GE Hitachi Nuclear Energy

Monte Carlo Simulation of Fuel Pellet Spills with Axial Inter-Pellet Moderation and Stochastic Geometry

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Data, Analysis, and Operations in Nuclear Criticality Safety - I

ANS Annual Meeting
June 13 – 17, 2010
San Diego, California

HITACHI

Overview

- Introduction
- Methodology
- Results
- Summary and Conclusions

Introduction

- In LWR nuclear fuel manufacturing facilities, spills of UO_2 pellets are of concern to criticality safety.
- Occurrence of a criticality incident or accident depends on the mass, geometry and moderation involved in a pellet spill.
- Criticality safety assessment of pellet spills must be performed in accordance with the Double Contingency Principle.

Introduction (cont)

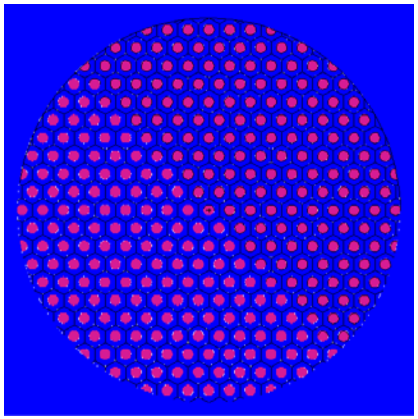
Consider a spill of sintered UO_2 pellets involving:

- 5 wt% U-235 fuel enrichment
- Hemispherical spill geometry involving 37 kg (safe mass of pellets).
- 12” concrete floor
- 12” water reflection on hemispherical surface
- Pellets modeled as rods (no axial spacing) or volume-equivalent spheres

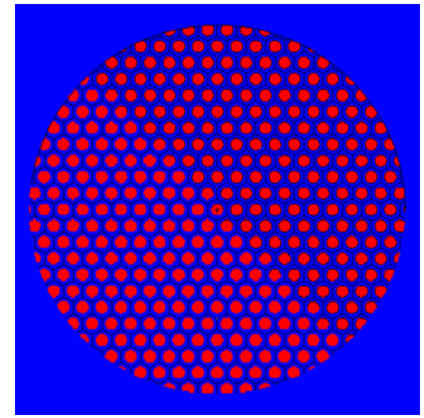
Analyzed with MCNP5 in KCODE mode with 10^6 active histories and standard deviation of about 0.0007.

Introduction (cont)

