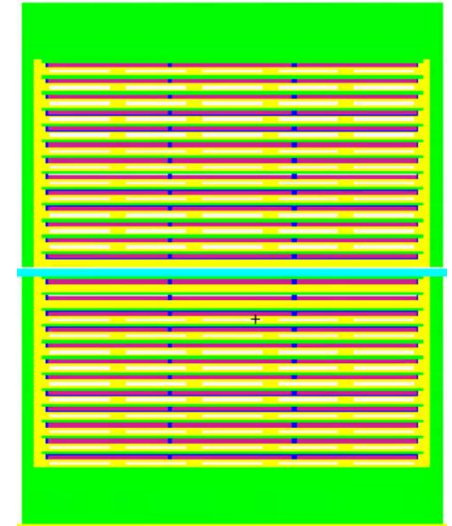


TEX-MOX experiments:

final design of critical experiments to mimic MOX fuel
in low moderation conditions



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AESJ Fall Meeting, 2024/09/12

Tohoku University, Sendai

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[INTRODUCTION

[REPRESENTATIVITY OF INDUSTRIAL CASES USING THE K_{EFF} SENSITIVITY TO NUCLEAR DATA

[THERMO-MECHANICAL DESIGN

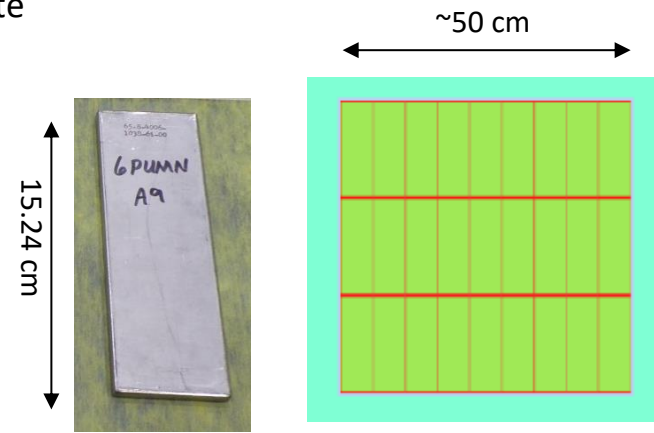
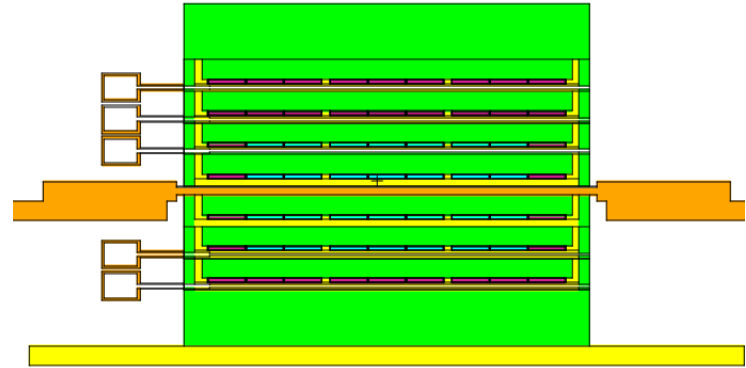
TEX-MOX experiments

[MOX FUEL CYCLE

- Criticality safety issue with low moderated **MOX powder** mixtures
- General lack in **intermediate energy** range critical configurations

[DESIGN OF EXPERIMENTS

- Collaboration with american NCSP (Nuclear Criticality Safety Programm)
- Neutronic optimisation to target the maximum sensitivity in the intermediate energy range using PUMN and PUMH fuel plates (from ZPPR experiments)
- Polyethylene selected as moderator and reflector



Fuel Name	Description	Alloy (wt% of Fuel)	²⁴⁰ Pu (wt% of Pu)	Pu (wt% of U+Pu)	²³⁵ U (wt% of U)
PUMN	Pu-U-Mo-NUMEC	2.5	11.6	28.8	0.2
PUMH	PUM-High Pu240 content	2.5	26.4	34.9	0.2

3 TEX-MOX experiments planned at NCERC[§] for 2025

Case	Mod. Thickness [cm]	Layers pattern	Reflector thicknesses axial/radial [cm]	Keff	Thermal fission rate (%)	Inter. fission rate (%)	Fast fission rate (%)	Expected exp. Uncertainty*
INTER1	0.36	25 full PUMN	7/1.5	1.00815	20.80	45.70	33.50	200 pcm
INTER2	0.7	4 full PUMN 10 partial PUMH 2 full PUMN	7.5/1.5	1.00972	37.54	37.87	24.59	167 pcm
THERM	2.6	2 full PUMN 4 partial PUMH 1 full PUMN	7.5/1.5	1.02146	68.38	18.11	13.51	126 pcm

