KIT and INL Results of the NEA/EGIEMAM-II Calculation Benchmark on Low Void SFR Burner Core

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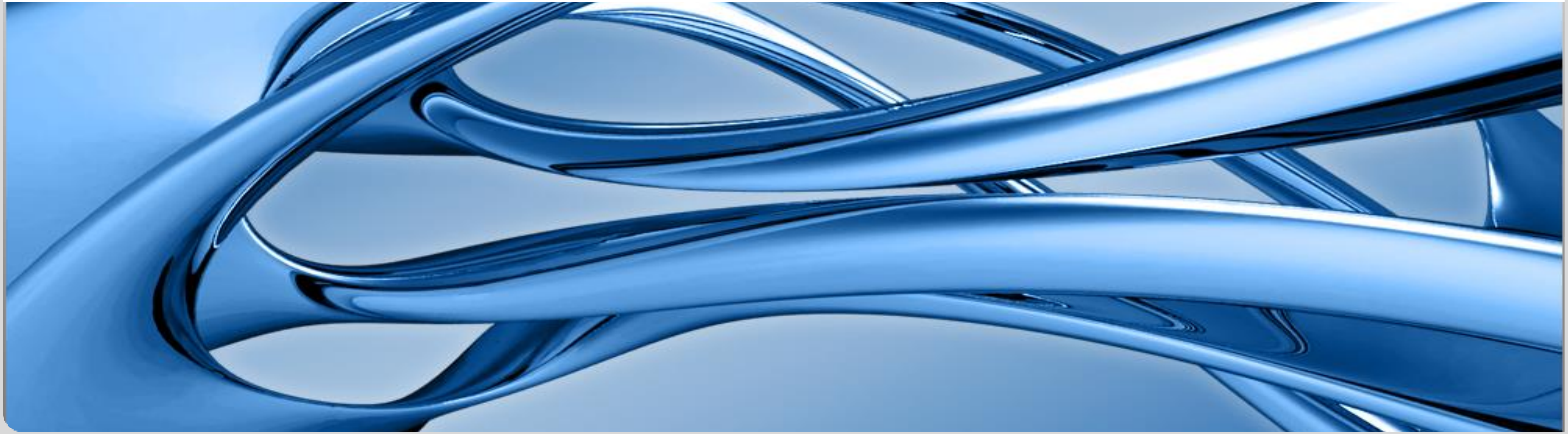

Aim of the benchmark

- **Evaluation of the impact of the uncertainties of MAs, U, and Na nuclear data on selected design parameters of a low void SFR MA burner model**

  - criticality level;
  - kinetics parameters (β_{eff} and Λ);
  - Doppler constant;
  - Sodium void effect.

- Studies have been performed in the past providing a preliminary evaluation of the impact of nuclear data uncertainties on the design parameters of SFRs*.

- **A further step is done here by considering a low coolant void SFR burner with low CR (~0.5-0.6) loaded with a significant amount of MAs (MA:Pu=1:2).**

- The SFR MS burner models is based on the 1500 MWth French ASTRID CFV-V1 (Coeur à Faible effet de Vide, i.e. low sodium void core) concept developed by CEA with support of AREVA and EdF.

*G. Palmiotti, M. Salvatores, G. Aliberti, et al., A Global Approach to the Physics Validation of Simulation Codes for Future Nuclear Systems, PHYSOR 2008, Interlaken, Switzerland, September 14-19, 2009.

Low Void SFR MA burners: model assessment

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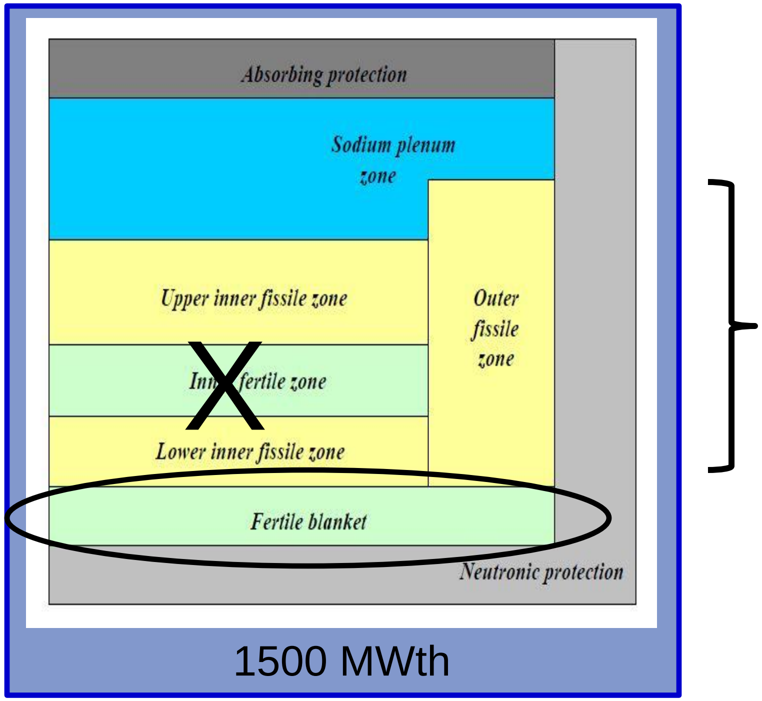
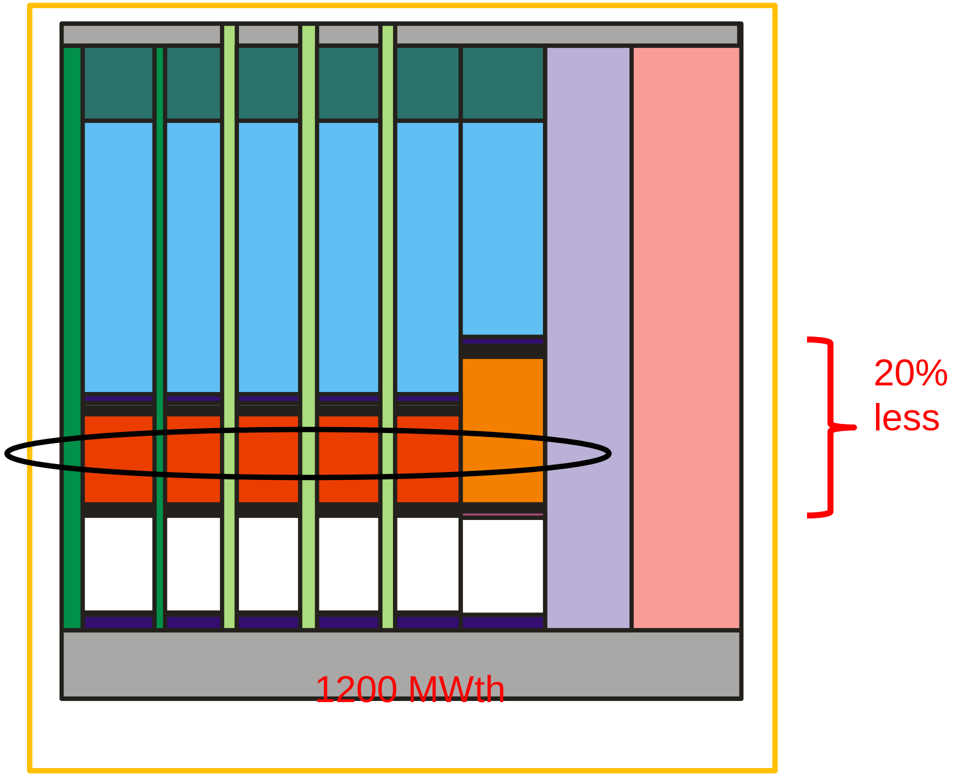