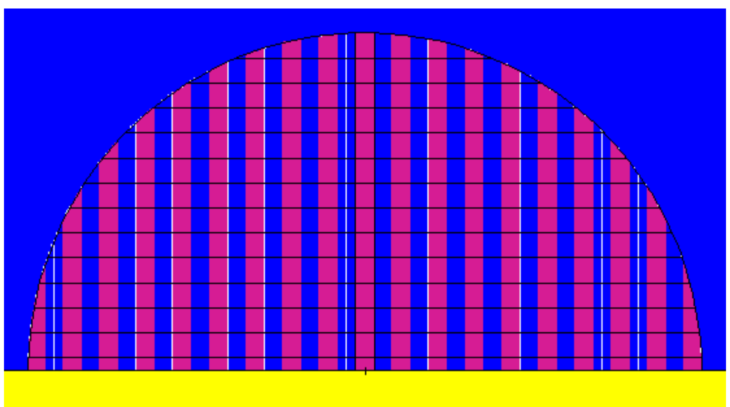
A) Array of rods

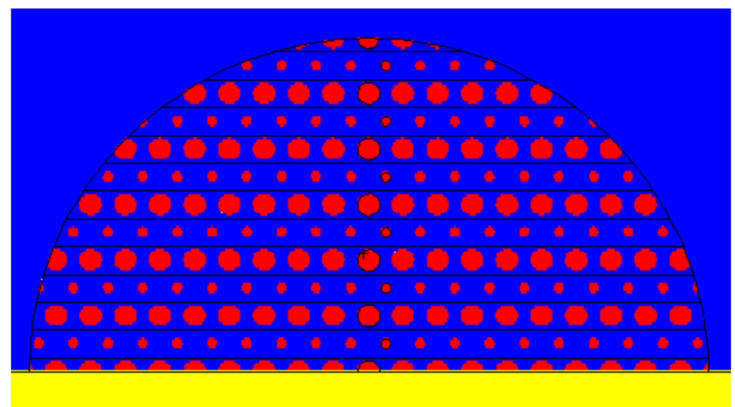


B) Array of equivalent spheres

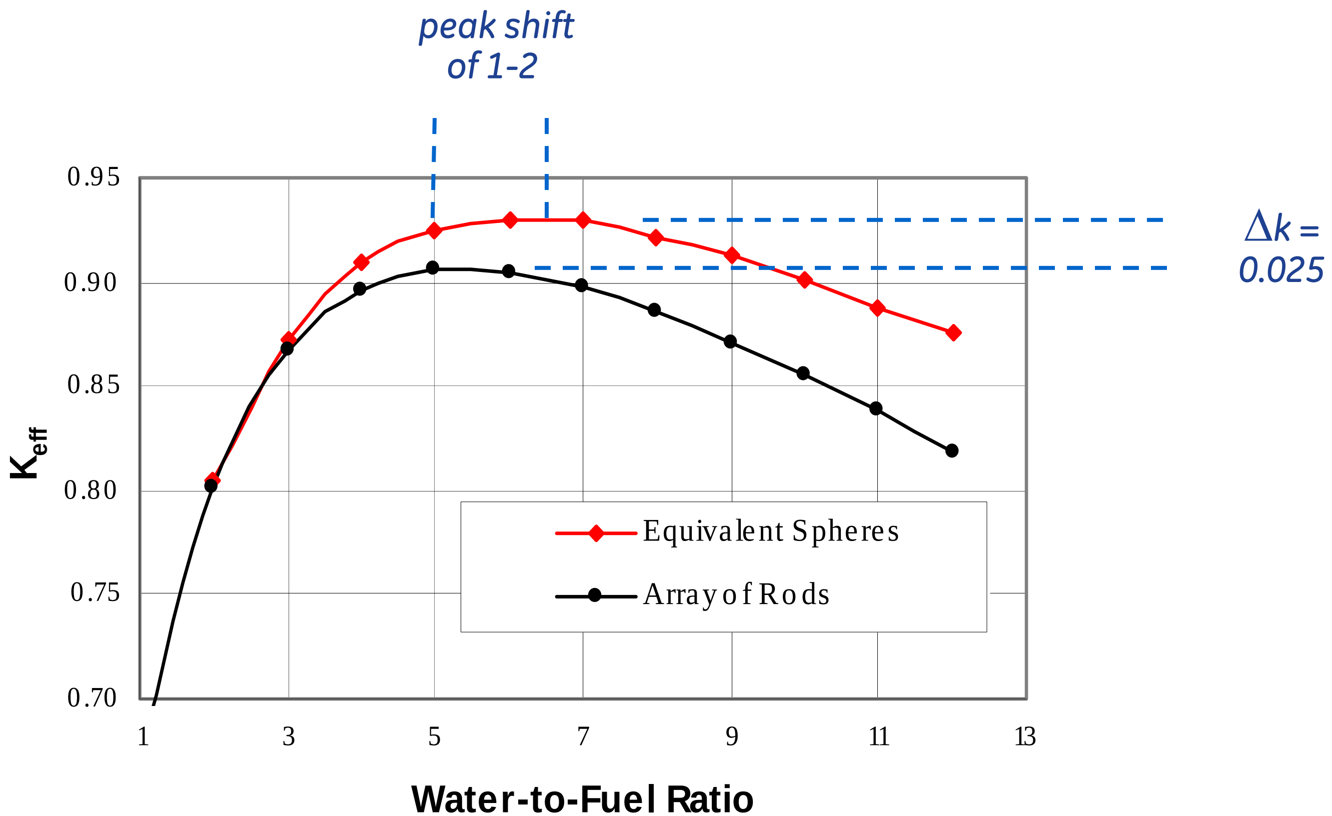


Hemispherical spill top and side cross-sectional views.





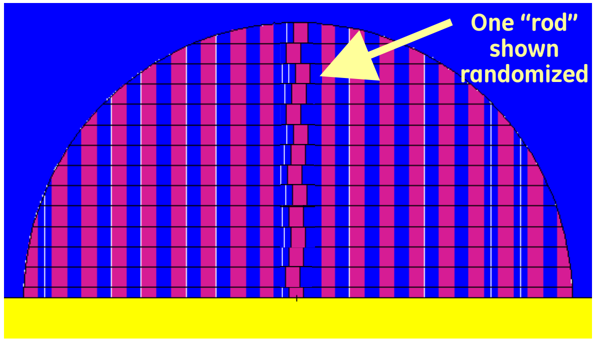
Introduction (cont…)

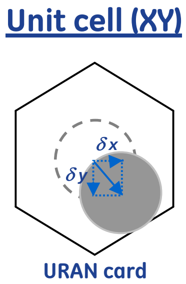


Investigate effect of modeling pellets explicitly
with axial spacing to isolate effect from sphere approximation.

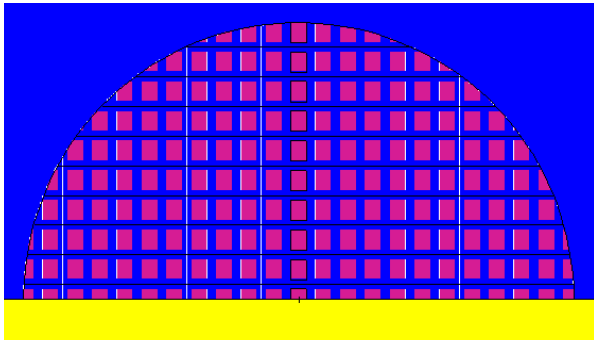
Methodology – Alternate arrangement of pellets in spills

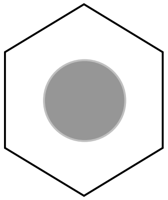
Stochastic rods: Array of pellets arranged *nominally* as rods but each pellet located randomly in XY.



