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Novel Modelling Approaches for Higher Enriched Fuels in the Sellafield Magnox Reprocessing Plant

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The Sellafield Magnox Reprocessing Plant

- Commissioned in 1964
- Handles dissolution and chemical separation of liquor for onward transfer to finishing plants
- Most standard Magnox fuel at natural enrichment, but all less than 1w/o U235.
- Very large quantities of irradiated fuel can be shown safe within the dissolver, even at the most reactive time in life, in highly optimised arrangements

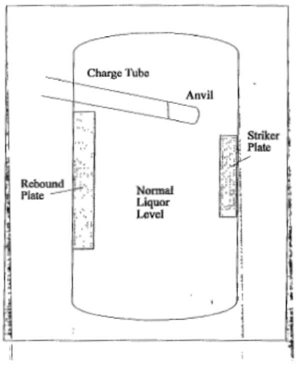
DFR Breeder Material

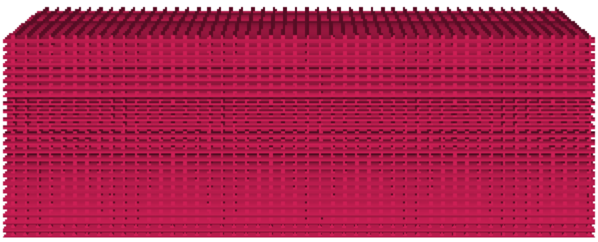
- Necessary to consider the feasibility of reprocessing an unusual material from the Dounreay Fast Reactor through the plant.
- Breeder Material – natural or depleted uranium metal placed in a blanket around the reactor core to demonstrate Pu breeding. More Pu than standard fuel.
- Material is not fuel – not part of the critical system and hence low fission product content
- Isotopic character challenges neutron monitors.

Dissolver Operations

- Rods or recans are loaded into magazines in the upstream fuel handling plant. One rod or recan is added to the dissolver at a time.
- The dissolver operates on a continuous feed, rather than batch, basis.
- Two possible approaches to deal with the material:
  - 'Drip Feed' a few DFR recans into every magazine of standard fuel
  - Feed filled magazines, but at a controlled interval

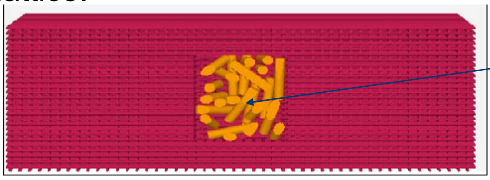
What is a reasonable rod arrangement?



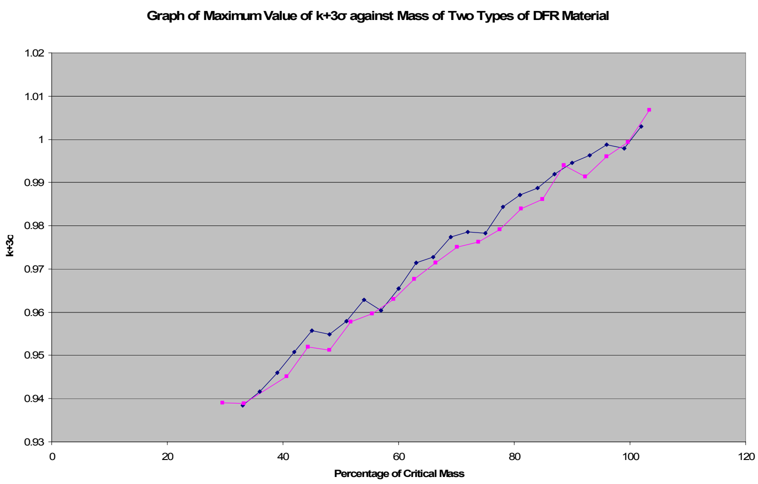


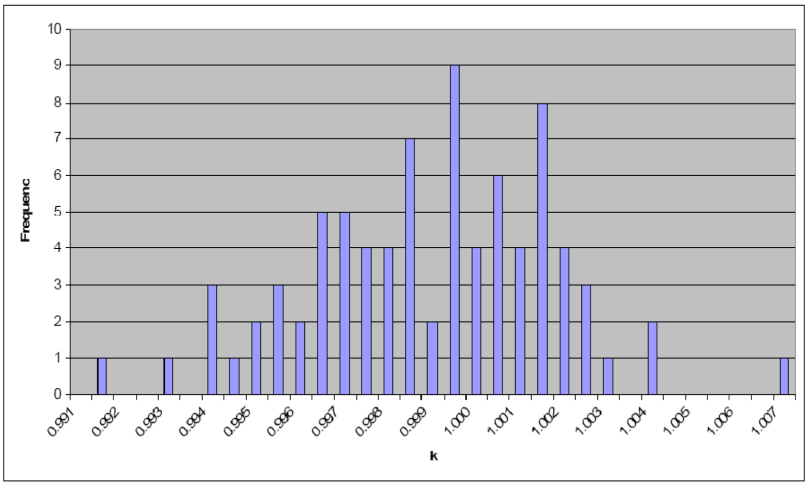
Modelling Strategy

- Model the equilibrium mass at each dissolver feed rate and vary geometry to establish the optimum
- RANDROD hole in the code MONK used to place a random accumulation of DFR slugs at the centre of the lattice.



Constrained within H=D cylinder.





