New Gadolinium parameters assemblage and preliminary benchmarking

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Background

Question marks on the Gd's thermal and low energy cross sections involving resolved resonance parameters for all evaluations arising from Naval Propulsion, BWR, and specific experiments (PSI LWR-Proteus svea96+, AECL ZED-2, …) feedbacks …

JEFF-3.1 evaluation

Isotope	Gd152	Gd154	Gd155	Gd156	Gd157	Gd158	Gd160	Gd0
Abundance	0.20%	2.18%	**14.80%**	20.47%	**15.65%**	24.84%	21.86%	
	0.0020	0.0228	**0.1480**	0.2047	**0.1565**	0.2484	0.2186	
Thermal XS	1056	85	**60732**	2	**253250**	3	1	48627
Cont. to Gd0	0.00%	0.00%	**18.48%**	0.00%	**81.51%**	0.00%	0.00%	
R.I.	989	248	**1547**	101	**763**	63	9	394
Cont. to Gd0	0.50%	1.43%	**58.08%**	5.24%	**30.30%**	3.98%	0.47%	

➔ NUCLEAR SCIENCE AND ENGINEERING:154,261–279 (2006)
Neutron Capture and Total Cross-Section Measurements and Resonance Parameters of Gadolinium G. Leinweber,*D.P. Barry, M.J. Trbovich, J.A. Burke, N.J. Drindak, H.D. Knox, R.V. Ballad And R.C. Block,Y. Danon, and L.I. Severnyak

➔"Atlas of Neutron Resonances", S.F. Mughabghab March, 2006 (BNL)

Assemblage

With JEFF-3.1 (based on JENDL-3.2) or ENDF/B-VII ??

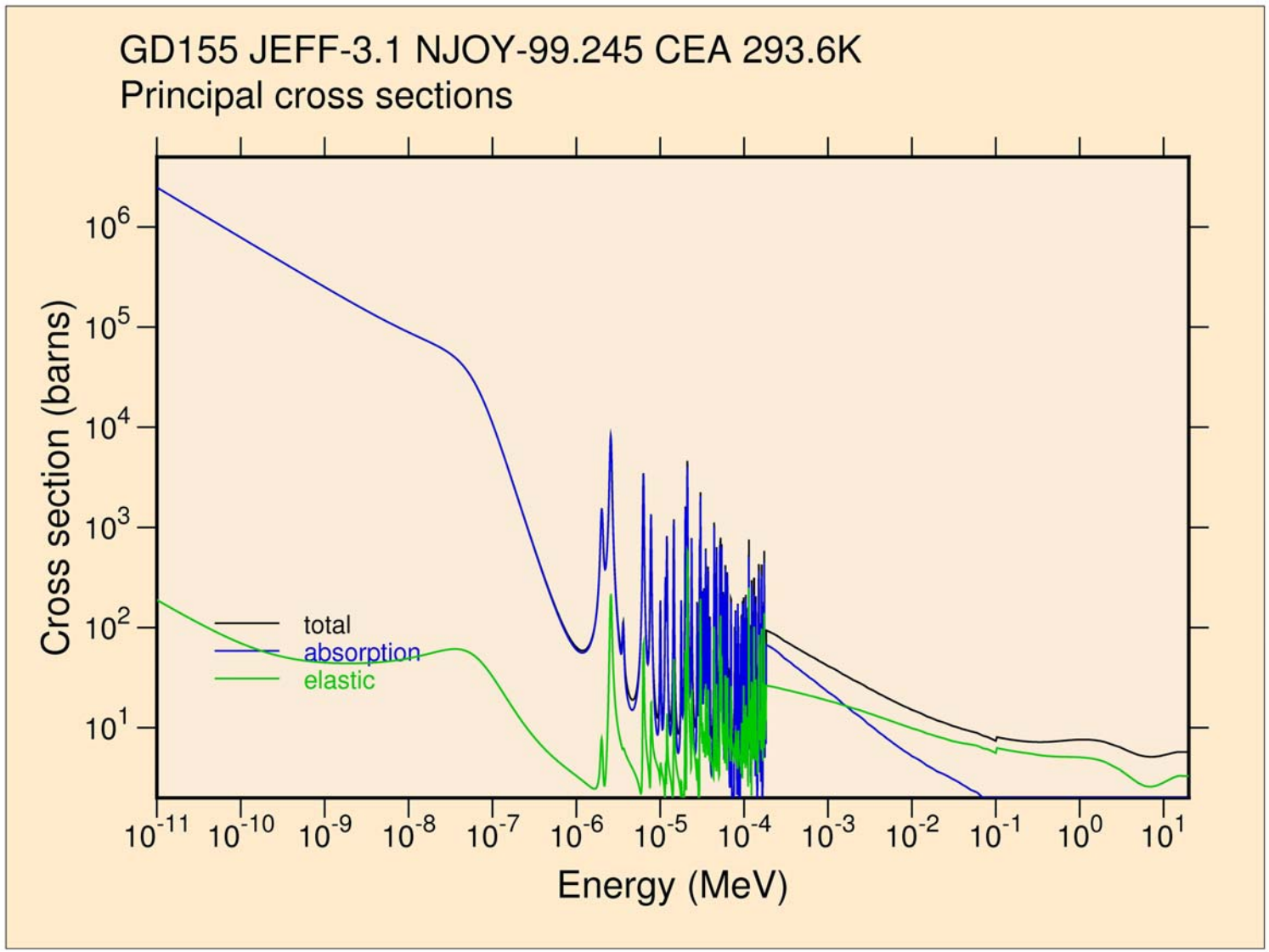
64-Gd-157 NEA RCOM-JUN82 E. MENAPACE ET.AL.
RRR 215 eV (56 resonances) – no URR in MF-2