ASTRID design (J.P. Grouiller, FR13)



ASTRID-like burner *

Power: 1500 MWth → 1200 MWth (20% less)

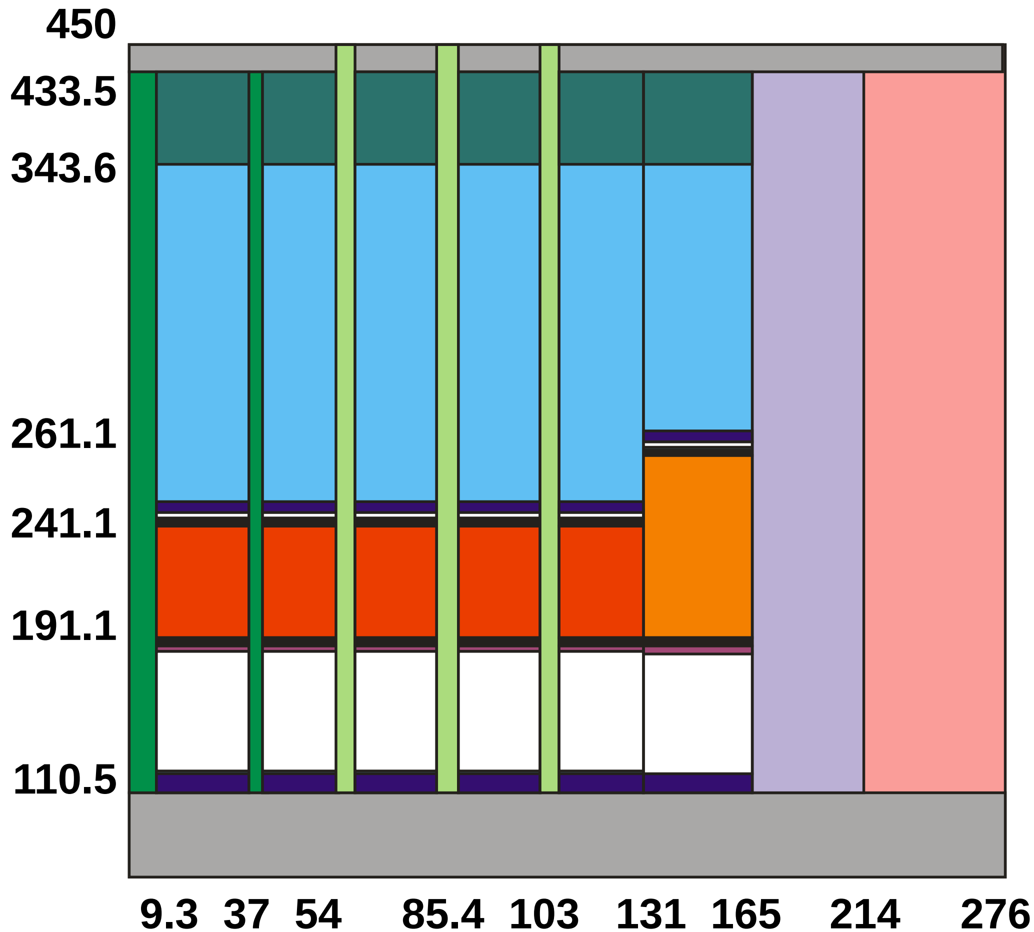
Active height: reduced by 20%

Internal fertile blanket: removed

Lower fertile blanket: reduced to 2 cm

*F. Gabrielli, A. Rineiski, B. Vezzoni, W. Maschek, C. Fazio, M. Salvatores, ASTRID-like Fast Reactor Cores for Burning Plutonium and Minor Actinides, Energy Procedia 71 (2015) 130 – 139

Low Void SFR MA burners: model assessment



- **TRU content increased** and **core height reduced** → compensate the reactivity increase (increased Pu content) and the deterioration of safety parameters (MAs into fuel).
- Fissile core height reduced by 20% (**50/70 cm**) and **1200 MWth** power (same power density as in ASTRID).
- **Internal fertile blanket removed** and **2 cm lower blanket height**.
- Lower blanket: **homogeneous mixture of depleted U and MAs (10 wt.%)** → proliferation performance and core safety improvement (increase of the neutron leakage from the core → reduction of the sodium void reactivity worth).

Characteristics of the SFR MA burner

Parameter	Value
Inner/Outer SAs[1]	177/114
Reflector SAs[1]	216
Radial shielding SAs[1]	334
Dummy SAs[1]	4
Control/Safety SAs[1]	12/6
Inner/Outer core Fuel material[2]	$(U\text{-}TRU)O_2$
Power (MWth) [2]	1200
MA:Pu ratio[2]	**1:2**
Inner/Outer Pu enr. (wt.%) [2]	22.5/24.5
Blanket material[2]	(Depleted U-MA)
MA enrich in the LB (wt.%)[2]	10

[1]MS. Chenaud, N. Devictor, G. Mignot, et al., Status of the ASTRID core at the end of the pre-conceptual design phase 1, Proc. of Int. Conf. on Fast Reactors and related Fuel Cycles: Safe Technologies and Sustainable Scenarios, Paris, France, 4-7 March; 2013.

[2]F. Gabrielli, A. Rineiski, B. Vezzoni, W. Maschek, C. Fazio, M. Salvatores, ASTRID-like Fast Reactor Cores for Burning Plutonium and Minor Actinides, Energy Procedia 71 (2015) 130 – 139.

U-TRU fuel

- Mixed U-TRU oxide (MOX) fuel with MA:PU=1:2.

- The Pu and MA isotopic vectors corresponding to those in MOX SNF reprocessed after 30 years after irradiation in a PWR, i.e. with a burn-up of about 45 MWd/kg (used in the past for EFIT design studies)*.

