Non-LWR Analysis with SCALE 6.3

Horizontal Split Table Conceptual Design for Validation of Nuclear Data used in Advanced Reactors

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Mathieu Dupont

Justin Clarity

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   - Evaluation of nuclear data tested by the experimental configuration
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Motivation

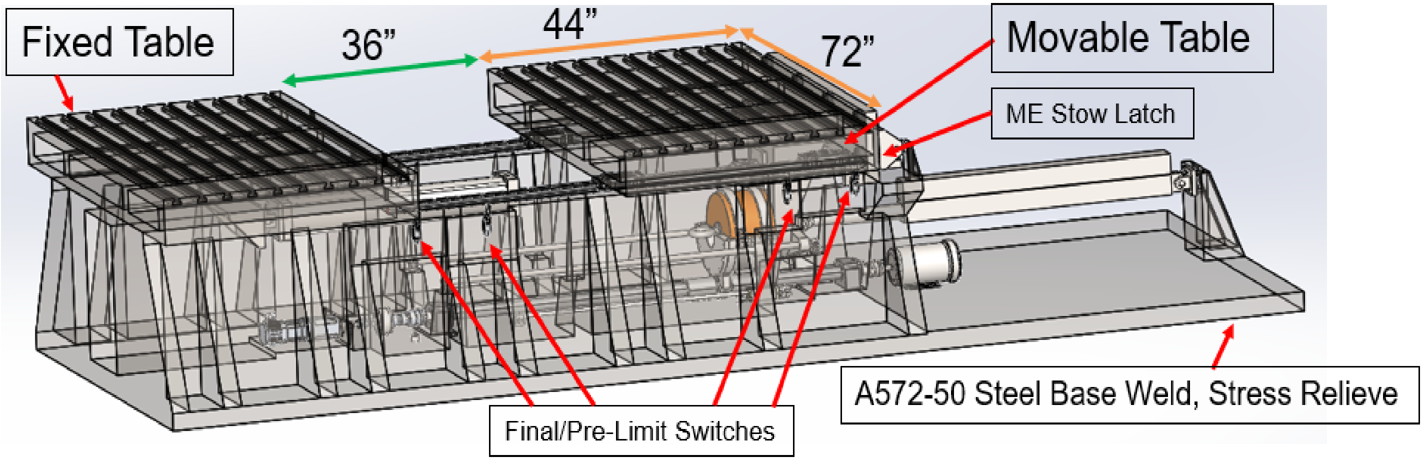
- Advanced reactors designs use different material, energy spectrum, and/or temperature conditions than current commercial nuclear reactors
- Potential nuclear data gap or high uncertainties exist on some materials (e.g., graphite, sodium)
- To help judge the adequacy of available nuclear data, a design of benchmark critical experiments similar to those advanced reactors is proposed

Motivation

- Lawrence Livermore National Laboratory is leading the overall and mechanical design (Catherine Percher and Daniel Siefman), ORNL is leading the criticality/nuclear data need design
- LLNL proposed a horizontal-split-table design
- The choice of type of advanced reactor for the conceptual design is based on *F. Bostelmann, G. Ilas, W. A. Wieselquist "Key Nuclear Data Impacting Reactivity in Advanced Reactors," ORNL/TM-2020/1557 (2020)*

Motivation

- From LLNL, limitation on the geometry of the table, and on the mass and size of material on it



Example rendering of the Horizontal Split Table concept proposed by LLNL (Catherine Percher)

	Table Part	Dimension	Cm
Maximum Table dimensions	Both tables	**Width**	**182.88**
	Fixed table	length	121.92
	Moving table	length	121.92
	Total	**length**	**243.84**

Maximum Surface Area	
cm^2	44593
m^2	4.46

Methods

For each Horizontal split table advanced reactor type concept studied, a similar process is followed:

1. **Determination of a critical core experimental configuration**
2. **Evaluation of nuclear data tested by the experimental configuration**
3. **Assessment of horizontal split table mechanical tolerances**

