Serco Assurance

A Helium Cooled Particle Fuelled Reactor for Fuel Sustainability

T D Newton, P J Smith, Y Askan

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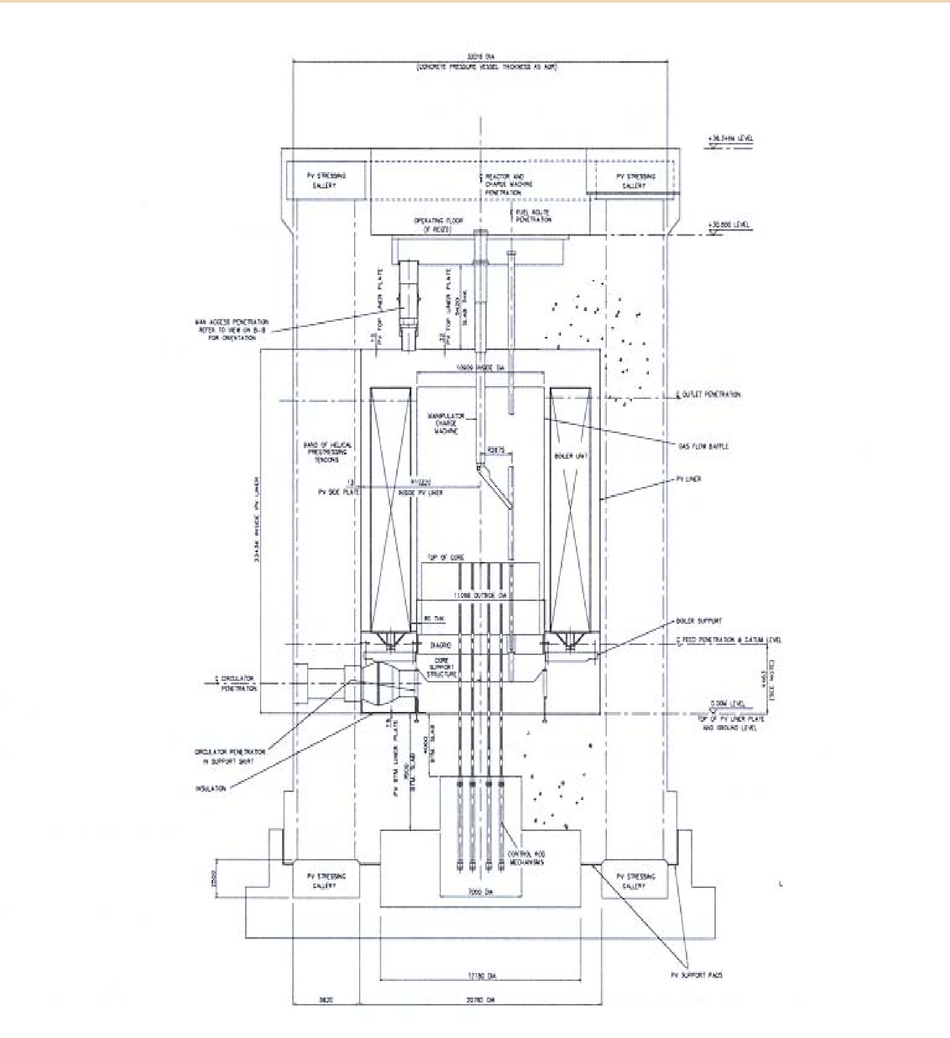
Background

- New generation of reactor designs to meet the needs of the 21st century
- Fuel sustainability is a key goal
  - Self generating core with a breeding gain close to zero
  - Low plutonium inventory (< 20 tonnes)
- Significant interest in the Gas Cooled Fast Reactor
  - Benign and readily available gaseous coolant
  - Low void coefficient affords a high degree of flexibility
  - Hard neutron spectrum allows for effective transmutation of plutonium and minor actinides

