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Paul Scherrer Institut

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PROTEUS FDWR-II (HCLWR) program summary for SG-39; Status of Re-analysis for Core 7, 8 & 9

[a] Now at NAGRA

Outline

Reminder of FDWR Experiments at PROTEUS

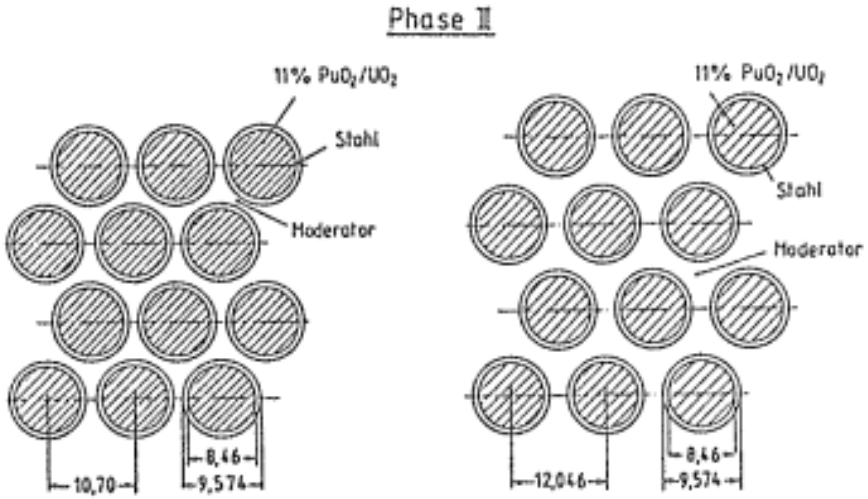
Status of PSI experimental data contribution to SG39

Status of Re-analysis work at PSI

- Preliminary C/E
- Preliminary sensitivity coefficients

Conclusion and outlook

FDWR-II – Experimental Configurations



Kern	p/d	V_M/V_F	Moderator	Eff. Moderation
7	1.12	0.48	H_2O	0.48
8	1.12	0.48	ohne	0.00
9	1.12	0.48	Dowtherm	0.28
10	1.12	0.48	Dowtherm	0.28
11	1.12	0.48	ohne	0.00
12	1.12	0.48	H_2O	0.48
13	1.26	0.95	H_2O	0.95
14	1.26	0.95	ohne	0.00
15	1.26	0.95	Dowtherm	0.55
16	1.26	0.95	H_2O	0.95
17	1.26	0.95	ohne	0.00
18	a)	2.07	H_2O	2.07
19	1.26	0.95	H_2O	0.95
20	1.26	0.95	D_2O	-

FDWR Phase II

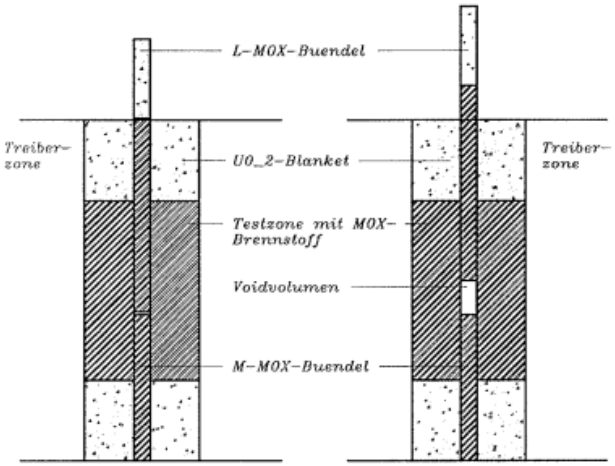
- From 1985 to 1990 in PROTEUS reactor

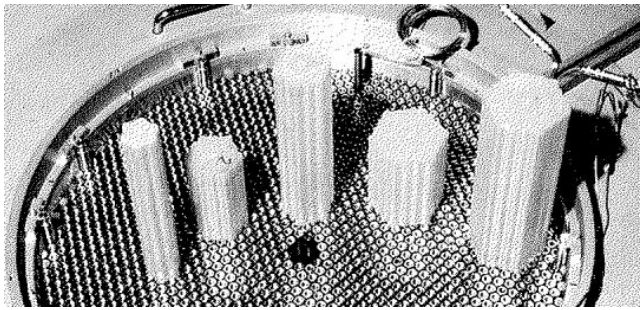
- PROTEUS is a driven system whose test zone contains the FDWR lattices