Methods

1. **Determination of a critical core experimental configuration**
   - Search to find a publicly available and trustworthy advanced reactor benchmark model
   - Conversion of the model to a SCALE KENO-VI format if needed
   - Modification of the model to accommodate a rectangular shape and the maximal required dimensions of 182.88 x 243.84 cm
   - Incremental SCALE 6.3 KENO-VI calculations with ENDF/B-VII.1 cross-section library to determine a critical core, adjusting reflector/moderator in priority, active core region if needed
   - Separation of the model in half to correspond to the two sides of the split-table

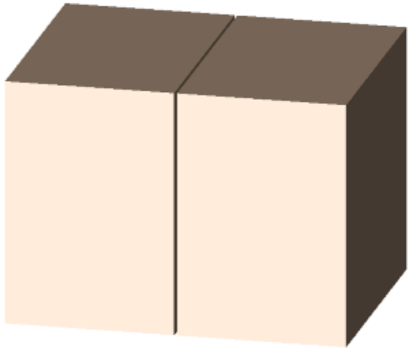
Methods

2. **Evaluation of nuclear data tested by the experimental configuration**
   - Creation of a TSUNAMI model of the critical core
   - Calculation of the k_{eff} uncertainty due to the use of ENDF/B-VII.1 cross-section library
   - Observation of the materials and/or nuclear isotopes responsible for the highest k_{eff} sensitivity
   - Creation of sensitivity data file (.sdf)
   - Assessment of the correlation between the HST .sdf file and the original application benchmark .sdf file with TSUNAMI-IP
   - **If c_k, the correlation coefficient determine by TSUNAMI-IP is high, it means a useful critical experiment benchmark concept for nuclear data validation of advanced reactors materials**

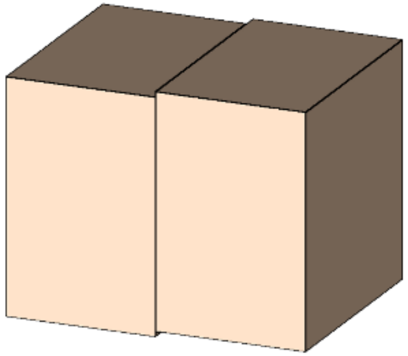
Methods

3. Assessment of horizontal split table mechanical tolerances

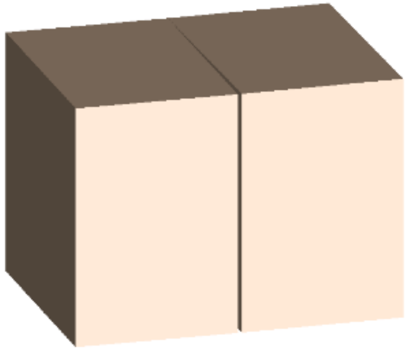
- What is the influence on k_{eff} of mechanical uncertainties in the table design?
  - Horizontal gap
  - Vertical gap
  - Angular gap
  - Torsion gap
- Quadratic fit to determine a k_{eff} uncertainty per mechanical uncertainty



