The ThorEA organisation

ThEC
THORIUM ENERGY CONFERENCE 2010

Roger Barlow

Manchester University and the Cockcroft Institute

Roger.Barlow @ manchester.ac.uk

A brief account of some topics studied under the umbrella of the ThorEA organisation and reported at their meetings: (1) Making Uranium from Thorium through spallation neutrons (2)Fast and thermal systems (3) running an existing reactor as an ADSR

Example 1: FERFICON

Concept: Irradiation of Thorium fuel rods by spallation neutrons to produce ^{233}U

(Separating the Accelerator from the Reactor)

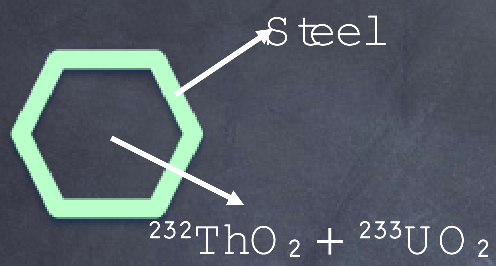
Q: What fraction of ^{233}U does a ^{232}Th fuel rod placed in a conventional reactor need in order to make a positive contribution to the neutronics?
A. ~ 6% for a light water moderator, ~2% for heavy water

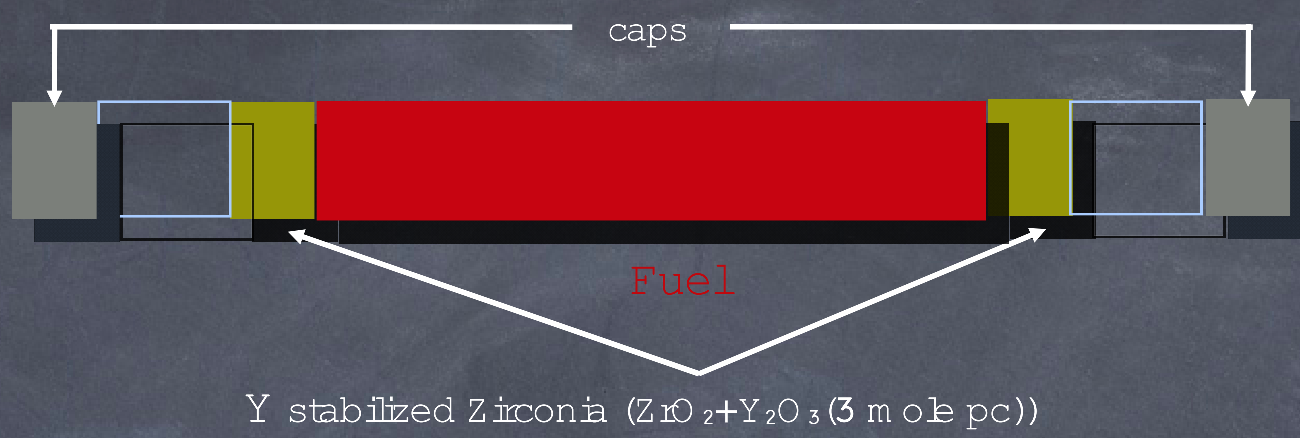
Proposal: Irradiate rod at accelerator. Transport (rapidly!) to reactor.

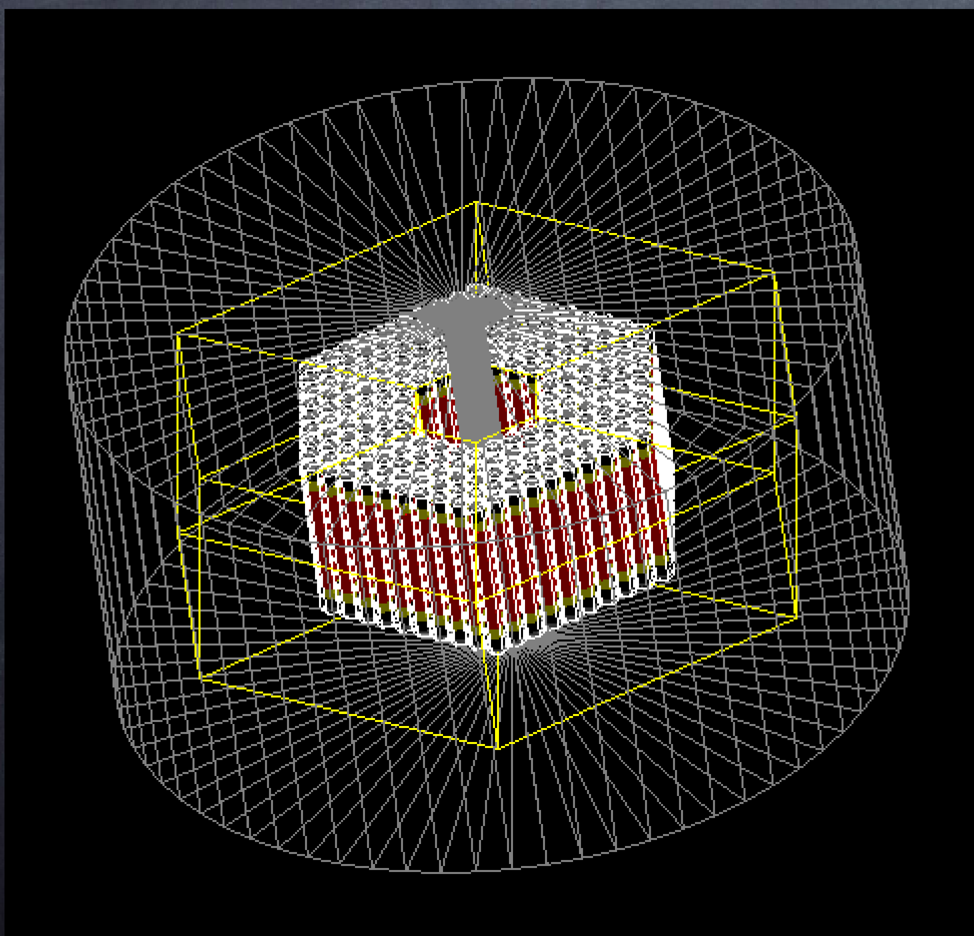
Studies done (by Cristian Bungau) using GEANT4
(MCNPX being used as confirmation)
- access to physics codes for high energy reactions
- flexibility of design, using C++ classes
- sophisticated geometry and graphics features