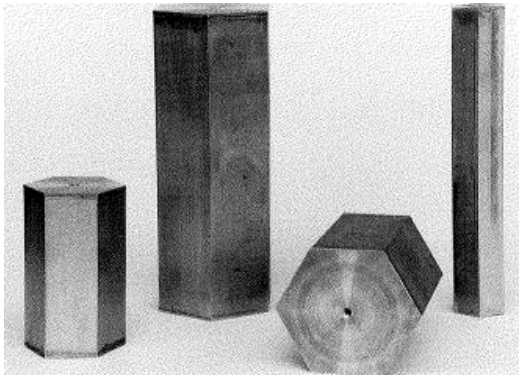
- UO_2/PuO_2 pellets with 11% PuO_2
- Pu(8/9/0/1/2): 1%, 64%, 23%, 8%, 4%
- Fuel diameter: 8.46mm
- Fuel total height: 84 cm
- 2 axial blankets:
  - Udep. 0.224w% ^{235}U
  - 28-cm high each

- Several moderation conditions
  - Two triangular pitches
  - Different moderators (water, downterm, air)

FDWR-II – Measurement types







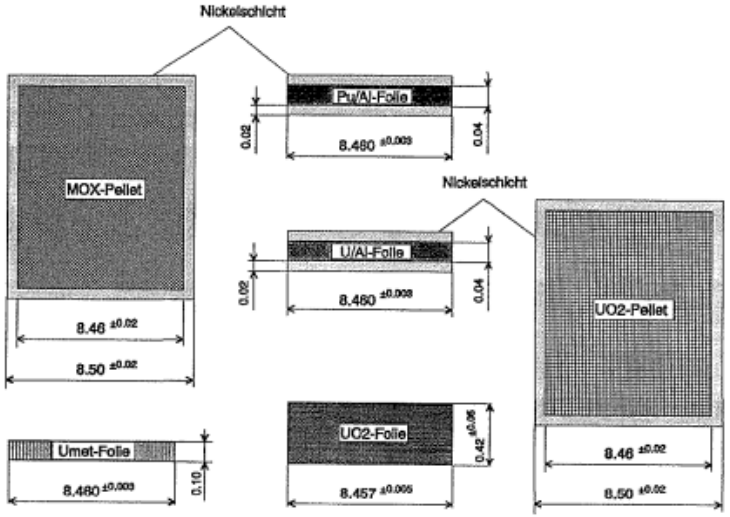
$$k_\infty = 1 + B^2 \cdot M^2$$

$$\frac{\rho_Z}{\rho_S}\frac{S}{R_f} = \bar{\nu}\frac{\overline{\Phi^+}^X}{\overline{\Phi^+}^S}\left(1 - \frac{1}{k^+}\right)$$

- K∞ measurements
  - Using axial and radial bucklings
  - Using compensation methods with auto-rod and a ^{252}Cf source
- Reactivity effects
  - Void volume
  - Moderator volume
  - Absorber rods

Absorber	Form	Durchmesser	Cladding	Bemerkung
B_4C(nat)	Pellet	7.473	ja	Referenzabsorber
B_4C(nat)	Pulver	7.430	ja	
B_4C(93%) ^{10}B	Pellet	7.430	ja	
Ag15In5Cd	Legierung	8.830	nein	
Hafnium	Metall	8.350	ja	
Gd_2O_3	Pellet	8.310	ja	
Sm_2O_3	Pellet	7.000	ja	
Tantal	Metall	8.290	ja	
Eu_2O_3	Pellet	8.243	ja	
Zircaloy-2	Legierung	8.300	nein	Strukturmaterial
Stahl	Metall	8.240	nein	Strukturmaterial

