

# Uncertainty & Sensitivity Analyses of Th-MOX Fuels in ABWRs

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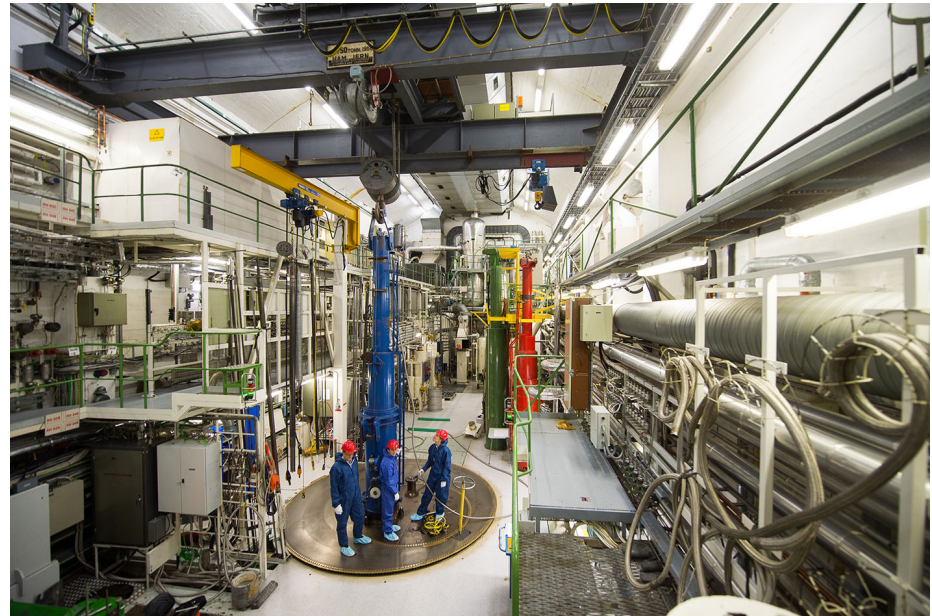
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# Outline

- Introduction & background
- Motivation & scope of project
- Methodology
  - Benchmarking WIMS vs. Serpent
  - Uncertainty & sensitivity analyses
- Results
- Conclusions & future work

# Introduction & Background

- Collaboration with Thor Energy for development of Th-MOX LWR fuel
- ‘Qualify thorium fuel for use in existing and future LWRs’
- Norwegian thorium resources are ~87,000T [1]
- Can be used in reactors operating today – PWRs/BWRs
- High Pu incineration efficiency [2]
- Irradiation programme underway at Halden research reactor - April 2018 [3]
- Uncertainty & sensitivity analyses crucial next step for safety case



# Motivation & Scope

- **Objectives:**

- Perform uncertainty & sensitivity analysis on Th-MOX fuel in an ABWR fuel assembly, using both Serpent & WIMS, for comparison with UOX & MOX assemblies

- **Motivation:**

- Uncertainties in U-233 & Th-232 NDLs are higher than U-235/8 – how does this translate to uncertainties in operating parameters?
- Sensitivity analysis will identify the key data to refine further to lower this uncertainty