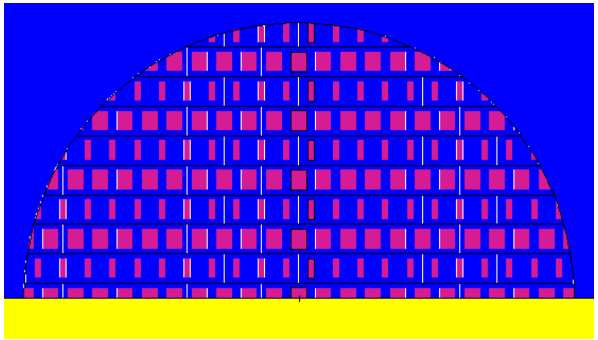


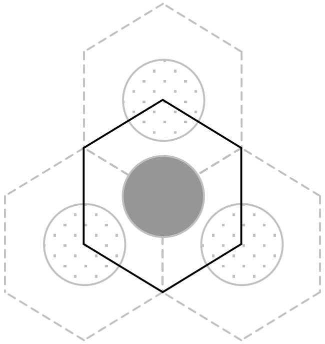
Type I (axial spaced): Array of pellets similar to the array of rods but adjacent pellets separated from each other in Z. Adjacent pellets are in-line in the Z direction.



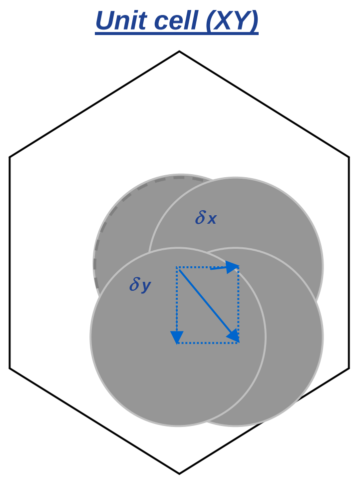


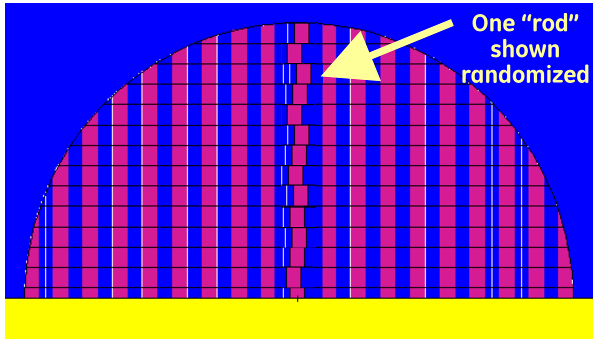
Type II (offset axial spaced): Fully triangular-pitched array of pellets similar in arrangement to the array of spheres. Pellets are centered between three pellets in adjacent plane in Z.





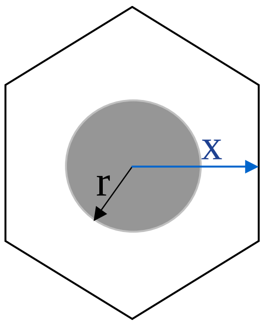
Methodology – Stochastic geometry in MCNP



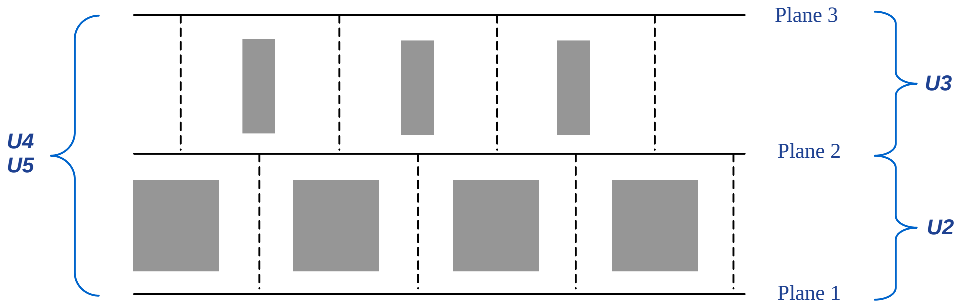


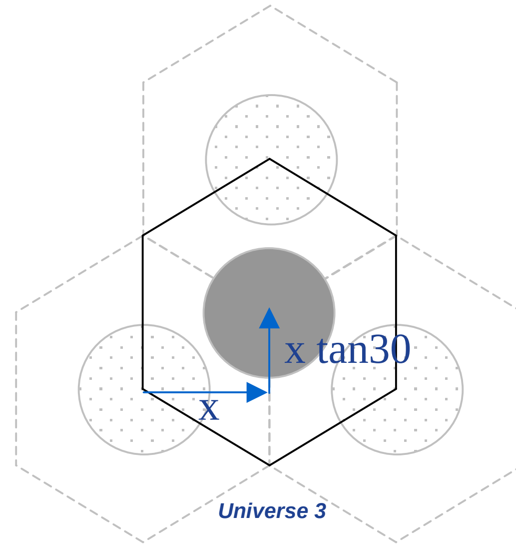
	universe	dx_{max}	dy_{max}	dz_{max}
URAN	1	0.6	1.0	0.0