Isotope	wt.%
PU238	3.737006
PU239	46.4457
PU240	34.1214
PU241	3.844722
PU242	11.85002
PU244	1.154E-3

Isotope	wt.%
NP237	3.8844
AM241	75.51
AM242M	0.2536
AM243	16.054
CM243	0.0662
CM244	3.0014
CM245	1.13922
CM246	0.0885
CM247	1.67630E-3
CM248	1.0089E-4

*C. Artioli, et al., Minor actinide transmutation in ADS: the EFIT core design, Proc. Int. Conf. PHYSOR 2008, Interlaken, Switzerland, September 14-19; 2008.

Expected Results (1/2)

1. **Criticality level**

2. **Kinetics parameters:**
   2.1 Effective delayed neutron fraction (β_{eff});
   2.2 Mean Neutron generation time (Λ).

3. **Doppler constant**
   3.1 For the whole core: it is calculated for **ΔT** =1500 K-2500 K and **ΔT** =900 K-1500 K for fuel and fertile, respectively.
   3.2 Region-wise (fuel and blanket) Doppler effect can be optionally evaluated.

4. **Spatial distribution of the sodium void reactivity effect**: evaluation of the reactivity effect induced by removing the coolant only inside the wrapper.
   4.1 **Sodium void reactivity effect in the inner and in the outer core regions**
   4.2 **Extended sodium void reactivity effect**

5. **Integrated (with or w/o group splitting) uncertainty results should be given**
   - Elastic, inelastic, nu-bar, capture and fission cross-sections for fuel isotopes: ^{235}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{241}Am, ^{242m}Am, ^{243}Am, ^{237}Np, ^{243}Cm, ^{244}Cm, and ^{245}Cm.
   - Elastic and inelastic cross-sections for ^{23}Na and ^{56}Fe.

Expected Results (2/2)

- Each parameter is proposed to be computed by employing one or several nuclear data libraries.

- **Uncertainty results may be evaluated by each participant by employing any calculation procedure, i.e. perturbation/sensitivity method or direct calculation (i. e. numerical differentiation).**

- **Moreover, as far as possible participants should use actual covariance data (e.g. documented by WPEC Subgroup 39).**

Participants

- CEA
- CNRS
- ENEA
- INL
- IPPE
- KIT
- JAEA

- Preliminary results have been shown in the last EGIEMAM-II meeting (NEA Headquarter, 2016, April 6-7).

- Final results are expected by end of May 2016.

Calculation Details

- The **ERANOS 2.2 code** has been employed.

- Self-shielded neutron XSs at **33 energy-groups (collapsed from 1968 groups)** have been processed by means of the ECCO code.

  - Heterogeneous description of the fuel and blanket SAs.
  - Homogeneous description for all the other reactor regions.

- Reference Libraries: **ENDF/B VII.0 (INL)** and **JEFF3.1 (KIT)**.

- 2D (RZ) core calculations performed by means of the **BISTRO** transport solver (P1-S4).

- **EGPT for sensitivity analyses, GPT for kinetics parameters**.

- **COMMARA2.0 Covariance Matrix data employed**.

Results: Core Parameters (1/2)

Parameter	INL	KIT
k_{eff} (Reference)	1.03058	1.01799
β_{eff} (pcm)	283.6	275.6
Λ (μs)	0.410	0.419

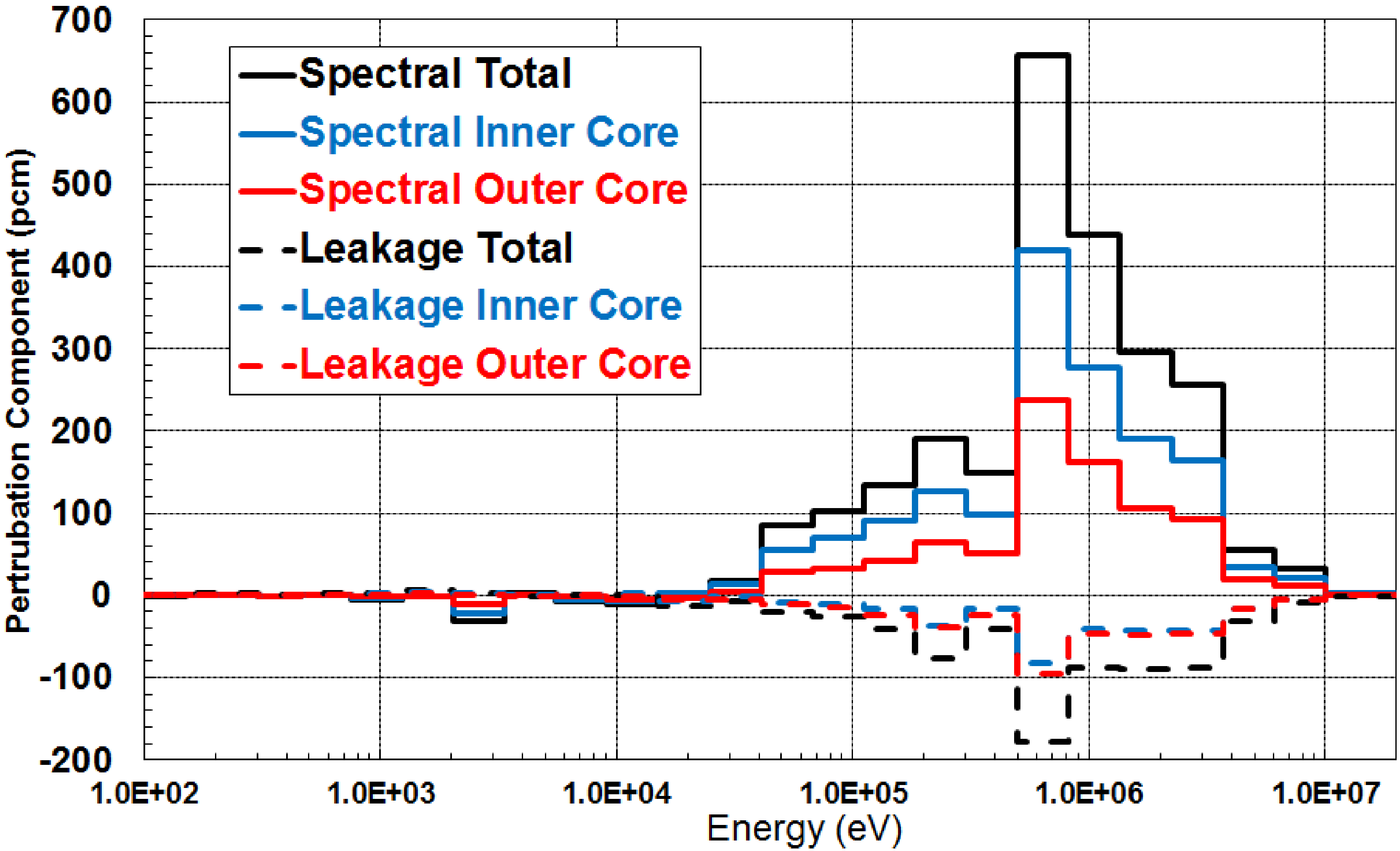
Doppler $\Delta\rho$ (pcm)	INL	KIT
Blanket + Inner + Outer Core	-104	-151
Inner + Outer core	-98	-145
Blanket	-6	-6

- Discrepancies on the Doppler Effect under investigation.