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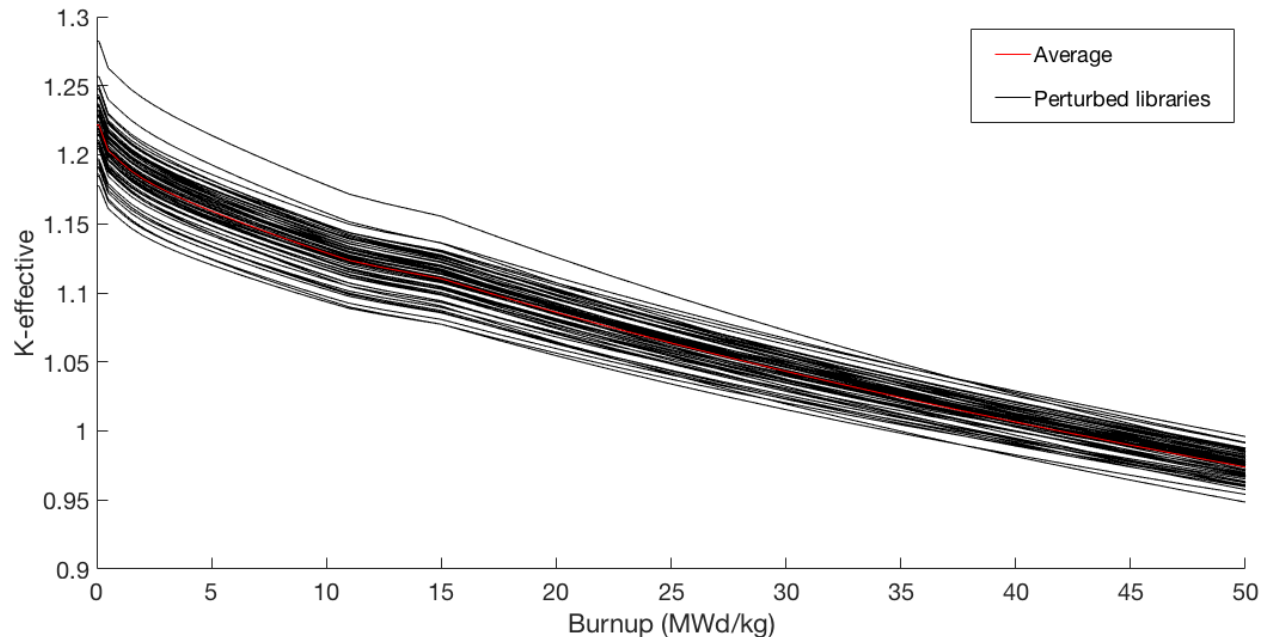
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- **PART 4:** Uncertainty calculation from sensitivity data
  - Utilise 'sandwich rule' to find uncertainties from Serpent
  - Compare with WIMS



# Methodology - Total Monte Carlo

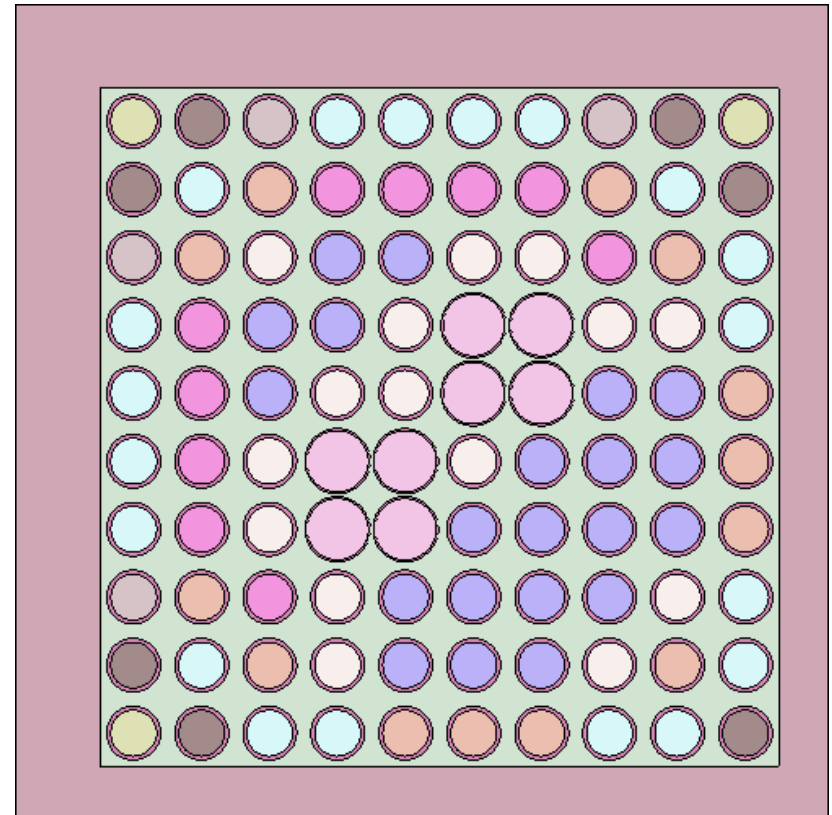
- Total Monte Carlo method used to generate 60 perturbed WIMS libraries
- JEF3.2 library with all XS perturbed randomly within error tolerances