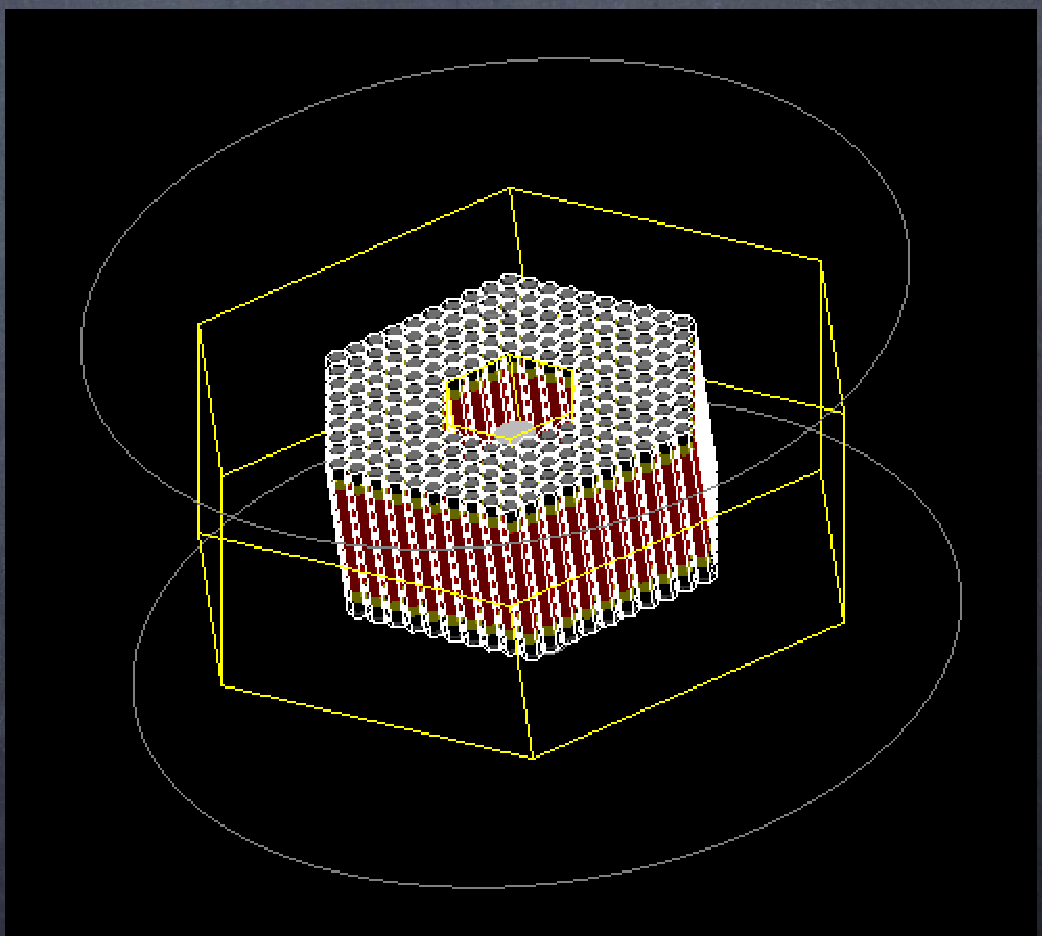
Needed to add new classes to put time-dependence into the code

