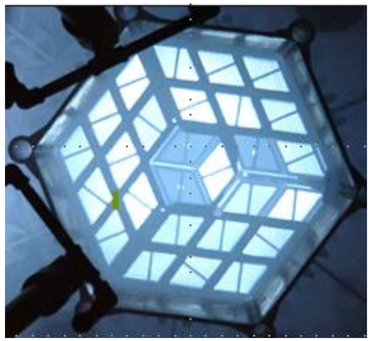
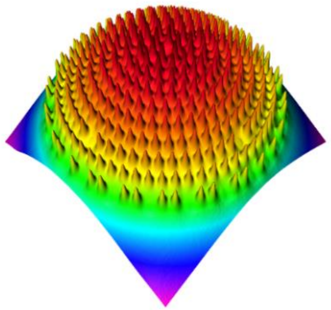
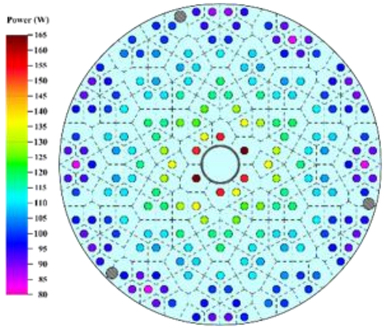
MITR End Fitting Structural Rigidity Analysis

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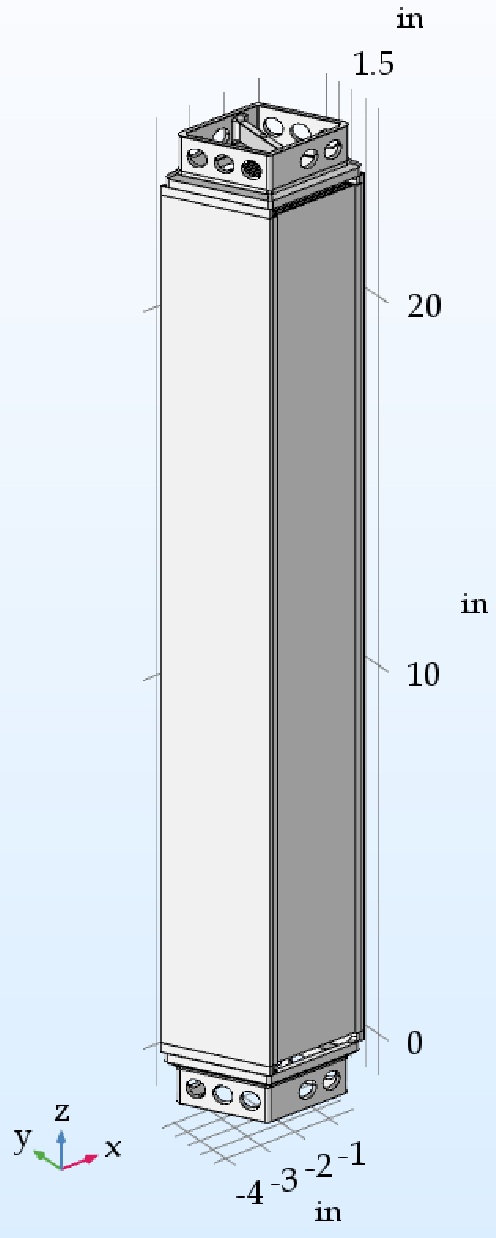
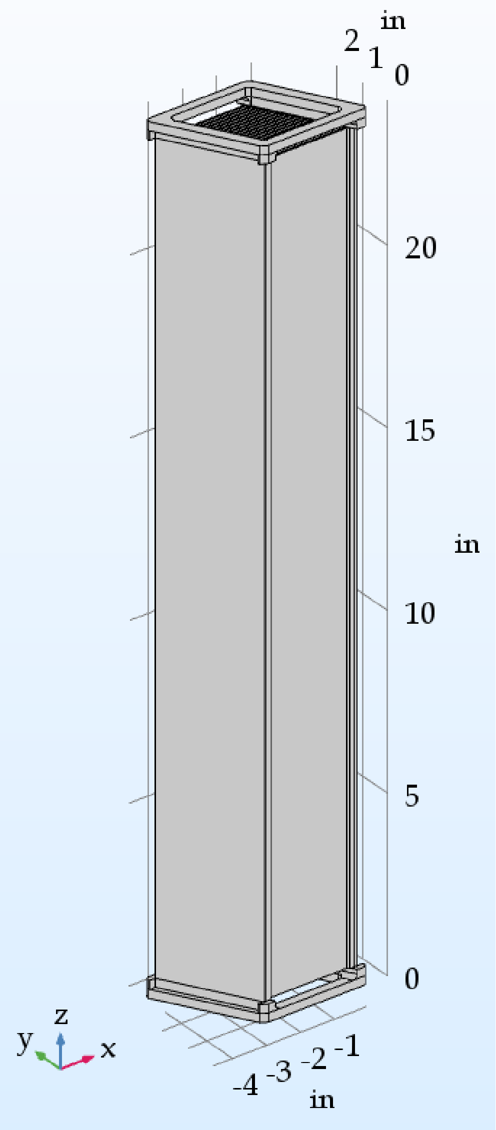
Outline

- Introduction
- FE Model Development
- Selected Loading Cases
  - Point Load
  - Line Load
  - Thermal Load
- Concluding Remarks