FDWR-II – Measurement types

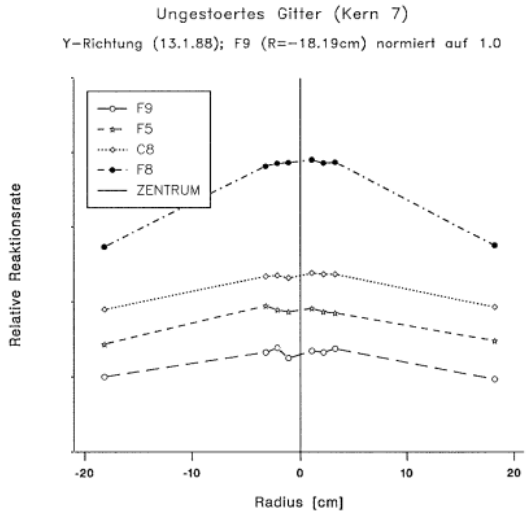


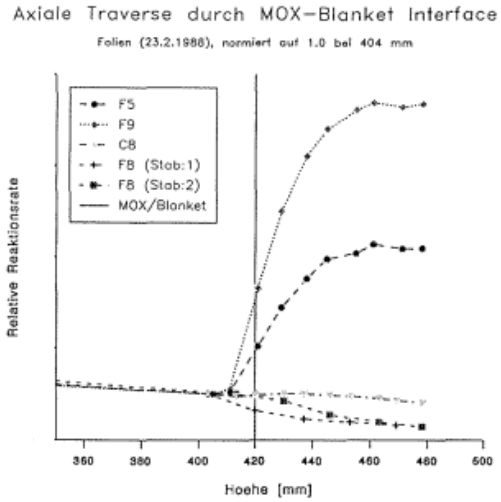
Spectral index measurements (core 7)

- F5/F9 ~0.91 F1/F9 ~ 1.68
- F8/F9 ~1.14e-2 C2/F9 ~ 1.12
- C8/F9 ~7.8e-2
- Typical uncertainties

F5: 1.8%, F8: 1.9%, F9:1.5%, C8: 1.8%

Reaction rate radial and axial traverses





PSI experimental data contribution to SG39

Experiments done with support of FRAMATOME/SIEMENS/AREVA

- **PSI willing to share against in-kind contributions**
  - Joint publications, Swiss National Science Foundation proposal, etc…

PSI will provide

- **C/E**
- **Experimental uncertainties**
- **Sensitivity coefficients**
- **Infinitely dilute cross sections (which spectrum?)**

Status of Re-analysis work at PSI

Master student developed pincell model with MCNP6 & SERPENT2

- **Short project (14 days only) focused on spectral indices comparison with experiments and preliminary sensitivity analysis**
- **Results shown today reflect current state of advancement**

Currently looking for another student to work on HCLWR re-analysis(~ 3-4 months)

- **Construction of a 3D models**
- **Enhanced S/U analysis with comparison between codes (MCNP, SERPENT, TSUNAMI) and methods**
- **Formatting of results according to specifications of SG39**

Data Delivery

- **Specification of deadline (Dependent on workforce available)**
- **SG33 formatted**
- **Responses of interest for SG39 should be provided (and prioritization)**
- **Which sensitivity should be provided**
  - Local where measurement has be done
  - Fuel wise
  - Cell wise
  - Full geometry wise

Selected C/E values

C/E obtained with ENDF/B-VII.0

C/E	Core 7			Core 8			Core 9		
	Value	Rel. unc.	Abs. unc.	Value	Rel. unc.	Abs. unc.	Value	Rel. unc.	Abs. unc.
C8/F9	1.007	1.80%	0.018	1.021	1.60%	0.016	0.989	1.70%	0.017
F8/F9	1.024	1.90%	0.019	1.003	1.81%	0.018	1.017	1.80%	0.018
F5/F9	1.017	1.50%	0.015	1.023	1.30%	0.013	1.023	1.50%	0.015
F1/F9	0.988	3.00%	0.030	1.011	3.00%	0.030	0.987	5.00%	0.049
C2/F9	1.044	3.01%	0.031	1.132	3.00%	0.034	1.035	3.02%	0.031

No obvious bias , except maybe for Pu-242 capture in Core 8 (~ 3.8 std).