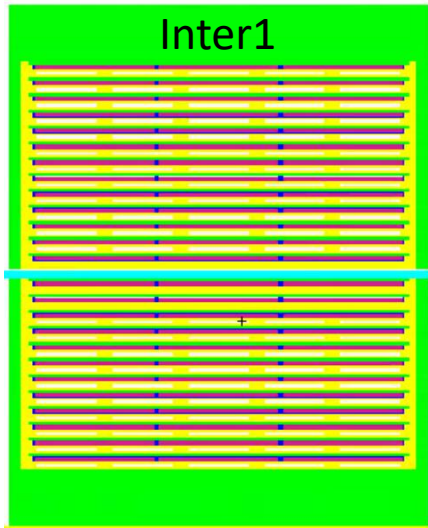
- Thick axial reflector increased to cut the room effect
- Radial reflector: trade off between room effect and neutron thermalization
- Only limited number of PUMH (High Pu240 content) available -> in the center to maximize the sensitivity to Pu240

Designs selected as the most « representative » of industrial cases

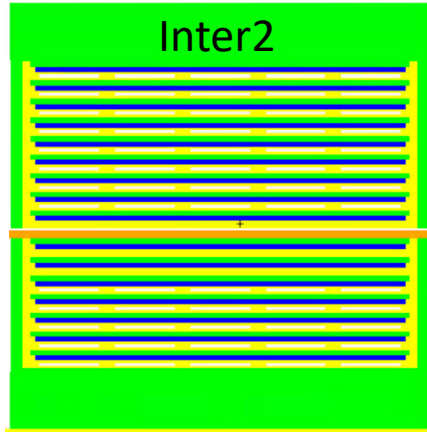
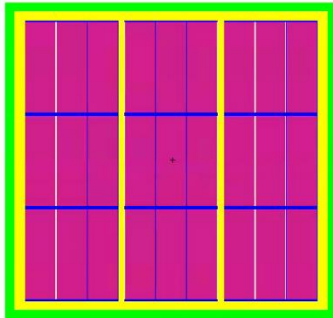
[§] NCERC : National Criticality Experiments Research Center (NCERC), Nevada, USA

* Fuel composition measurements are not yet satisfying, may increase the total uncertainty

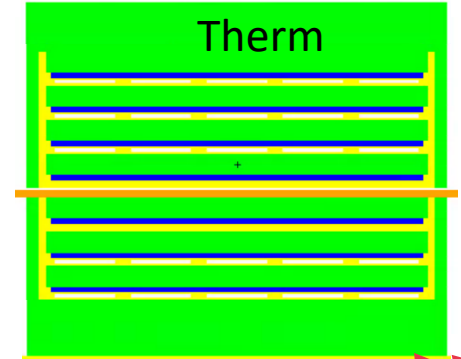
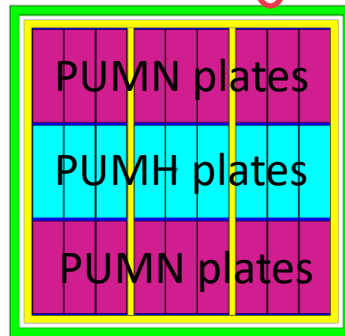
3 TEX-MOX experiments planned at NCERC for 2025



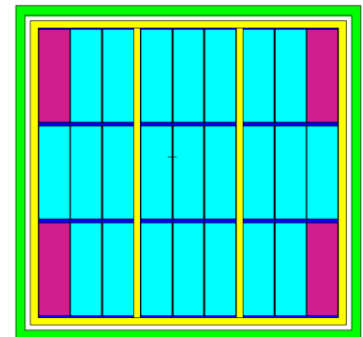
PUMN layer



10 Partial PUMH layers



4 Partial PUMH layers



High ²⁴⁰Pu content

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Representativity study

Similarity coefficient C_k , that represents the similarity between two cases for a given nuclear data covariance matrix, is calculated with the TSURFER tool from SCALE 6.2 suite using the 44 energy groups covariance data of ENDFB-7.0 library. It is defined as follows:

C_{lm} is the similarity coefficient between case l and case m :

$$C_{lm} = \frac{S_l^T C_{\alpha\alpha} S_m}{\sigma_l \sigma_m}$$

nuclear data covariance matrix

sensitivity vector

uncertainty on the k_{eff} on the case l or m due to nuclear data

$C_k \sim 0.8$ indicates good representativity

Shared sensitivity ratio (SS) provides the part of the sensitivity profile of the application case that is also present in the experiment configuration.