MITR LEU fuel element



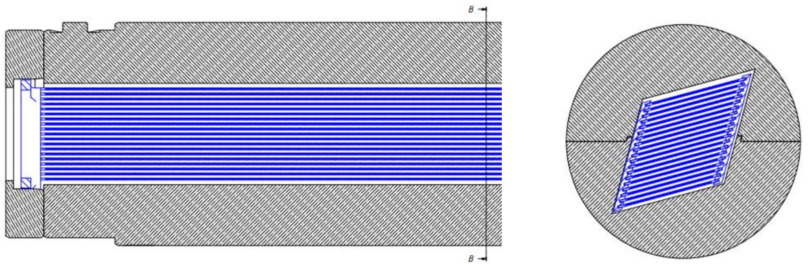
MITR DDE



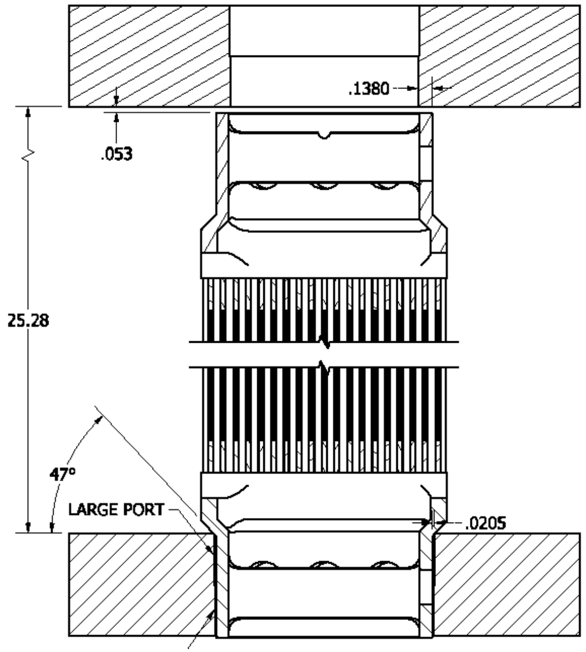
Introduction

- As an additional experimental campaign in the USHPRR conversion efforts, a full prototypic MITR element serving as the Design Demonstration Element (DDE) will be irradiated in the BR2 test reactor in Belgium
- The design of the DDE end fittings is different from the end fittings on the LEU fuel elements, characterized mainly by considerably smaller overall size & weight of these end fittings to meet specific experiment needs, e.g.,
  - compatibility with the geometrical restrictions of the DDE testing location, and
  - to allow for proper inspection of these test elements during the experiments
- The end fittings in the MITR LEU fuel element are designed primarily for proper handling and flow distribution. The stiffness of the end fittings also constitutes some fraction of the total stiffness of the entire fuel element.
- Assessment undertaken to understand the extent end fittings provide structural rigidity to the MITR LEU fuel element
- Also compare LEU fuel elements to the DDE fuel element with modified end fittings
- Objective is to understand role of end fittings in providing structural support (i.e. relative contribution of the end fitting to the overall stiffness)

