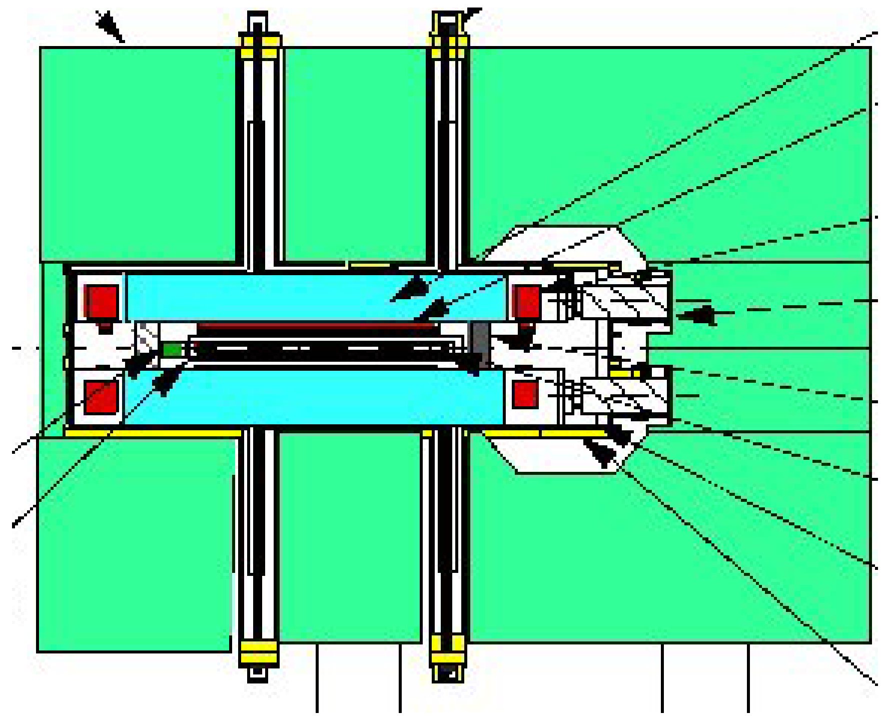
I
C

Combine the high-energy isochronous cyclotron of PSI:



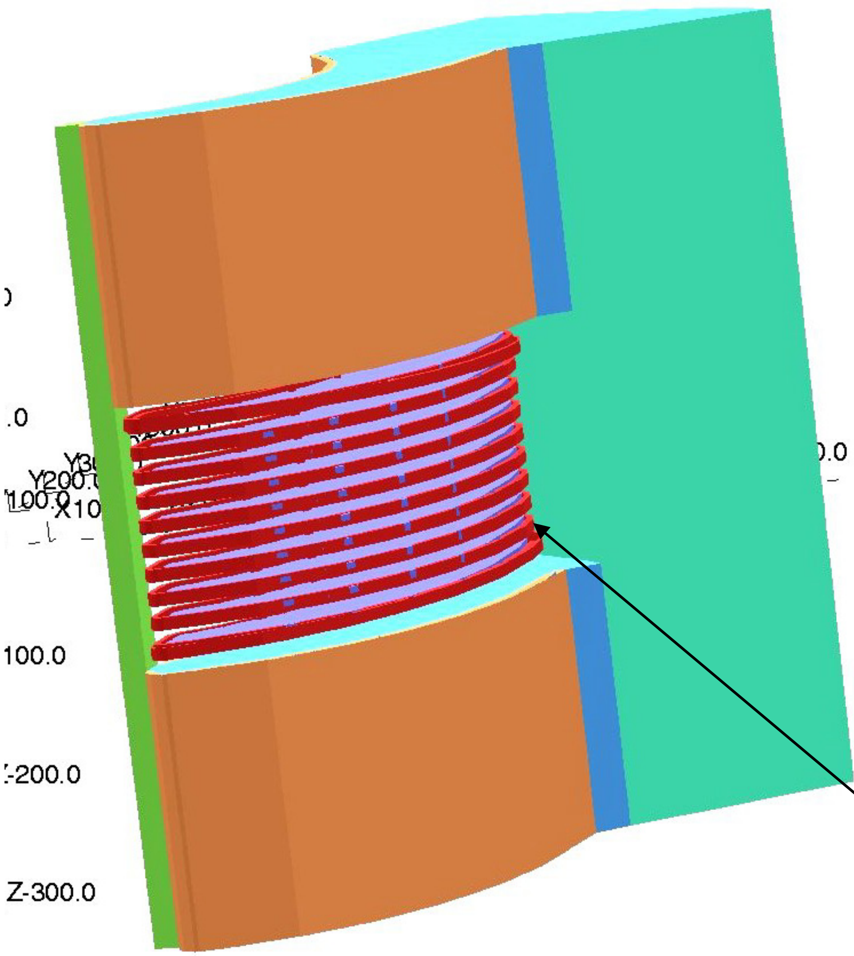
590 MeV, 2 mA

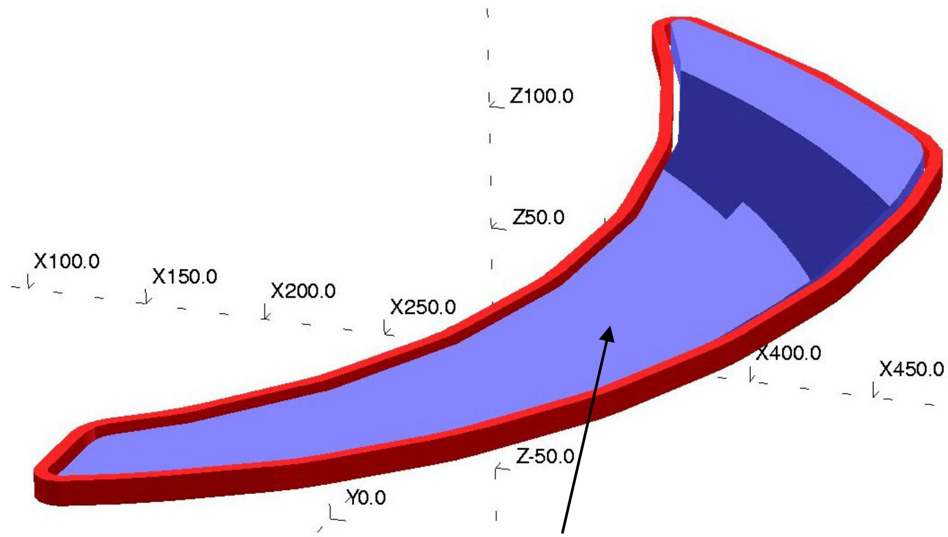
and the superconducting magnet design of Riken:



Superconducting coil, cold iron flux plate, warm iron flux return

Each pole has 3-7 apertures, trims for isochronism and mid-plane symmetry





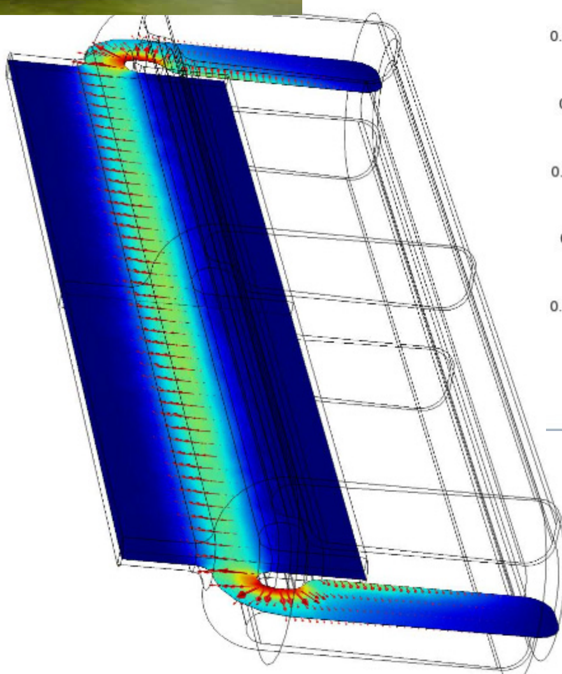
Flux plate = NbTi superconducting coil, contoured steel plate