64-Gd-157 BNL,ORNL+EVAL-APR06 Rochman, Mughabghab, Leal, Kawano+
RRR 306 eV (56+4 resonances) – URR 55 keV

Resolved Resonance parameter sets rather similar but EMPIRE model calculation, gamma production and covariance data are available in ENBF/B-VII. It makes it an obvious choice,

Sorry Enzo !! “Riposa in pace” old friend…

Gd155 cross-section (JEF-2.2=JEFF-3.1=JENDL-3.2)



Gd's NJOY thermal quantities at 293.6 K = 0.0253 eV

		JEFF-3.1	ENDF/B-VII	Delta	Mu06	Unc.	Unc	B-VII+RPI	Δ/ B-VII	Δ/ J3.1
Gd152	0.20%	0.0020								
		1.0558E+03	7.3498E+02	30.4%	735	20	2.7%	1.0497E+03	42.8%	-0.6%
		9.3349E+02	6.4884E+02	30.5%	880			9.1023E+02	40.3%	-2.5%
		9.8921E+02	5.6053E+02	43.3%	2020	160	7.9%	4.7586E+02	-15.1%	-51.9%
Gd154	2.28%	0.0228						B-VII neg.		
		8.5005E+01	8.5176E+01	-0.2%	85	12	14.1%	8.6222E+01	1.2%	1.4%
		7.5342E+01	7.4713E+01	0.8%				7.5641E+01	1.2%	0.4%
		2.4767E+02	2.1680E+02	12.5%	245	30	12.2%	2.6012E+02	20.0%	5.0%
Gd155	**14.80%**	**0.1480**								
Thermal		**6.0732E+04**	**6.0730E+04**	0.0%	**60900**	500	**0.8%**	**6.0149E+04**	**-1.0%**	-1.0%
Thermal capture int.		4.5405E+04	4.5404E+04	0.0%				4.4510E+04	-2.0%	-2.0%
Res. Integral		**1.5467E+03**	**1.5426E+03**	0.3%	**1537**	100	**6.5%**	**1.5676E+03**	**1.6%**	1.4%
Gd156	20.47%	0.2047								
Thermal		1.5358E+00	1.7947E+00	-16.9%	1.8	0.7	38.9%	1.8327E+00	2.1%	19.3%
Thermal capture int.		1.3618E+00	1.5914E+00	-16.9%				1.6251E+00	2.1%	19.3%
Res. Integral		1.0085E+02	1.0776E+02	-6.9%	104	15	14.4%	1.0561E+02	-2.0%	4.7%
Gd157	**15.65%**	**0.1565**								
		2.5325E+05	**2.5372E+05**	-0.2%	**254000**	815	**0.3%**	**2.2563E+05**	**-11.1%**	-10.9%
		1.9110E+05	1.9138E+05	-0.1%				1.7098E+05	-10.7%	-10.5%
		7.6293E+02	**7.5424E+02**	1.1%	**754**	20	**2.7%**	**7.8827E+02**	**4.5%**	3.3%
Gd158	24.84%	0.2484						B-VII neg.		
		2.5004E+00	2.2022E+00	11.9%	2.2	0.2	9.1%	2.2617E+00	2.7%	-9.5%
		2.2172E+00	1.9527E+00	11.9%				2.0055E+00	2.7%	-9.5%
		6.3070E+01	6.8405E+01	-8.5%	68	7	10.3%	7.1531E+01	4.6%	13.4%
Gd160	21.86%	0.2186						B-VII neg.		
		7.7008E-01	1.4100E+00	-83.1%	1.4	0.3	21.4%	1.4009E+00	-0.6%	81.9%
		6.8253E-01	1.2496E+00	-83.1%				1.2416E+00	-0.6%	81.9%
		8.5519E+00	8.1578E+00	4.6%	7.4	1	13.5%	7.9230E+00	-2.9%	-7.4%
Gd0 Thermal		48627	48700		48890	104	**0.2%**	**44218**	-9.2%	-9.1%
Gd0 Res. Integral		388	388		390	10	2.6%	397	2.4%	2.3%

