NCSP Technical Program Review

FY 21 Integral Experiments Technical Presentations

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

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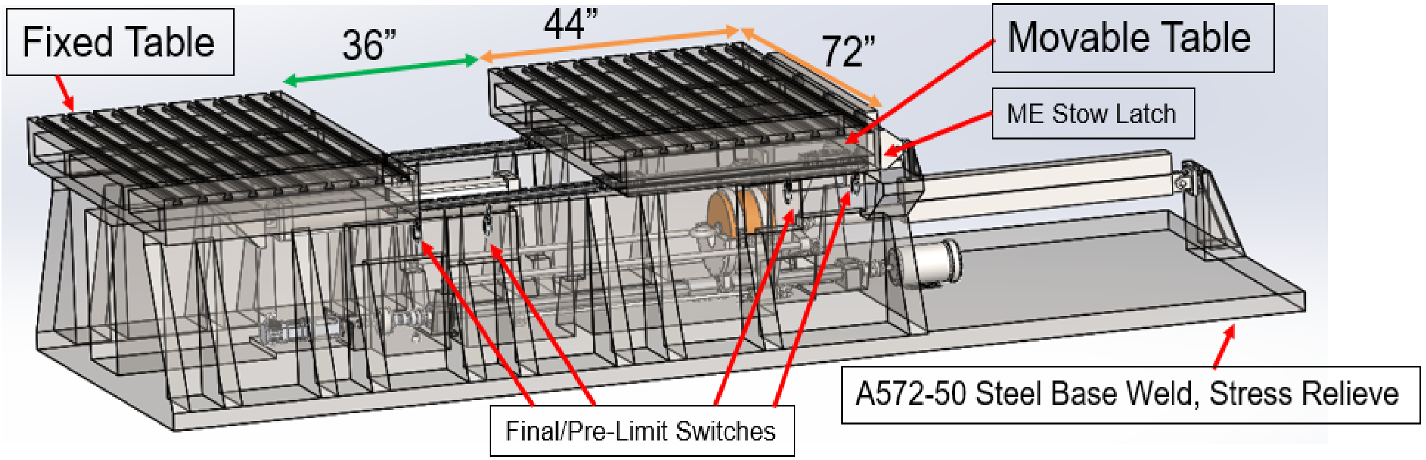
Motivation

- This talk is partly Integral Experiments and Analytical Methods: description of a methodology created and used for a FY21 CED-1 report
- Advanced reactors' designs use different materials, energy spectra, 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 (Justin Clarity and Mathieu Dupont)
- 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



Example rendering of the Horizontal Split Table concept proposed by LLNL

- From LLNL, limitation on the geometry of the table, and on the mass (6 tons) and size (4.46 m^2) of material on it

	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**

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

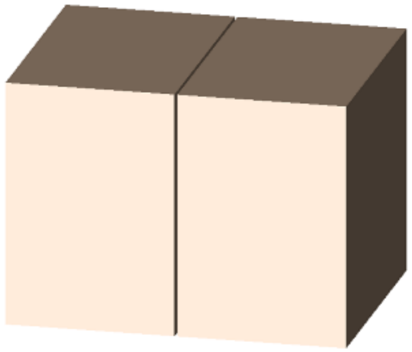
Methods

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 available
   - **If c_k, the correlation coefficient determined by TSUNAMI-IP is high, it means a useful critical experiment benchmark concept for nuclear data validation of advanced reactors materials**