DDE element in the basket

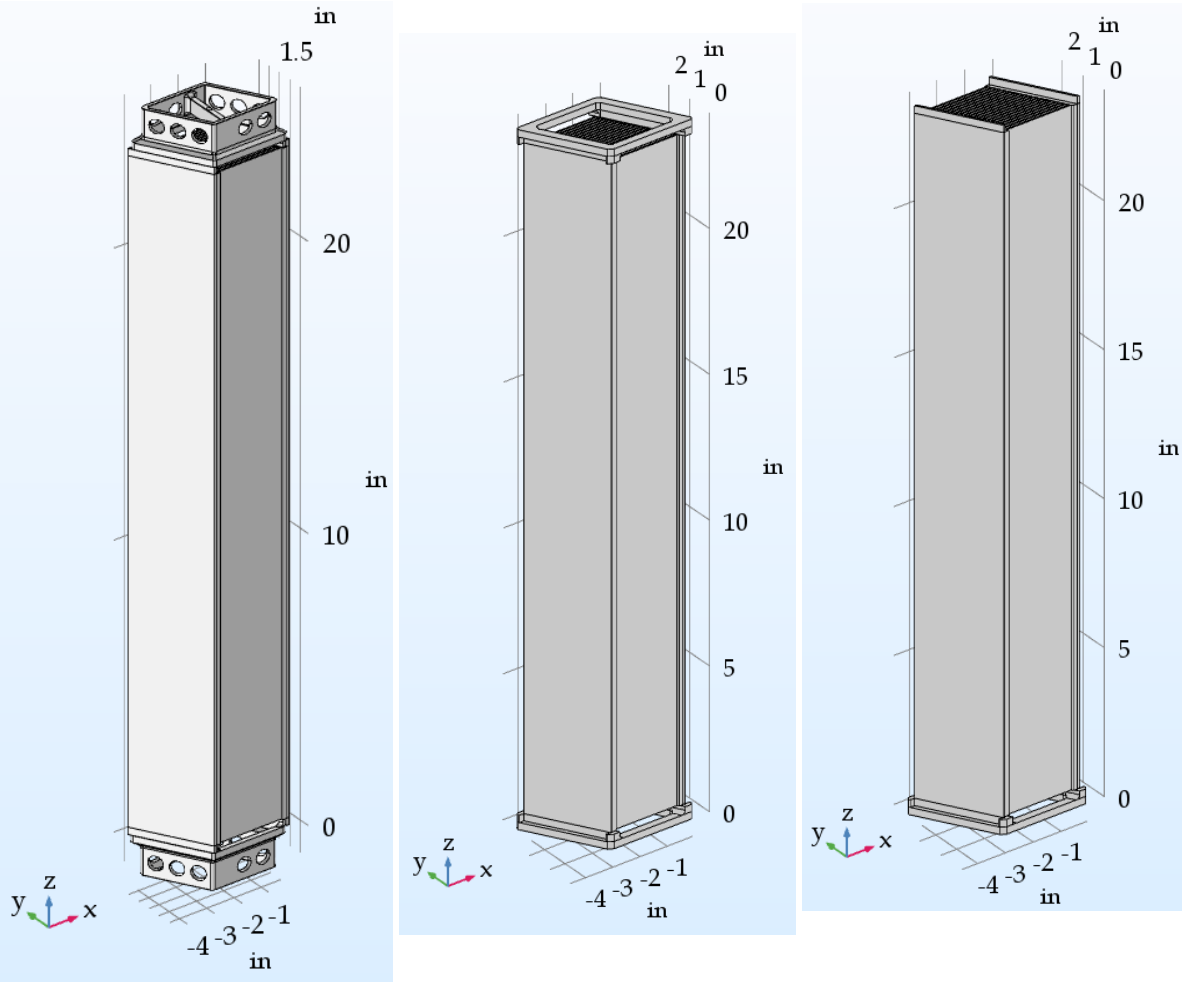


MITR element in the core



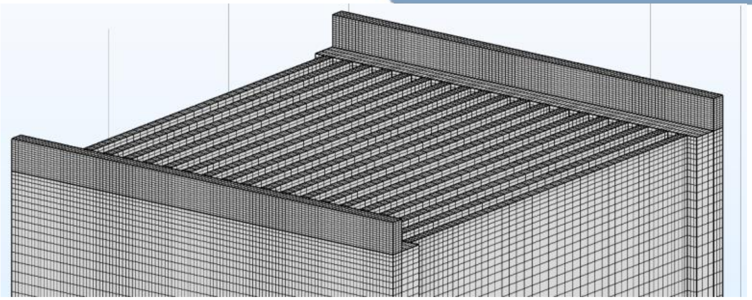
End Fitting Evaluation Loadings

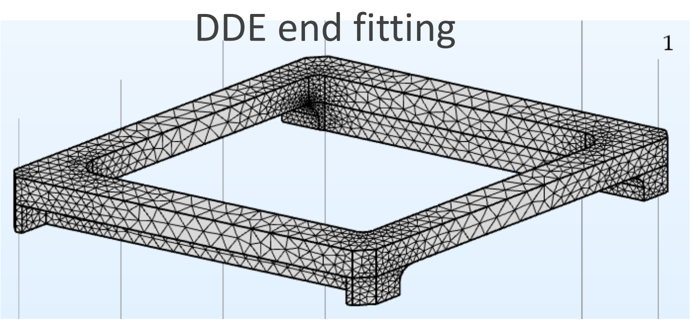
- Estimation of all possible loads would require significant effort and lengthy multiphysics analysis
  - Where results show significant deformations, further loads could be assessed as needed
- Elastic deformations are proportional to loads expected (resting mass, etc.), therefore simplified loading cases are considered adequate
- Objective is to compare the (local) stiffness of the elements (MITR LEU Fuel Element vs MITR DDE vs. No end fitting):
  - Point load
  - Line load
  - Thermal load
- These analyses are primarily meant, to answer the question to what extent does the stiffness of the end fitting contribute to the stiffness of an entire element of these 3 types

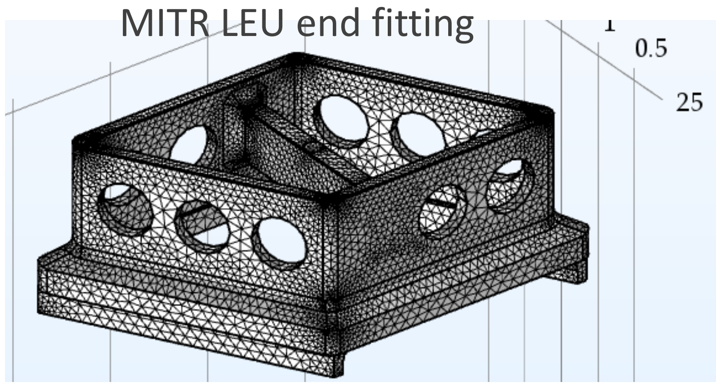


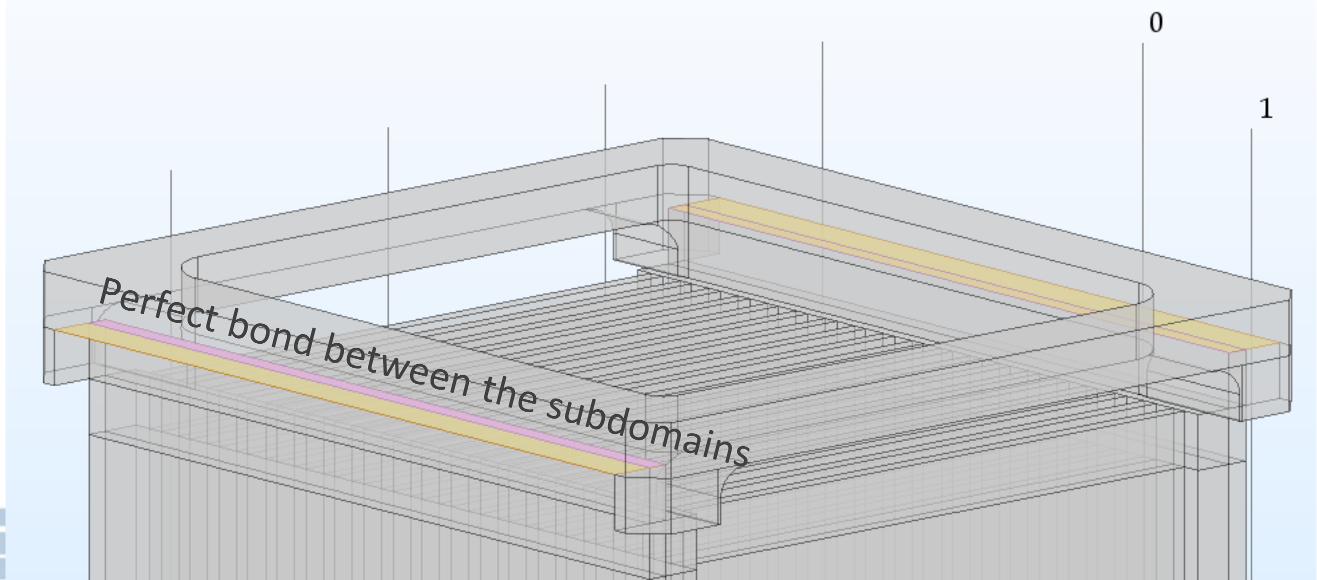
Computational Model

- Comsol v5.3a finite element solver has been used
- 750,000 quadratic elements
- Up to 10M degrees of freedom
- Separate meshing for end fittings (tetrahedral) and the plates (hexahedral)
- Perfect bond between the lip of the side plate and the end fitting simulating the weld
- Perfect elastic material model with aluminum properties for all components
- Assumption of small deformations