Methodology – Fully triangular pitched arrays



Universe 2

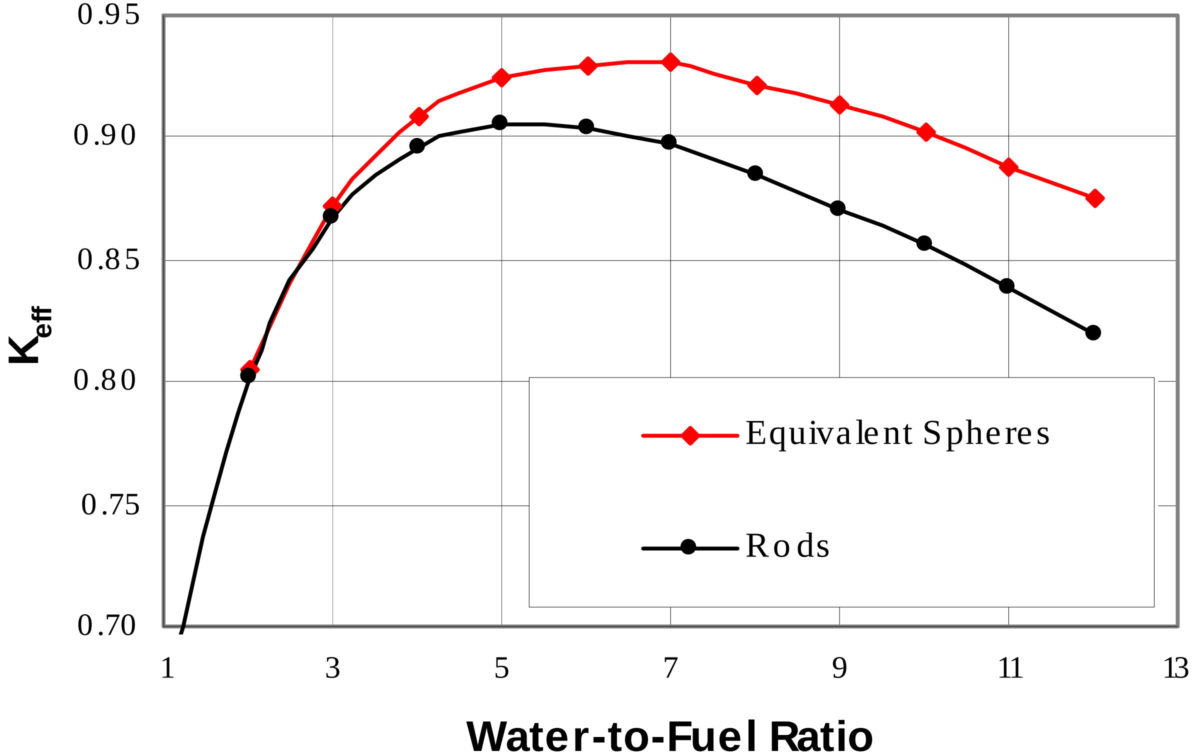




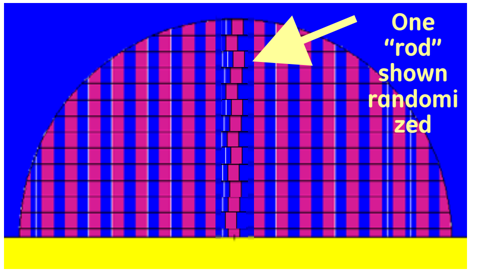
Universe 3

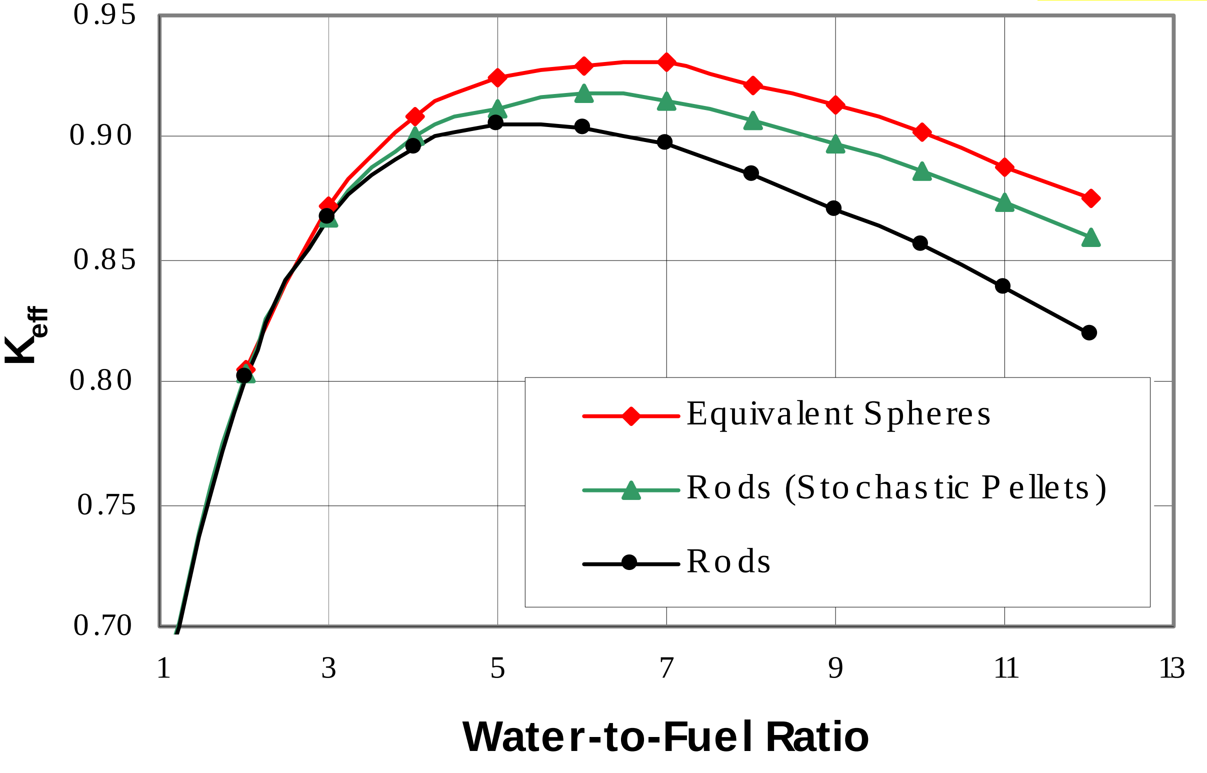
- An individual fuel pellet surrounded by water (***Universe 1***) is placed in an hexagonal prism and specified as a hexagonal lattice (lat=2) (***Universe 2***).
- A second hexagonal prism lattice is created translated by (x, x tan30, z) (***Universe 3***).
- *Universe 2* is used to fill an infinite region defined by Planes 1 and 2 creating an infinite planar array of triangular-pitched pellets. *Universe 3* is used to fill an infinite region defined by Planes 2 and 3. Together these two regions define ***Universe 4***.