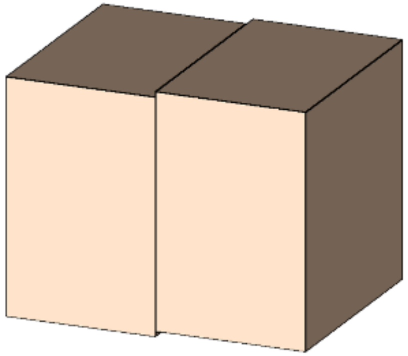
Methods

3. Assessment of horizontal split table mechanical tolerances

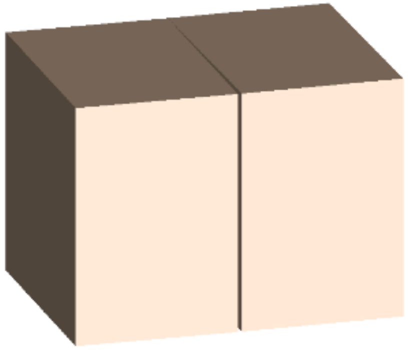
- What is the influence on k_{eff} of mechanical uncertainties in the table design?
  - Horizontal gap
  - Vertical gap
  - Angular gap
  - Torsion gap
- Quadratic fit to determine a k_{eff} uncertainty per mechanical uncertainty



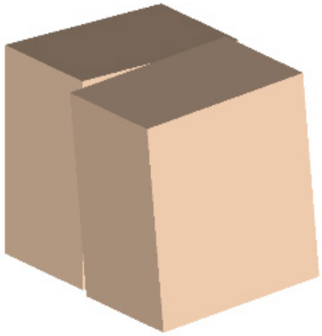
Horizontal gap



Vertical gap



Angular gap



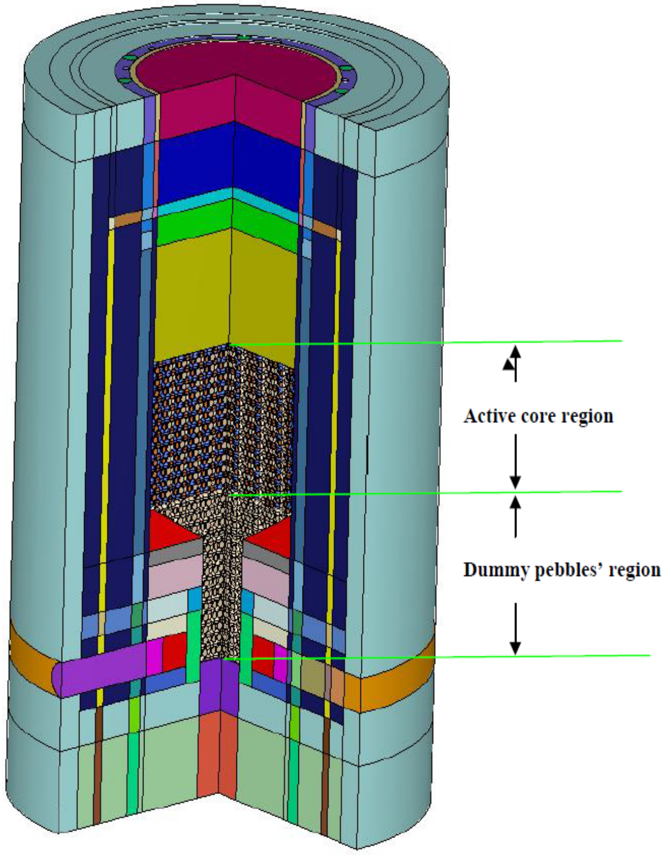
Torsional offset

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

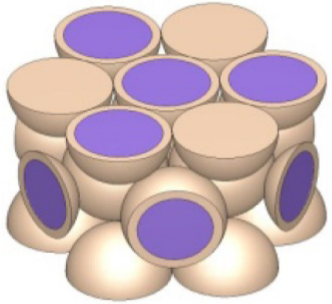
- Described in IRPhEP, *Evaluation of the Initial Critical Configuration of the HTR-10 Pebble-Bed Reactor, HTR10-GCR-RESR-00 (2007)*
- Previously modeled in SCALE KENO-VI by *G. Ilas et al., "Validation of SCALE for High Temperature Gas-Cooled Reactor Analysis," NUREG/CR-7107, ORNL/TM-2011/161 (2012)*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