Investigation of C2/F9 discrepancies

Pu-239 fission is well calculated/measured (consistency of other C/Es)

Issue with calculation / measurement of Pu-242 capture

- **C2 is very low for Core 8**
- **Measurement is difficult**
  - low energy of the gamma-ray radiation (84 keV)
  - short half-life of the Pu-243 decay (4.96 hours)
  - low amount of Pu-242 on the deposit.
- **10% constant difference between ENDF/B-VII.0 and JEFF-3.1 from 2 keV to 1 MeV for Pu-242 capture**

SI	B70		J311	
	Value	Discrepancy in sigma	Value	Discrepancy in sigma
C8/F9	1.021	1.28	1.018	1.11
F8/F9	1.002	0.09	0.983	-0.96
F5/F9	1.023	1.70	1.025	1.88
F1/F9	1.011	0.38	1.022	0.72
C2/F9	1.133	3.90	1.230	6.23

Total k-eff sensitivities

Sensitivity of k-eff

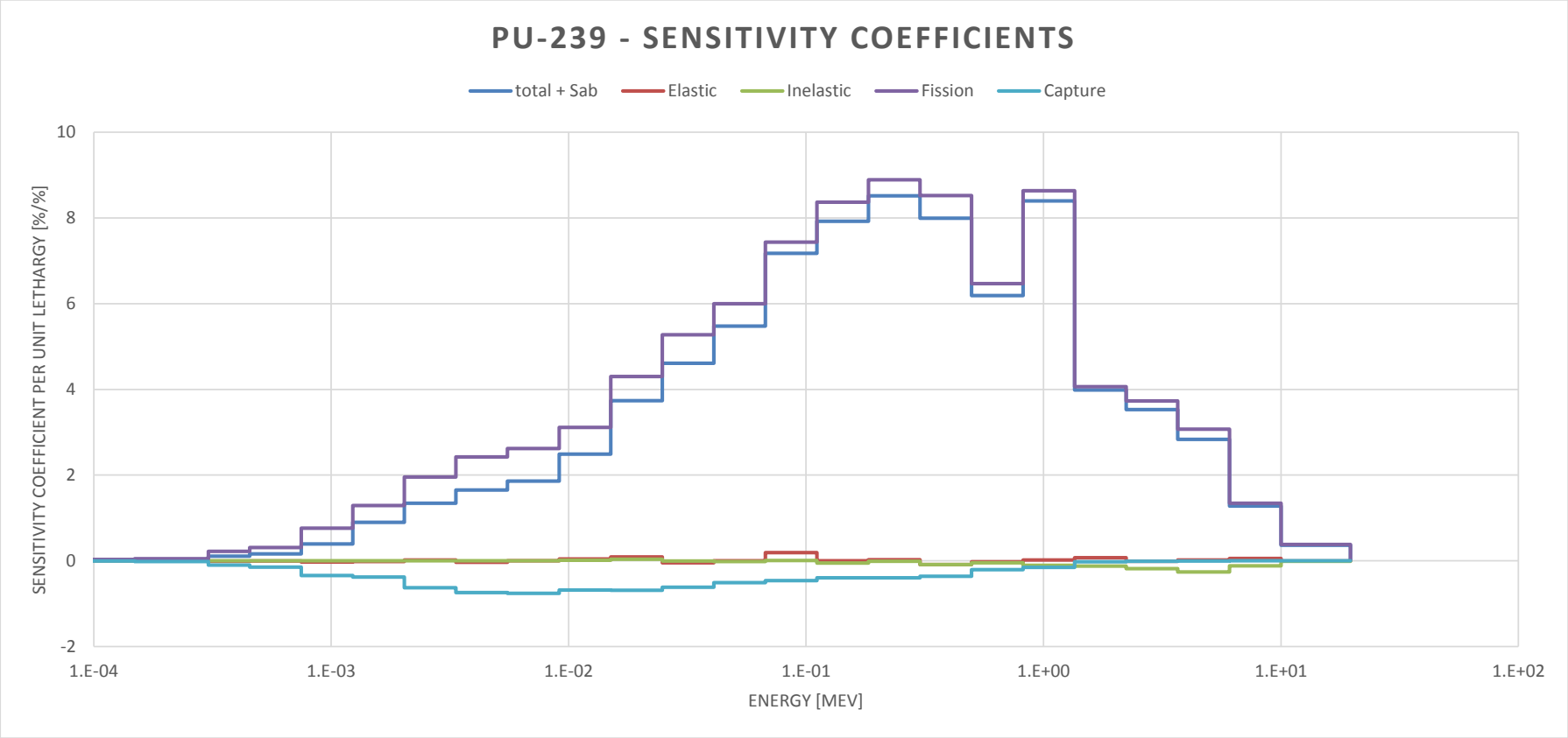
Total sensitivity (and uncertainty) for cores 7, 8 and 9