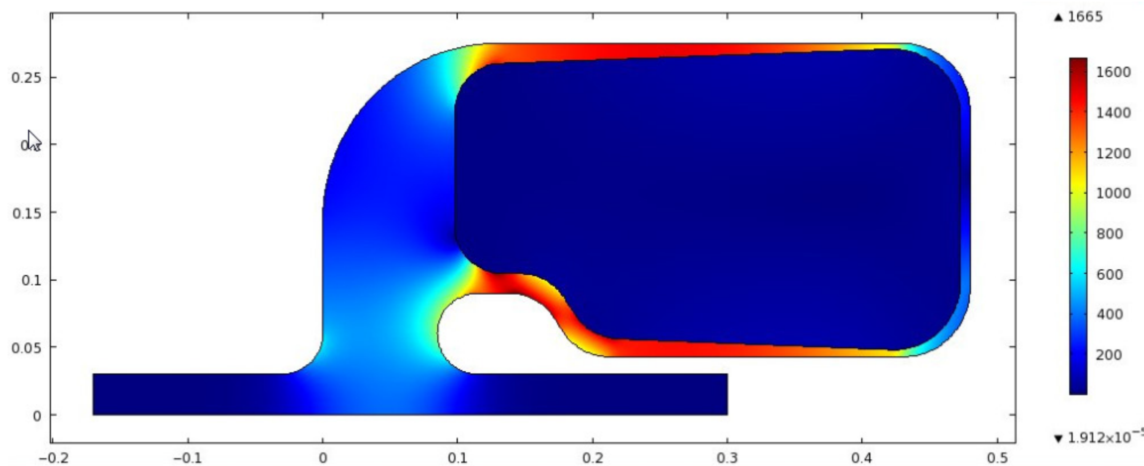
10 flux plates,
Top/bottom sacrificial gaps

$R = 2 \rightarrow 5$ m, 10 cm aperture – cold bore vacuum

RF is a particular challenge

- Need ~800 kV/gap, 4 gaps for good turn/turn separation at injection, extraction
- Need compact structure: 50 cm IC separation