# Fuel Assembly Benchmarking

## Th-MOX Fuel Data

Composition	2-15% Pu 73-86% Th
Fuel pin outer radius	0.513 cm
Pin pitch	1.295 cm
Coolant density	0.458 g/cm <sup>3</sup>
Moderator density	0.740 g/cm <sup>3</sup>



Serpent – simplified ABWR model to match WIMS

# Results - Benchmarking

Fuel type	WIMS	Serpent - simplified	Difference
Th-MOX	1.2209	$1.2271 \pm 0.0001$	0.0062
UOX	1.1181	$1.1171 \pm 0.0001$	0.0010
MOX	1.2338	$1.2514 \pm 0.0002$	0.0176

Results for  $k_{eff}$  at BOL for different assembly models

# Results - Benchmarking

Fuel type	Doppler Coefficient (pcm/degK)	
	WIMS	Serpent
Th-MOX	-3.42	-3.58
UOX	-1.87	-1.97
MOX	-3.17	-3.27

Fuel type	Void Coefficient (pcm/%void)	
	WIMS	Serpent
Th-MOX	-44.8	-43.1
UOX	-46.8	-46.2
MOX	-45.5	-45.0

Benchmarking results for DC and VC at BOL for different assembly models

# Results - Uncertainty Analysis

	Effective multiplication factor		
Fuel type	Mean Value	Standard Deviation	Percentage Error (%)
Th-MOX	1.2221	0.0188	1.54
UOX	1.1229	0.0066	0.58
MOX	1.2359	0.0086	0.69

Uncertainty results for  $k_{eff}$  and DC using 60 perturbed WIMS libraries

# Results - Uncertainty Analysis

	<b>Doppler Coefficient</b>		
<b>Fuel type</b>	Mean Value	Standard Deviation	Percentage Error (%)
Th-MOX	-2.85	0.22	7.58
UOX	-1.99	0.03	1.69
MOX	-2.35	0.03	1.40

	<b>Void Coefficient</b>		
<b>Fuel type</b>	Mean Value	Standard Deviation	Percentage Error (%)
Th-MOX	-44	4	9
UOX	-46	2	5
MOX	-45	2	4

Uncertainty results for DC and VC using 60 perturbed data libraries

# Results - Sensitivity Analysis

- Performed using new Serpent 2.1.29 capabilities
- Investigates the effects of perturbations to specific nuclear data on  $k_{eff}$
- All XS perturbed for individual nuclides in fuel

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# Results - Sensitivity Analysis