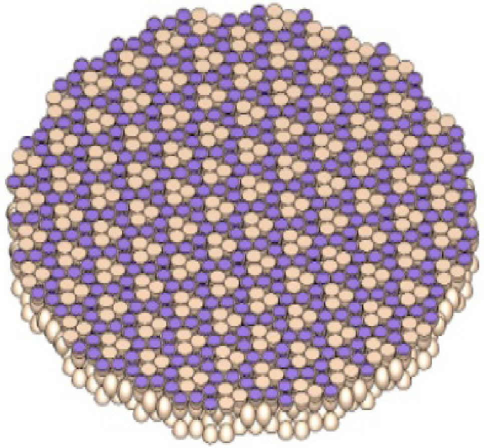
- Active core region is 123 cm high and 180 cm diameter, not far from the split-table requirements
- Total of 16890 pebbles, 9627 fuel, 8263 dummy
- Packing fraction 61%
- Pebble radius 3.0 cm, 2.5 cm fuel region and 0.5 cm radius graphite shell
- 8355 TRISO particles in each pebble
- TRISO: UO_2 kernel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



Full core model



Hexagonal prism unit cell



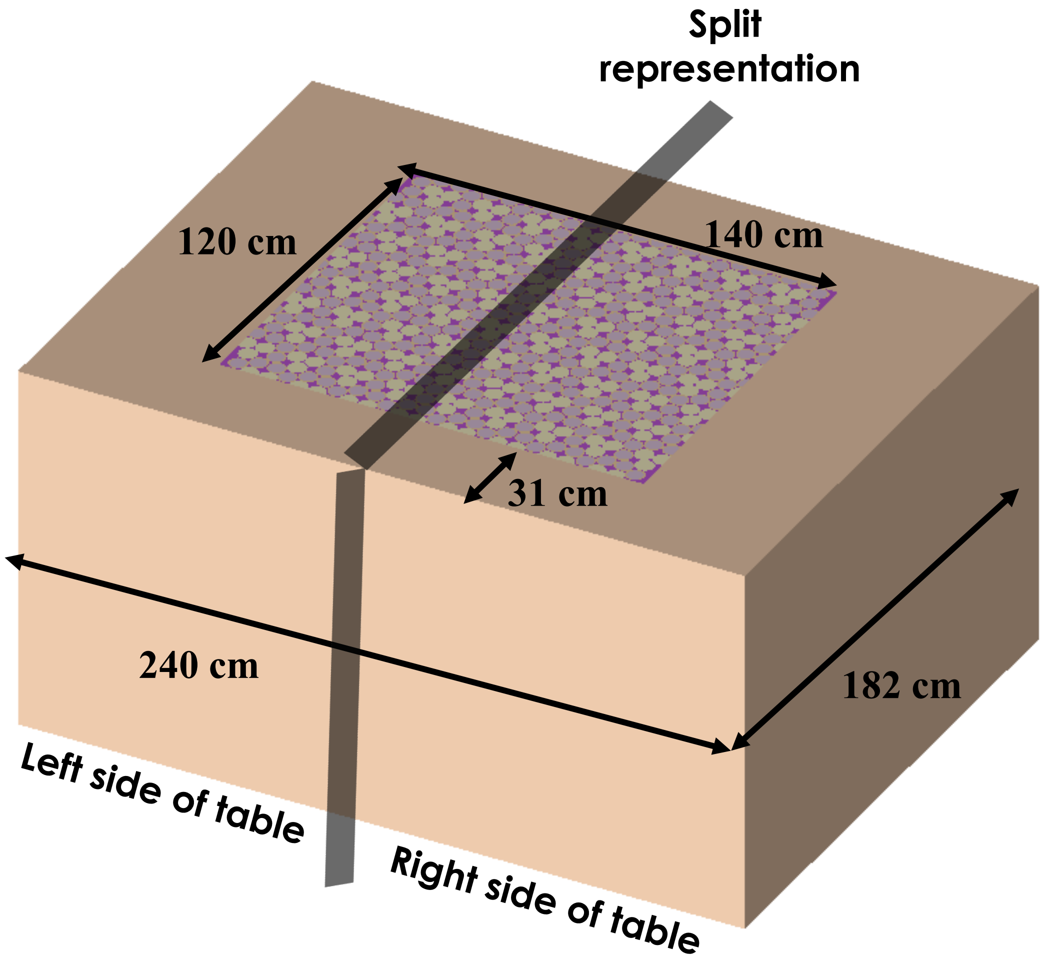
Layer of pebbles in active core region

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 240 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%