$$SS_{12} = \frac{\sum_{i,r} \sum_{Eg} \begin{cases} \text{if } S_1^{i,r,Eg} S_2^{i,r,Eg} > 0: \min(|S_1^{i,r,Eg}|, |S_2^{i,r,Eg}|) \\ \text{else:} & 0 \end{cases}}{\sum_{i,r} \sum_{Eg} |S_1^{i,r,Eg}|}$$

$S_1^{i,r,Eg}$ k_{eff} sensitivity values for the isotope i , reaction r , energy group Eg of the case 1

SS independant of the nuclear data covariances current knowledge

If the sensitivities of the two cases have opposite signs, nothing is added to the ratio.

Representativity study

- 4 application cases with PuO₂ and/or MOX in the **intermediate energy** range

Analysis looking at integral indicators (all isotopes and reactions)

SSR	INTER1	INTER2
General_sphere_puo2	0.63	0.59
Storage_mox_puo2	0.61	0.49
Storage_puo2	0.56	0.58
Container_mox	0.66	0.66

The highest SS ratios are in bold

C _k	INTER1	INTER2
General_sphere_puo2	0.87	0.84
Storage_mox_puo2	0.87	0.75
Storage_puo2	0.81	0.79
Container_mox	0.92	0.88

C_k > 0.8

Analysis looking at main isotope-reaction indicators

239Pu fission	SS ratio	C _k
	INTER1	INTER1
General_sphere_puo2	0.95	0.99
Storage_mox_puo2	0.85	0.91
Storage_puo2	0.94	0.98
Container_mox	0.95	0.99

240Pu capture	SS ratio	C _k
	INTER2	INTER2
General_sphere_puo2	0.76	0.91
Storage_mox_puo2	0.81	0.66
Storage_puo2	0.94	0.99
Container_mox	0.91	0.99

Conclusion:

- INTER1 very representative for 4 intermediate appl. cases for **global C_k et SS ratio + Pu239 fission**
- INTER2 representative for Pu240 capture (especially for SS ratio)

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Temperature challenge

[DECAY HEAT PRODUCED BY THE FUEL PLATES

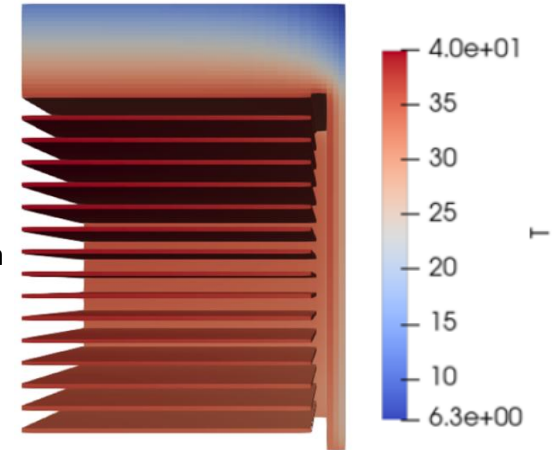
■ Temperature increase in the stack $< \Delta T = 40^{\circ}\text{C}$ without any active cooling

- with $T_{\text{room}} \sim 20^{\circ}\text{C}$, stack @ 60°C
- OK for safety (polyethylene fusion temperature $\sim 100^{\circ}\text{C}$)
- Not optimal for a clean benchmark (thermal gradient, thermal expansion, misalignment of elements)