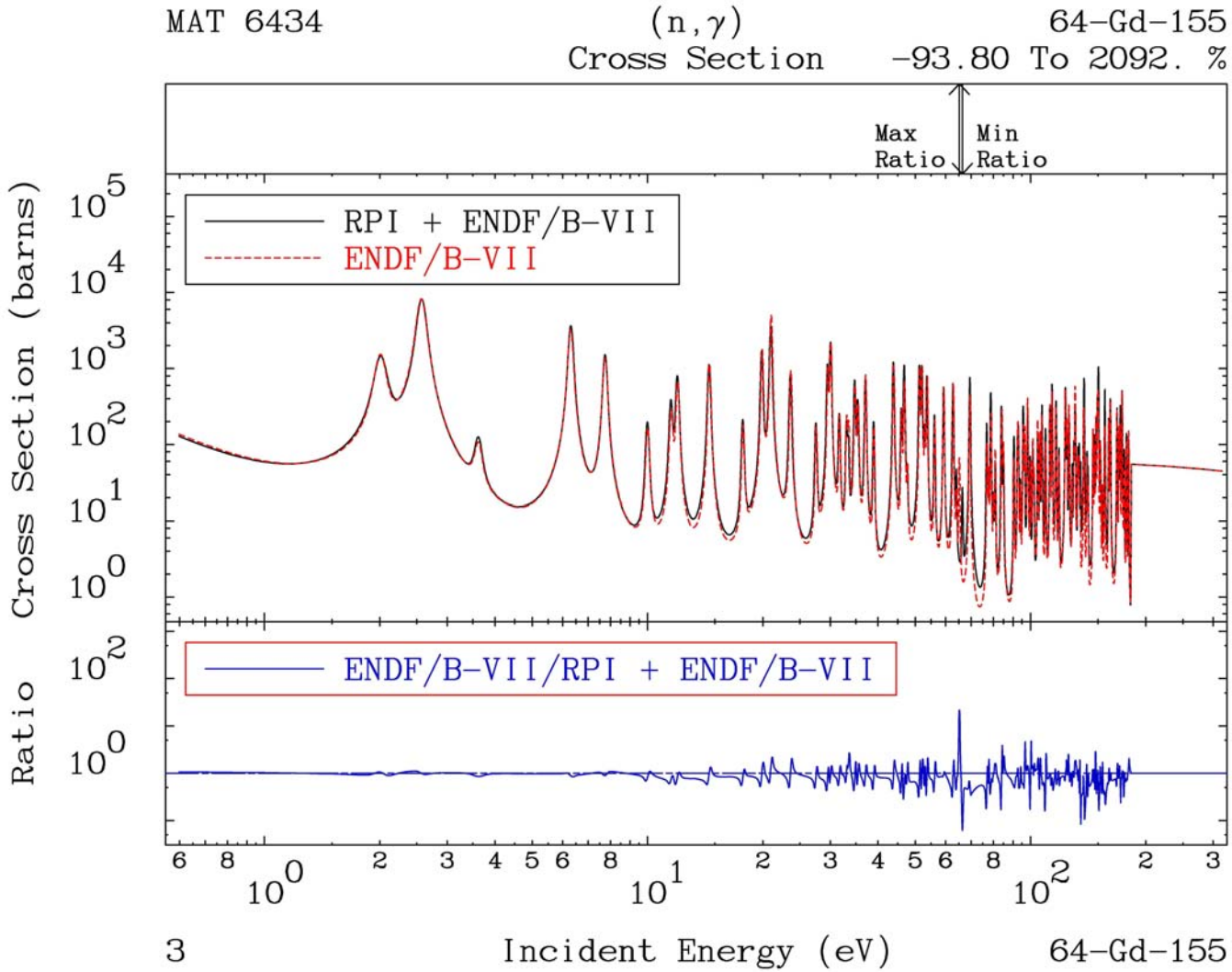
44450
+/-700
Higurashi (88)