Existing Technology Gas Cooled Fast Reactor



- Thermal output : 3600 MWth
- CO_2 coolant at an inlet pressure of 42 bar
- 300 °C inlet temperature
- PE16 clad fuel pins
- 760 °C limit on clad temperature
- 525 °C limit on outlet temperature
- Plutonium inventory in excess of 20 tonnes
  - too high to be considered practical

Objectives

- Reduce plutonium inventory to a practical level by increasing the volumetric rating
- Design changes
  - particulate fuel contained within a matrix
  - ceramic clad and matrix materials
  - He coolant
  - alternative fuel geometries : pin + block + plate
- Clad/matrix temperature limit > 1000 °C
- Outlet temperature limit > 900 °C
- Volumetric rating > 200 MW/m^3
- Plutonium inventory < 10 tonnes

Fuel Concept

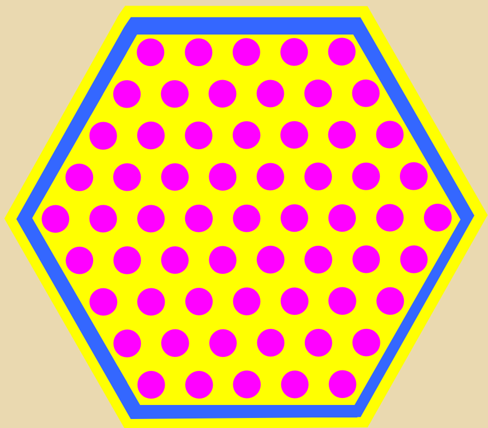
- TRISO particulate fuel within a SiC matrix
  - Particle kernel diameter : 0.85 mm
  - Particle packing fraction : 60%
  - Fuel density : 1.8 g/cm^3
- Coated particulate fuel in matrix is vibro-packed inside cladded pins, hexagonal blocks or plates
- Irradiation experience available for pin fuel in AGR and DFR
  - > 40 GWd/te discharge irradiation
- Experimental support for
  - 1000 °C clad temperature limit
  - 200 MW/m^3 volumetric rating limit

Core Design Parameters

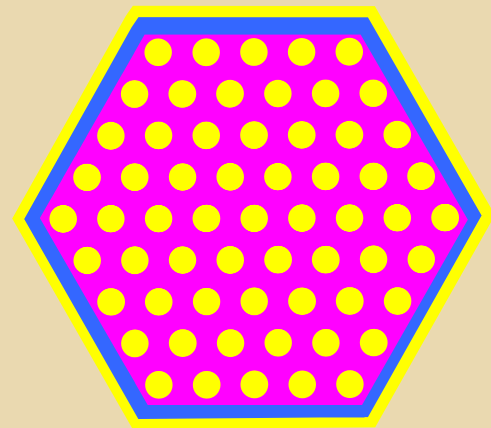
Core Power	2400 MWth
Coolant	He
Coolant Density	2.8314 kg/m^3
Coolant Pressure	60 bar
Coolant Pressure Drop Limit	3 bar
Core Inlet Temperature	530 °C
Core Outlet Temperature	900 °C
Cladding/Matrix Temperature Limit	1000 °C
Volumetric Rating Limit	180 MW/m^3
Channel Inlet Loss Coefficient	0.923
Channel Outlet Loss Coefficient	0.420
Grid Loss Coefficient	0.394