Active cooling system was introduced to produce high-quality benchmarks

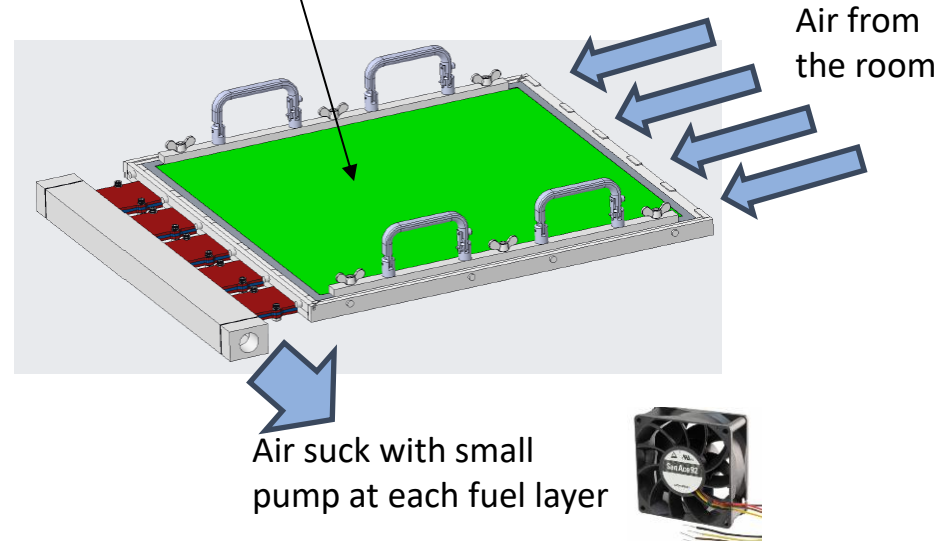
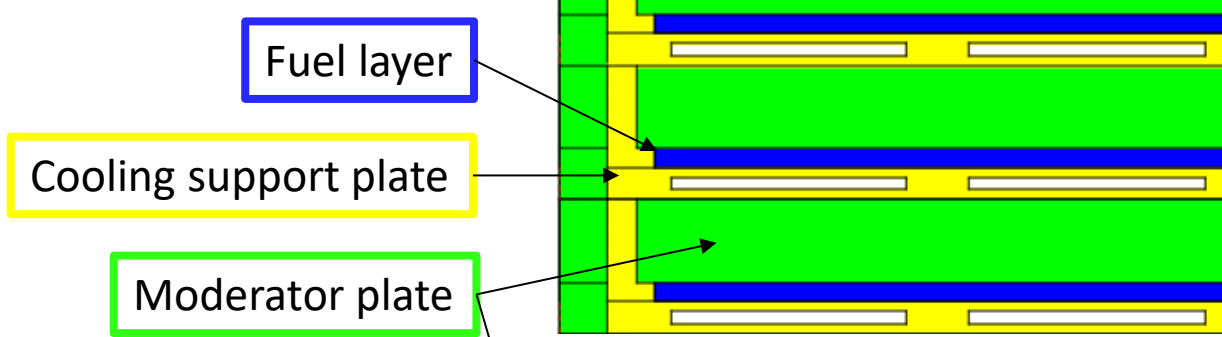
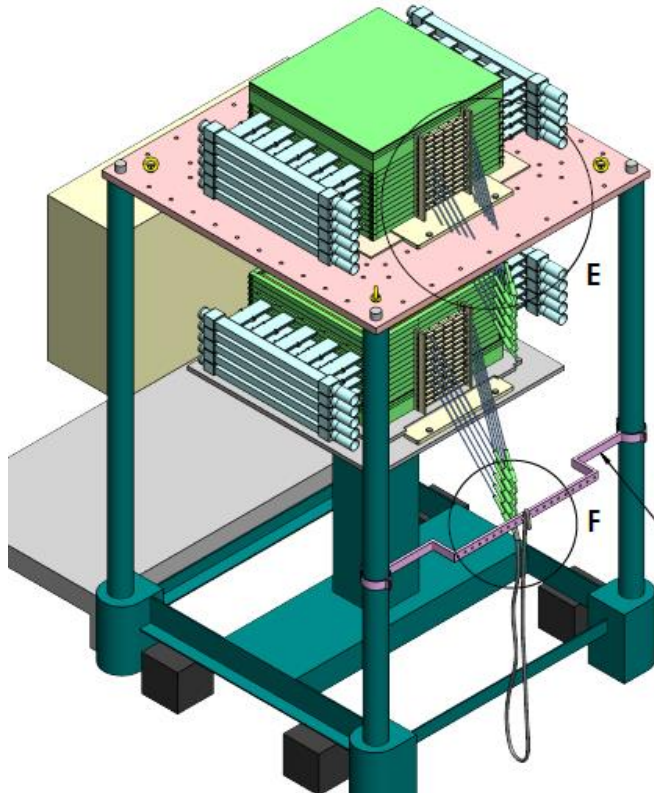
- Average temperature $< 30^{\circ}\text{C}$ (or 40°C)
- Thermal gradient within the assembly $< 15^{\circ}\text{C}$