0.2% a realistic number ?? When Gd-157 is at 3.2%

Gd-155 resonances

Th. -1.0%
60149 barns

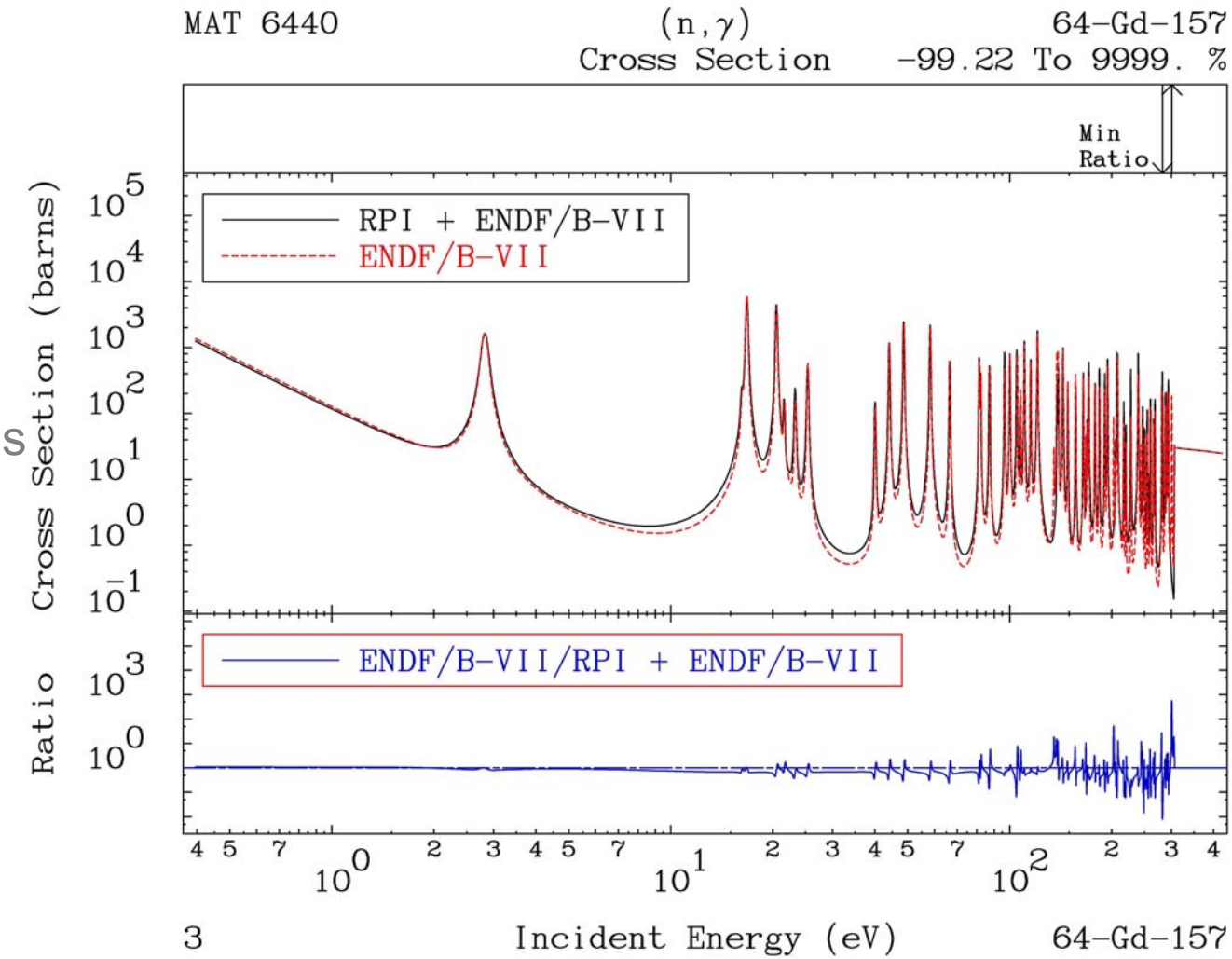
R.I. +1.6%
1568 barns



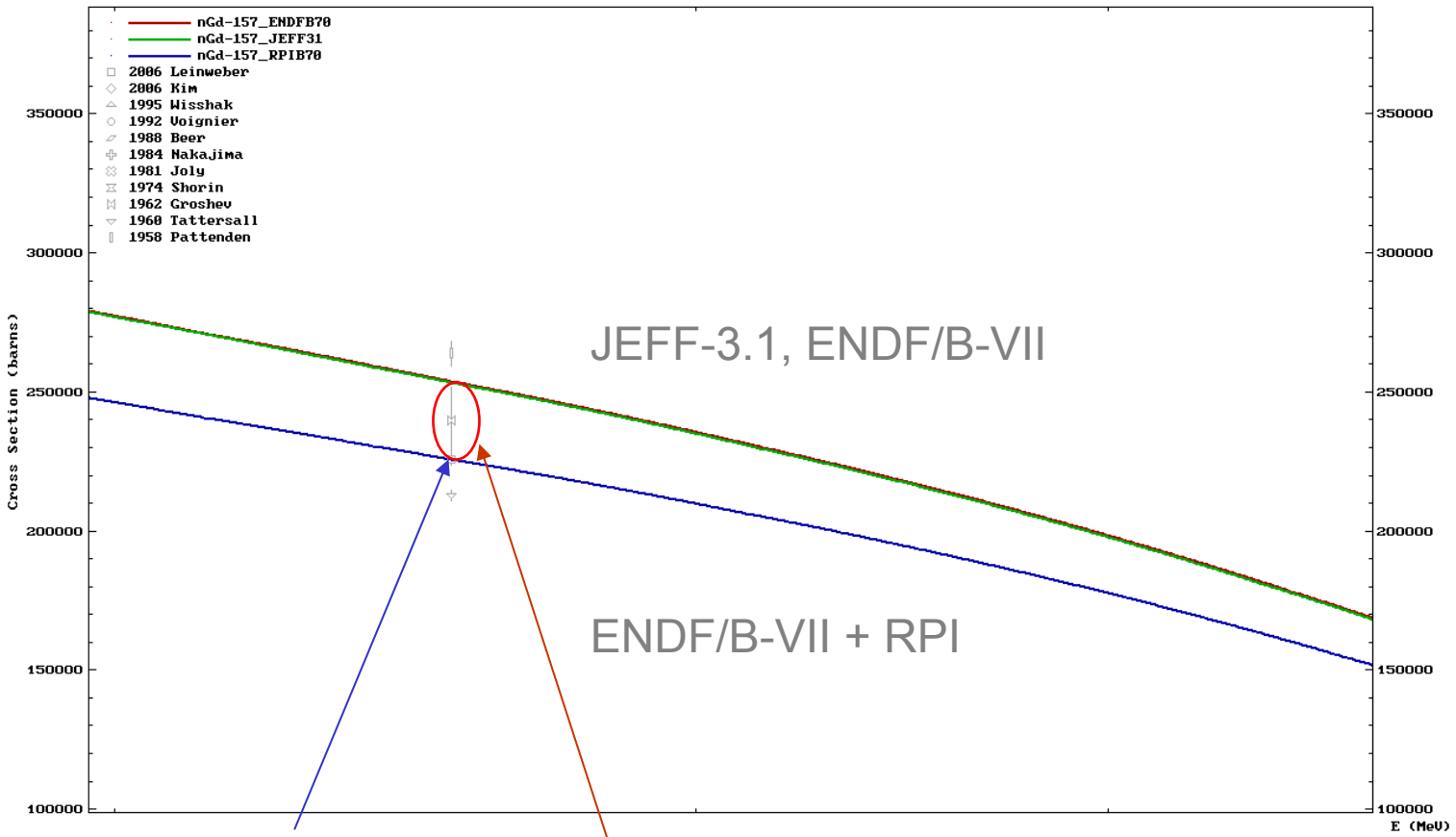
Gd-157 resonances

Th. -11.0%
225630 barns
x3.75 Gd155

R.I. +4.5%
788 barns
x0.5 Gd155



Gd-157 thermal cross-section



226000 +/-2260 1%	**G.LEINWEBER,ET.AL. (06)**
213000 +/- 2000 0.9%	R.B.TATTERSALL, (60)
264000 +/- 4500 1.7%	N.J.PATTENDEN (58)
240000 +/-12000 5%	**L.V.GROSHEV,ET.AL. (62)**
248000 +/- 4000 1.6%	OHNO,ET.AL (68)