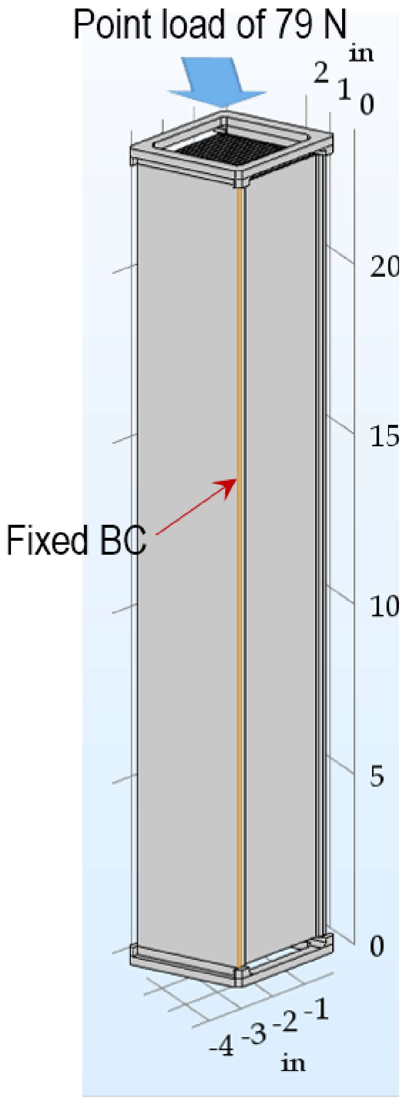




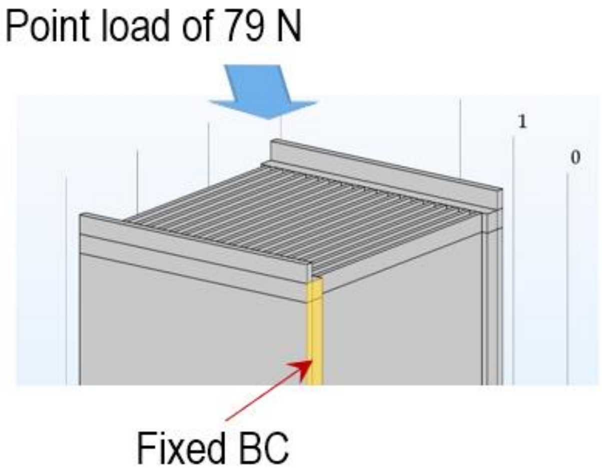


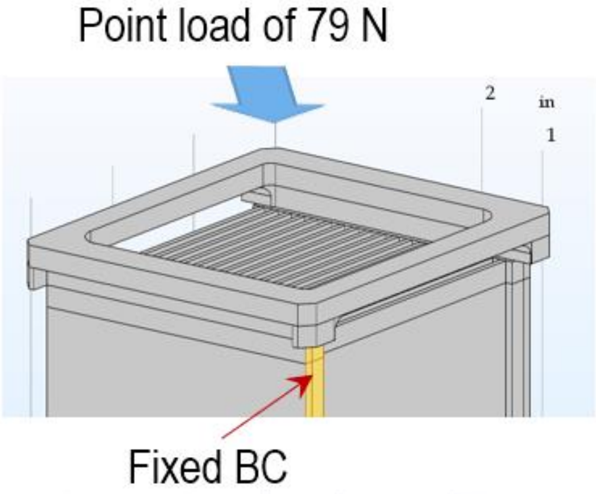


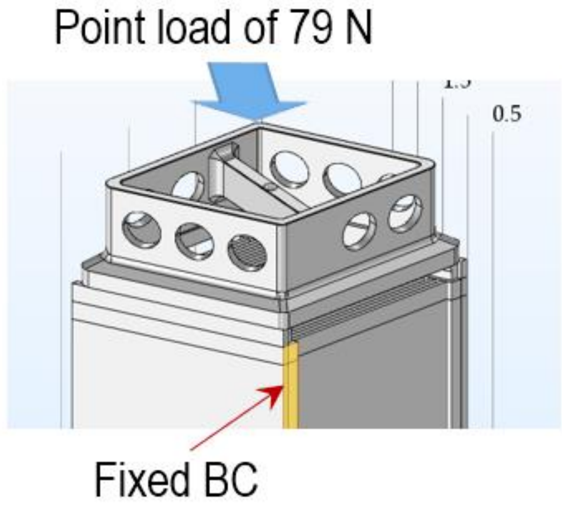
Lateral point load

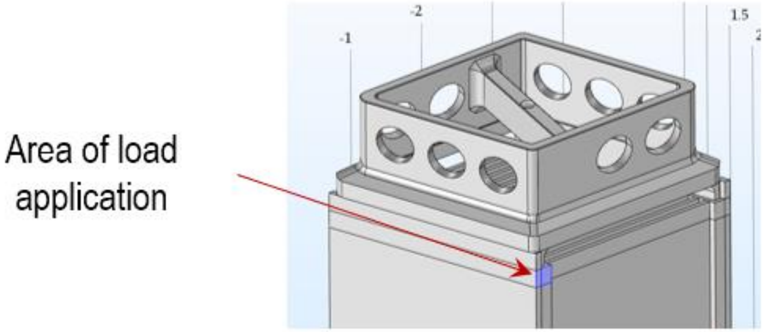


- Small patch (identical for all three models) load representing a point load (in purple below) equivalent to the weight of the MITR LEU element
- Opposite edge constrained (indicated in yellow)
- Since the material model is elastic and geometrical nonlinearity is deactivated, there is full proportionality of load to the displacement (double the load, the displacement doubles)









Note: Load equivalent to resting mass.