Sub-Assembly Geometry

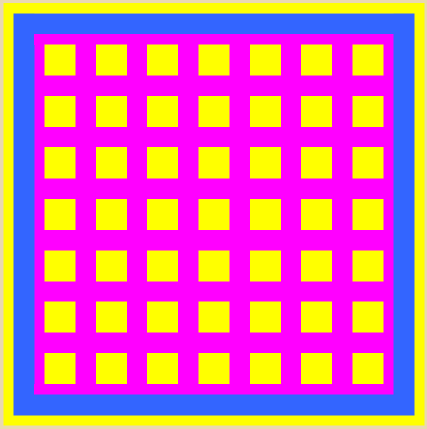
- Pin



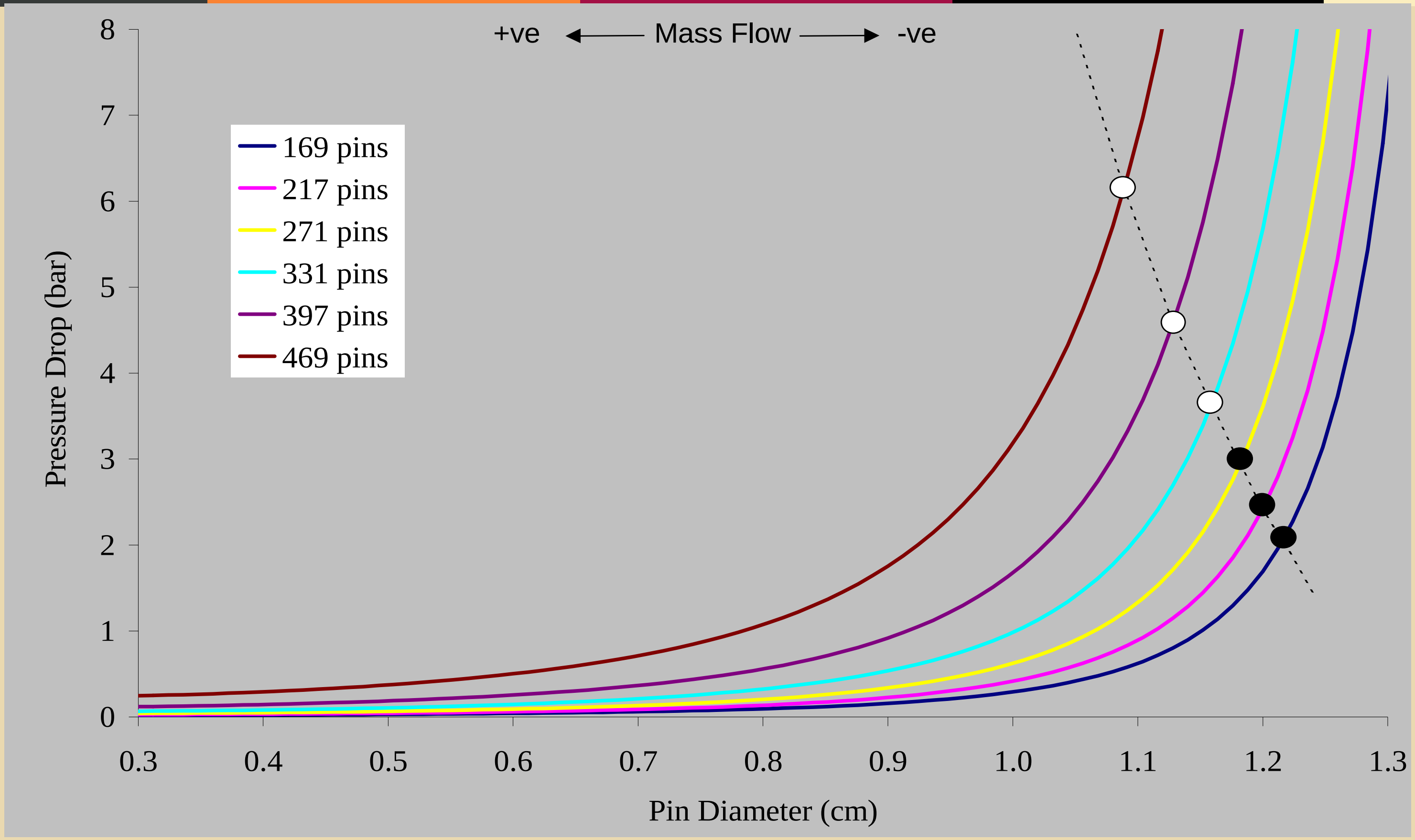
- Block