Weighted average
226268 +/-1647

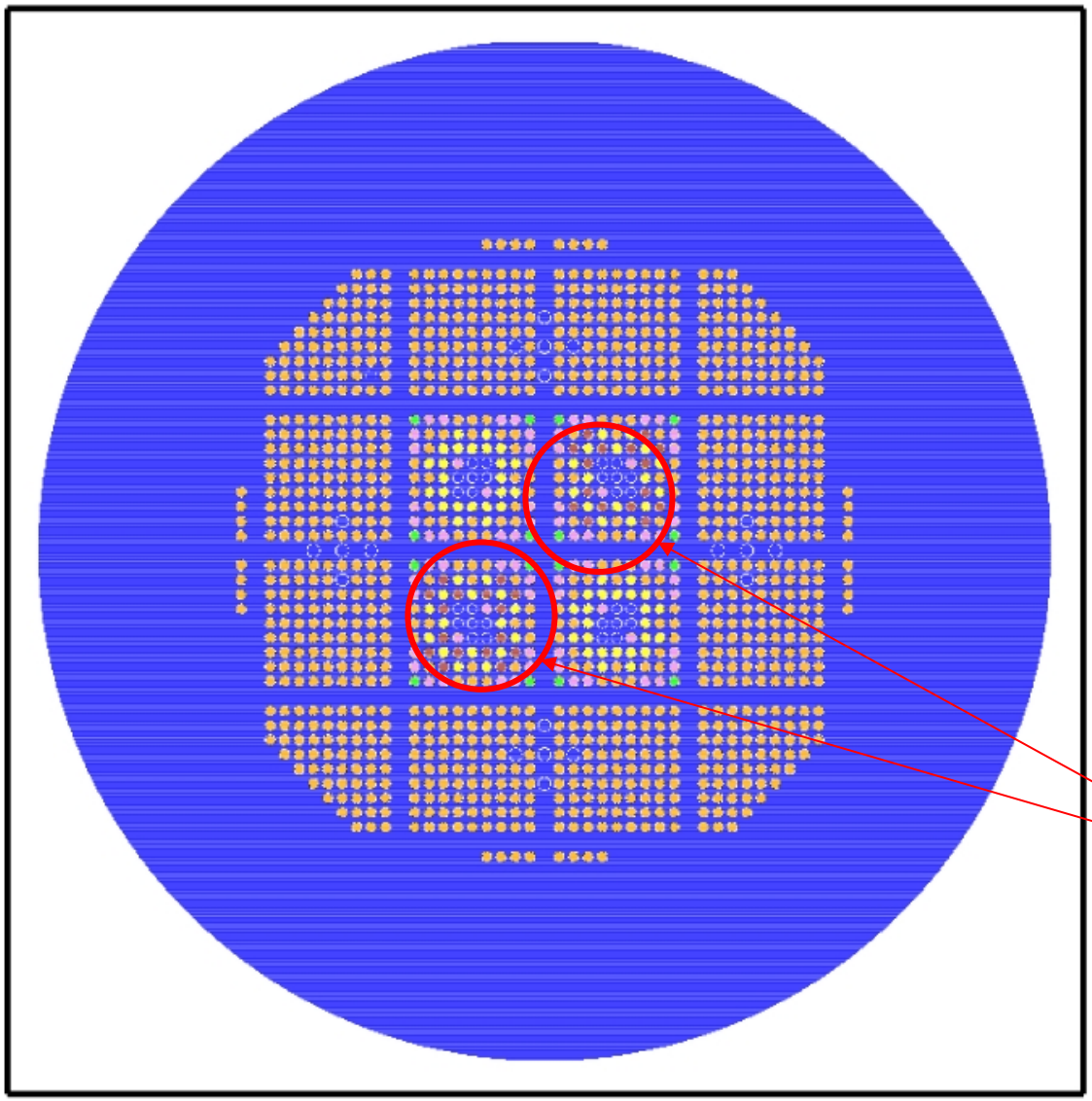
Preliminary benchmarking

- Cadarache EOLE zero power reactor
  Mox ABWR BASALA & Uox PWR CAMELEON cores

- ICSBEP NEA/NSC/DOC(95)03
  September 2007 Handbook Edition
  LEU-COMP-THERM-005 (Pacific Northwest-BNFL 16 cases)
  LEU-COMP-THERM-35 (JAERI TCA 3 cases)
  HEU-SOL-THERM-014 (Institute of Physic and Power Engineering 3 cases)
  +…..others are needed CRISTO-3 (1980-82), MISTRAL (1996-2000), PSI , AECL , etc…

  Monte Carlo code TRIPOLI-4.5 & JEFF-3.1 – ENDF/B-VII – news evaluations with CALENDF probability tables in the URR