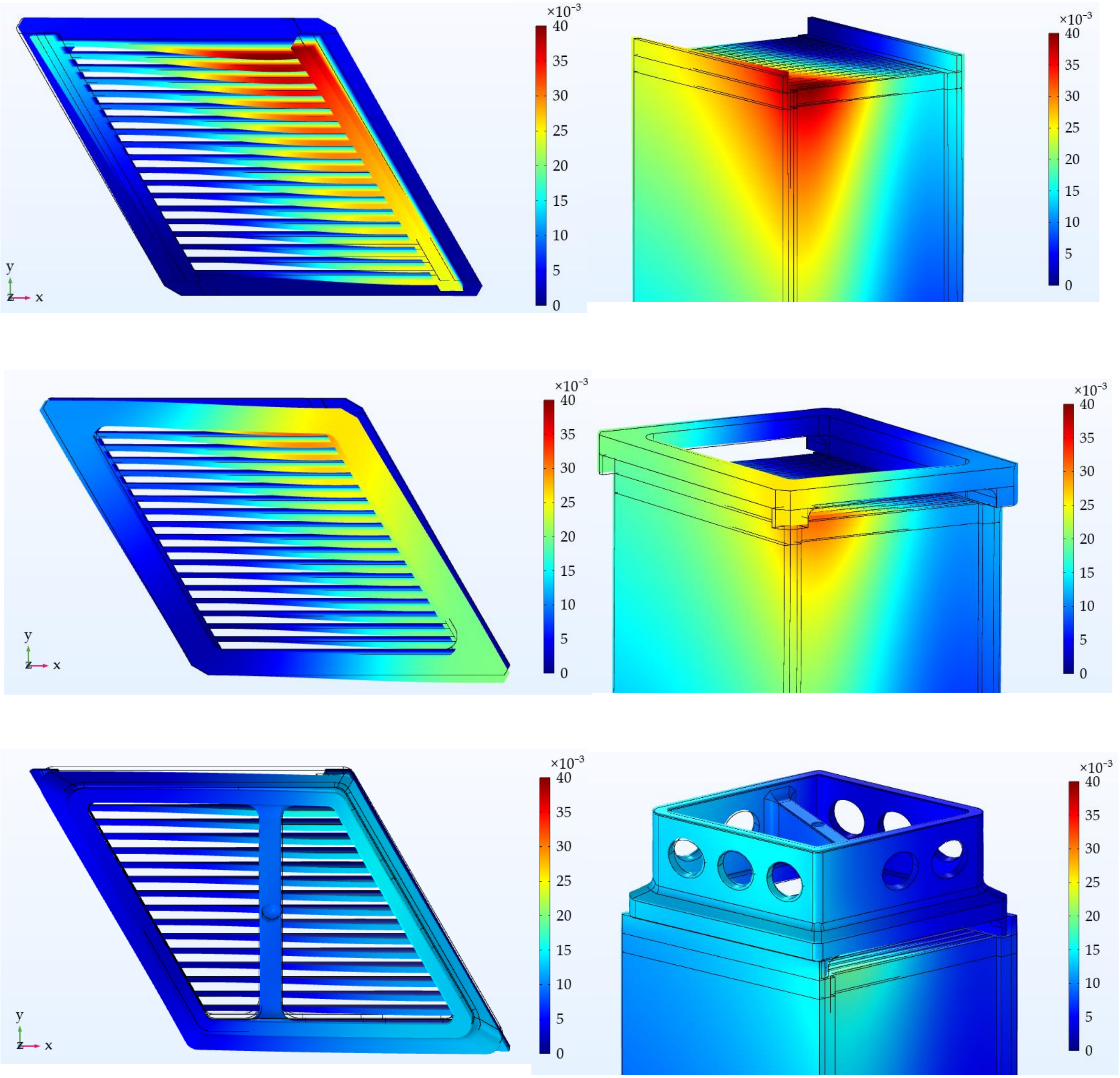
Lateral point load

Resultant displacement (mm)

No top end fitting

DDE end fitting

MITR LEU end fitting

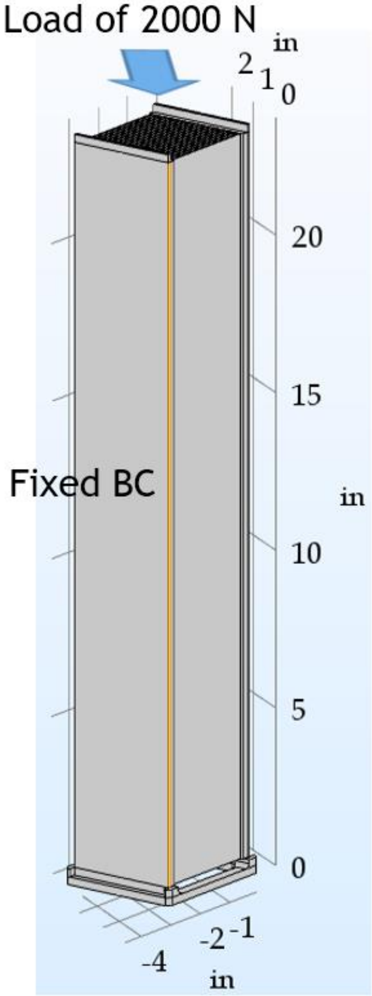


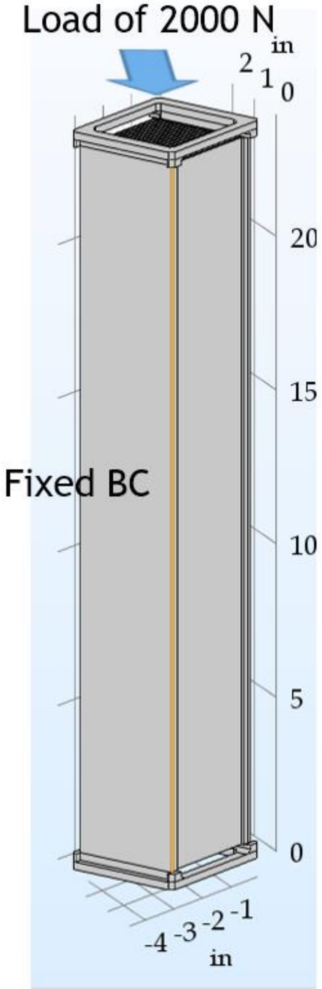
(displacement scaling factor of 100 used for visualization purposes)