Geometry details





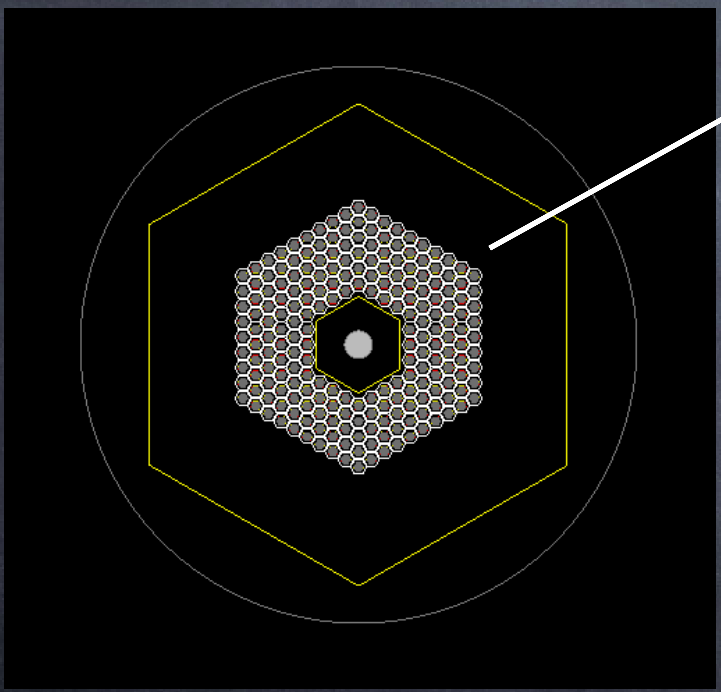


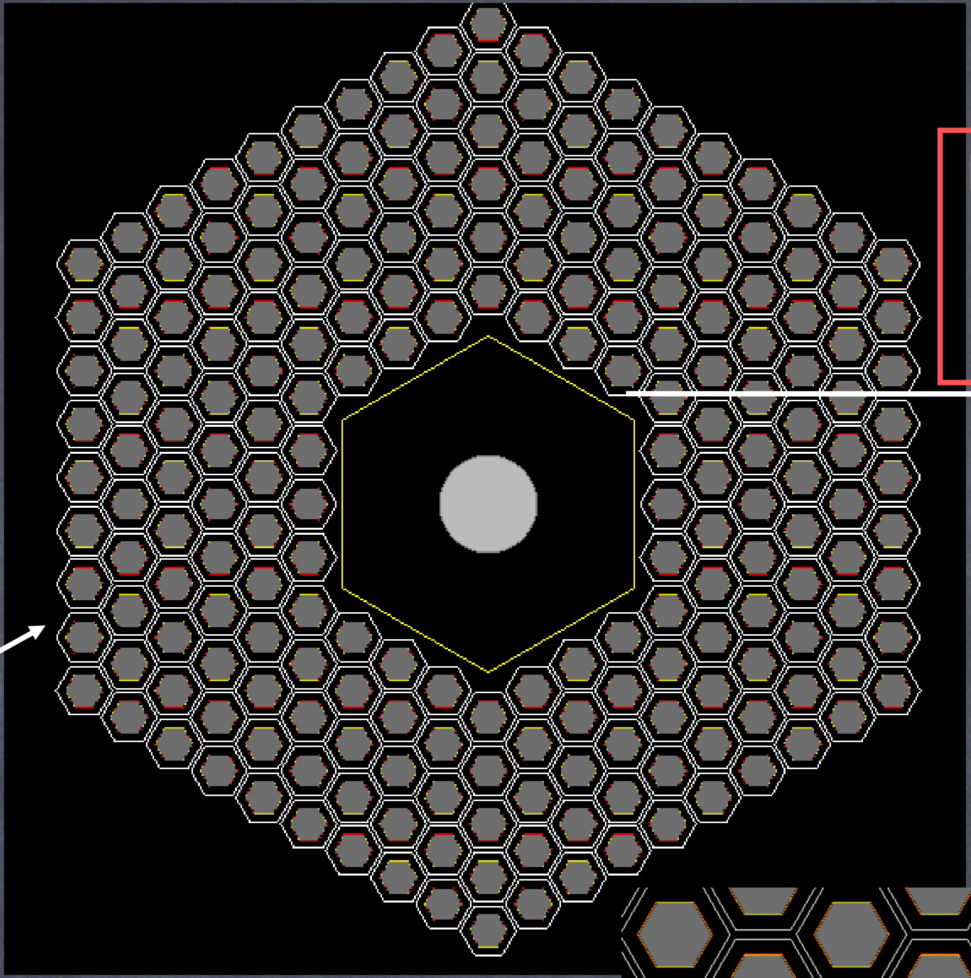


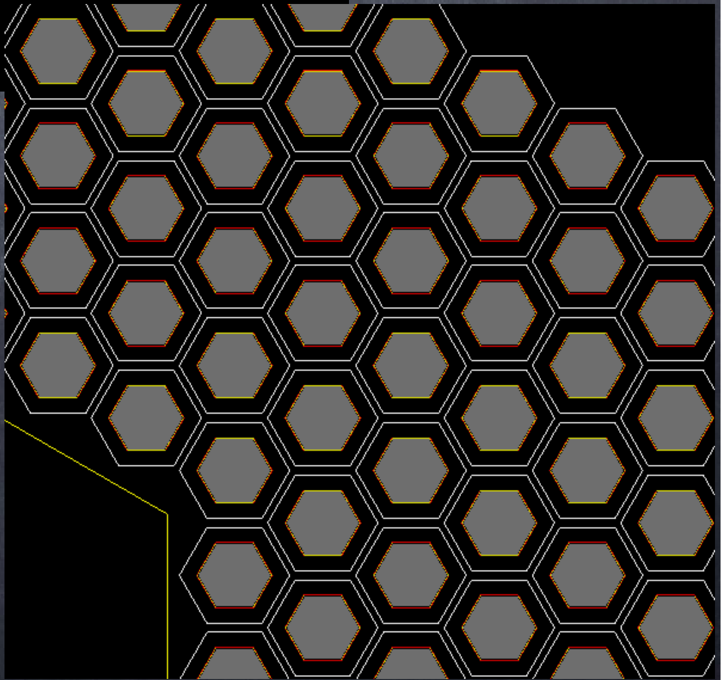
And in more detail...

In G4 one must NOT have overlapping volumes...

vertical view







Irradiation

For 1 GeV proton beams you can (just about) achieve 1 $^{232}Th \rightarrow ^{233}U$ conversion per incident proton, by suitable arrangement of target rods, reflectors, and general geometry.

Conversion of a usable fraction of a rod is possible, but will take many hours of exposure.

Must consider decays and other reactions as composition changes.

Also material stability of the ThO_2 under neutron bombardment and chemical changes: this looks hopeful

ThorEA the thorium energy amplifier association

ThEC THORIUM ENERGY CONFERENCE 2010

UNIVERSITY OF CAMBRIDGE

Reactor Physics Simulations of ADSR Concepts

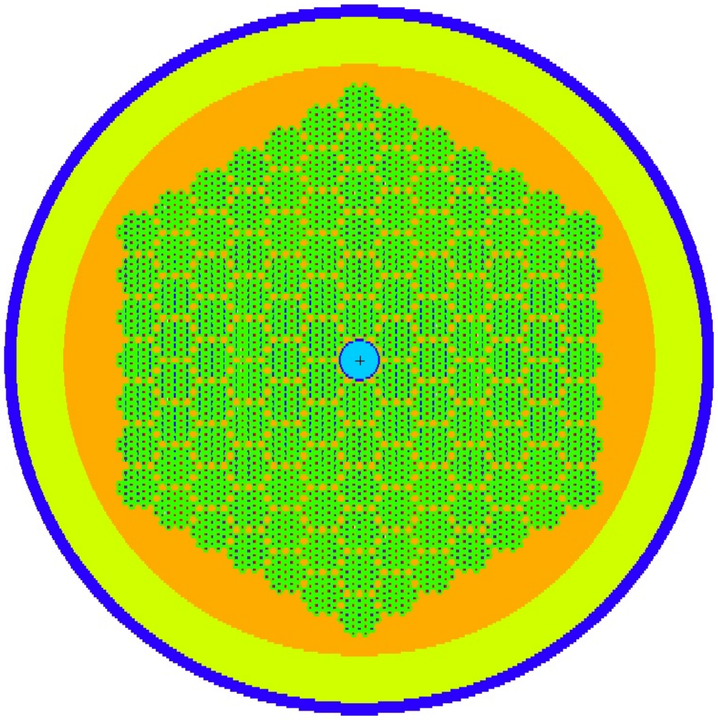
Ali Ahmad, Leo Gonçalves, **Geoff Parks**

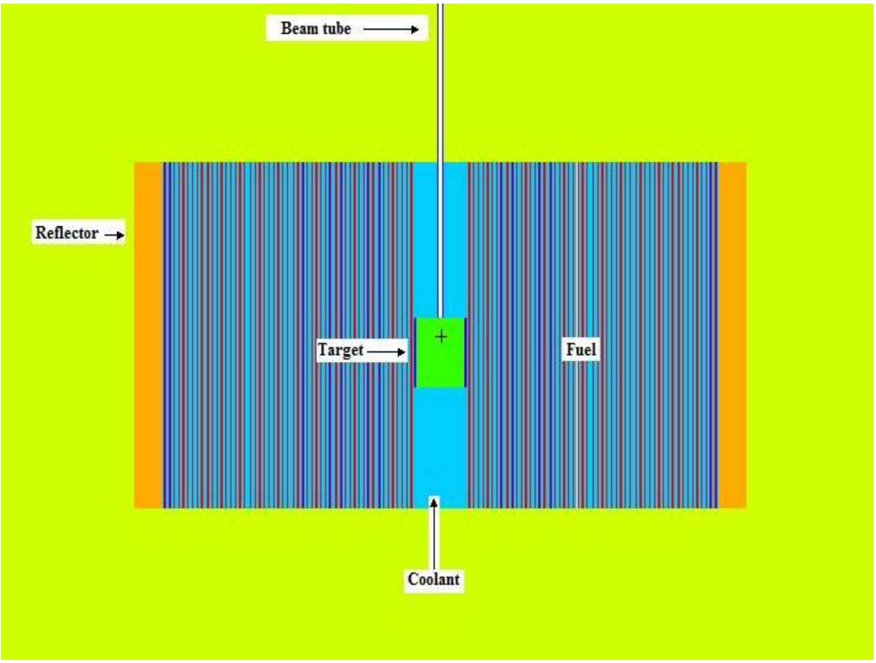
University of Cambridge

- Simulations performed using the MCNPX neutron transport code.
- E < 20 MeV : Nuclear data tables (ENDF/B-VI)
- E > 20 MeV : Nuclear models
  - Bertini model (Bertini 1969)
- Delayed neutrons and thermal treatment included

Core Geometry

UNIVERSITY OF CAMBRIDGE





UNIVERSITY OF CAMBRIDGE

Core Geometry

Parameter	Value/Choice
Container vessel outer radius	3 m
Container vessel inner radius	2.9 m
Container height	4 m
Core active radius	2.5 m
Fuel pin height	2 m
Fuel pin outer diameter	1.2 cm
Cladding thickness	0.3 cm
Pitch	1.25 cm
Fuel material (fast)	85% ThO_2 - 15% PuO_2
Fuel material (thermal)	98.2% ThO_2 - 1.8% PuO_2
Cladding	316 stainless steel