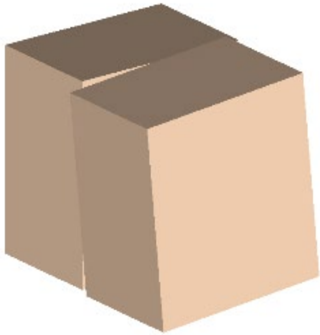
Horizontal gap



Vertical gap



Angular gap



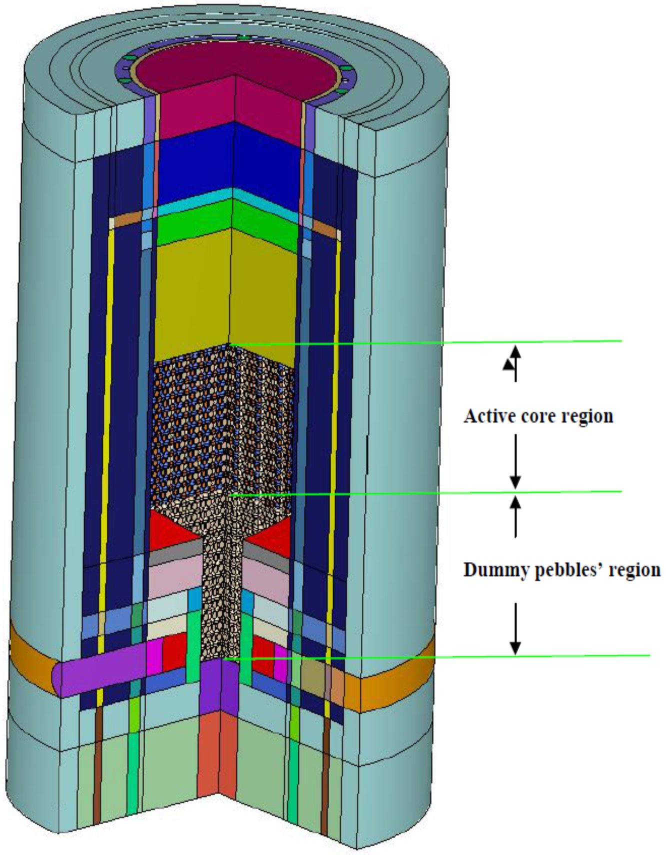
Torsional offset

Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

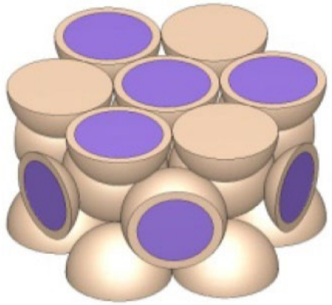
- Described in IRPhEP, *Evaluation of the Initial Critical Configuration of the HTR-10 Pebble-Bed Reactor, HTR10-GCR-RESR-00 (2007)*
- Previously modeled in SCALE KENO-VI by *G. Ilas et al., "Validation of SCALE for High Temperature Gas-Cooled Reactor Analysis," NUREG/CR-7107, ORNL/TM-2011/161 (2012)*
- Good candidate because of available information, model, and uncertainties on nuclear data used exist

Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

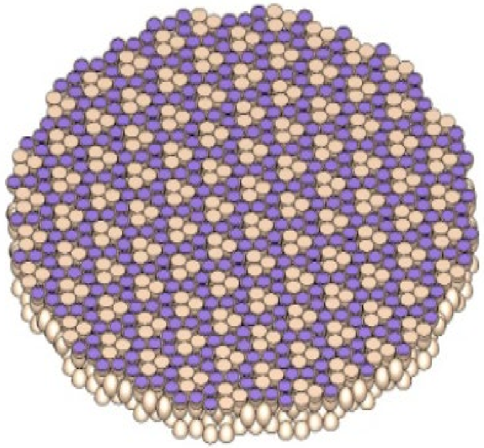
- Active core region is 123 cm high and 180 cm diameter, not far from the split-table requirements
- Total of 16890 pebbles, 9627 fuel, 8263 dummy
- Packing fraction 61%
- Pebble radius 3.0 cm, 2.5 cm fuel region and 0.5 cm radius graphite shell
- 8355 TRISO particles in each pebble
- TRISO: UO_2 kernel and layers of cladding