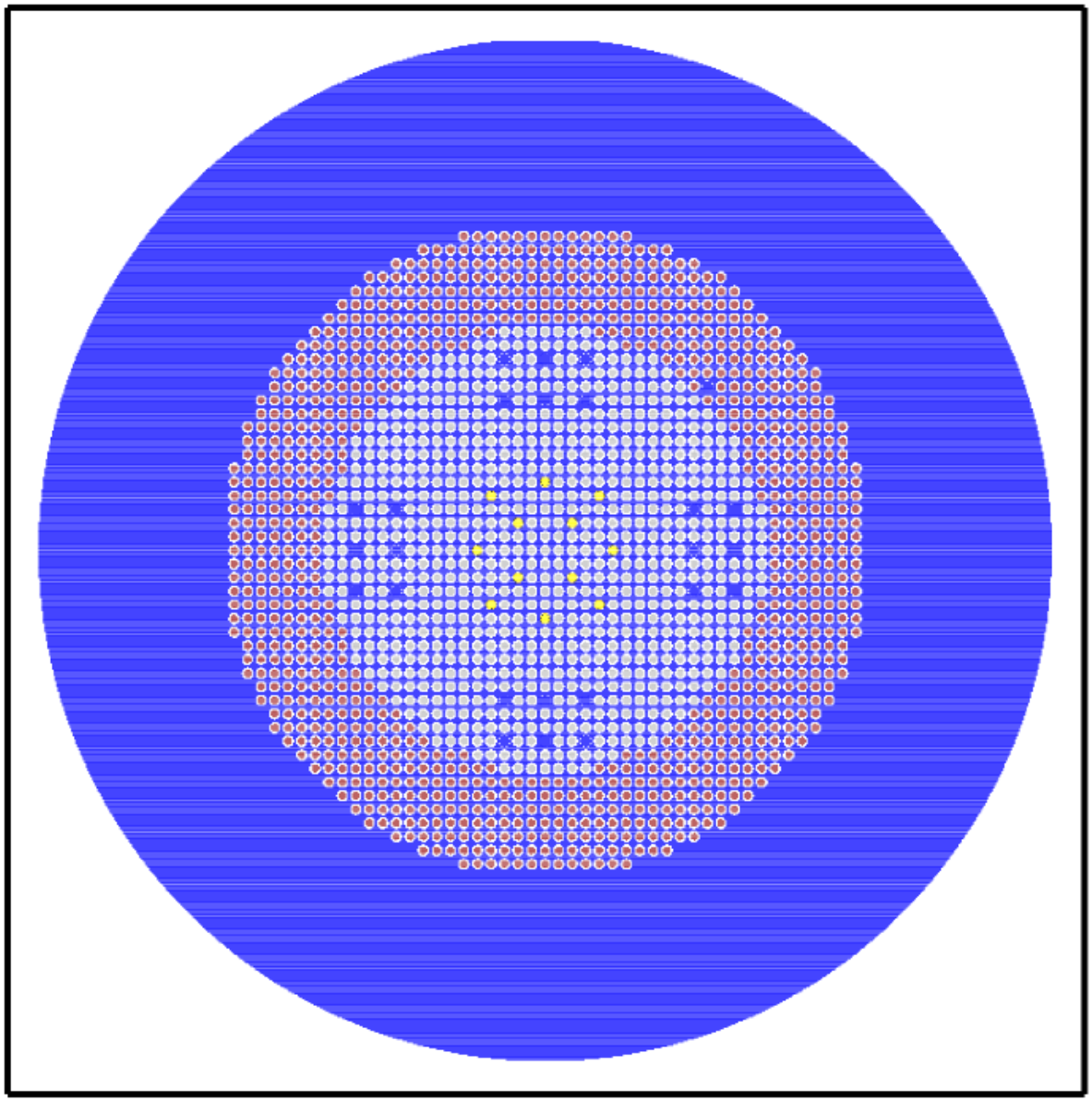
BASALA-C 16Gd configuration



BASALA-C
MOX pins (4 Pu contents)
3-8.7% Pu
H/HM = 9.
74 pins/assembly
0 ppm boron
Assembly pitch 13.5cm

Assemblies loaded with Gd pins (8 or 16 pin per assembly depending on the configuration)

CAMELEON 8-12D2-A configuration



CAMELEON
UOX pins 3%
(config. 8-12D2-A)

12 Gd pins

Reactivity effects; Gd's JEF-2.2 = JEFF-3.1

JEF-2.2/JEFF-3.1
test everything but the Gd's

Gd Reactivity worth
BASALA-H -2000pcm
BASALA-C -4000pcm

Δk/worth ~0.8% +/- 2%

A = 7%Gd, depleted U
B = 3% Gd, enriched U

Cores (mock-up) with Gadolinium configurations	Tripoli4 / JEF-2.2	Tripoli4 / JEFF-3.1	Tripoli4 / JEFF-3.1 +Gd from R.P.I.
BASALA-H / 8Gd	1.00582(10)	1.00729(10)	1.00745(10)
BASALA-H / 16Gd	1.00600(10)	1.00750(10)	1.00758(7)
BASALA-C / 8Gd	1.00526(10)	1.00643(10)	1.00671(10)
BASALA-C / 16Gd	1.00577(10)	1.00677(10)	1.00715(6)
CAMELEON 8-12D1-A	1.00257(17)	1.00127(17)	1.00151(17)
CAMELEON 8-12D2-A	1.00207(15)	1.00100(15)	1.00077(15)
CAMELEON 8-12D2-B	1.00309(15)	1.00132(15)	1.00177(15)

No significant trend observed with the use of Gd (R.P.I.) on reactivity for these thermal cores loaded with a few Gd-rods; those experiments are not sensitive to the Gd's thermal XS.

BASALA-C 8 Gd rods configuration

								-4.85
							0.14	-5.70
						1.23	-0.44	0.86
					1.73	0.77	-0.14	-0.09
						-1.51	-0.18	0.63
			-4.65			-0.69	-0.92	-1.05
		-0.28	0.19	-2.32	-0.17	-2.61	-1.22	-0.28
	2.75	-0.50	-0.48	0.98	-1.06	0.74	0.36	-0.54
2.04	0.22	-4.30	0.02	1.07	1.99	3.77	1.37	-4.39

- TRIPOLI-4.3 / JEF-2.2

< MOX > = (+0.2 +/- 1.3) %

< UOX-Gd > = (-4.8 +/- 0.6) %

	Moderator
	MOX 3%
	MOX 4.3%
	MOX 7%
	MOX 8.7%
	UO2-Gd2O3

No trend, within exp. uncertainty

								-3,09
							-0,37	-4,44
						-1,83	-1,07	-0,16
					0,32	-0,43	-0,37	0,02
						-2,04	-0,08	0,52
			-3,70			-0,64	-0,71	-0,61
		1,21	1,00	-1,43	-0,21	-1,94	-0,47	-0,55
	1,35	-0,35	0,19	0,74	-0,54	1,16	1,41	1,31
2,00	0,33	-3,30	0,32	1,30	0,93	2,00	1,44	-2,87

- TRIPOLI-4.4.1 / JEFF-3.1 / Gd R.P.I.