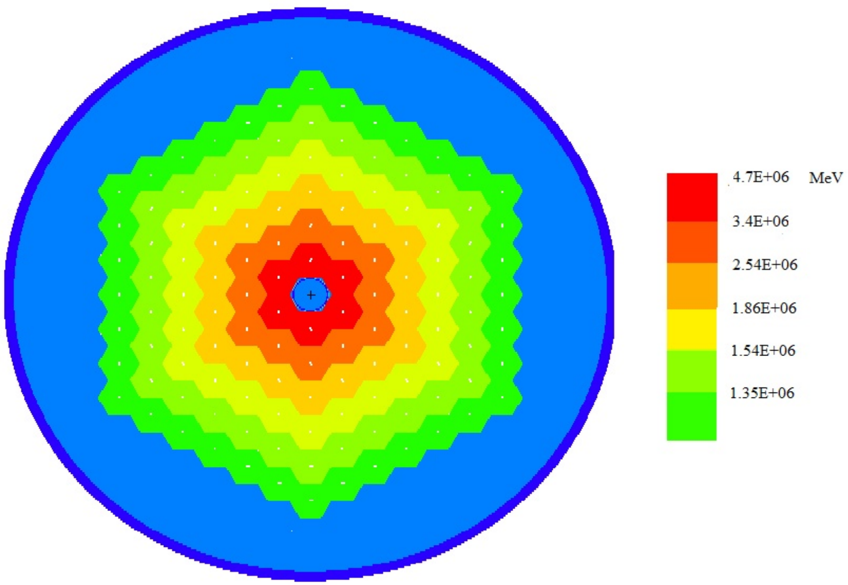
Spallation Target Geometry

Parameter	Value
Beam energy	1 GeV protons
Beam spatial profile	Parabolic
Spot diameter	8 cm
Target material	^{208}Pb
Target diameter	32 cm
Target length	40 cm
Target containment vessel	316 stainless steel

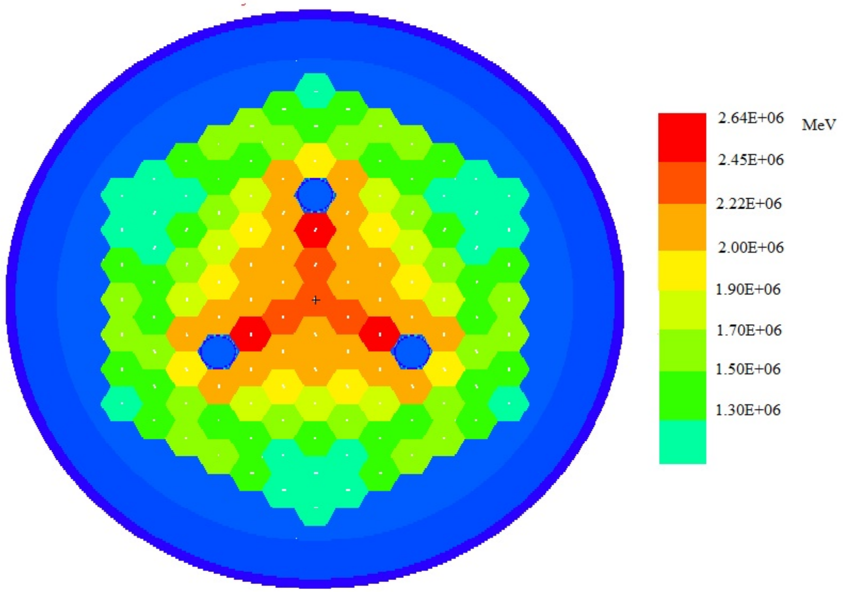
One Target vs Three Targets

Fast system (Pb coolant)

NB Different colour scales



One target- Fast



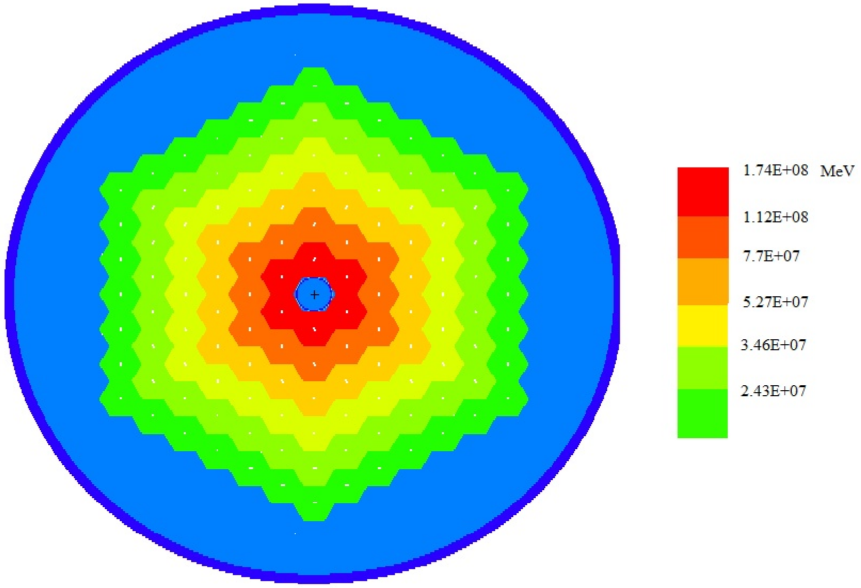
Three target - Fast

For the same beam power:

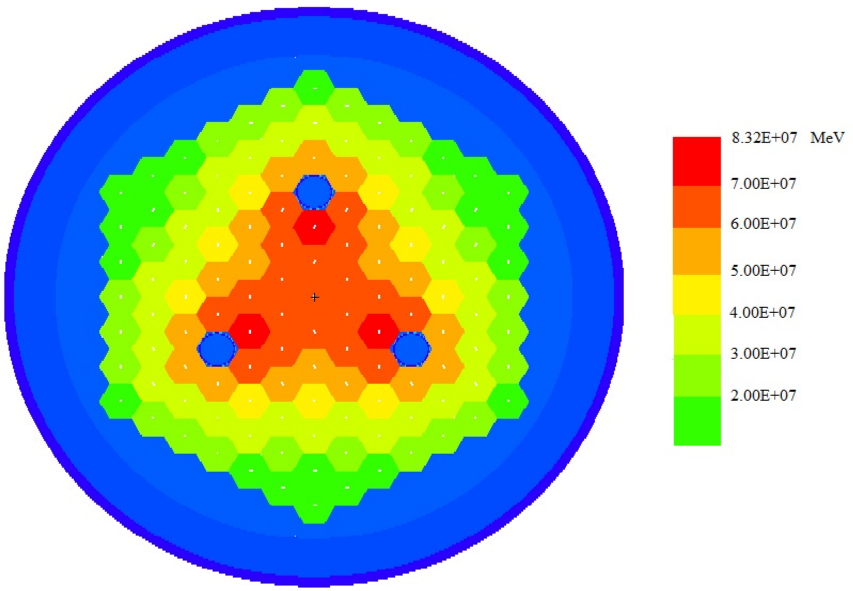
- Three targets lead to a flatter flux distribution but lower core power
- Three targets further out give a flatter flux profile but lower core power
- There is a trade-off between power peaking and core power