Inter1 case
No cooling system



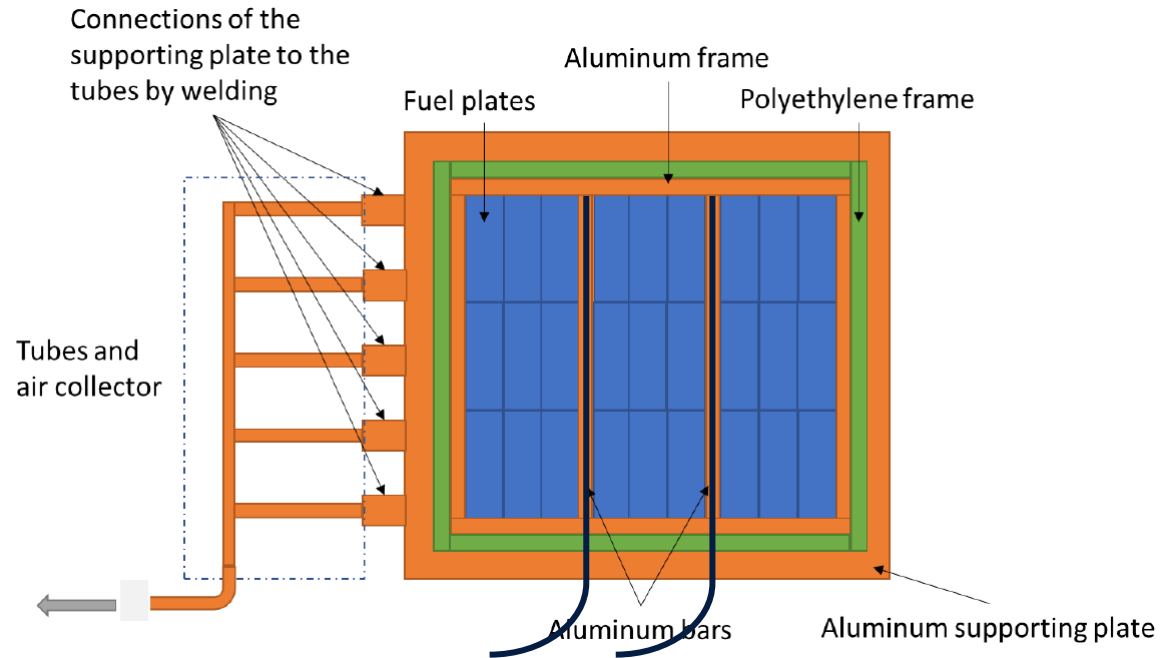
¼ of the fuel assembly : polyethylene temperature

Thermo-mechanical design



Measure the temperature gradients

- 25 Fiber Bragg Grating (FBG) sensors
 - To measure the temperature gradient within the assembly
 - Sensitive length : 456 mm
 - 10 FBG placements each 5 cm



Perspectives

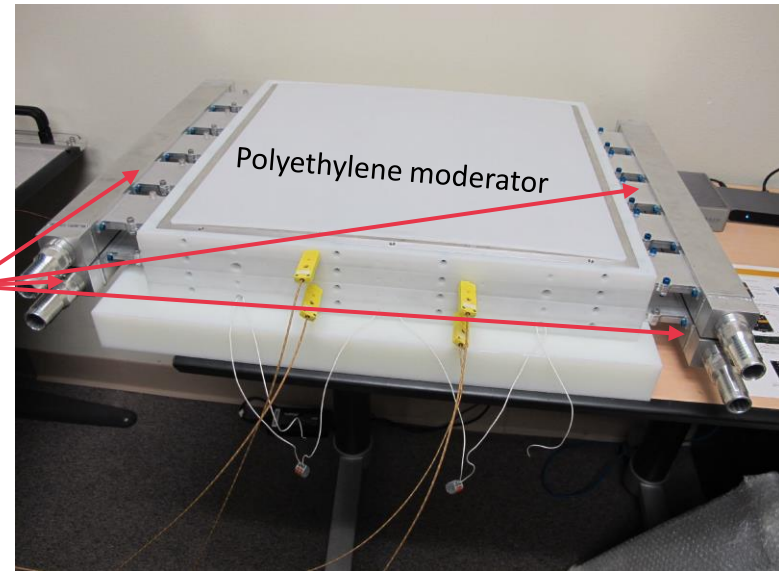
[3 CRITICAL TEX-MOX EXPERIMENTAL CONFIGURATIONS ARE PLANNED TO BE EXECUTED IN FY2025 IN USA

- Next week a campaign of measurements will be performed on the prototype at LANL
 - No nuclear material
 - Heating source to mimic the decay heat
 - To test cooling capacities and the measurement devices
 - Participation of IRSN staff



Air entrance

4 air extraction tubes for 4 layers



Thank you for your attention

ご清聴ありがとうございました

質問はありますか