Sub Critical Criterion for MONK Calculations

•Current UK practice recognizes the following error terms for a criticality calculation:

$$k\text{-eff} + E_{MC} <= 1.0 - X - E_{PD} - E_{SM} - E_R$$

E_{MC} = statistical error from the Monte Carlo calculation
X = subcritical margin
E_{PD} the bias and bias uncertainty in the code and nuclear data
E_{SM} is the total random error made up from random errors in the preparation and execution of calculation.
E_R is the bias to allow for operational or accidental changes causing increases in reactivity

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E_{SM}

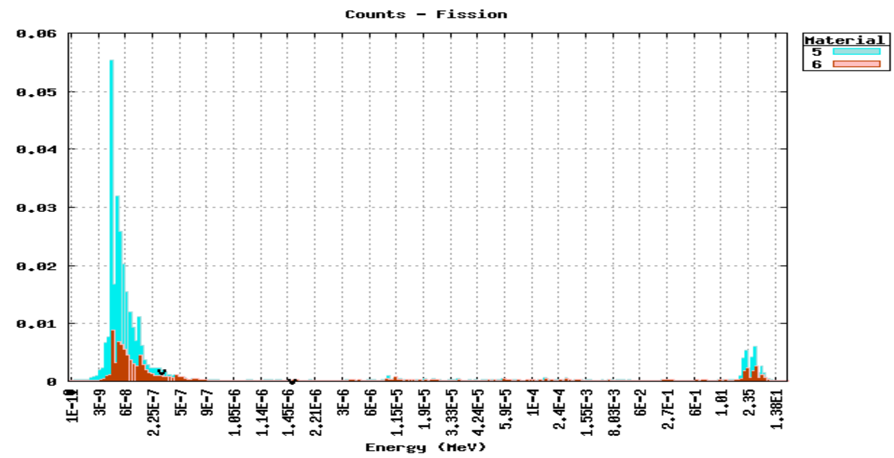
- Take half the range in k_{eff} for 100 runs near critical as E_{SM} (i.e. 0.007).
- Two immediate questions:-

  Is this range large enough? what is the probability of making an underestimate of $k_{eff?}$
- Assume range is big enough - assuming any symmetric distribution, probability of making an underestimate is 2^{-5} ^{or} in about 3% of cases
- Assuming normality, probability of making an underestimate of one MONK SD or greater in k is about 1 in 100 for the bounding case.

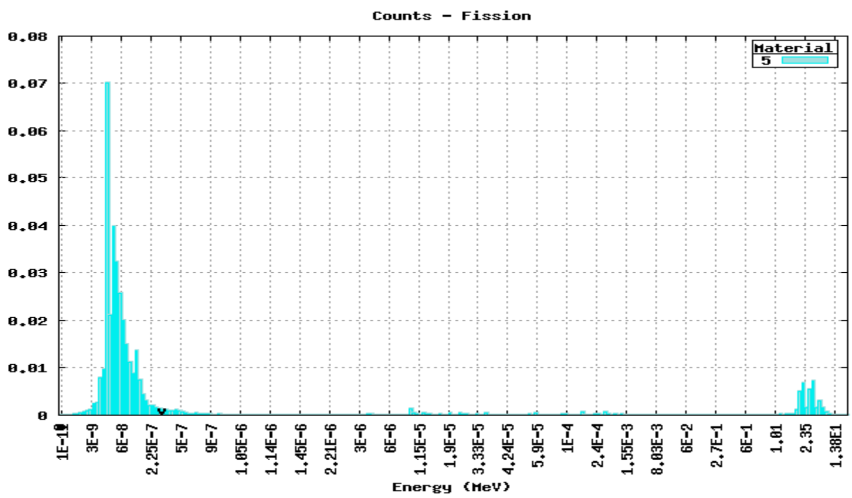
E_{PD}

- Reduced subcritical margin so E_{PD} may be important. Very few uranium metal validation experiments in MONK database.
- Inspection shows 30% of fissions in Pu Is this still valid?
- Energy profile of fissions at real and U-equiv isotopics was compared with graphing tools.
- Conservatively choose E_{PD}=0.01 as 1% is maximum credible underprediction for U235 systems

Actual Isotopics



U235-equivalent isotopics



Treatment of Uncertainties

- Unusual to have two uncertainties E_{SM} and E_{PD} to a model. Guidance suggests adding uncertainties linearly – no real justification for this.
- Linear application of errors is penalising.
- Errors are independent – justifiable to combine them in quadrature to preserve their distribution.
- Combined error term:

$$E = \sqrt{\left(E_{SM}^2 + E_{PD}^2\right)} = \sqrt{(0.007^2 + 0.01^2)} = 0.012.$$

MONK safety criterion becomes k+3σ≤0.968.

Modelling Pessimisms

- Still substantial modelling pessimisms:
  - More Magnox fuel mass modelled than realistically present
  - Moderator 3M nitric acid (starts at 6M and becomes 3M only at 300gU/l - (4% in k_{eff} near critical for 150gU/l)
  - Optimum burn up, optimum radius, optimum spacing of background Magnox fuel
  - DFR breeder material assumed to form an H=D cylinder
  - Assumption that DFR material can ‘float’, when undermoderated tight packing are more likely.
  - Assumption that all material is at the peak rod enrichment (about 2.5% in k_{eff} near critical)

Benefits

- 99.9% of the campaign would be safe with at least half of the magazine filled
- 61% of campaign would still be safe with a full magazine
- Would not have been possible to demonstrate safety of such loadings with more conventional modelling and/or traditional use of 0.95 safety criterion. Processing the material would not have been feasible.
- Experience being used to review modelling for other facilities on the Sellafield site.