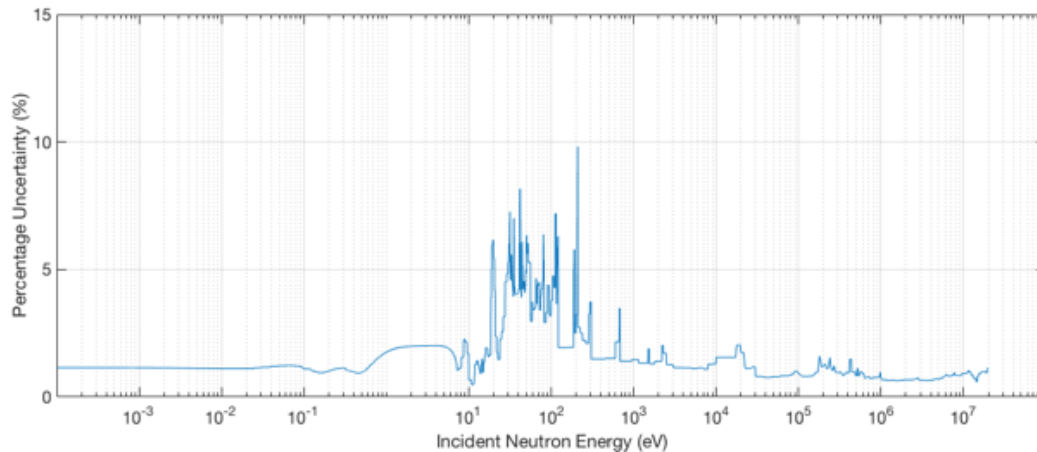
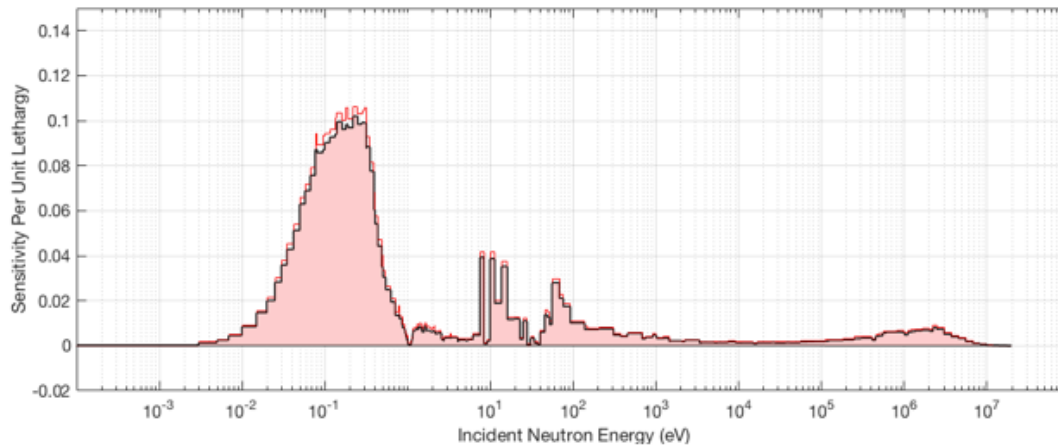
- Th-232 largest sensitivity is capture (expected)
- Largest sensitivity for Th-MOX overall = Pu-239(n,fission)
- Five greatest contributing nuclides for Th-MOX fuel:
  1.  $^{239}\text{Pu}(\text{n,fission})$
  2.  $^{239}\text{Pu}(\text{n},\gamma)$
  3.  $^{232}\text{Th}(\text{n},\gamma)$
  4.  $^{241}\text{Pu}(\text{n,fission})$
  5.  $^{242}\text{Pu}(\text{n},\gamma)$

Material	Perturbation	Sensitivity
Th-232	Elastic scattering	0.0004
	Inelastic scattering	-0.0035
	Capture	-0.1489
	Fission	0.0065
Pu-239	Elastic scattering	-0.0006
	Inelastic scattering	-0.0001
	Capture	-0.2145
	Fission	0.3368

Sensitivity data generated by Serpent



# Sandwich Rule Application



Pu-239 (n,fiss) energy-dependent sensitivity from Serpent and uncertainty from NDLs

$$C_y = S_{x/y} C_x S_{x/y}^T \quad [4]$$

- $S_{y/x}$  calculated by Serpent
- Covariance matrix taken from JANIS database
- Allows us to compute a new nuclide XS-specific uncertainty

# Comparison WIMS vs. Serpent

	Standard deviation $\sigma$
WIMS (total Th-MOX)	0.0188
Serpent total	0.0265
- Th-232(n, $\gamma$ )	0.0148
- Pu-239(n,fission)	0.0032
- Pu-239(n, $\gamma$ )	0.0023
- Pu-241(n,fission)	0.0030
- Pu-242(n, $\gamma$ )	0.0032

Uncertainty results and specific nuclide breakdown for Serpent data

# Summary & Future Work

- Uncertainty and sensitivity analyses completed for Th-MOX fuel in ABWRs
- Uncertainty is found to be ~3X larger for Th-MOX than for UOX or MOX – must be reduced before commercial use could be considered
- Sensitivity analysis performed with new Serpent 2.1.29 tools is found to match well with results from WIMS
- Most important XS to refine to reduce overall uncertainty in Th-MOX fuel is  $^{232}\text{Th}(n,\gamma)$

# Thank you for your attention!

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# References

- [1] – Data taken from 'Uranium 2016: Resources, Production & Demand', OECD Nuclear Energy Agency and the IAEA
- [2] – E. Shwageraus, P. Hejzlar, M. Kazimi, 'Use of thorium for transmutation of plutonium and minor actinides in PWRs', *Nuclear Technology*, 147(1):53-68, July 2004
- [3] – Website, thorenergy.no, viewed on 01/11/17
- [4] – D. Cacuci, 'Handbook of Nuclear Engineering', pg 1923, Springer, August 2010