SERPENT2 and MCNP6.1.1 return consistent results for core 7

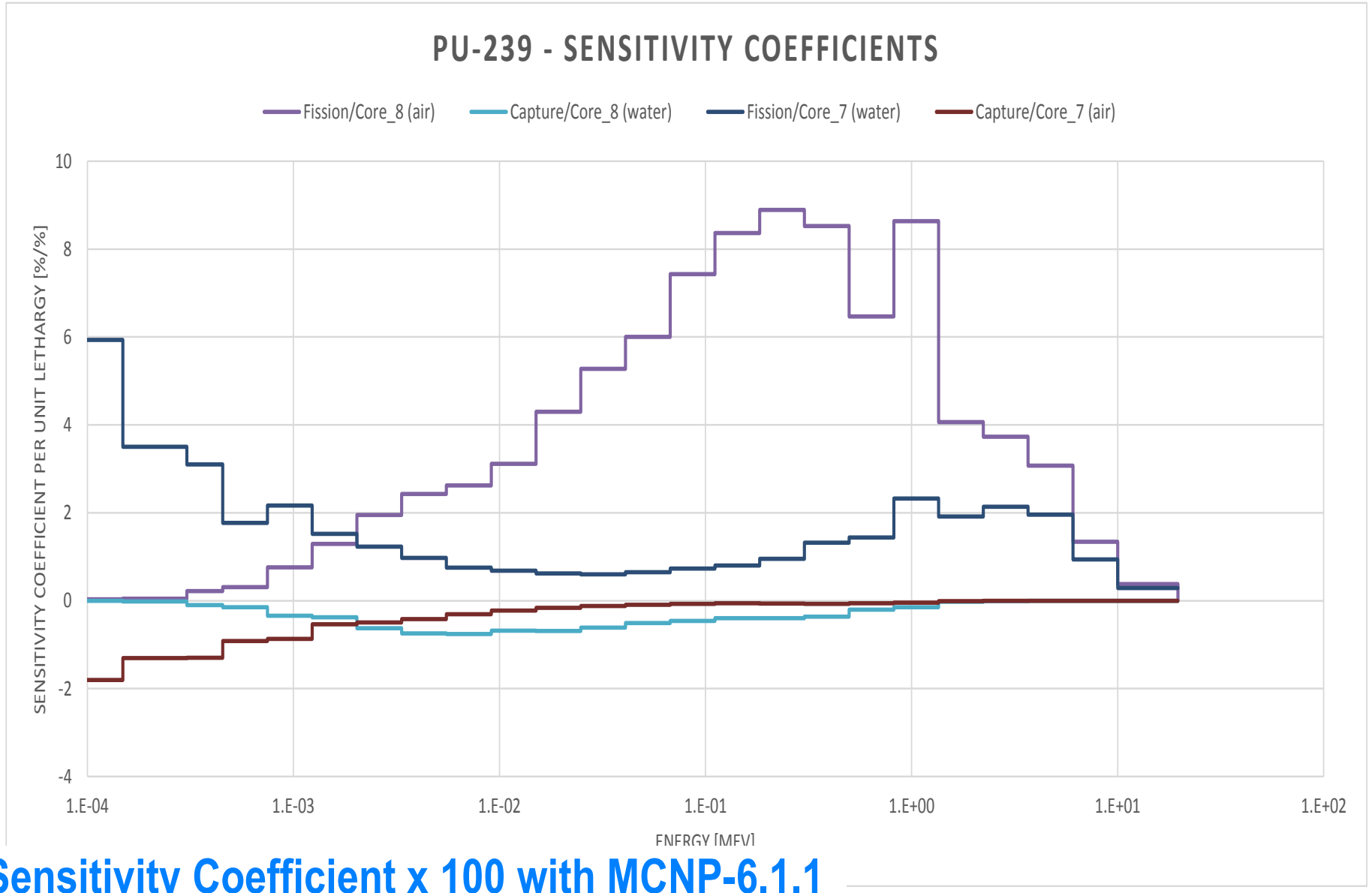
Configuration		Core 7				Core 8		Core 9	
Code		MCNP6		SERPENT		MCNP6		MCNP6	
Isotope	reaction	sensitivity	rel. unc.	sensitivity	rel. unc.	sensitivity	rel. unc.	sensitivity	rel. unc.
Pu-239	fission	0.3746	0.2%	0.3679	0.2%	0.4455	0.1%	0.3845	0.2%
Pu-239	total + sab	0.2244	0.6%	0.2178	0.6%	0.4053	0.3%	0.2588	0.6%
U-238	capture	-0.1744	0.2%	-0.1769	0.2%	-0.2654	0.2%	-0.2055	0.2%
Pu-239	capture	-0.1493	0.2%	-0.1505	0.2%	-0.0380	0.2%	-0.1268	0.3%
U-238	total + sab	-0.0885	3.3%	-0.0922	3.3%	-0.2245	1.7%	-0.1197	3.4%
Pu-241	fission	0.0801	0.4%	0.0789	0.4%	0.0713	0.3%	0.0844	0.4%
U-238	fission	0.0743	0.5%	0.0754	0.5%	0.1150	0.3%	0.0839	0.6%
Pu-240	capture	-0.0679	0.4%	-0.0674	0.4%	-0.0141	0.3%	-0.0507	0.6%
Pu-241	total + sab	0.0640	0.6%	0.0627	0.6%	0.0673	0.4%	0.0705	0.7%
Pu-240	total + sab	-0.0512	1.2%	-0.0514	1.2%	0.0184	0.7%	-0.0311	2.4%