- Plate

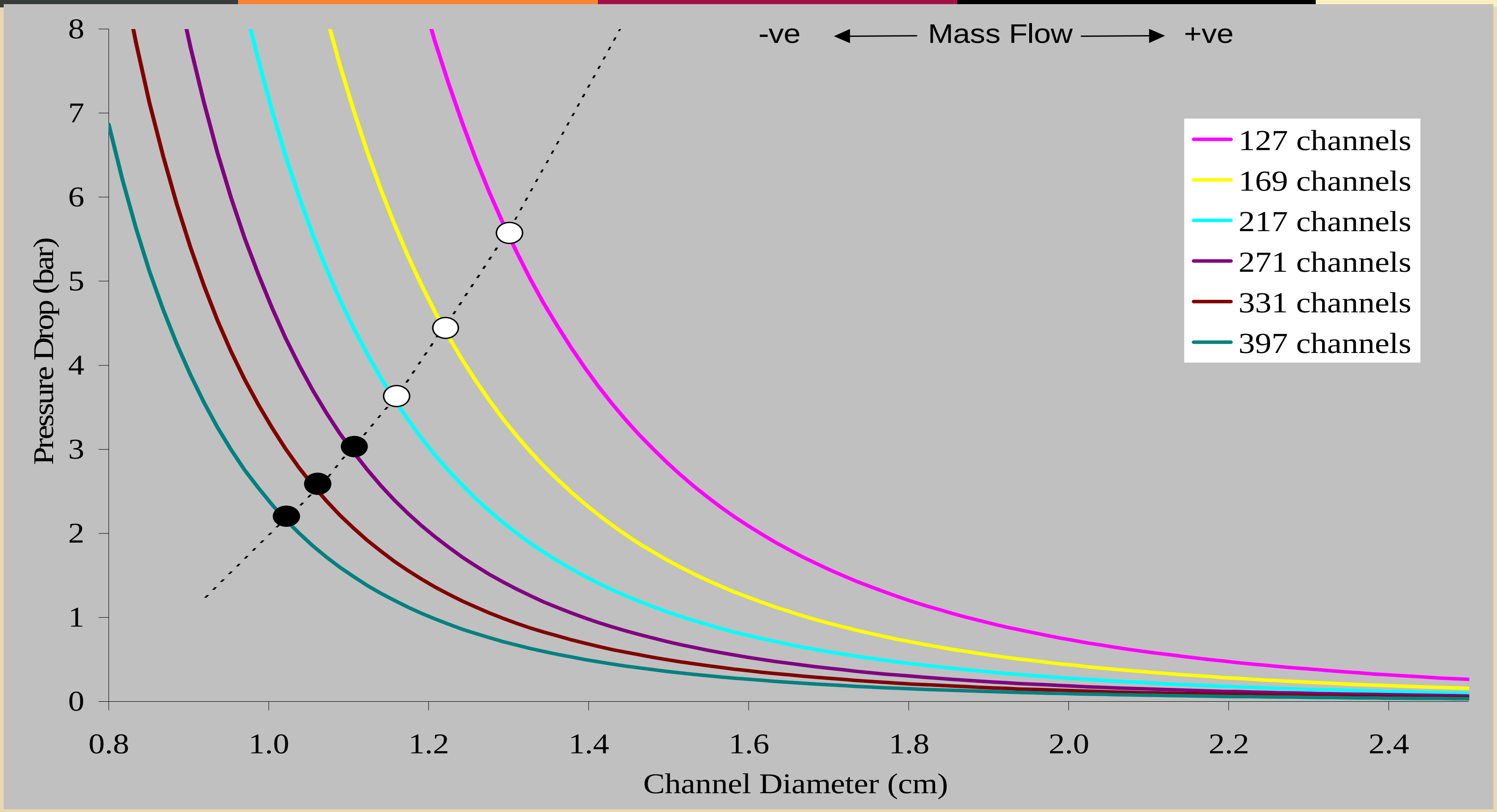


Pin Sub-Assembly Design



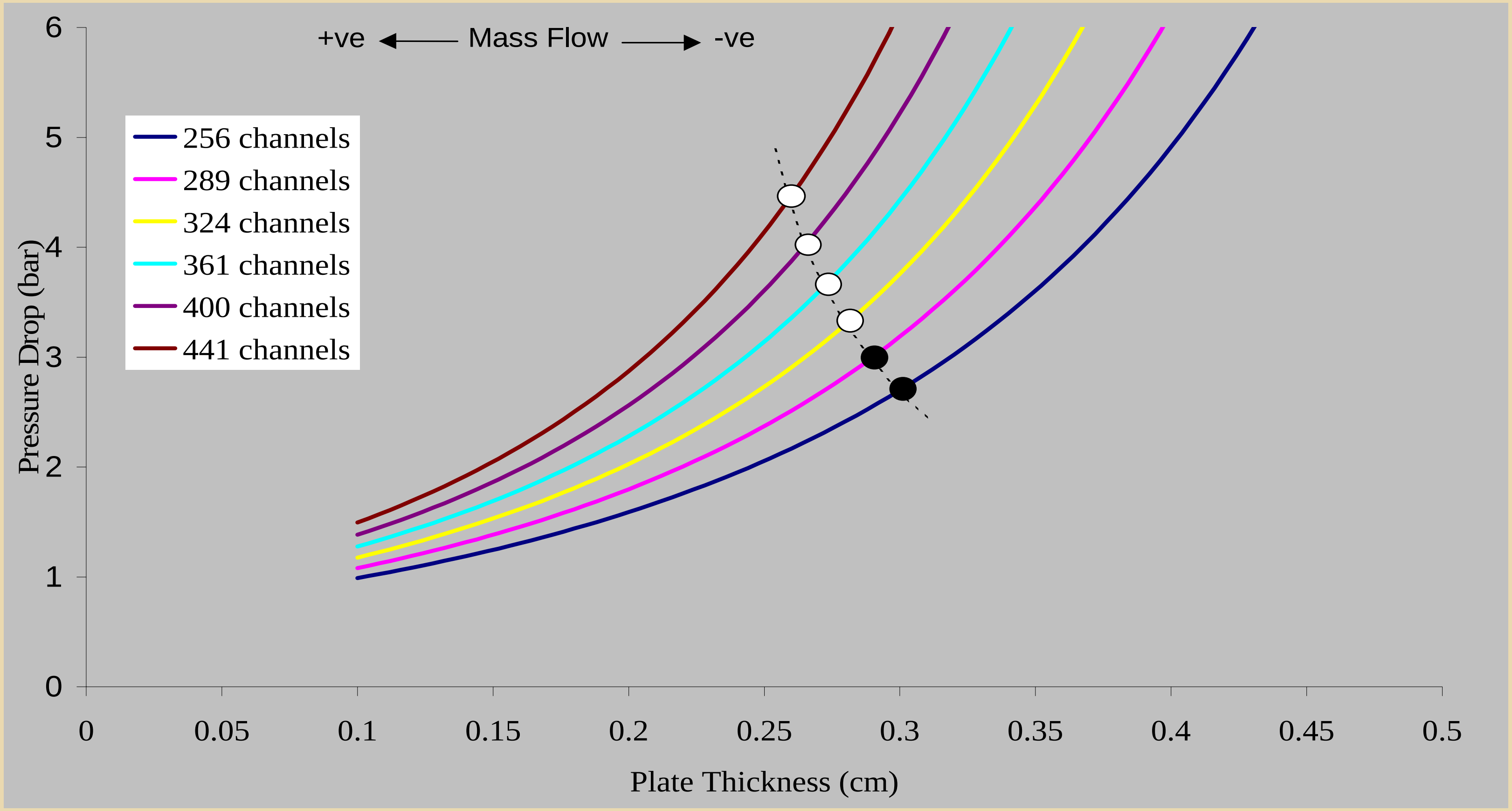
- 271 pins per sub-assembly
- Sub-assembly pitch : 25.29 cm, SiC wrapper
- Pin outer diameter : 11.39 mm
- Actinide Volume Content : 6.49 %