< MOX > = (+0.1 +/- 1.1) %

< UOX-Gd > = (-3.5 +/- 0.6) %

BASALA-C 16 Gd rods configuration

- TRIPOLI-4.3 / JEF-2.2

< MOX >= (+ 0.2 +/- 1.2) %

< UOX-Gd >=(- 3.8 +/- 0.8) %

								0,85
							-1,16	-0,27
						-1,09	-4,78	1,02
					0,22	-4,07	-0,87	1,77
						-0,29	-1,71	0,56
			1,54			-4,46	-1,68	1,91
		-0,64	-2,85	0,86	-3,99	-1,12	-3,95	1,40
	0,24	-2,64	-1,83	-0,12	-1,86	-3,35	0,22	2,00
1,11	1,16	-0,65	0,00	-0,85	0,86	1,16	0,88	1,24

- TRIPOLI-4.4.1 / JEFF-3.1

< MOX >= (+ 0.2 +/- 1.0) %

< UOX-Gd >=(- 4.8 +/- 0.6) %

								0,65
							-0,58	0,07
						-1,25	-5,47	0,27
					0,43	-5,16	-0,15	0,98
						-0,88	-1,26	0,65
			1,17			-5,30	-1,76	2,43
		0,31	-4,52	0,56	-4,78	-1,34	-5,40	2,00
	-0,45	-3,60	-1,38	-0,19	-0,08	-4,50	-0,05	1,61
1,50	0,71	0,04	-0,69	-0,17	0,72	0,87	1,12	1,72

No trend, but better consistency between the two 8 and 16 Gds configurations with JEFF-3.1 + Gd's RPI

	Moderator
	MOX 3%
	MOX 4.3%
	MOX 7%
	MOX 8.7%
	UO2-Gd2O3

- TRIPOLI-4.4.1 / JEFF-3.1 / Gd R.P.I.

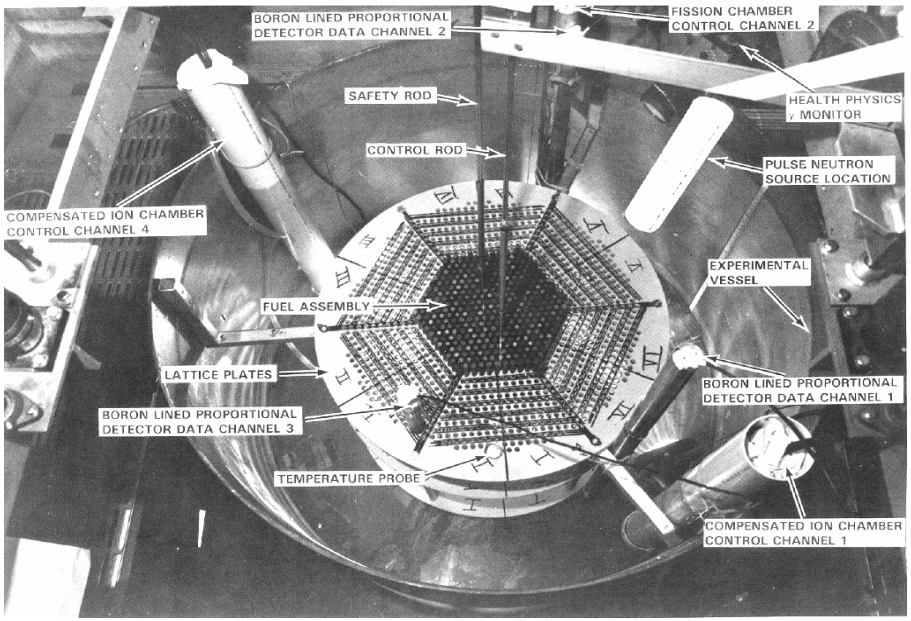
< MOX >= (+ 0.3 +/- 1.0) %

< UOX-Gd >=(- 3.5 +/- 0.6) %

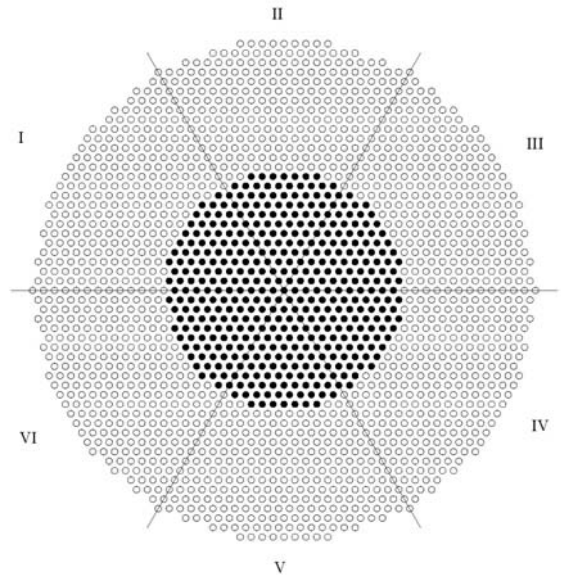
								0,48
							-0,37	0,35
						-0,69	-4,25	0.93
					1.38	-3,77	0,07	0,29
						-0,95	-1,23	0,22
			1,62			-3.62	-1.31	2,24
		0,11	-3,17	0,96	-3,41	-1.56	-3,89	1,61
	-0,32	-2,42	-1.62	-0.52	-0,72	-3.29	0,01	1,22
0,90	0.56	-0,94	-0,71	-0.59	0,68	1,41	1.35	0.90