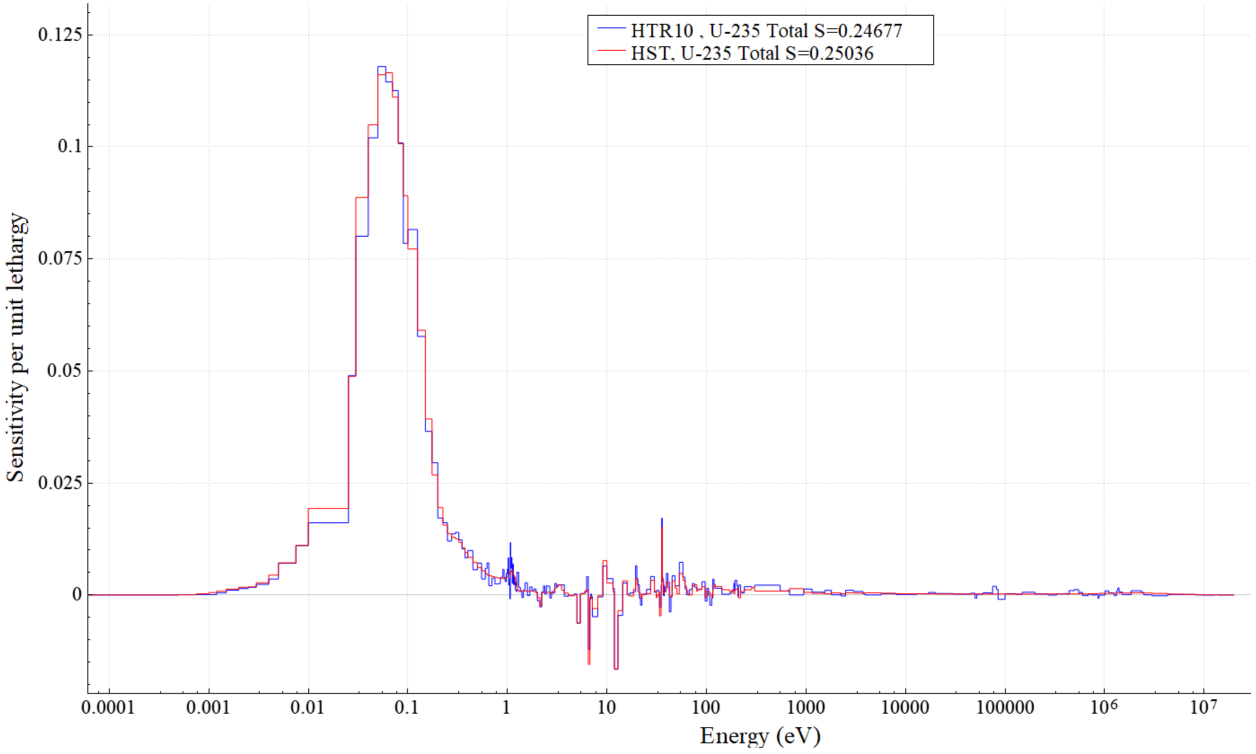
Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

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, Highest c_k from available ICSBEP benchmarks are 0.7164 and 0.7080 from IEU-SOL-THERM-001-003 and LEU_SOL-THERM-006-005

- **Goal is achieved: This design could help for cross-section validation of pebble-bed advanced reactor similar to the HTR-10**



U235 total cross section sensitivity profiles for the HTR10 whole core and the Horizontal Split Table concept