Results: Core Parameters (2/2)

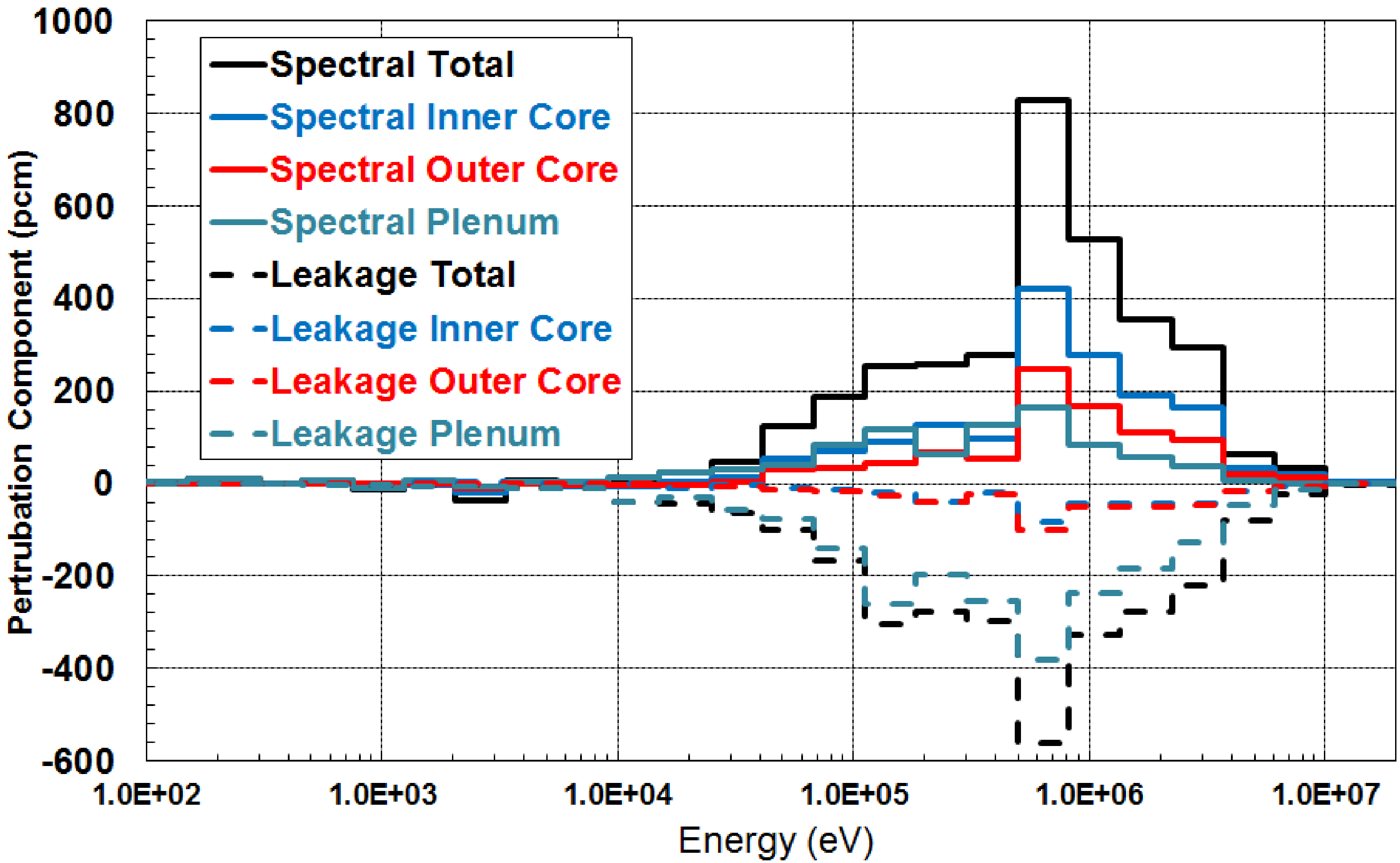
Effect of Coolant Void	INL	KIT
Inner+Outer Core (pcm)	1830	1821
Inner+Outer Core + Plenum (pcm)	512	593
Inner Core (pcm)	1339	1338
Outer Core (pcm)	547	540

Reactivity Components: Inner+Outer Core Void



	Capture	Fission	Leakage	Scattering	Sum
Inner Core	87	8	-313	1523	1305
Outer Core	42	7	-375	832	506
Sum	130	15	-688	2355	1812

Reactivity Components: Inner+Outer Core + Plenum Void



	Capture	Fission	Leakage	Scattering	Sum
Inner Core	82	11	-333	1525	1285
Outer Core	42	8	-389	863	524
Plenum	41	0	-2076	885	-1150
Sum	165	19	-2798	3272	659

CEA Calculations: effect of libraries

DE LA RECHERCHE À L'INDUSTRIE

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RZ CALCULATIONS : CORE PARAMETERS

Neutronic parameters				
	ENDF/B7	JEFF 3.1	JEFF 3.2	JENDL 4.0
Reactivity (pcm)	1549	2967	-1645	2138
Beff (pcm)	290,4	287,3	292,1	289,3
Beff per group (pcm)				
Group 1	4,58	4,53	4,55	4,59
Group 2	48,55	48,16	48,61	48,50
Group 3	17,79	17,59	17,74	17,78
Group 4	43,84	43,38	44,02	43,68
Group 5	91,59	90,63	92,00	91,29
Group 6	35,05	34,60	35,57	34,76
Group 7	33,34	32,94	33,61	33,16
Group 8	15,65	15,44	15,94	15,49
Mean neutron generation time (s)	4,24E-07	4,22E-07	3,97E-07	4,29E-07
Kd core (pcm)	-272,4	-278,9	-236,1	-261,70
Kd fuel (pcm)	-260,3	-266,6	-225,7	-249,8
Kd blanket (pcm)	-12,1	-12,3	-10,4	-12,2
Inner core sodium void worth ($)	3,67	3,61	3,82	3,94
Outer core sodium void worth ($)	1,47	1,38	1,39	1,60
Core sodium void worth ($)	5,02	4,88	5,1	5,40
Extended sodium void worth (w/ plenum) ($)	0,592	0,239	0,314	0,892

Gérald Rimpault, Timothée Kooyman, BENCHMARK ON LOW VOID SFR BURNER CORE: CEA CADARACHE RESULTS, EGIEMAM-II Meeting, NEA, Paris, 2016, April 6-7.