Full core model



Hexagonal prism unit cell



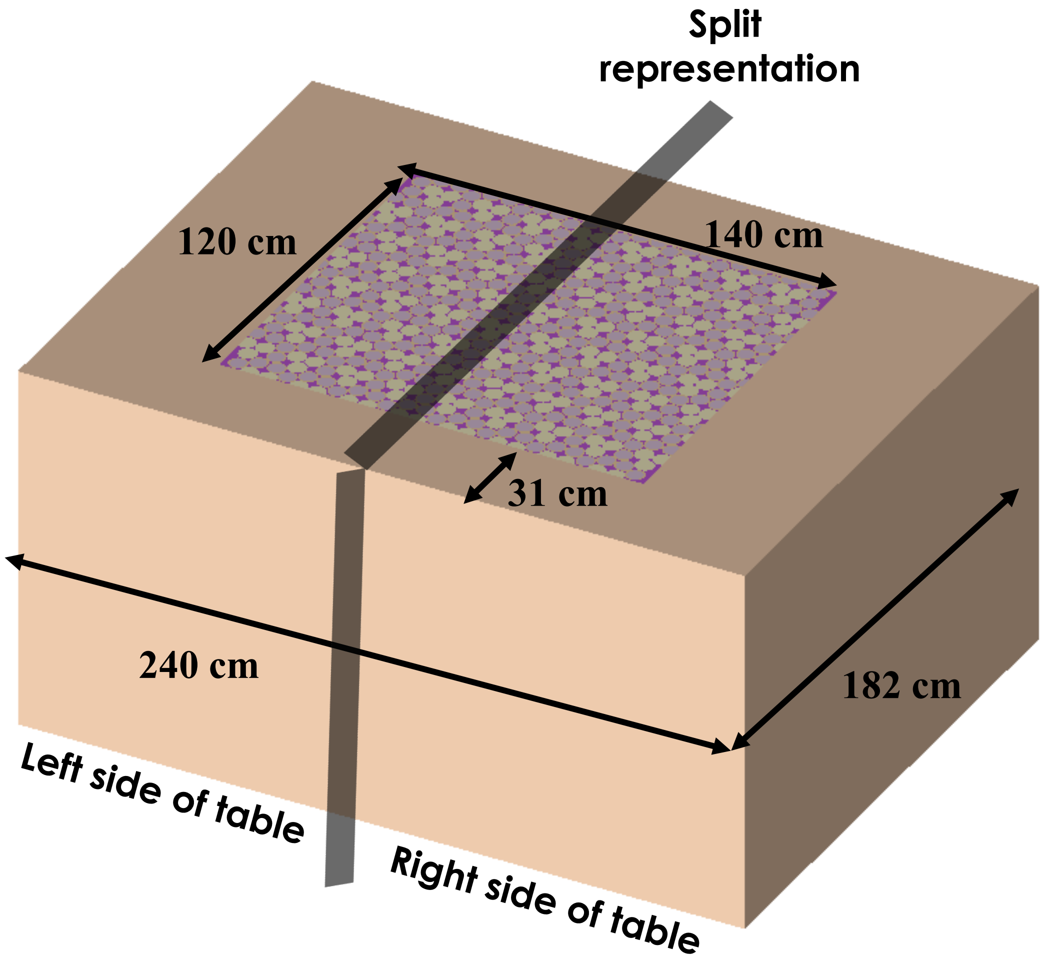
Layer of pebbles in active core region

From *G. Ilas et al., "Validation of SCALE for High Temperature Gas-Cooled Reactor Analysis," NUREG/CR-7107, ORNL/TM-2011/161 (2012)*

Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

1. **Determination of a critical core experimental configuration**

- Critical configuration is obtained with SCALE 6.3 KENO-VI calculations using ENDF/B-VII.1 cross-section library
- Modeled active core region is 120 x 140 x 123 cm high
- Modeled graphite reflector is 182 x 220 x 242.57 cm high