One Target vs Three Targets

Thermal system (H_2O coolant)



One target - Thermal



Three target- Thermal

$k_{\mathrm{eff}} = 0.98$

NB Different colour scales

Discussion: Fast vs Thermal

For the same core geometry and k_{eff} value:

- Core power, for the same beam current, is much higher in a thermal system

or

- Current requirement is much lower for the same core power

For the same core geometry and k_{eff} value:

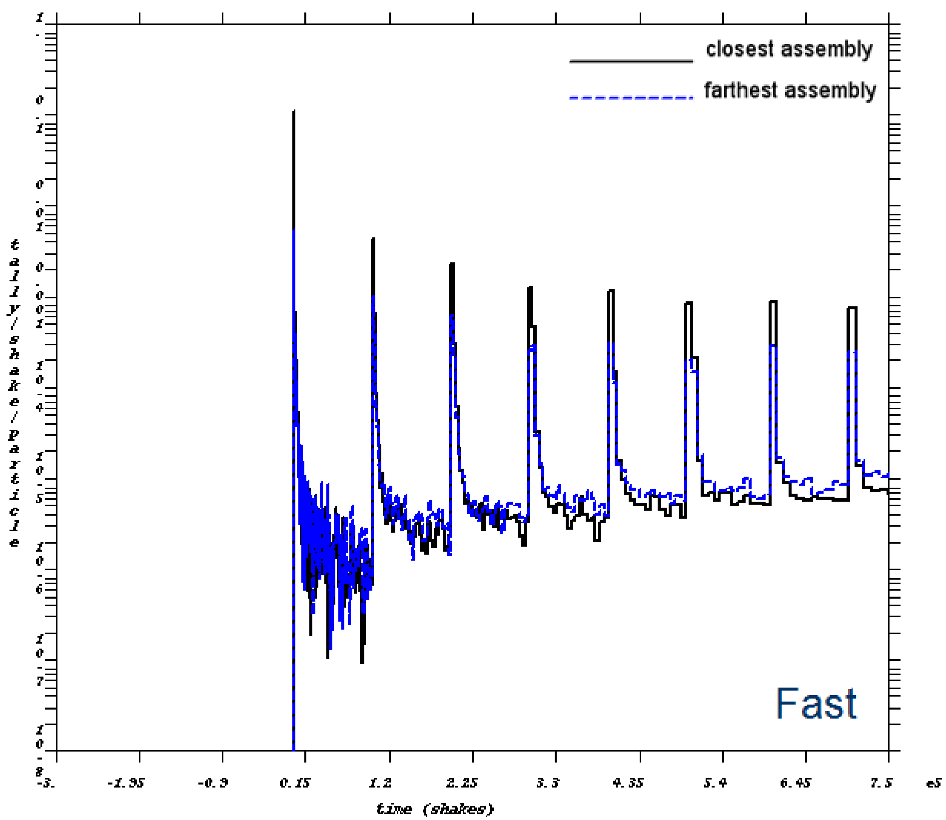
- Less fissile starter material is required in a thermal system

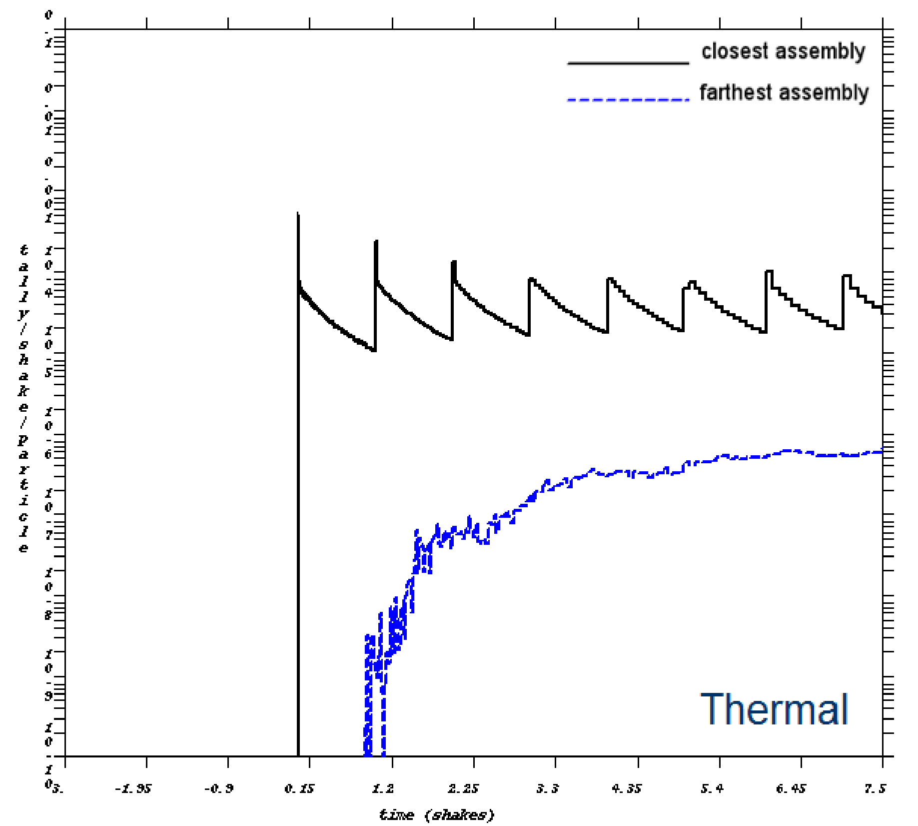
Starting from pure thorium fuel:

- The breeding time to reach the point of significant power generation is much less for a thermal system

Pulsed Beam Operation

UNIVERSITY OF CAMBRIDGE





The much longer average neutron lifetime in a thermal system will naturally ‘dampen’ the neutronic response of a thermal system to beam losses or pulsed beam operation.