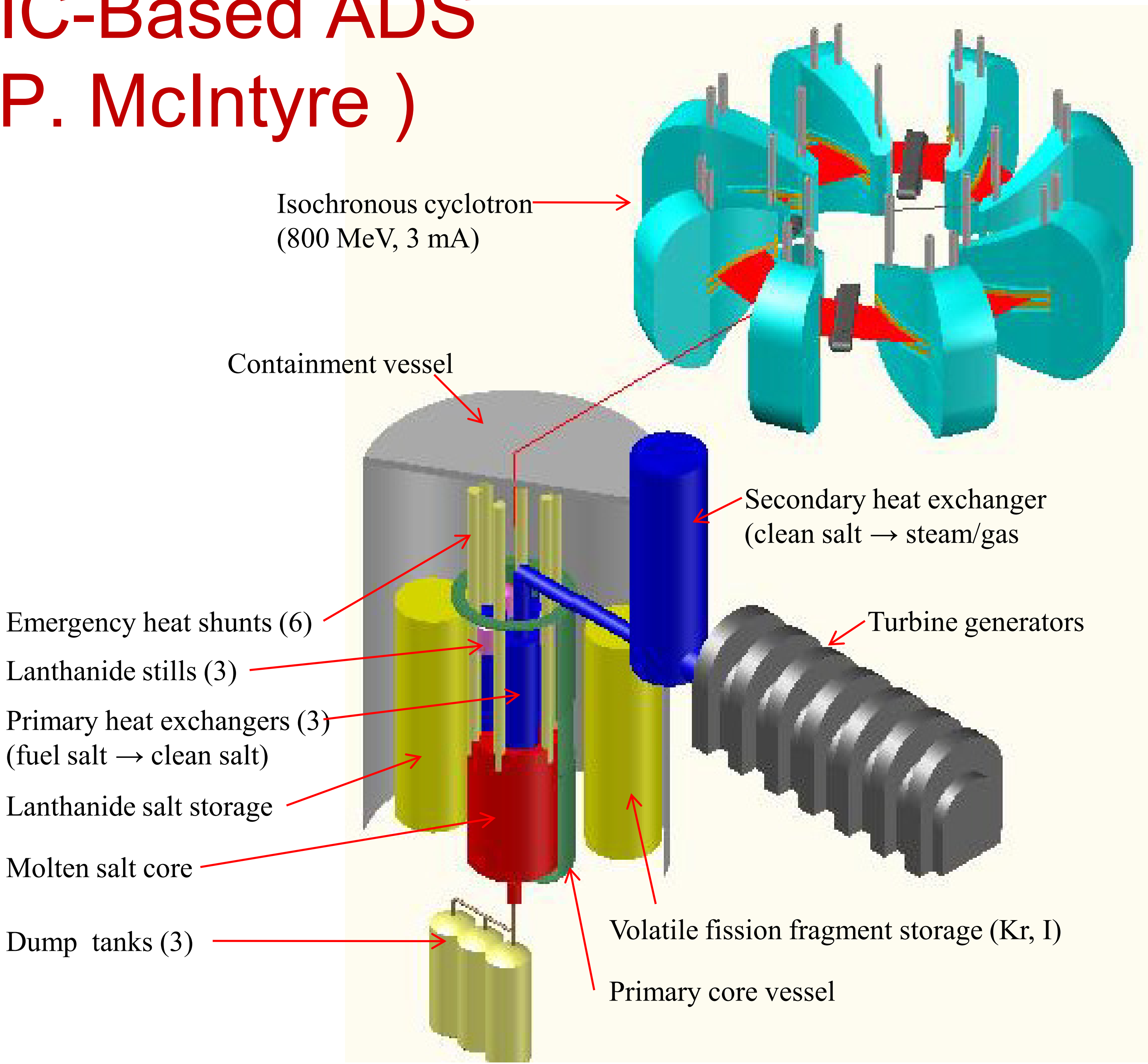




2 W/m @ 5 K

5 kW/m @ 80 K

Integrate IC-Based ADS System (P. McIntyre)