Block Sub-Assembly Design



- 271 coolant channels per sub-assembly
- Sub-assembly pitch : 25.29 cm, SiC wrapper
- Channel outer diameter : 11.03 mm
- Actinide Volume Content : 8.01 %

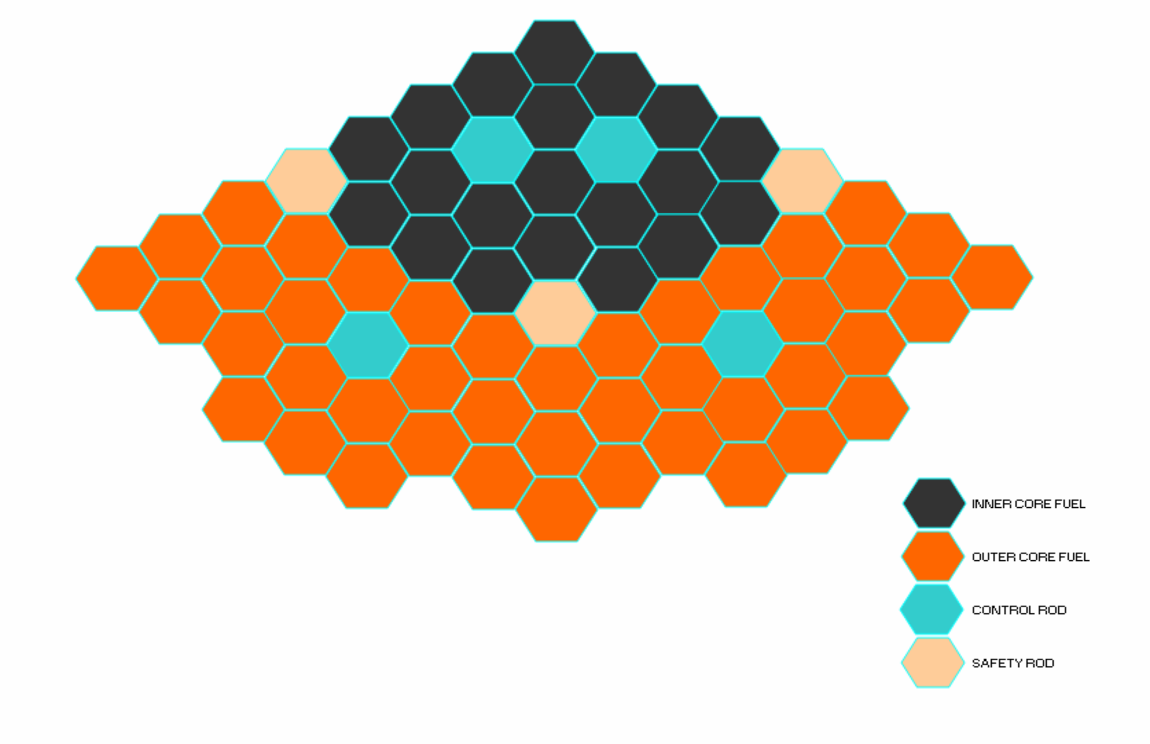
Plate Sub-Assembly Design



- 289 coolant channels per sub-assembly
- Sub-assembly pitch : 25.29 cm, SiC wrapper
- Channel outer dimension : 11.00 mm
- Actinide Volume Content : 7.29 %

Pin Core Design Parameters

- 181 fuel sub-assemblies : 61 inner core - 120 outer core
- Pu enrichment : 53.0% inner core, 54.5% outer core
- Plutonium inventory : 6.9 tonnes
- Fuel cycle : 4 x 188 efpd