Uncertainty Analysis (INL): k_{eff}

- Results in % (1%=1000 pcm).

Isotope	σ_{cap}	σ_{fiss}	n	σ_{el}	σ_{inel}	Total
^{235}U	0.005	0.002	0.001	0.000	0.001	**0.006**
^{238}U	0.112	0.029	0.111	0.143	**1.105**	**1.126**
^{238}Pu	0.047	0.067	0.071	0.002	0.024	**0.111**
^{239}Pu	0.131	0.161	0.046	0.023	0.129	**0.250**
Total (U+Pu)	**0.179**	**0.177**	**0.139**	**0.145**	**1.113**	**1.158**
^{241}Am	**0.165**	0.085	**0.125**	0.010	0.080	**0.238**
^{242m}Am	0.002	0.023	0.002	0.000	0.001	**0.023**
^{243}Am	0.070	0.096	0.021	0.001	0.037	**0.126**
^{237}Np	0.014	0.011	0.005	0.000	0.006	**0.019**
^{243}Cm	0.000	0.005	0.002	0.000	0.000	**0.005**
^{244}Cm	0.050	0.060	0.045	0.000	0.003	**0.090**
^{245}Cm	0.004	**0.255**	0.029	0.000	0.002	**0.256**
Total MA	**0.186**	**0.292**	**0.138**	0.010	**0.089**	**0.383**
^{23}Na	0.006	0.000	0.000	0.030	0.128	0.131
^{56}Fe	0.076	0.000	0.000	0.092	0.208	0.240
Total Others	0.076	0.000	0.000	0.097	0.244	0.274
Total All	**0.269**	**0.342**	**0.196**	**0.175**	**1.143**	**1.251**

Uncertainty Analysis (Comments): k_{eff}

➢ Results in % (1%=1000 pcm).

INL

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
U+Pu	0.179	0.177	0.139	0.145	**1.113**	**1.158**
MAs	**0.186**	**0.292**	**0.138**	0.010	0.089	**0.383**
Others	0.076	0.000	0.000	0.097	**0.244**	**0.274**
Total	**0.269**	**0.342**	**0.196**	**0.175**	**1.143**	**1.251**

KIT

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
U+Pu	0.173	0.176	0.139	0.136	**1.164**	**1.206**
MAs	**0.182**	**0.290**	**0.139**	0.010	0.093	**0.381**
Others	0.068	0.000	0.000	0.090	**0.231**	**0.257**
Total	**0.260**	**0.339**	**0.197**	**0.163**	**1.191**	**1.290**

➢ INL and KIT results in reasonable agreement.

➢ Uncertainties on minor actinide data are relatively small and do not contribute much to the total uncertainty.

➢ The realism of these small values is still under discussion → future integral experiments devoted to MAs and their analysis will give a credible answer.

➢ As in other cases, the U-238 inelastic cross section uncertainty dominates the total uncertainty.

Uncertainty Analysis (INL): Coolant Void – Inner+Outer Core

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- **Inner + Outer Core:** $\Delta\rho$=1830 pcm (results in % of $\Delta\rho$)

Isotope	σ_{cap}	σ_{fiss}	n	σ_{el}	σ_{inel}	Total
^{235}U	0.015	0.010	0.004	0.000	0.001	0.018
^{238}U	**0.640**	0.042	0.088	0.202	0.446	**0.812**
^{238}Pu	0.183	**0.454**	0.097	0.010	0.014	0.499
^{239}Pu	0.406	**0.630**	0.209	0.061	0.188	0.802
Total (U+Pu)	**0.780**	**0.777**	**0.247**	**0.211**	**0.484**	**1.246**
^{241}Am	**0.643**	0.131	0.082	0.041	0.086	**0.668**
^{242m}Am	0.007	0.052	0.005	0.000	0.001	0.053
^{243}Am	**0.290**	**0.114**	0.020	0.005	0.065	**0.319**
^{237}Np	0.073	0.007	0.003	0.001	0.007	0.074
^{243}Cm	0.001	0.014	0.005	0.000	0.000	0.015
^{244}Cm	0.206	0.049	0.023	0.001	0.002	0.213
^{245}Cm	0.010	**0.455**	0.095	0.000	0.004	**0.465**
Total MA	**0.739**	**0.492**	0.129	0.042	0.108	**0.905**
^{23}Na	0.116	0.000	0.000	1.800	4.257	4.624
^{56}Fe	0.206	0.000	0.000	0.283	-0.074	0.342
Total Others	0.236	0.000	0.000	1.822	4.257	4.636
Total All	**1.100**	**0.920**	**0.278**	**1.835**	**4.285**	**4.885**

Uncertainty Analysis (KIT): Coolant Void – Inner+Outer Core

➢ **Inner + Outer Core:** $\Delta\rho$=1821 pcm [$\Delta\rho$(INL)=1830 pcm] (results in % of $\Delta\rho$)

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total (KIT)	Total (INL)
^{235}U	0.014	0.009	0.004	0.000	0.001	0.018	0.018
^{238}U	**0.630**	0.047	0.110	0.123	0.264	**0.704**	0.812
^{238}Pu	0.138	**0.655**	0.114	0.010	0.010	**0.679**	0.499
^{239}Pu	0.381	**0.610**	0.199	0.061	0.150	**0.764**	0.802
Total (U+Pu)	**0.749**	**0.897**	**0.254**	**0.138**	**0.304**	**1.241**	
Total (U+Pu) (INL)	**0.780**	**0.777**	**0.247**	**0.211**	**0.484**		**1.246**
^{241}Am	**0.628**	0.144	0.089	0.041	0.085	**0.657**	0.668
^{242m}Am	0.007	0.052	0.005	0.000	0.001	0.052	0.053
^{243}Am	**0.301**	0.122	0.021	0.005	0.083	**0.336**	**0.319**
^{237}Np	0.073	0.006	0.004	0.001	0.009	0.074	0.074
^{243}Cm	0.001	0.015	0.005	0.000	0.000	0.016	0.015
^{244}Cm	0.246	0.051	0.027	0.001	0.006	0.253	0.213
^{245}Cm	0.010	**0.455**	0.094	0.000	0.005	**0.465**	**0.465**
Total MAs	**0.742**	**0.498**	**0.134**	**0.041**	**0.119**	**0.912**	
Total MAs (INL)	**0.739**	**0.492**	**0.129**	**0.042**	**0.108**		**0.905**
^{23}Na	0.094	0.000	0.000	2.033	3.669	4.196	4.624
^{56}Fe	0.207	0.000	0.000	0.301	-0.037	0.363	0.342
Total Others	0.227	0.000	0.000	2.055	3.669	4.211	
Total Others (INL)	**0.236**	**0.000**	**0.000**	**1.822**	**4.257**		**4.636**

Uncertainty Analysis: Inner + Outer Core Void

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➢ Results in % of Δρ.