- *Universe 4* is used to fill the region defined by planes 1 and 3, but using the square lattice (lat=1) and results in ***Universe 5***.
- *Universe 5*, is used to fill the fuel region resulting in an array of triangular pitched pellets.

Results


0.95
0.90
0.85
0.80
0.75
0.70
Keff
1
3
5
7
9
11
13
Water-to-Fuel Ratio
Equivalent Spheres
Rods

Results


One
"rod"
shown
randomi
zed


0.95
0.90
0.85
0.80
0.75
0.70
K_{eff}
1
3
5
7
9
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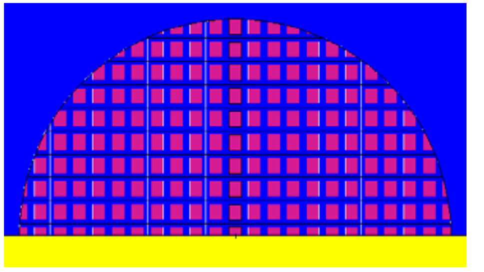
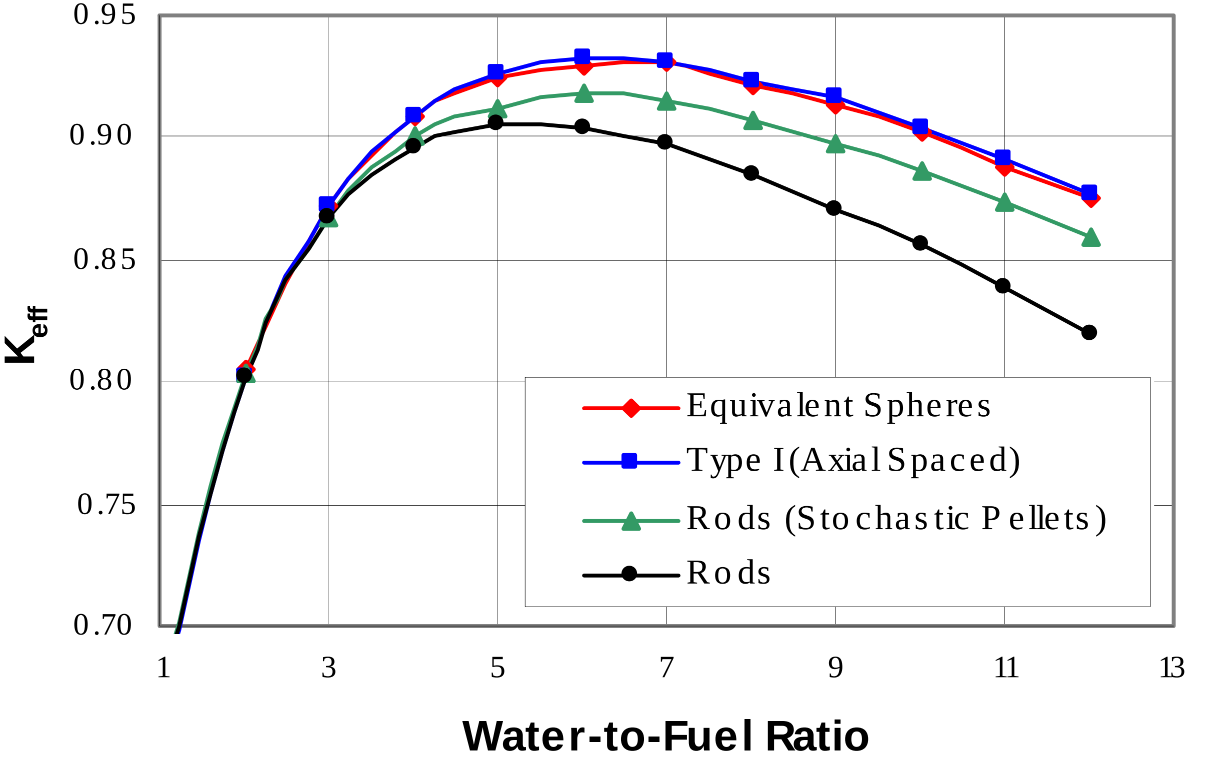
13
Water-to-Fuel Ratio
Equivalent Spheres
Rods (Stochastic Pellets)
Rods