Block Core Design Parameters

- 181 fuel sub-assemblies : 61 inner core - 120 outer core
- Pu enrichment : 40.5% inner core, 43.5% outer core
- Plutonium inventory : 7.1 tonnes
- Fuel cycle : 4 x 188 efpd

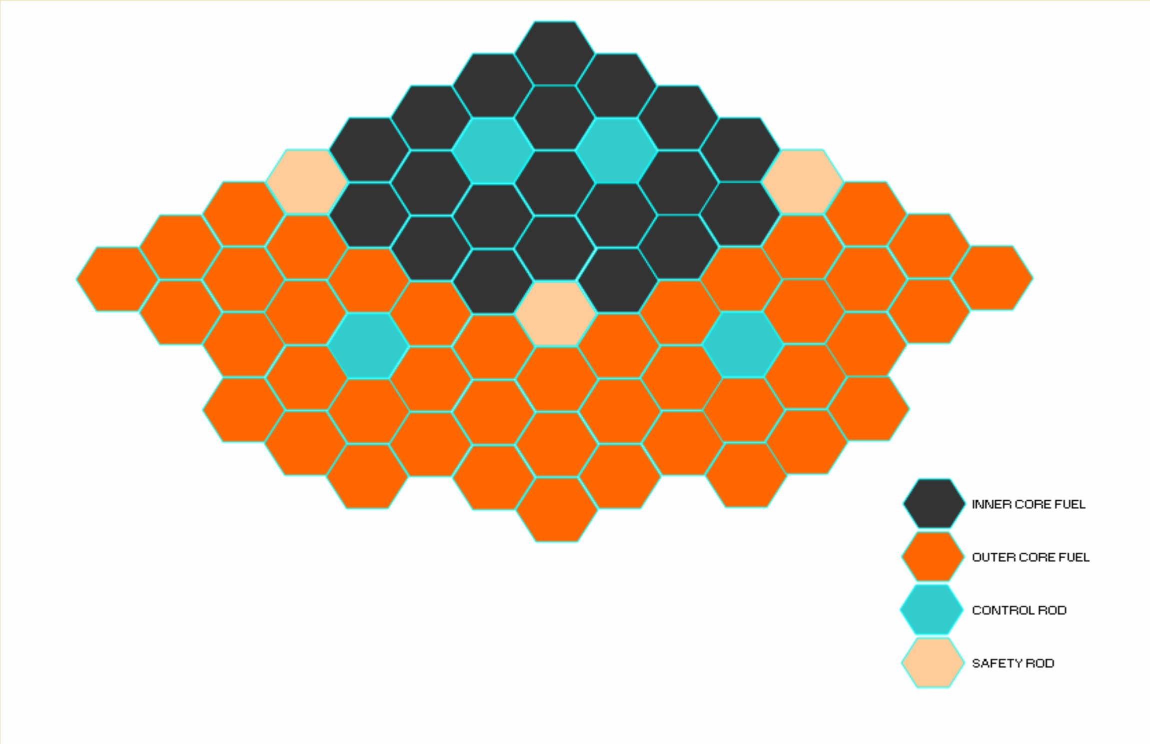
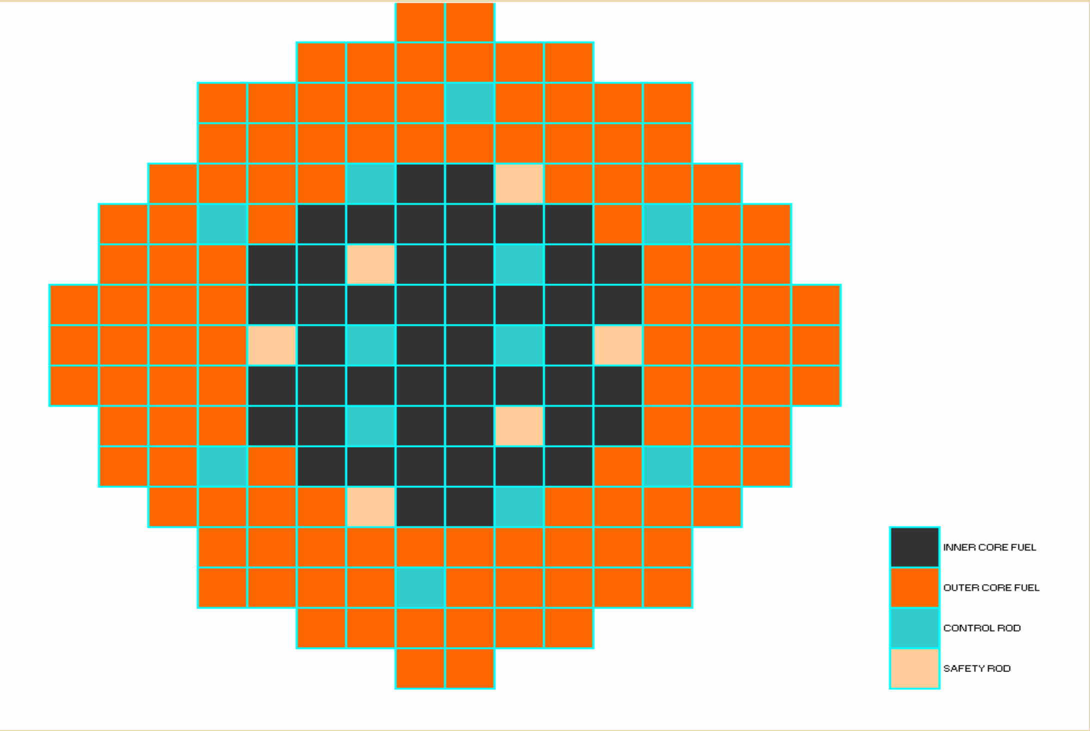