➢ Δρ=+1830 pcm — **INL**

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	**Total**
U+Pu	0.780	0.777	0.247	0.211	0.484	**1.246**
MAs	**0.739**	**0.492**	**0.129**	**0.042**	**0.108**	**0.905**
Others	0.236	0.000	0.000	1.822	4.257	4.636
Total	**1.100**	**0.920**	**0.278**	**1.835**	**4.285**	**4.885**

➢ Δρ=+1821 pcm — **KIT**

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	**Total**
U+Pu	**0.749**	**0.897**	0.254	0.138	0.304	**1.241**
MAs	**0.742**	**0.498**	**0.134**	**0.041**	**0.119**	**0.912**
Others	0.227	0.000	0.000	2.055	3.669	4.211
Total	**1.078**	**1.026**	**0.287**	**2.060**	**3.683**	**4.484**

➢ INL and KIT results in reasonable agreement.

➢ Uncertainties are relatively small and are dominated by the uncertainty of the Na elastic and inelastic effects.

Uncertainty Analysis (INL): Coolant Void - Extended

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- **Plenum + Inner + Outer Core:** $\Delta\rho$=512 pcm (results in % of $\Delta\rho$)

Isotope	σ_{cap}	σ_{fiss}	n	σ_{el}	σ_{inel}	Total
^{235}U	0.046	0.038	0.017	-0.004	0.007	0.062
^{238}U	**2.775**	0.153	0.604	**2.772**	**8.702**	**9.565**
^{238}Pu	0.698	1.764	0.239	0.044	0.188	**1.921**
^{239}Pu	1.305	2.884	0.796	0.497	1.166	**3.501**
Total (U+Pu)	**3.145**	**3.384**	**1.027**	**2.816**	**8.781**	**10.365**
^{241}Am	**2.964**	0.624	**0.762**	0.159	**0.936**	**3.264**
^{242m}Am	0.030	0.169	0.020	0.001	0.006	**0.173**
^{243}Am	**1.270**	0.532	0.116	0.050	0.351	**1.427**
^{237}Np	0.295	0.097	0.034	0.008	0.047	**0.316**
^{243}Cm	0.004	0.057	0.019	0.000	0.001	**0.060**
^{244}Cm	**0.789**	0.426	0.330	0.014	0.022	**0.955**
^{245}Cm	0.043	**1.393**	0.393	0.002	0.024	**1.448**
Total MA	**3.333**	**1.684**	**0.927**	**0.167**	**1.001**	**3.979**
^{23}Na	0.921	0.000	0.000	5.792	16.224	17.252
^{56}Fe	2.554	0.000	0.000	12.427	1.531	12.779
Total Others	2.715	0.000	0.000	13.710	16.296	21.469
Total All	**5.327**	**3.780**	**1.384**	**13.998**	**18.539**	**24.170**

Uncertainty Analysis (KIT): Coolant Void - Extended

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- **Plenum + Inner + Outer Core**: $\Delta\rho$=593 pcm [$\Delta\rho$(INL)=512 pcm] (results in % of $\Delta\rho$)

	Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total (KIT)	Total (INL)
	^{235}U	0.038	0.029	0.013	-0.003	0.006	0.050	0.062
	^{238}U	**2.252**	0.092	0.365	2.070	**6.083**	**6.819**	9.565
	^{238}Pu	0.469	2.205	0.251	0.039	0.110	**2.271**	1.921
	^{239}Pu	**1.063**	**2.274**	0.625	0.401	0.764	**2.727**	3.501
Total (U+Pu)		**2.534**	**3.169**	**0.766**	**2.109**	**6.132**	**7.688**	
Total (U+Pu) (INL)		**3.145**	**3.384**	**1.027**	**2.816**	**8.781**		**10.365**
	^{241}Am	**2.328**	0.544	0.575	0.165	0.659	**2.551**	**3.264**
	^{242m}Am	0.025	0.140	0.018	0.001	0.007	0.144	0.173
	^{243}Am	**1.047**	0.364	0.078	0.034	0.378	**1.174**	**1.427**
	^{237}Np	0.244	0.076	0.023	0.007	0.041	**0.260**	0.316
	^{243}Cm	0.002	0.045	0.015	0.000	0.001	0.048	0.060
	^{244}Cm	**0.756**	0.326	0.278	0.009	0.031	**0.869**	**0.955**
	^{245}Cm	0.035	**1.058**	0.317	0.002	0.021	**1.105**	**1.448**
Total MAs		**2.673**	**1.297**	**0.718**	**0.169**	**0.762**	**3.155**	
Total MAs (INL)		**3.333**	**1.684**	**0.927**	**0.167**	**1.001**		**3.979**
	^{23}Na	0.666	0.000	0.000	5.406	12.039	13.214	17.252
	^{56}Fe	1.973	0.000	0.000	9.079	1.171	9.364	12.779
Total Others		2.082	0.000	0.000	10.566	12.096	16.195	
Total Others (INL)		2.715	0.000	0.000	13.710	16.296		**21.469**

Uncertainty Analysis: Extended Void

Idaho National Laboratory — Karlsruher Institut für Technologie

- Results in % of $\Delta\rho$.

- $\Delta\rho$=+512 pcm — **INL**

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	**Total**
U+Pu	**3.145**	**3.384**	1.027	**2.816**	**8.781**	**10.365**
MAs	**3.333**	**1.684**	**0.927**	**0.167**	**1.001**	**3.979**
Others	2.715	0.000	0.000	13.710	16.296	21.469
Total	**5.327**	**3.780**	**1.384**	**13.998**	**18.539**	**24.170**

- $\Delta\rho$=+593 pcm — **KIT**

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	**Total**
U+Pu	**2.534**	**3.169**	0.766	**2.109**	**6.132**	**7.688**
MAs	**2.673**	**1.297**	**0.718**	**0.169**	**0.762**	**3.155**
Others	2.082	0.000	0.000	10.566	12.096	16.195
Total	**4.231**	**3.424**	**1.050**	**10.776**	**13.583**	**18.203**

- INL and KIT results in reasonable agreement.
- When plenum is added, uncertainties increase substantially.
- The total nominal value decreases since a strong negative leakage component is introduced.
- A more detailed analysis, based on a splitting of the void effect in its components, could help to explain effects e.g. the strong inelastic XS effect. This may be due to a high energy spectrum modification that could impact the leakage component.