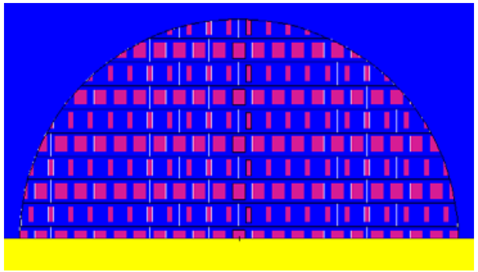
Results

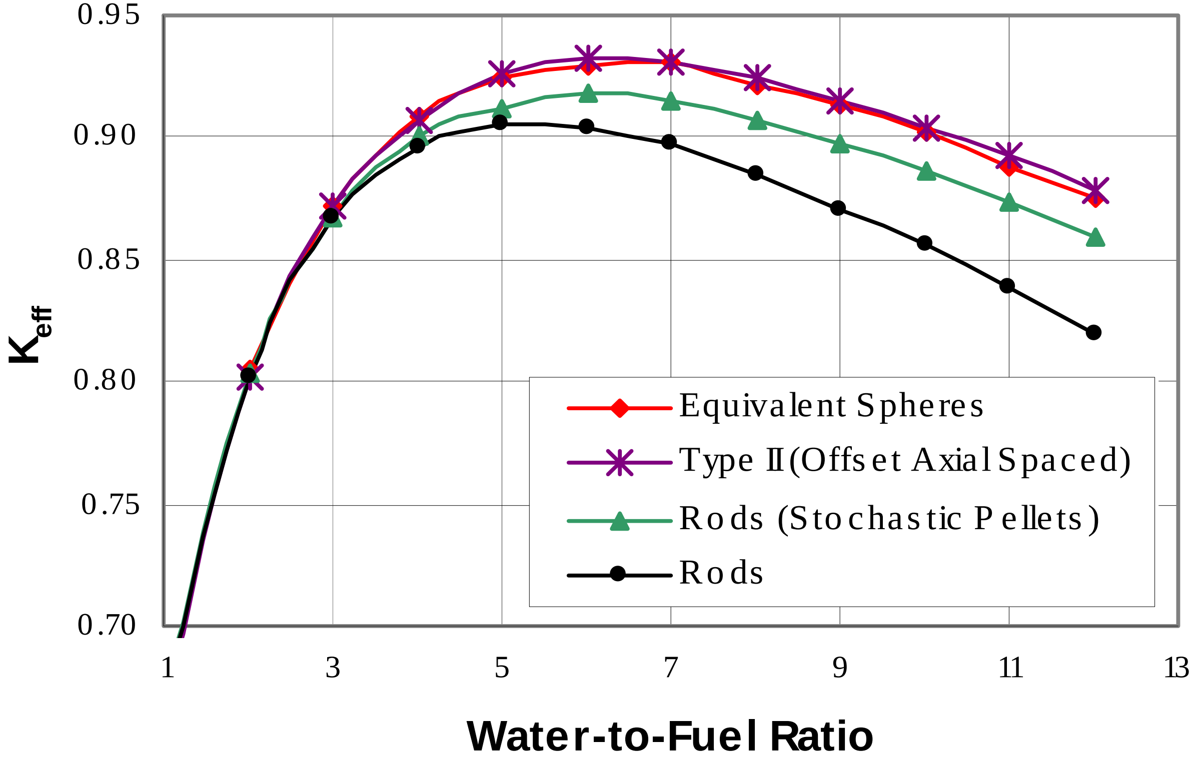




0.95
0.90
0.85
0.80
0.75
0.70
Keff
1
3
5
7
9
11
13
Water-to-Fuel Ratio
Equivalent Spheres
Type I (Axial Spaced)
Rods (Stochastic Pellets)
Rods