Conclusions

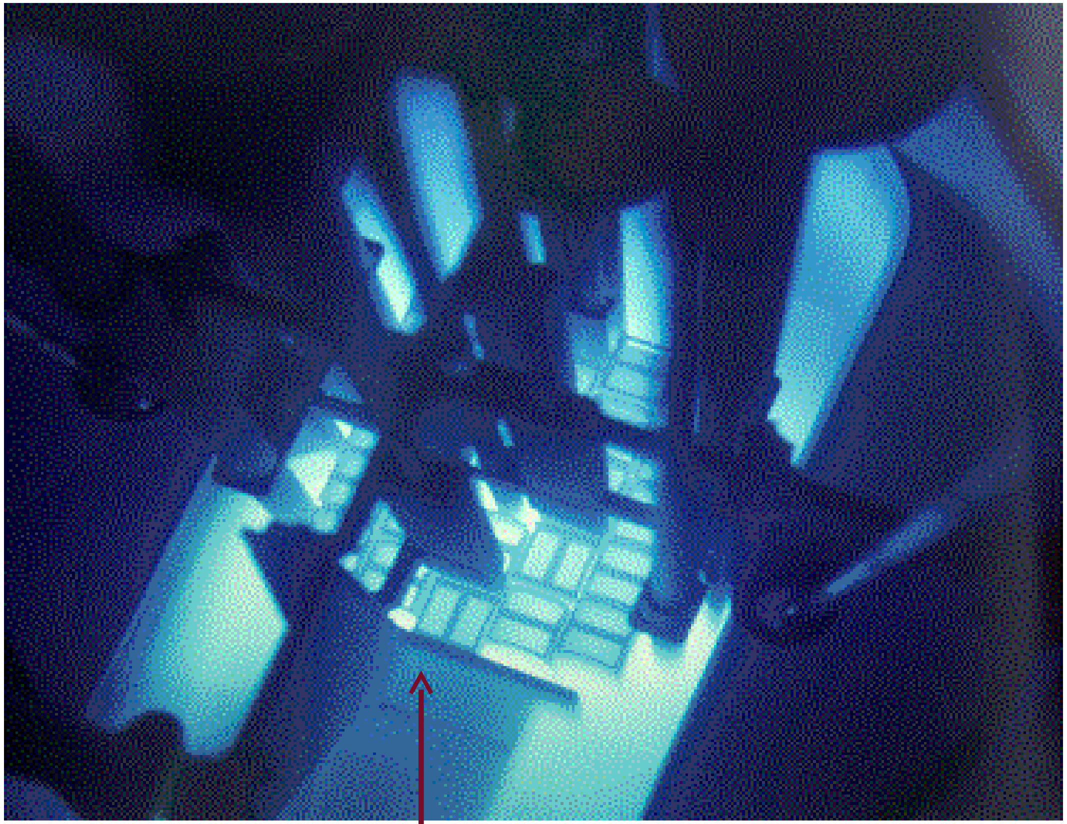
- There are some advantages to multi-target configurations but trade-offs are involved
- There are a number of advantages of thermal spectrum operation over fast – the normal assumption that ADSRs should be fast systems merits reassessment

CONSORT Reactor – Criticality Test/Fuel Irradiation Test

UK's only civil research reactor
100 kW, ~1m3 core
235U plate fuel

Discussion:
Solid W spallation target
& 230 MeV proton cyclotron
1 uA, 230 W target, 2kW in reactor

Studies by Trevor Chambers (Imperial) and Hywel Owen (Manchester) + student Elsa Benguigui



180 deg irradiation tube-
145mm x ~2.5m (to final quad)

ThorEA
the thorium energy amplifier association

Current Strategy

ThEC
THORIUM ENERGY CONFERENCE 2010

Imperial College London

- Operate for next two to three years whilst preparing for decommissioning
- Explore further training, commercial and research possibilities
- Continue negotiations with NDA regarding final decommissioning
- Decide long term strategy ie further use or decommissioning

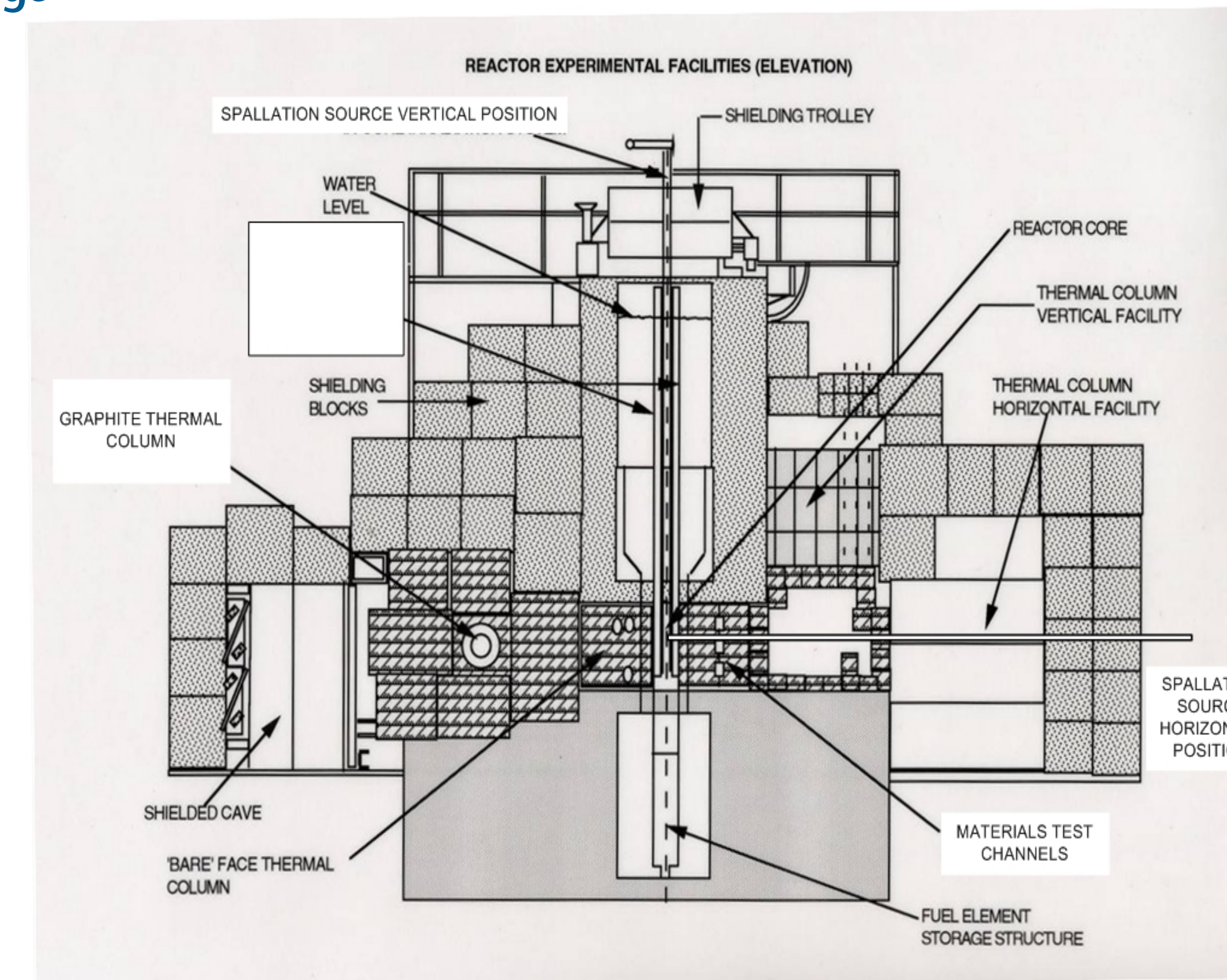
Possibilities for ADSR Test Bed

Imperial College London

Basic scheme for test bed considered

- Spallation target locations
- Accelerator type and location
- Potential experimental programme
- Timescales
- Cost
- Potential to support prototype ADSR programme
- Basic principle to convert CONSORT to ADSR test bed has NII support subject to safety case approval