CEA Uncertainty Analysis - Effect of the libraries

EXTENDED VOID WORTH UNCERTAINTIES BREAKDOWN

Total per isotopes				
Uncertainties by isotope (pcm)	ENDFB7.1	JEFF 3.1	JEFF 3.2	JENDL4.0
^{235}U	0,211	0,497	0,438	0,207
^{238}U	39,267	35,474	32,730	11,771
^{238}Pu	1,276	3,248	2,708	2,069
^{239}Pu	9,336	57,429	43,008	5,622
^{241}Am	8,947	21,823	17,939	19,648
^{242m}Am	0,489	1,214	0,918	0,174
^{243}Am	4,260	10,324	8,549	3,035
^{237}Np	1,889	4,800	3,682	0,400
^{243}Cm	0,069	0,430	0,347	0,046
^{244}Cm	1,151	4,970	3,530	0,777
^{245}Cm	0,000	3,828	2,949	0,000
^{23}Na	49,512	40,804	31,466	27,927
^{56}Fe	28,651	35,768	27,954	16,852
Total	70,756	90,324	71,628	40,428

Total per reactions				
Uncertainties by isotope (%)	ENDFB7.1	JEFF 3.1	JEFF 3.2	JENDL4.0
σ_{cap}	23,90	39,12	31,65	21,12
σ_{fiss}	8,54	55,72	42,16	5,43
ν	4,60	11,50	9,54	2,78
σ_{el}	32,21	44,46	31,68	14,51
σ_{inel}	57,48	37,61	35,45	30,67
Total	70,76	90,32	71,63	40,43

Note : the values here were not normalized to $\Delta\rho$ due to small values of $\Delta\rho$.

There are important variations between the contribution of ^{238}U, ^{239}Pu and ^{241}Am, ^{56}Fe and ^{23}Na for each library.

Gérald Rimpault, Timothée Kooyman, BENCHMARK ON LOW VOID SFR BURNER CORE: CEA CADARACHE RESULTS, EGIEMAM-II Meeting, NEA, Paris, 2016, April 6-7.

Uncertainty Analysis (INL): Coolant Void - Inner Core

Idaho National Laboratory

Karlsruher Institut für Technologie

➢ **Inner Core:** $\Delta\rho$=1139 pcm (results in % of $\Delta\rho$).

Isotope	σ_{cap}	σ_{fiss}	n	σ_{el}	σ_{inel}	Total
^{235}U	0.012	0.009	0.003	0.000	0.001	0.015
^{238}U	**0.562**	0.042	0.085	0.119	**0.522**	0.782
^{238}Pu	0.160	0.407	0.101	0.009	0.008	0.449
^{239}Pu	0.348	0.585	0.190	0.007	0.171	0.727
Total (U+Pu)	**0.680**	**0.714**	**0.232**	**0.120**	**0.549**	1.159
^{241}Am	**0.575**	0.146	0.127	0.029	0.068	**0.611**
^{242m}Am	0.006	0.049	0.005	0.000	0.001	**0.049**
^{243}Am	**0.255**	0.149	0.027	0.006	0.060	**0.302**
^{237}Np	0.065	0.010	0.005	0.000	0.006	**0.066**
^{243}Cm	0.001	0.013	0.005	0.000	0.000	**0.014**
^{244}Cm	0.180	0.071	0.036	0.001	0.003	**0.197**
^{245}Cm	0.009	**0.440**	0.087	0.000	0.004	**0.449**
Total MA	**0.658**	**0.495**	**0.161**	**0.030**	**0.091**	**0.844**
^{23}Na	0.103	0.000	0.000	1.951	3.888	4.351
^{56}Fe	0.211	0.000	0.000	0.259	0.035	0.336
Total Others	0.235	0.000	0.000	1.968	3.888	4.364
Total All	**0.975**	**0.869**	**0.282**	**1.972**	**3.928**	**4.594**

Uncertainty Analysis (KIT): Coolant Void - Inner Core

➢ **Inner Core**: $\Delta\rho$=1338 pcm [$\Delta\rho$(INL)=1339 pcm] (results in % of $\Delta\rho$)

	Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total (KIT)	Total (INL)
	^{235}U	0.011	0.008	0.003	0.000	0.001	0.015	0.015
	^{238}U	**0.553**	0.047	0.107	0.089	**0.319**	**0.655**	0.782
	^{238}Pu	0.122	0.592	0.115	0.008	0.009	**0.615**	0.449
	^{239}Pu	0.326	0.565	0.180	0.016	0.134	**0.690**	0.727
Total (U+Pu)		**0.654**	**0.820**	**0.239**	**0.090**	**0.346**	**1.134**	
Total (U+Pu) (INL)		**0.680**	**0.714**	**0.232**	**0.120**	**0.549**		**1.159**
	^{241}Am	**0.559**	0.156	0.134	0.028	0.078	**0.601**	**0.611**
	^{242m}Am	0.006	0.048	0.005	0.000	0.001	0.049	0.049
	^{243}Am	**0.263**	0.155	0.028	0.005	0.074	**0.316**	0.302
	^{237}Np	0.065	0.009	0.006	0.000	0.008	0.066	0.066
	^{243}Cm	0.001	0.014	0.005	0.000	0.000	0.014	0.014
	^{244}Cm	0.215	0.072	0.036	0.001	0.006	**0.229**	0.197
	^{245}Cm	0.009	**0.439**	0.086	0.000	0.004	**0.448**	**0.449**
Total MAs		**0.657**	**0.499**	**0.166**	**0.028**	**0.108**	**0.849**	
Total MAs (INL)		**0.658**	**0.495**	**0.161**	**0.030**	**0.091**		**0.844**
	^{23}Na	0.083	0.000	0.000	2.182	3.314	3.969	4.351
	^{56}Fe	0.214	0.000	0.000	0.276	0.048	0.353	0.336
Total Others		0.230	0.000	0.000	2.200	3.314	3.984	
Total Others (INL)		0.235	0.000	0.000	1.968	3.888		**4.364**

Uncertainty Analysis: Inner Core Void

- Results in % of $\Delta\rho$.

INL — $\Delta\rho$=+1339 pcm

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
U+Pu	0.680	0.714	0.232	0.120	0.549	1.159
MAs	0.658	0.495	0.161	0.030	0.091	0.844
Others	0.235	0.000	0.000	1.968	3.888	4.364
Total	0.975	0.869	0.282	1.972	3.928	4.594

KIT — $\Delta\rho$=+1338 pcm

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total
U+Pu	0.654	0.820	0.239	0.090	0.346	1.134
MAs	0.657	0.499	0.166	0.028	0.108	0.849
Others	0.230	0.000	0.000	2.200	3.314	3.984
Total	0.955	0.960	0.291	2.202	3.334	4.228

- INL and KIT results in reasonable agreement.
- Uncertainties are relatively small and are dominated by the uncertainty of the Na elastic and inelastic effects.