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

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

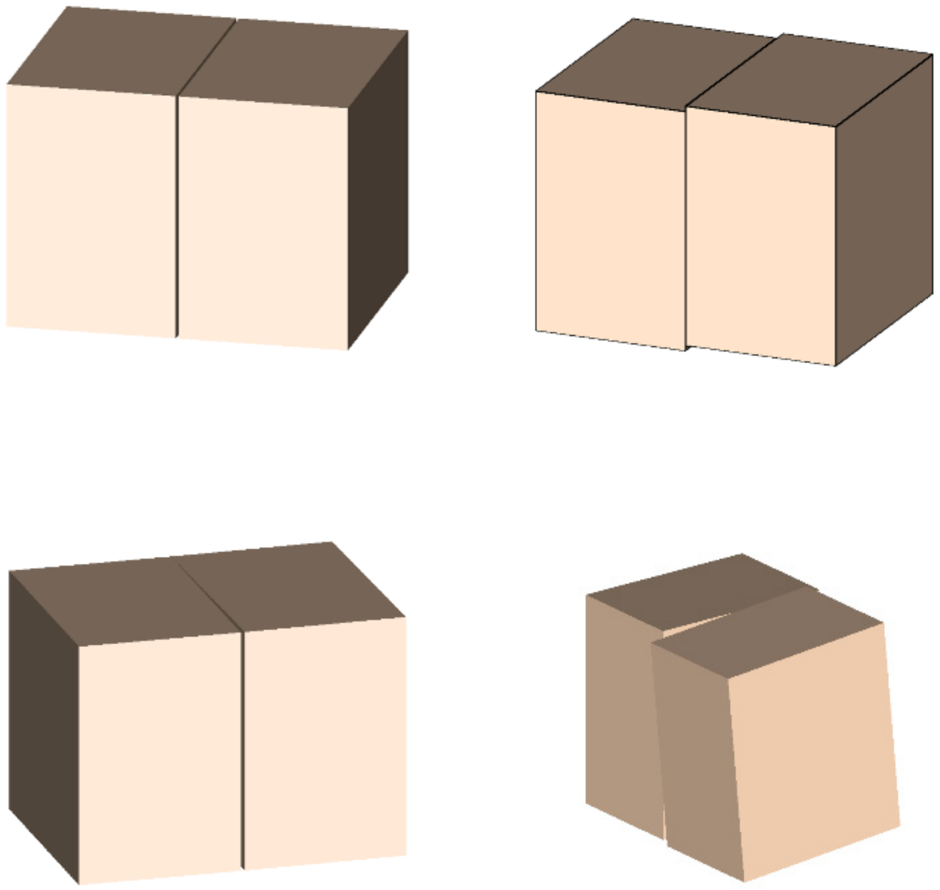
- Additional study: Effects of changing the cross-section library
- About 1000 pcm difference between ENDF/B-VII.1 and ENDF/B-VII.0
- Difference mostly due to carbon cross-section updates in ENDF/B-VII.1

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**

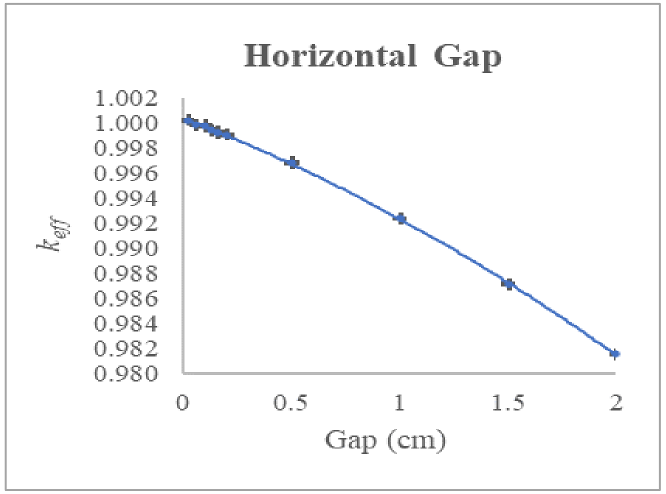
- Parametric study performed with KENO-VI