Reactor Cross Section showing Central Spallation Target Location

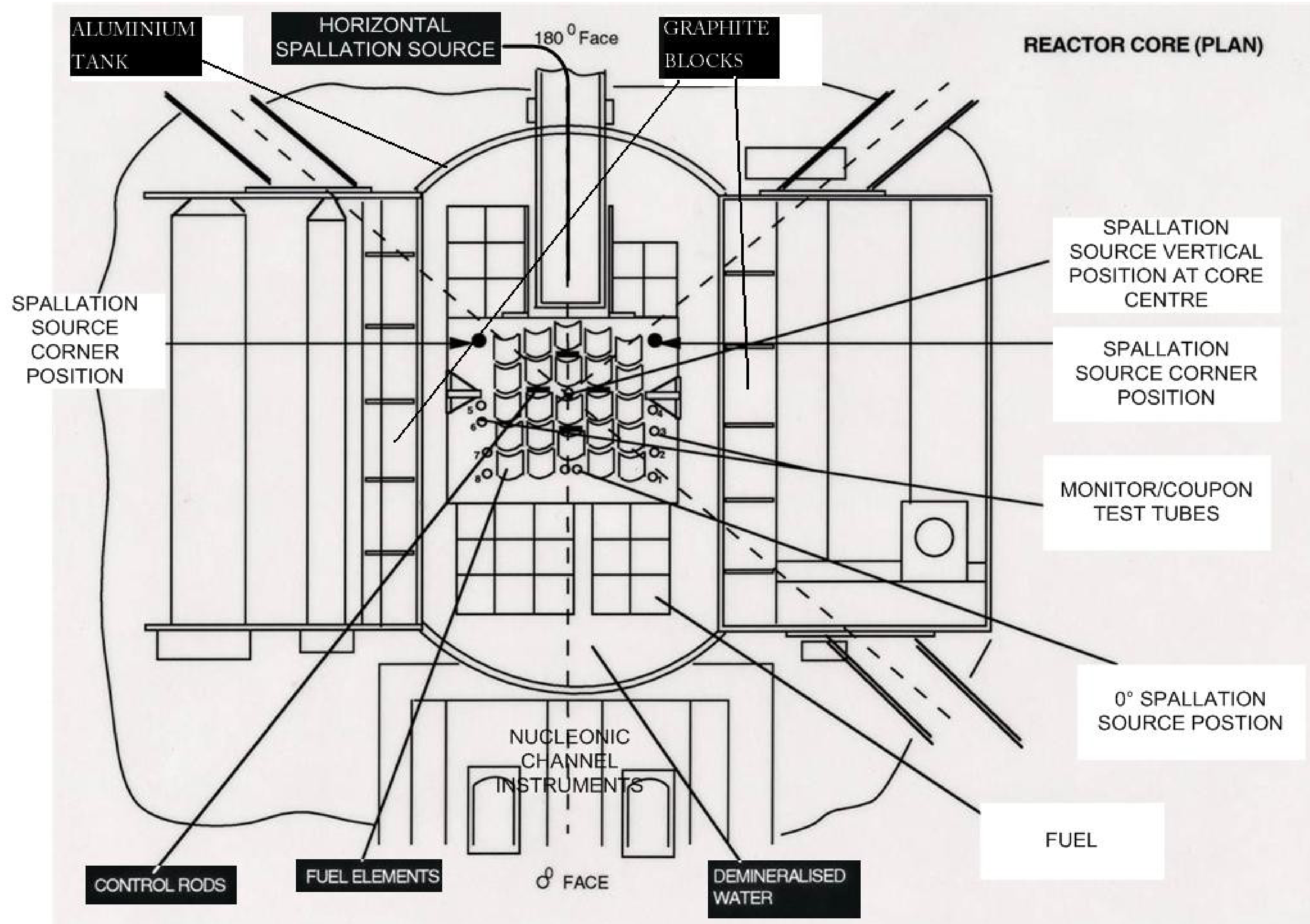


Plan of Core showing Alternative Spallation Target Locations

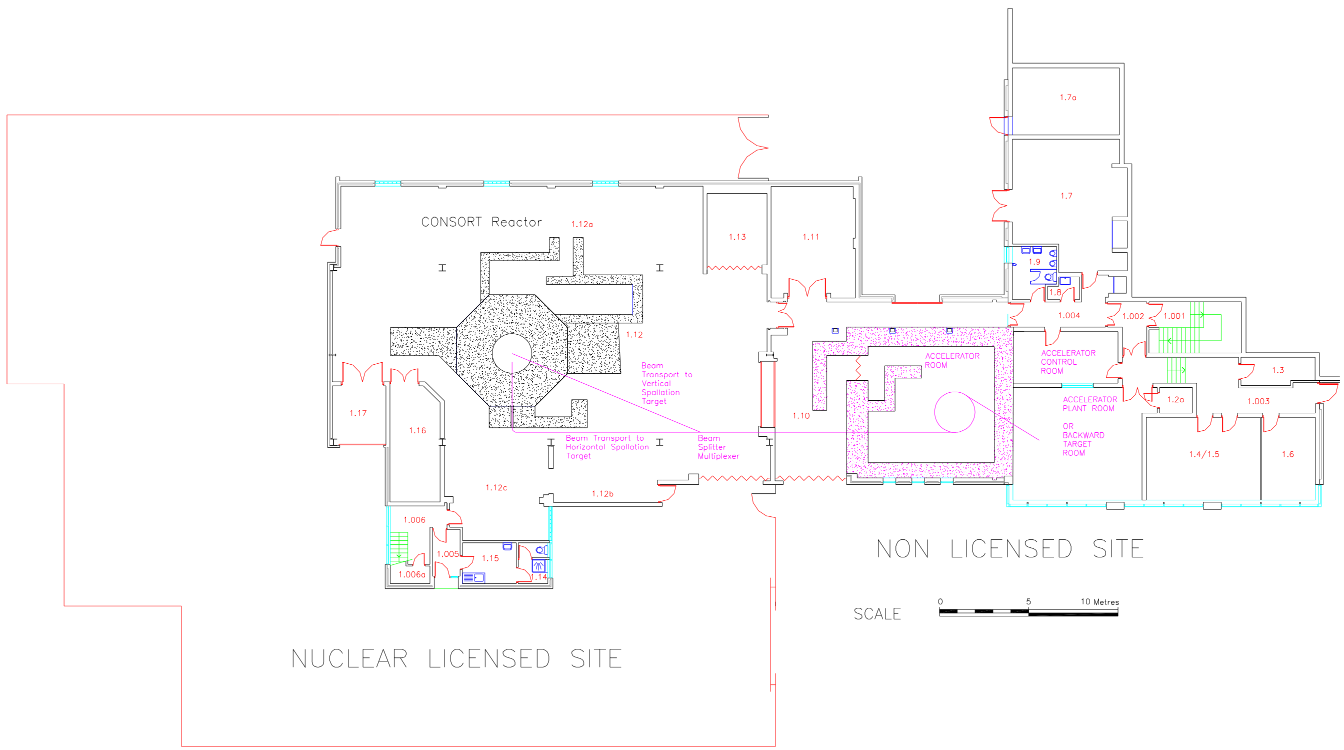
ThorEA the thorium energy amplifier association