Center cut plane top view of SCALE KENO-VI model

Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

2. **Evaluation of nuclear data tested by the experimental configuration**

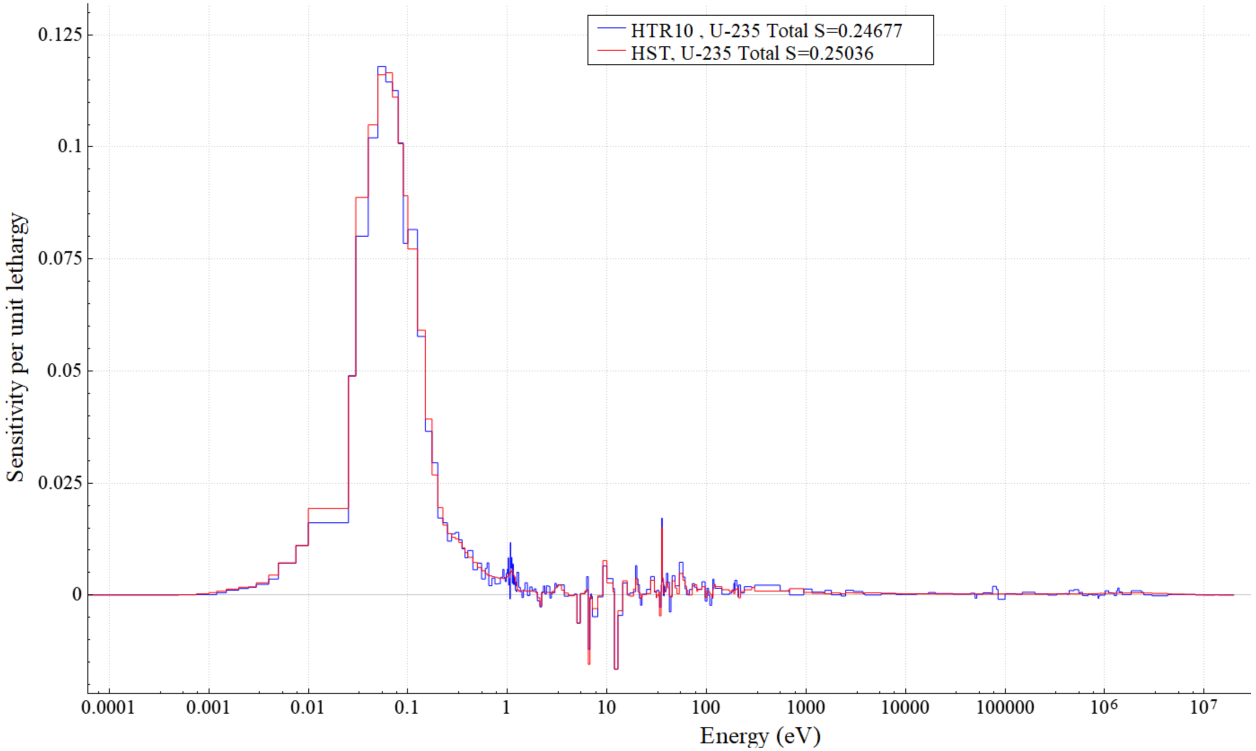
- TSUNAMI is used to calculate k_{eff} sensitivities of the HST conceptual design
- Most significant contributors are Uranium and graphite

Material #	Nuclide	Corresponding physical element in model	TSUNAMI Results	
			Sensitivity	Relative uncertainty (%)
1	u-235	Fuel kernel -UO_2	0.25036	0.02%
2	u-238	Fuel kernel -UO_2	-0.03782	-0.12%
3	c-graphite	Graphite matrix in pebble	0.42285	2.89%
4	c-graphite	Pebble Shell	0.07597	3.35%
5	c-graphite	Dummy Pebble	0.15208	3.59%

Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

2. **Evaluation of nuclear data tested by the experimental configuration**

- U-235 sensitivities profiles for the HST concept design and the original HTR-10 application are matching
- Correlation coefficient c_k=0.9982, proof of a high correlation between both systems
- **Goal is achieved: This design could help for cross-section validation of pebble-bed advanced reactor similar to the HTR-10**



U^{235} total cross section sensitivity profiles for the HTR10 whole core and the Horizontal Split Table concept

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Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