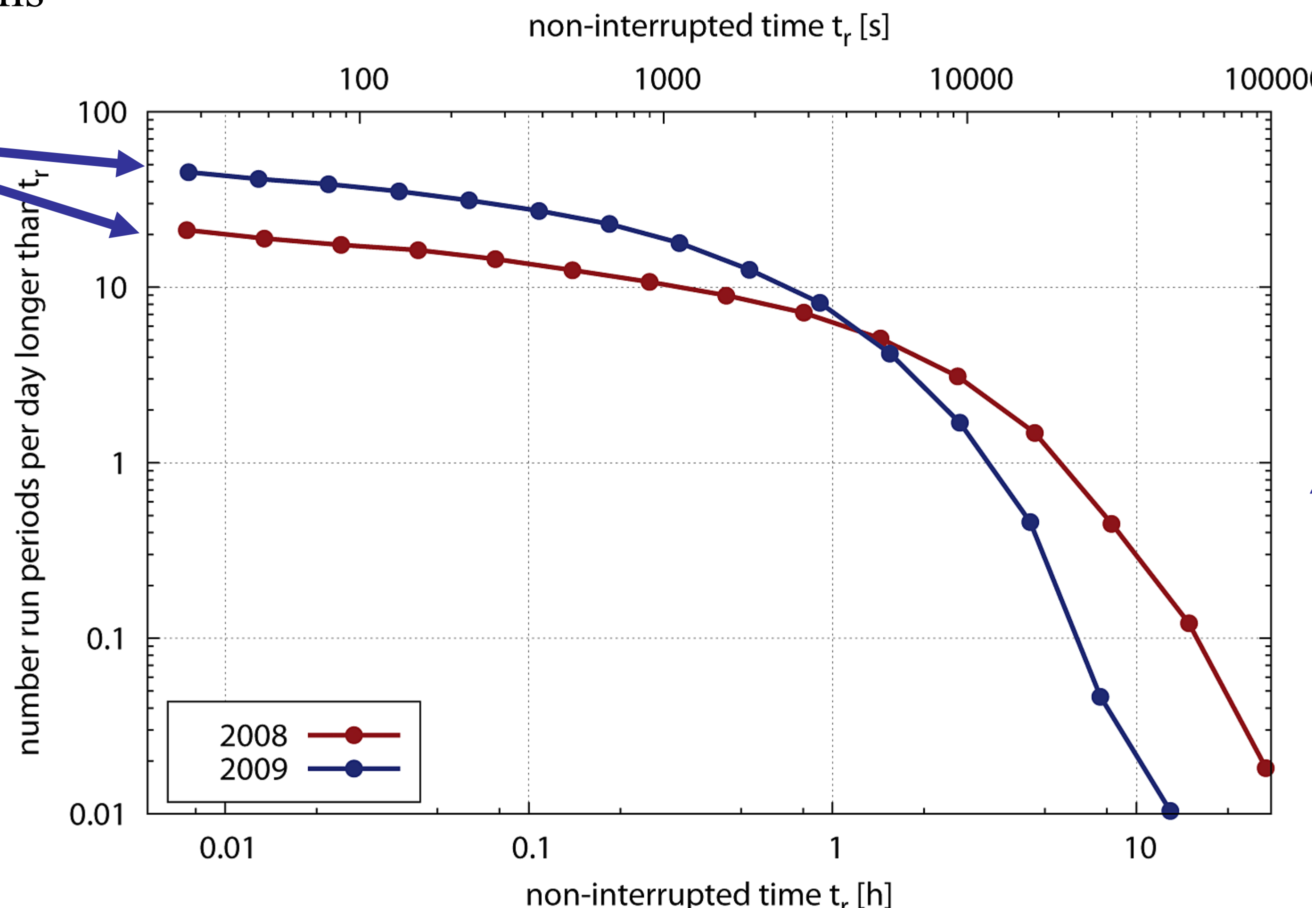


PSI: statistics of run durations 08/09

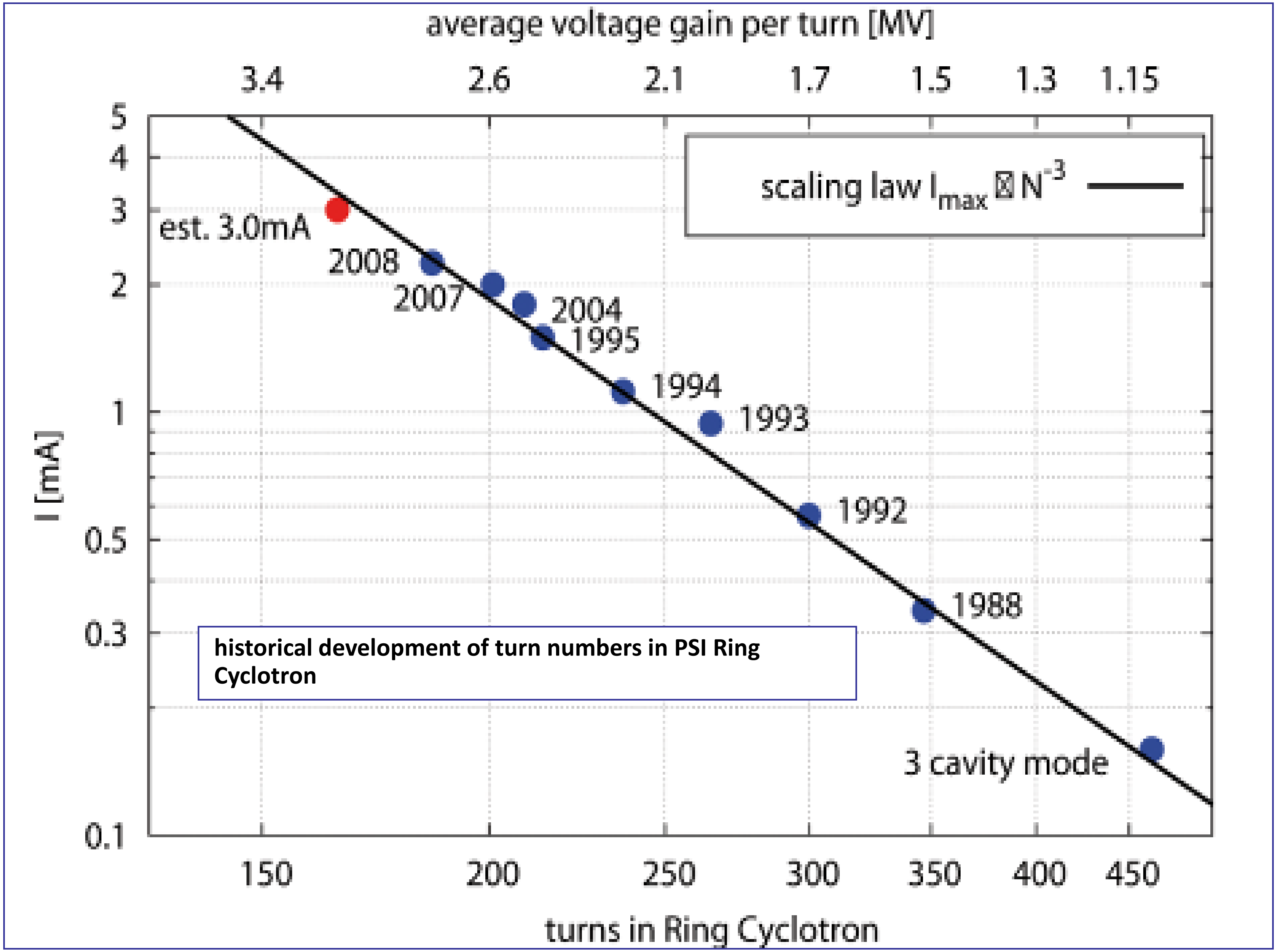
➔ histogram for occurrence of uninterrupted run periods as function of duration, integrated from right; average number per day; comparison 2008/2009

➔ high reliability is important for our users and for other potential high power applications of cyclotrons

total number of runs/interrupts per day [integrated histogr.]



read this plot as follows:
there are typically *n* run periods per day that last longer than *t*



(Courtesy of M. Seidel [2])

Phase I, 3 ring Flux-coupled IC

- Prepare the optimum phase space distribution of the injected bunches. It has been found that due to strong transverse-longitudinal coupling in the cyclotron, a round beam is a stationary distribution over the acceleration cycle with little emittance degradation and beam loss [5].
- Provide large enough energy gain per turn of about 3.2 MV to reduce number of turns to less than 170 to achieve 3mA, as shown in Figure 3.
- Provide enough beam separation at extraction to maintain beam loss <10-4.
- Provide appropriate beam collimation and scraping to assure beam loss <10-4during acceleration.
- Assure accelerator reliability of better than 90%, with trip rate less than 5 per hour.

4. Comparative Advantages

	Advantages	Disadvantages
1. IC,	existing model matched target/window could be more reliable adjustable for Keff less cost	limited power output
2. SRF Linac	Flexible power choice	no operating model Harder to make reliable cost more

5. Summary and Conclusions

- ADS has role to play in both ATW and power
- Challenging in terms of beam power, reliability, and interface with core
- Multi-Beam may be needed to meet those challenges in near future
- 3-Ring stack Isochronous cyclotron can be developed for specific application
- More aggressive R&Ds are needed for realization for a specific application, which determines details of performance requirements.

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