Results





0.95
0.90
0.85
0.80
0.75
0.70
K_eff
1
3
5
7
9
11
13
Water-to-Fuel Ratio
Equivalent Spheres
Type II (Offset Axial Spaced)
Rods (Stochastic Pellets)
Rods

Results

Model description	Peak reactivity (k_{eff})	Reactivity for low W/F (k_{eff}) (W/F=0.577)
Array of rods (deterministic)	0.905	0.577
Equivalent volume spheres	0.930	n/a
Array of rods (stochastic pellets)	0.918	0.576
Type I model (axial spaced)	0.932	0.575
Type II model (offset axial spaced)	0.932	0.575

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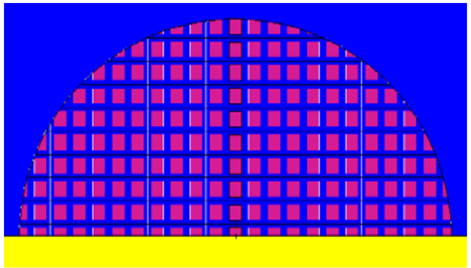
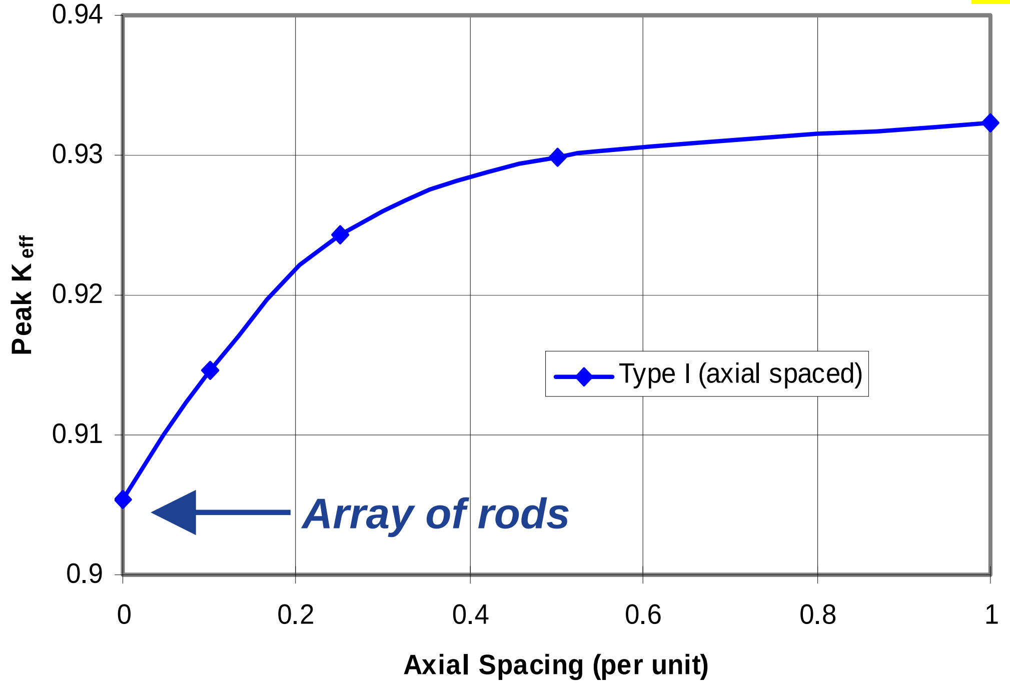
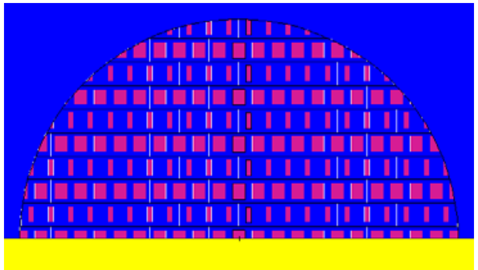
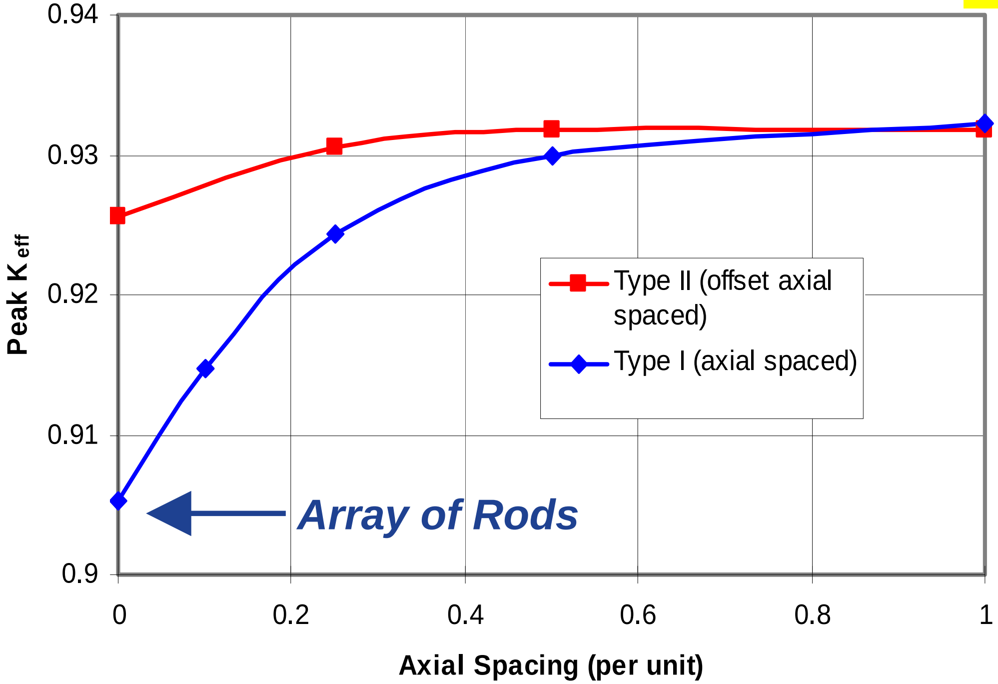
Results – Axial spacing