2. **Evaluation of nuclear data tested by the experimental configuration**

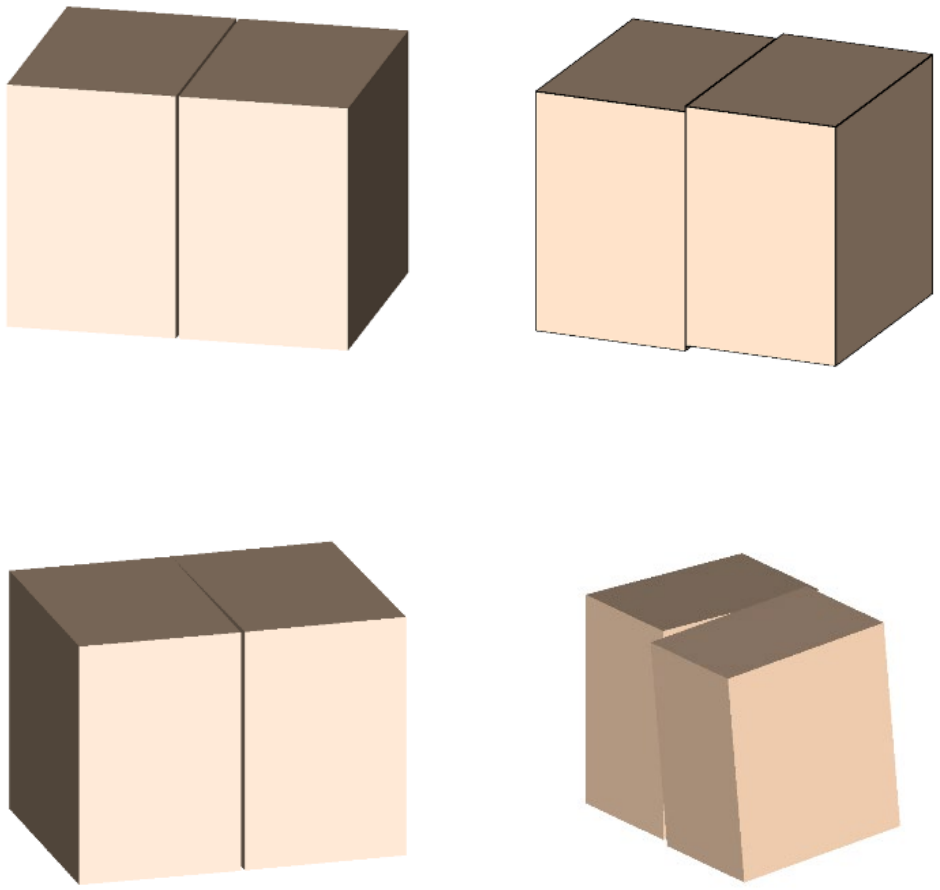
- Additional study: Effects of changing the cross-section library
- About 1000 pcm difference between ENDF/B-VII.1 and ENDF/B-VII.0
- Difference mostly due to carbon cross-section updates in ENDF/B-VII.1

Model	Table size	Cross-section library	k_{eff}	Delta k_{eff} (pcm)
Critical core ENDF/B-VII.1	240x182x242.574	ENDF/B-VII.1	0.99963	-
		ENDF/B-VII.0	1.01225	+1262
Critical core ENDF/B-VII.0	240x182x220	ENDF/B-VII.0	1.00075	-
		ENDF/B-VII.1	0.99082	-993

Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

3. **Assessment of horizontal split table mechanical tolerances**

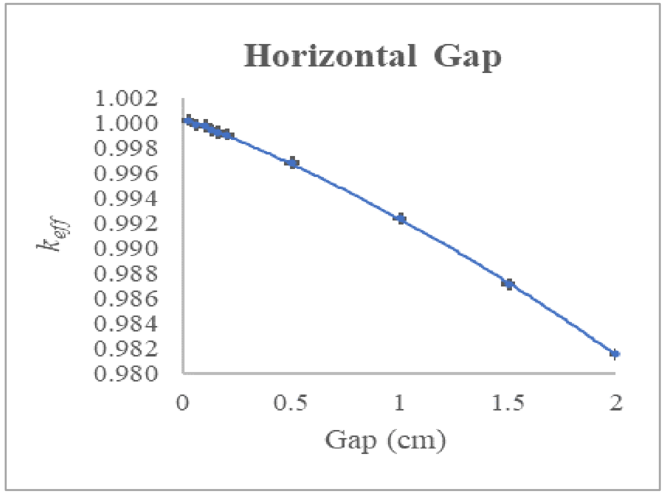
- Parametric study performed with KENO-VI