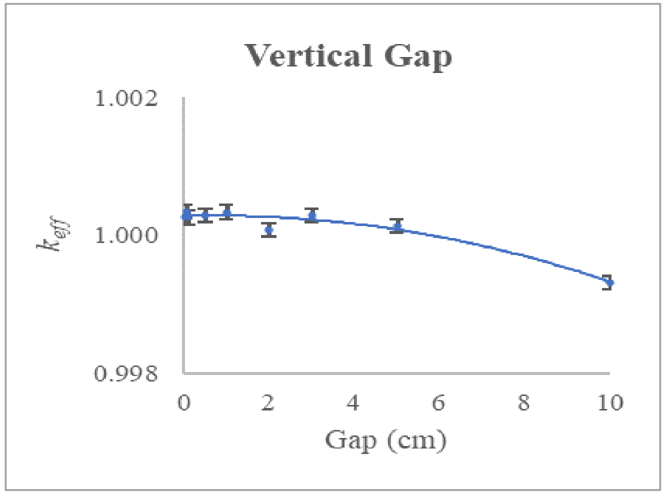


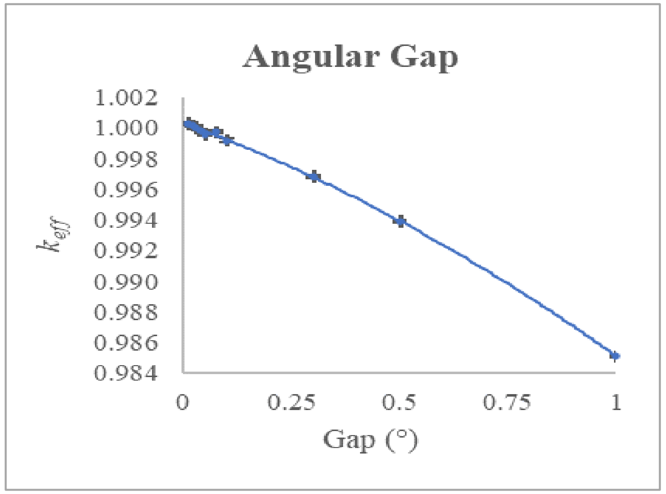
Example concept: Pebble-bed High-Temperature Gas-cooled reactor - HTR-10 application case

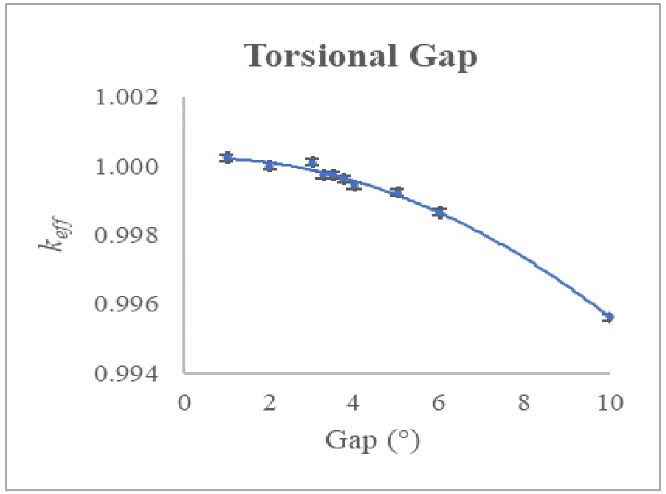
3. Assessment of horizontal split table mechanical tolerances

- Most significant effects are from **horizontal** and **angular** gaps
- Logical result: in the 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 the 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 the design is similar to the application, and performing such critical experiments would help nuclear data testing and validation
- This proof-of-concept was included in the IER-539 CED-1:Preliminary Design of a New Horizontal Split Table report (https://doi.org/10.2172/1825856)
- Other concepts could be explored if needed, such as Molten-salt reactor, Sodium-cooled fast reactor or Heat pipe reactors/Microreactor

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