ThEC THORIUM ENERGY CONFERENCE 2010

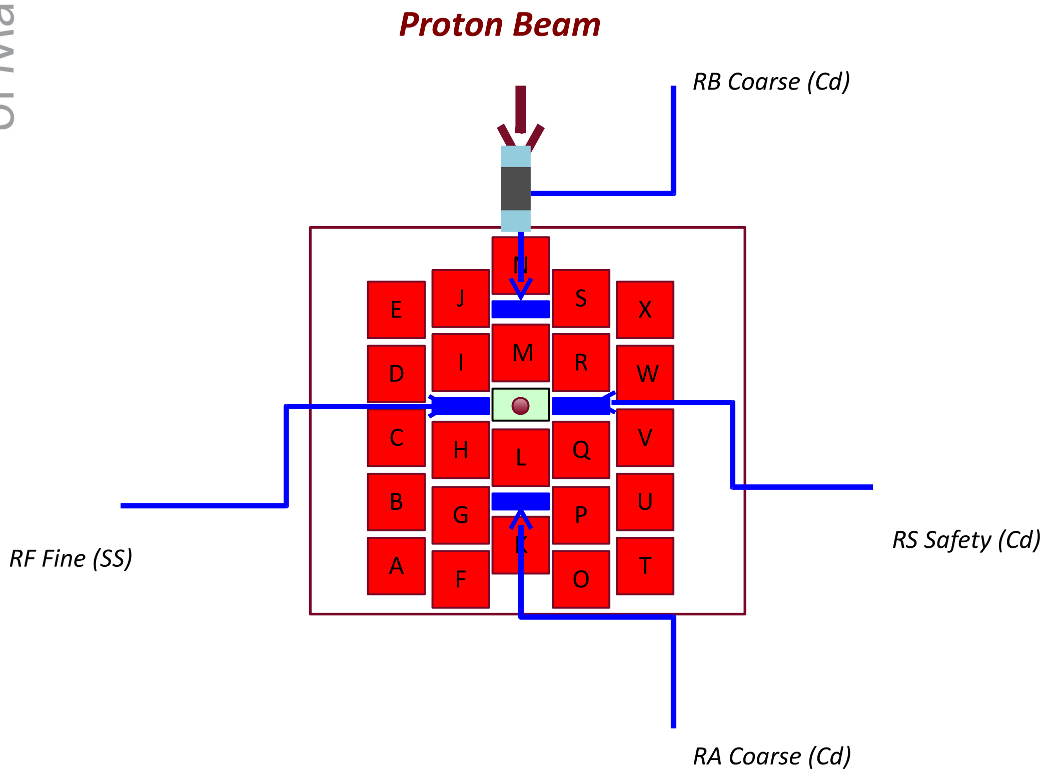
Imperial College London



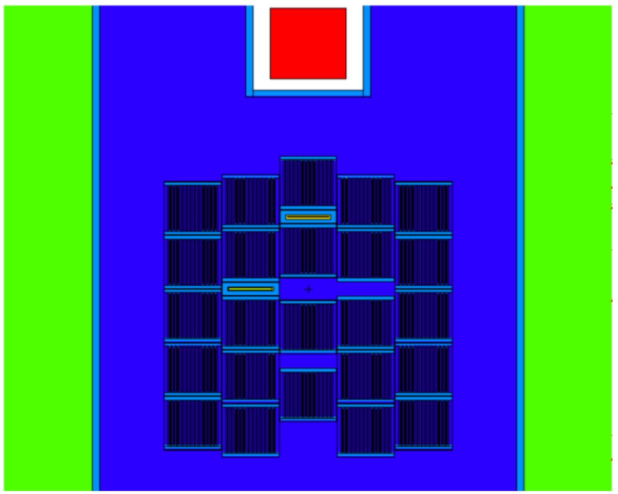
Accelerator Location and Type



Target and Core

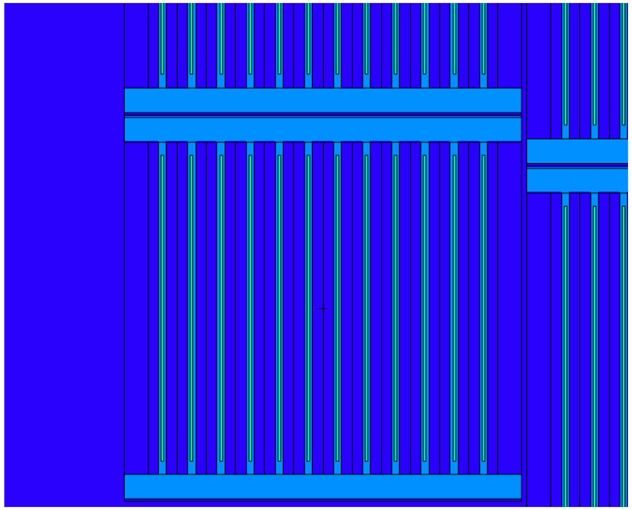


Schematic



MCNPX Model
(Type I elements only)

Fuel plates



Close-up of fuel plates
Lots of detail in the model!!

- Issues:
  - Curvature of fuel plates (not included)
  - Water moderator gap (nominally 4mm)
  - Fuel plate actual vs. theoretical thickness
  - Cd Control rod thickness
  - Fuel composition
    - burn-up vs original
    - total U mass
- Procedure:
  - Use flat plates
  - Adjust 235U/238U mass (not volume)
  - Match to experimental k=1 with model control rods in experimental positions (coarse and fine both at 30cm)
  - This is similar to Imperial modelling procedure
- (Type II/III fuel not yet included in model)

Rod-worths and keff Matching

(before fuel mass adjustment)

Configuration	keff	st. dev	Reactivity
No rods	1.0271	0.0008	2.64%
Fine	1.0221	0.0009	2.16%
1 Coarse	1.0160	0.0009	1.57%
1 Coarse+Fine	1.0102	0.0009	1.01%

Rod worth = reactivity change for complete rod insertion

Coarse: 1.1% in model cf. 1.5% in original published design – needs resolving.

Reactivity changes by correct amount for fine (Stainless) rod, but not for coarse (Cd) rod – difference in real vs. 1965 design thickness of rod

- Procedure:
  - Match keff to 0.99930+/-0.007 by fuel mass adjustment with C/F rods at 30cm (half-way into core)
  - Insert C/F rods to 60cm: keff=0.9872+/-0.0009
  - Add external neutron source at spallation position (direct spallation target calculation crashes)
    - MCNPX multiplication is 68.4 (nout/nin)
    - Theoretical value 64.1 (nout/nin)

Potential Experimental Programme

- Assess optimum sub-criticality using control rods and current fuel
- Assess use of multiple spallation targets
- Assess suitability of different spallation target materials
- Assess transmutation possibilities
- Assess Thorium fuel designs
- Assess control of Thorium fuelled ADSR
- Assess potential to load follow with Thorium ADSR
- PIE of fuel and targets
- Potential to test ns-FFAG when built

Potential to Support Prototype ADSR Programme

Imperial College London

Cost effective solution to provide:

- early data to feed into prototype design details such as spallation targets, fuel designs, core layout, level of sub-criticality
- data to assess transmutation possibilities and hence core arrangement
- data to assist design of reactor control systems
- confidence to commercial backers and government

Summary

Those are 3 topics out of many

To learn more, visit the website