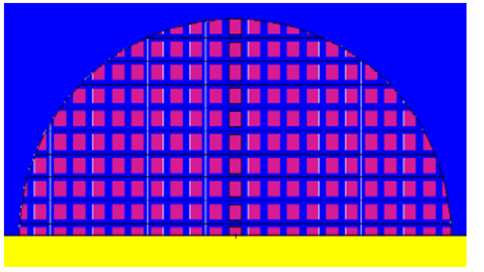
Results – Axial spacing

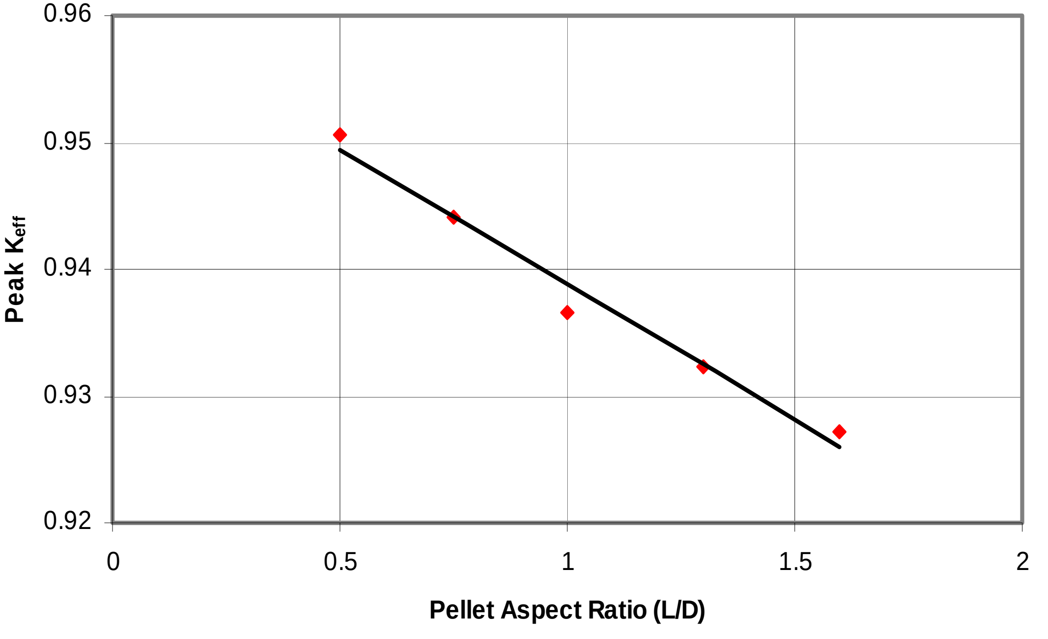




Offset axial spaced pellets give an axial moderation effect even without axial spacing.

Results – Pellet aspect





Summary and conclusions

Dry conditions

- For low moderation conditions axial spacing had no effect.

Moderated conditions

- Limited stochastic treatment of array of pellets as rods gives an axial moderation effect but below models with explicit axial spacing.
- Array of equivalent volume spheres, or pellets with axial spacing (Type I or II), gave similar results and were the most conservative models.

Application

- If axial spacing at optimum moderation is a credible condition, axial spacing can be significant to safe operation.
- However for typical applications both conditions wouldn't exist simultaneously as pellets would be expected to spill into a relatively close-packed array resulting in low W/F. As the W/F effect is significantly greater than the axial spacing effect, the array of rods model remains conservative and considering axial spacing can be used for added conservatism.