Core 8 Pu-239 Sensitivity

Sensitivity Coefficient x 100 with MCNP-6.1.1

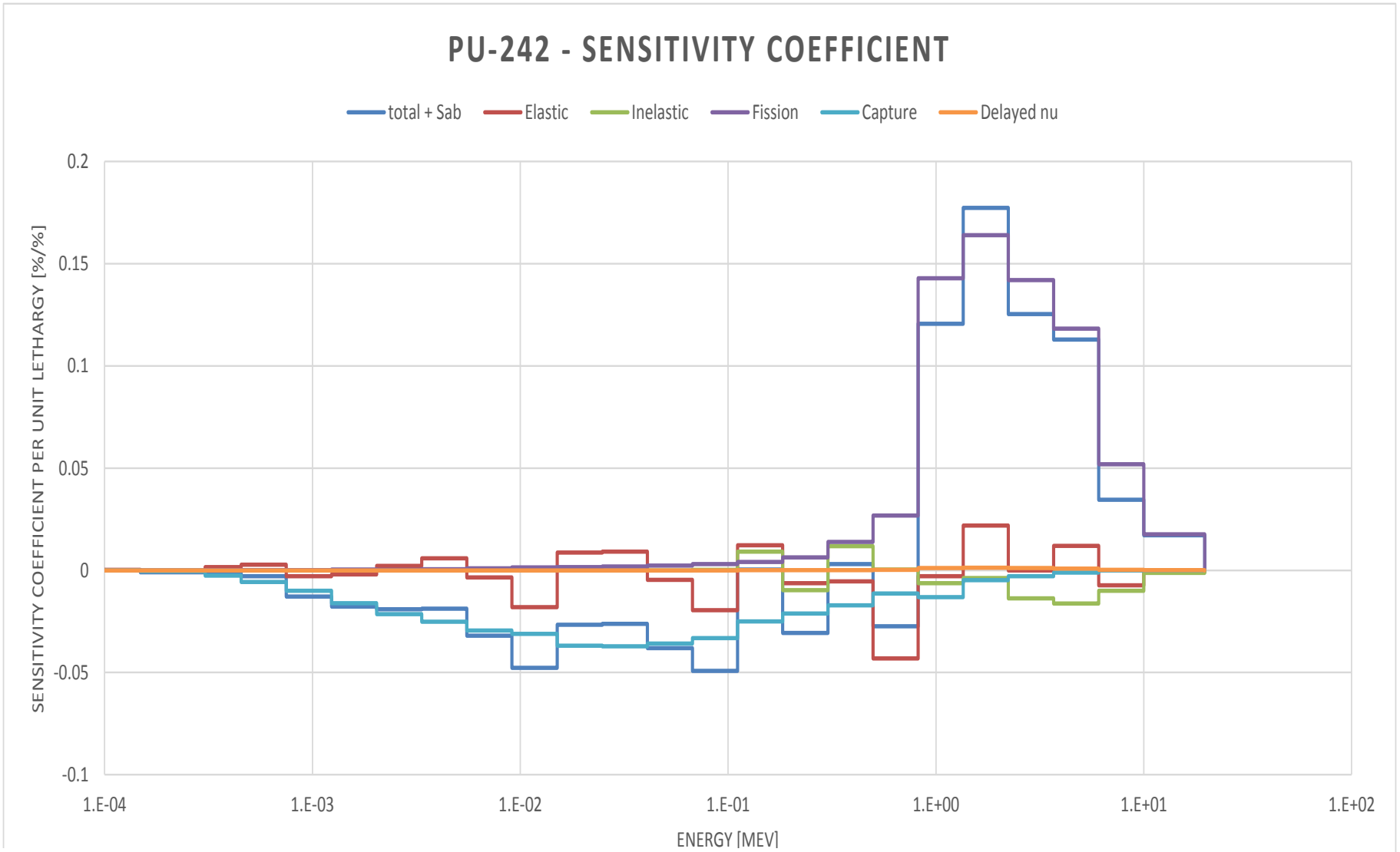


Fission and capture SC of water- and air-moderated core configurations (7 & 8)



Sensitivity Coefficient x 100 with MCNP-6.1.1

Core 8 Pu-242 Sensitivity



Sensitivity Coefficient x 100 with MCNP-6.1.1

Conclusion

Re-analysis of FDWR experiments at PROTEUS with modern modeling tools has started