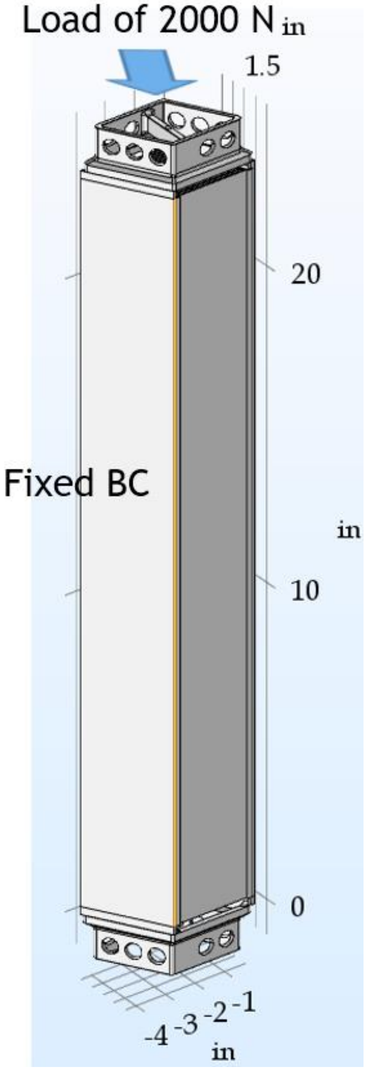
- For the point load case the maximum displacements were:
  - No end fitting: 0.042 mm (1.6 mil)
  - DDE end fitting: 0.032 mm (23% lower than in the case without end fitting)
  - MITR LEU end fitting: 0.019 mm (53% lower than in the case without end fitting)
- Range with different end fittings ~20-30 µm (normalized to resting mass)

MATERIAL MANAGEMENT AND MINIMIZATION

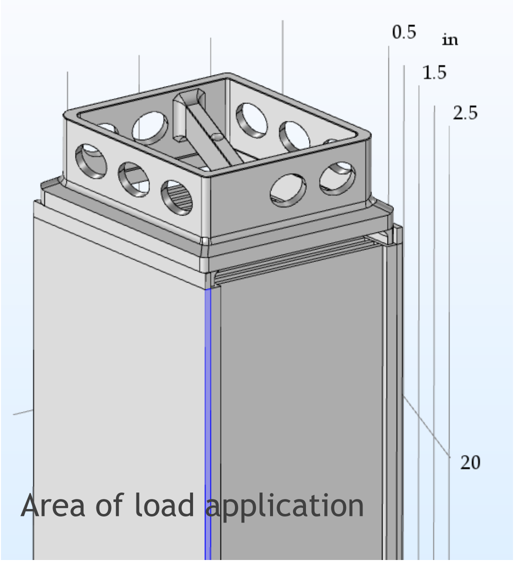
Lateral line load







- Narrow patch (identical for all three models) load representing a line load (rigid press; indicate in blue below)
- Load magnitude equivalent to 25 times the resting mass of the MITR LEU element
- Opposite edge constrained (indicated in yellow)