Plate Core Design Parameters

- 166 fuel sub-assemblies : 48 inner core - 118 outer core
- Pu enrichment : 40.0% inner core, 43.1% outer core
- Plutonium inventory : 7.0 tonnes
- Fuel cycle : 4 x 188 efpd



Core Performance

	Pin	Block	Plate
Peak Volumetric Rating (MW/m^3)	186	178	187
Peak Burnup (% heavy atoms)	20.8	20.4	20.7
Peak Damage (dpa NRT Fe)	85	94	97
Reactivity Loss per Cycle (pcm)	5326	4448	3716
Delayed Neutron Fraction (pcm)	299	305	306
Plutonium Consumption (kg/TWhe)	75.5	59.3	59.6
Minor Actinide Production (kg/TWhe)	-9.4	-9.0	-8.9
Doppler Coefficient (pcm)	-686	-593	-595
Coolant Void Worth (pcm)	-260	-187	-181
Water Ingress Reactivity Effect (pcm)	+557	+414	+407

- Peak volumetric rating within design limits
- High reactivity loss - control rod worth sufficient to meet shutdown criteria
- High plutonium consumption
- Acceptable safety parameters

Fuel Sustainability

- Plutonium inventory has been significantly reduced
- Plutonium enrichment is significantly above the level required to achieve a self generating core
    - particulate fuel provides for a low fuel density
    - Pu enrichment for pin core is incompatible with PUREX reprocessing
- Further design optimisation is required to increase actinide content
    - high density carbide or nitride fuel
    - alternative particle coatings (ZrC, TiN)
    - micro or macro dispersed fuel (CERCER, CERMET)

Conclusions

- Results of this study show the general feasibility of a helium cooled particulate fuel core design.
- High plutonium enrichment due to low fuel density.
- Optimisation to increase actinide content
  - nitride + carbide fuels
  - micro/macro dispersed fuels