- Limited resources
- Cell models only
- Preliminary results were presented

For the considered core configurations, no obvious bias besides C2/F9

Consistent sensitivity information were generated with SERPENT-2 and MCNP6.1.1

Dissemination of information has been ok'ed by PSI

- Deadline?
- Prioritization of responses
- How to proceed practically?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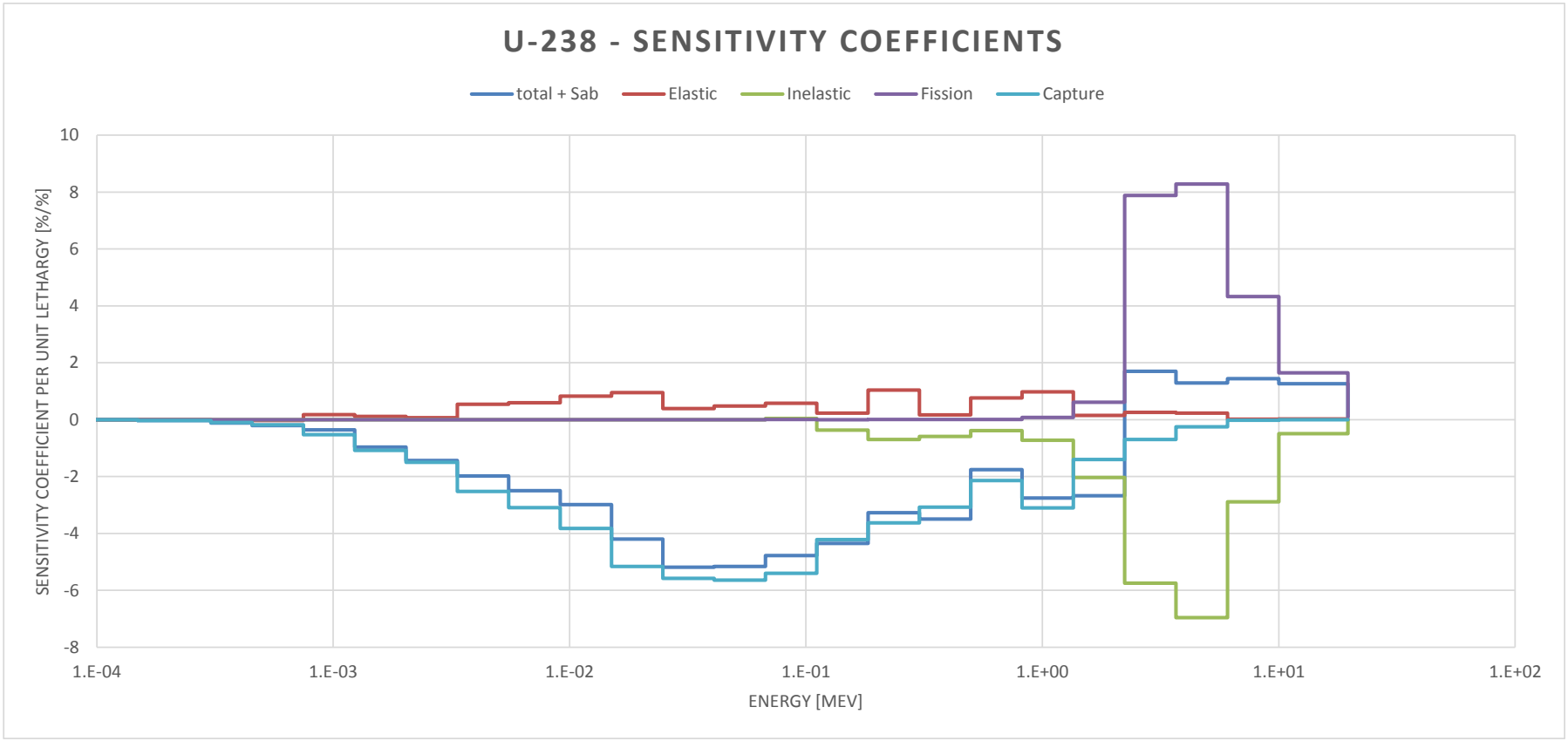
Core 8 U-238 Sensitivity

Sensitivity Coefficient x 100 with MCNP-6.1.1



Nuclear Data Comparison

Reaction	Core 7		Core 8	
	J311/B70	JN40/B70	J311/B70	JN40/B70
F5	1.001	0.998	1.004	0.987
F8	0.983	0.995	0.983	1.001
F9	1.002	1.003	1.002	1.008
F0	0.999	0.983	1.006	0.981
F1	1.002	0.997	1.012	0.991
C8	1.002	1.000	0.999	0.993
C2	0.980	0.985	1.088	1.039