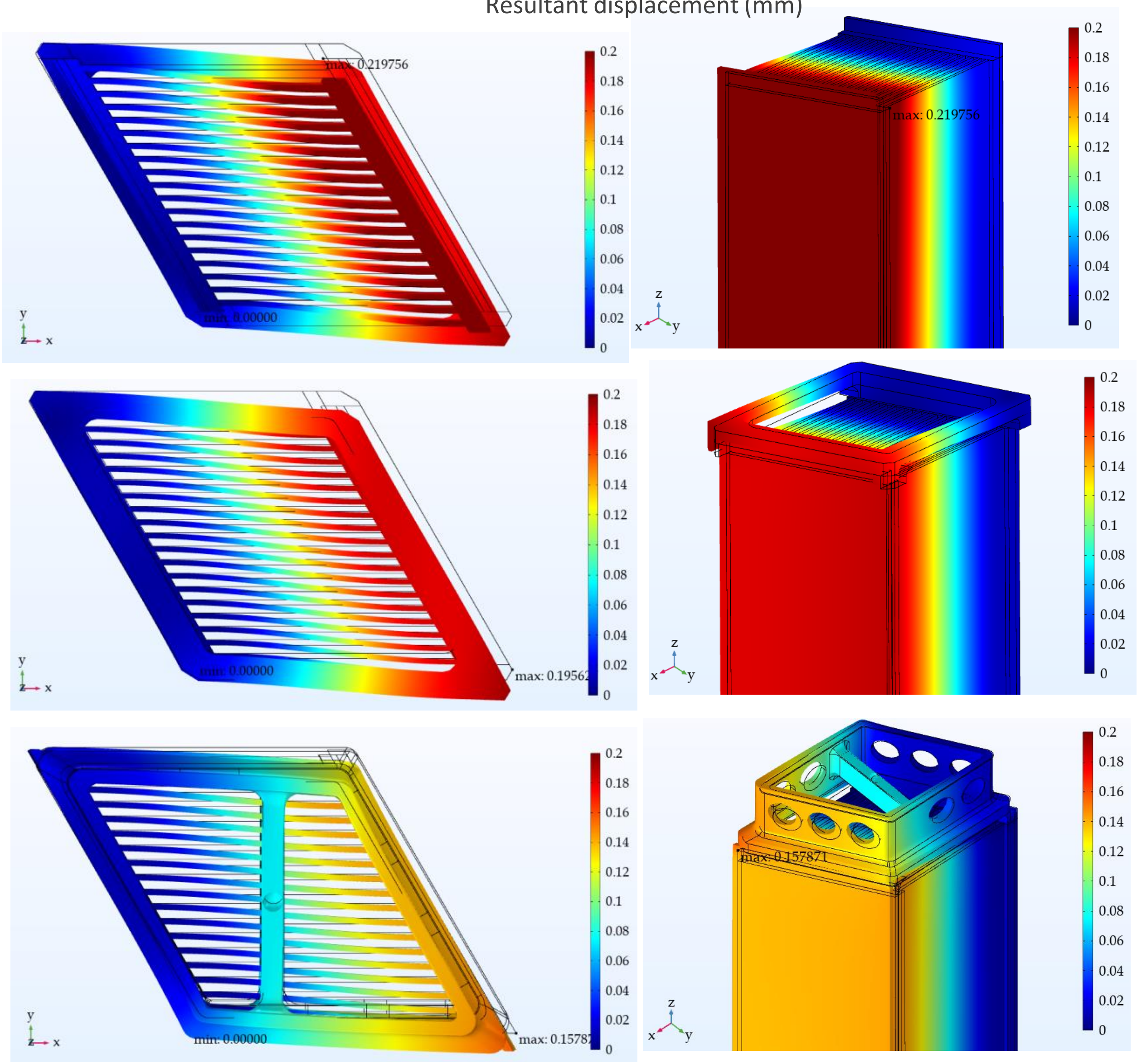
Lateral line load

No top end fitting

DDE end fitting

MITR LEU end fitting

Resultant displacement (mm)

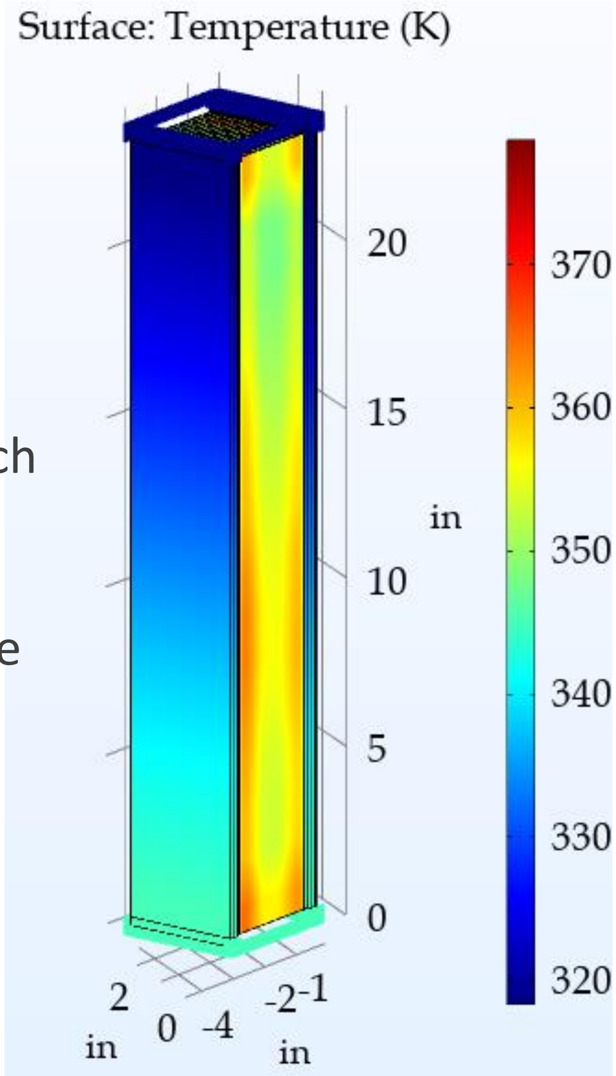


(displacement scaling factor of 25 used for visualization purposes)

- For the line load case the maximum displacements were:
  - No end fitting: 0.22 mm (8.7 mil)
  - DDE end fitting: 0.19 mm (15 % lower than in the case without end fitting)
  - MITR LEU end fitting: 0.15 mm (33% lower than in the case without end fitting)
- Range with different end fittings ~6-8 µm (divide by 25 when normalized to resting mass)

Thermal Load

- Temperatures in the fuel core and on the cladding surface on both sides of the plate were available from the prior MITR LEU transition core analysis
- While the analyzed cases do not exactly match the conditions that the MITR DDE will experience during irradiation in the BR2 reactor, they are representative enough to be used for the purposes of this work
- A thermal-hydraulic (T&H) analysis of the MITR DDE is planned, and will be available in later stages of the experiment

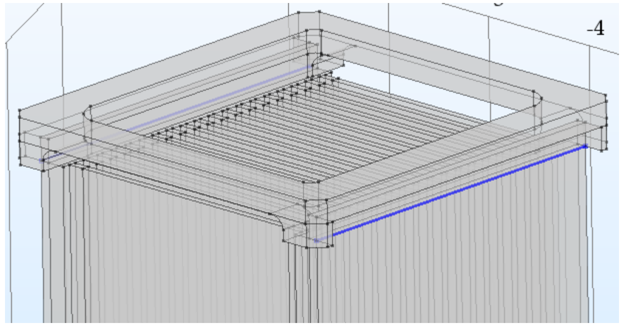


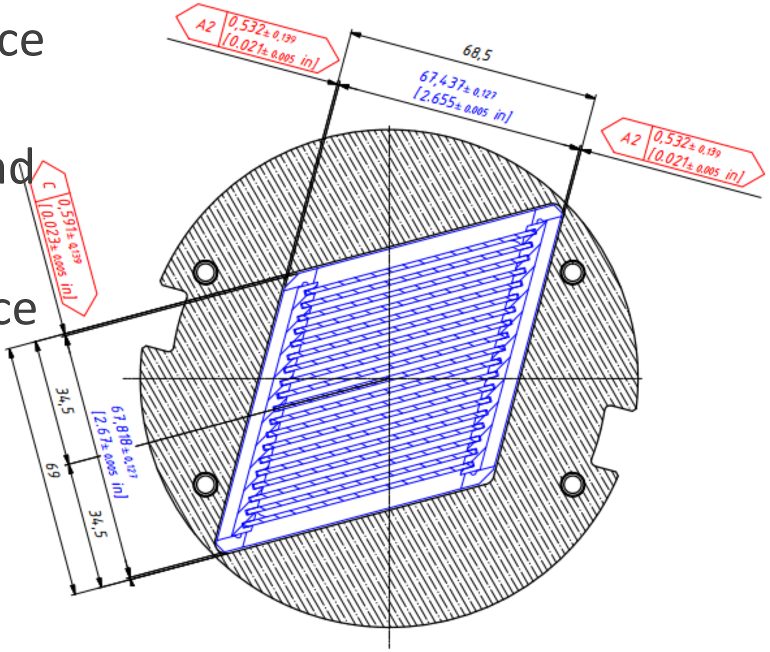
Temperature distribution in plate 15 of Cycle 1 BOC for MITR LEU element