Uncertainty Analysis (INL): Coolant Void - Outer Core

- **Outer Core:** $\Delta\rho$=547 pcm (results in % of $\Delta\rho$)

Isotope	σ_{cap}	σ_{fiss}	n	σ_{el}	σ_{inel}	Total
^{235}U	0.025	0.014	0.005	-0.002	0.001	**0.029**
^{238}U	**0.951**	0.035	0.067	0.463	0.579	**1.208**
^{238}Pu	0.268	0.649	0.087	0.019	0.037	**0.709**
^{239}Pu	0.611	**0.843**	0.292	0.158	0.273	**1.126**
Total (U+Pu)	**1.162**	**1.065**	0.312	0.490	0.641	**1.798**
^{241}Am	**0.929**	0.146	0.081	0.084	0.213	**0.971**
^{242m}Am	0.010	0.066	0.007	0.000	0.002	**0.067**
^{243}Am	**0.426**	0.036	0.012	0.016	0.087	**0.436**
^{237}Np	0.106	0.014	0.005	0.003	0.010	**0.108**
^{243}Cm	0.001	0.019	0.007	0.000	0.000	**0.020**
^{244}Cm	0.302	0.042	0.043	0.005	0.003	**0.307**
^{245}Cm	0.014	**0.519**	0.126	0.001	0.006	**0.534**
Total MA	**1.071**	**0.546**	**0.157**	**0.085**	**0.231**	1.237
^{23}Na	0.170	0.000	0.000	1.726	5.915	6.164
^{56}Fe	0.255	0.000	0.000	1.482	-0.176	1.493
Total Others	0.306	0.000	0.000	2.274	5.912	6.342
Total All	**1.610**	**1.197**	**0.349**	**2.328**	**5.952**	**6.707**

Uncertainty Analysis (KIT): Coolant Void - - Outer Core

- **Outer Core**: Δρ=540 pcm [Δρ(INL)=547 pcm] (results in % of Δρ)

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	Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	Total (KIT)	Total (INL)
	^{235}U	0.025	0.013	0.005	-0.002	0.001	0.029	0.029
	^{238}U	**0.942**	0.040	0.090	0.308	0.268	**1.031**	1.208
	^{238}Pu	0.203	**0.938**	0.116	0.021	0.023	**0.968**	0.709
	^{239}Pu	**0.580**	**0.825**	0.280	0.162	0.224	**1.083**	1.126
Total (U+Pu)		**1.125**	**1.250**	**0.317**	**0.349**	**0.350**	**1.782**	
Total (U+Pu) (INL)		**1.162**	**1.065**	**0.312**	**0.490**	**0.641**		**1.798**
	^{241}Am	**0.917**	0.175	0.077	0.086	0.180	**0.957**	0.971
	^{242m}Am	0.011	0.067	0.007	0.000	0.002	0.068	0.067
	^{243}Am	**0.448**	0.032	0.009	0.015	0.119	**0.465**	0.436
	^{237}Np	0.107	0.016	0.004	0.003	0.012	**0.109**	0.108
	^{243}Cm	0.001	0.019	0.007	0.000	0.000	0.020	0.020
	^{244}Cm	**0.366**	0.046	0.056	0.004	0.009	**0.373**	0.307
	^{245}Cm	0.014	**0.523**	0.126	0.001	0.007	**0.538**	0.534
Total MAs		**1.089**	**0.559**	**0.159**	**0.087**	**0.216**	**1.256**	
Total MAs (INL)		**1.071**	**0.546**	**0.157**	**0.085**	**0.231**		**1.237**
	^{23}Na	0.139	0.000	0.000	2.023	5.210	5.591	6.164
	^{56}Fe	0.237	0.000	0.000	1.496	-0.060	1.514	1.493
Total Others		0.275	0.000	0.000	2.516	5.210	5.792	
Total Others (INL)		**1.610**	**1.197**	**0.349**	**2.328**	**5.952**		6.34

Uncertainty Analysis: Outer Core Void

- Results in % of $\Delta\rho$.

- $\Delta\rho$=+547 pcm — **INL**

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	**Total**
U+Pu	**1.162**	1.065	0.312	0.490	0.641	**1.798**
MAs	**1.071**	**0.546**	**0.157**	**0.085**	**0.231**	**1.237**
Others	0.306	0.000	0.000	2.274	5.912	6.342
Total	**1.610**	**1.197**	**0.349**	**2.328**	**5.952**	**6.707**

- **$\Delta\rho$=+540 pcm** — **KIT**

Isotope	σ_{cap}	σ_{fiss}	ν	σ_{el}	σ_{inel}	**Total**
U+Pu	**1.125**	1.250	0.317	0.349	0.350	**1.782**
MAs	**1.089**	**0.559**	**0.159**	**0.087**	**0.216**	**1.256**
Others	0.275	0.000	0.000	2.516	5.210	5.792
Total	**1.590**	**1.370**	**0.354**	**2.542**	**5.226**	**6.189**

- INL and KIT results in reasonable agreement.

- Uncertainties are relatively small and are dominated by the uncertainty of the Na elastic and inelastic effects.

Conclusions (1/2)

- KIT and INL did employ the ERANOS 2.2 code to perform the Low Void SFR calculation benchmark.

- The impact of MA Nuclear data uncertainty on Integral parameters has been evaluated by means of sensitivity and uncertainty analyses.

- Two different reference data libraries have been employed: ENDF/BV VII.0 (INL) and JEFF3.1 (KIT).

- Results show, as expected, a reasonable agreement between the two calculations (INL and KIT).

- Major source of discrepancy on k_{eff} is ^{238}U inelastic.

Conclusions (2/2)

- **The uncertainties associated to MA for the criticality level and for the reactivity effect due to sodium void look quite small, but should be confirmed, in particular using adapted MA integral experiments.**

- As for the **Na void coefficient**, the uncertainties associated to the elastic and inelastic contribution of Na rather large → **their compatibility with integral experiment analysis should be verified.**

- More analyses are needed to understand the impact of the inelastic scattering uncertainty on plenum void reactivity effect.

- **As for Doppler**, **neutron cross section uncertainties do not have a very significant impact on spectrum effects**. However additional analyses are needed to investigate the origin of the KIT/INL discrepancies on the calculated reactivity feedback.

- **Finally uncertainty data on delayed neutron parameters are needed for a meaningful β_{eff} uncertainty analysis.**

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