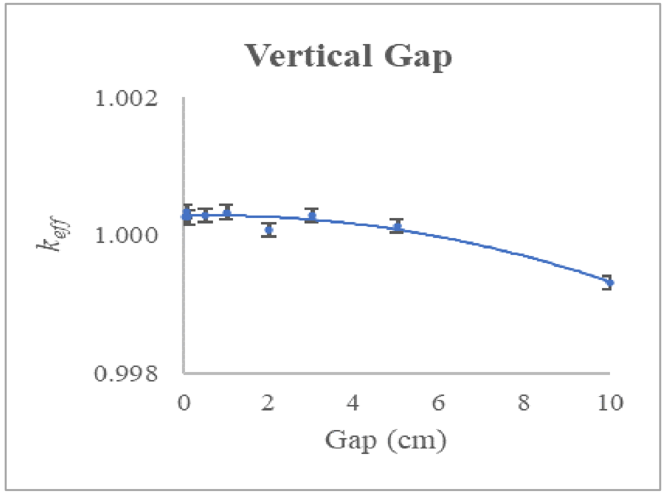


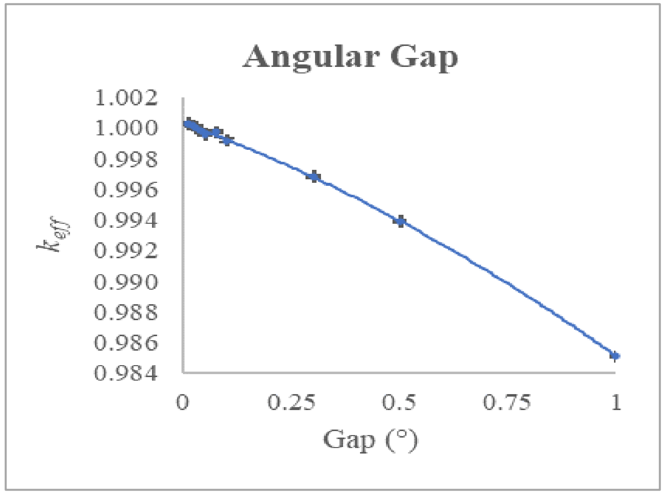
Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

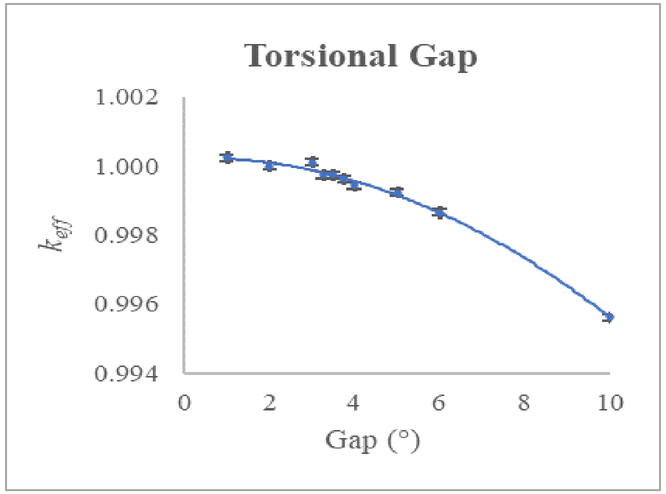
3. Assessment of horizontal split table mechanical tolerances

- Most significant effects are from **horizontal** and **angular** gaps
- Logical result: in vertical and torsional gaps effects, the tables sides are still connected









Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

3. **Assessment of horizontal split table mechanical tolerances**

- Most significant effects are from **horizontal** and **angular** gaps
- Logical result: in vertical and torsional gaps effects, the tables sides are still connected

Interpolated Δk_{eff}	Horizontal Gap (cm)	Vertical Gap (cm)	Angular Gap (°)	Torsional Offset (°)
-0.00010	0.040	5.00	0.0235	2.10
-0.00020	0.055	6.00	0.033	2.60
-0.00050	0.099	8.10	0.061	3.68
-0.00100	0.170	10.70	0.106	4.95
-0.00200	0.308	14.45	0.191	6.78

Interpolated geometric uncertainties necessary to yield experimental uncertainties

Summary and next concepts in mind

- A methodology to create conceptual designs of benchmark critical experiments for advanced reactors nuclear data testing and validation was developed
- A first concept was explored, pebble-bed high-temperature gas cooled reactor, based on the HTR-10 reactor
- The very high correlation is a proof of concept that our design is similar to the application, and performing such critical experiments would help nuclear data testing and validation
- Next concepts being explored:
  - Molten-salt reactor
  - Sodium-cooled fast reactor
  - Heat pipe reactors/Microreactor

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Questions?

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