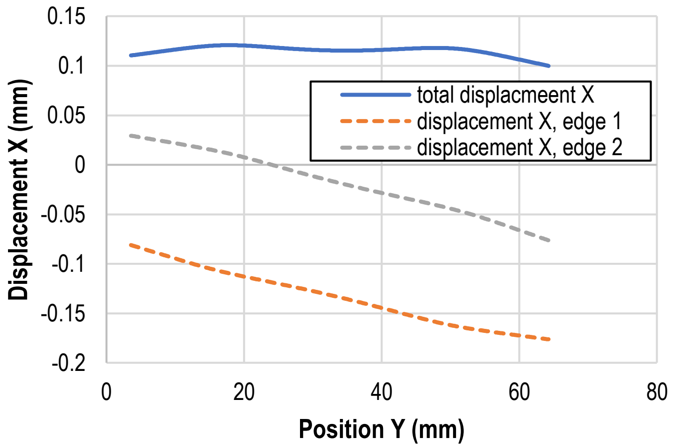
PLATE 16 axial node	stripe 1 avg temp (C)	stripe 2 avg temp (C)	stripe 3 avg temp (C)	stripe 4 avg temp (C)
1	91.23	79.12	80.09	95.60
2	84.02	74.75	75.16	88.05
3	87.38	78.64	78.95	91.66
4	90.25	82.16	82.98	95.62
5	93.91	84.72	85.39	98.10
6	94.98	86.35	87.76	100.65
7	97.50	88.17	89.09	101.48
8	97.26	88.55	89.63	103.42
9	98.95	89.57	91.26	104.95
10	100.75	90.46	91.62	105.55
11	99.51	89.77	90.75	105.09
12	97.55	88.26	89.62	103.87
13	95.72	86.55	87.87	102.20
14	93.50	84.65	85.62	99.97
15	91.43	82.31	83.96	98.08
16	94.74	85.31	86.61	102.22

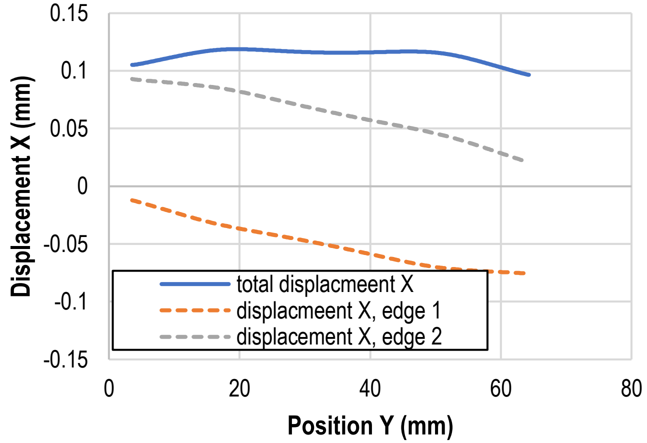
Thermal Load

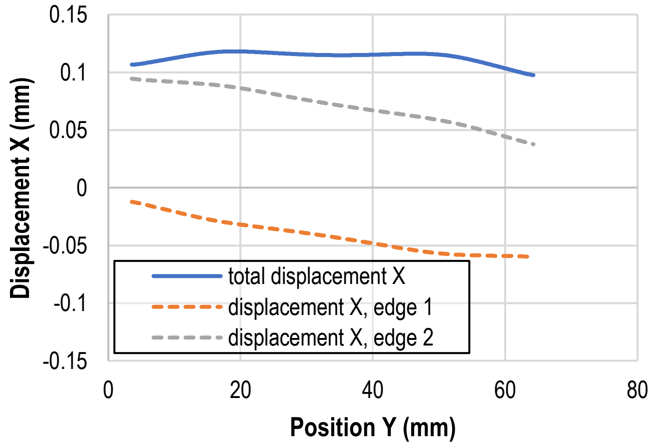
- This analysis only covers the expansion due to the thermal load
- In the reactor core, additional effects, like the swelling due to the irradiation, will contribute to the overall deformation of the element
- In the design of the basket, the clearance between the end fitting and the basket caps is 0.53 mm on both sides of the end fitting, 1.06 mm in total
- Due to thermal expansion, this clearance will be reduced by 0.13 mm
- No significant differences are expected (within 2.5%) regarding the clearance between the test article and the irradiation basket if the MITR LEU end fittings are used instead











Concluding Remarks

- Components of overall stiffness of the MITR LEU fuel element assessed
  - **Fuel plates swaged to the side plates provide majority** of the overall stiffness
  - In some cases, end fittings provide substantial stiffness (e.g. point or line load)
  - In others, end fittings provide little additional stiffness (e.g. thermal load)
- End fittings in the MITR LEU fuel element were compared to those of the DDE
  - LEU end fitting design unchanged from current HEU fuel element
  - DDE end fitting design modified to allow insertion in test reactor and inspection
  - Both end fitting designs perform similarly
    - DDE end fittings allow larger displacement to some extent
    - Both end fittings resulted in relatively small displacement ~20-30 μm (point) ~6-8 μm (line), load normalized per resting mass
    - Channel closure not yet investigated but expected to be less than displacements
    - Fabrication tolerances typically ~±200 μm (not related to normalized loading)
- **The structural function of end fittings is adequate for the DDE experiment** (i.e. not substantially different from the MITR LEU end fitting)
- Additional investigation indicated that the **thermal expansion** under simplified loading conditions is well within the tolerances of the basket

Acknowledgement and Disclaimer

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Thank you!

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