Absorption worth of Gadolinium-poisoned solution

Code						Tripoli-4.5		JEFF-3.1		
Library		Pitch	Rods			JEFF-3.1	s.d.	No Gd's	s.d.	Gd's worth
LCT-005	U Oxide 4.31%			Keff	Unc.	Kcalc		Kcalc		Δ Kcalc
0.482 gGd/l	c-4	2.398	593	1.0000	250	0.99846	13	1.28087	15	**28240**
1.481	c-11	1.801	1533	1.0000	430	1.00342	13	1.21367	15	**21025**
0.121	c-13	1.598	1495	1.0000	640	1.01129	13	1.03266	13	**2137**
	U Oxide 2.35%									
0.120	c-15	1.895	842	1.0000	200	1.01750	13	1.10440	16	**8690**



B.14 EXPERIMENT: 2.35-000-160



FUEL:	2.35 wt% ^{235}U ENRICHED UO_2
PITCH:	1.895
GADOLINIUM:	0.0 g Gd/litre
RODS:	431 UO_2 RODS AT •

Preliminary ICSBEP benchmarking

Specifications to ICSBEP NEA/NSC/DOC(95)03												
September 2007 Handbook Edition												
Code						Tripoli-4.5		Tripoli-4.5		Tripoli-4.5		
Library						ENDF/B-VII	s.d.	JEFF-3.1	s.d.	+Gd's rpi	s.d.	
		Pitch	Rods	Keff	Unc.			Kcalc		Kcalc		Δ Kcalc
HST-014	U Nitrate 70 gU/l 89.95%											
	c-1			1.0000	280	0.99504	16	0.99430	16			
Gd												
0.1 gGd/l	c-2			1.0000	520	1.00996	16	1.01034	16	1.01903	16	869
0.19 gGd/l	c-3			1.0000	870	1.01827	16	1.01852	16	1.03370	16	1518
Average						1.01411		1.01443		1.02636		
Δ (C-E)						**1411**		**1443**		**2636**		**1194**
LCT-035	U Oxide 2.6% = LCT-006											
B 70ppm	c-1			1.0000	180	1.00091	9	1.00049	9			
B 148ppm	c-2			1.0000	190	0.99978	9	0.99937	9			
Average						1.00034		0.99993				
64ppm 0.064 gGd/l	c-3	1.956	399	1.0000	220	0.99591	9	0.99556	9	0.99935	9	378
Δ (C-E)						**-409**		**-444**		**-65**		**378**

- The HST-014 may be considered as unreliable but, they set the pace
- The LCT-035 correspond to the LCT-006 JAERI TCA assembly, excellent trend and now agreement within the experimental uncertainty !!!

Preliminary ICSBEP benchmarking

Specifications to ICSBEP NEA/NSC/DOC(95)03												
September 2007 Handbook Edition												
Code						Tripoli-4.5		Tripoli-4.5		Tripoli-4.5		
Library						ENDF/B-VII	s.d.	JEFF-3.1	s.d.	+Gd's rpi	s.d.	
		Pitch	Rods	Keff	Unc.			Kcalc		Kcalc		Δ Kcalc
LCT-005	U Oxide 4.31%											
0.000 gGd/l	c-1	2.398	132	1.0000	230	1.00337	13	1.00257	13			
0.068	c-2	2.398	167	1.0000	210	1.00029	13	1.00006	13	1.00466	13	460
0.438	c-3	2.398	515	1.0000	290	0.99907	13	1.00002	13	1.01651	13	1648
0.482	c-4	2.398	593	1.0000	250	0.99721	13	0.99846	13	1.01602	13	1755
Δ (C-E)						0.99886		0.99951		1.01240		1288
0.000	c-5	1.801	378	1.0000	470	1.00598	13	1.00489	13		13	
0.122	c-6	1.801	476	1.0000	420	1.00684	13	1.00697	13	1.00962	13	265
0.400	c-7	1.801	630	1.0000	430	1.00191	13	1.00258	13	1.00846	13	587
0.908	c-8	1.801	959	1.0000	210	1.00163	13	1.00295	13	1.01213	13	917
1.246	c-9	1.801	1260	1.0000	400	1.00257	13	1.00379	13	1.01459	13	1081
1.448	c-10	1.801	1482	1.0000	280	1.00135	13	1.00290	13	1.01474	13	1184
1.481	c-11	1.801	1533	1.0000	430	1.00165	13	1.00342	13	1.01544	13	1202
Δ (C-E)						1.00266		1.00377		1.01250		873
0.000	c-12	1.598	1185	1.0000	660	1.00709	13	1.00527	13			
0.121	c-13	1.598	1495	1.0000	640	1.01309	13	1.01129	13	1.01303	13	174
	U Oxide 2.35%											
0.000	c-14	1.895	431	1.0000	200	0.99885	13	0.99842	13			
0.120	c-15	1.895	842	1.0000	200	1.01751	13	1.01750	13	1.02436	13	685
0.000	c-16	1.598	1029	1.0000	320	1.01366	13	1.01279	12			

Reminder
CAMELEON
3% ~ 300 gGd/l
= black absorber

Trend with pitch
Trend with enrichment

C-E without Gds ??
Experimental uncertainties ??

Conclusions

- The new parameters are of better quality than the old ones
- The thermal XS and RI trend are corroborated by some, but not all ICSBEP experiments described in this analysis, more
- JEFF-3.1 (or ENDF/B-VII) perform rather well on those benchmarks
- ENDF/B-VII + RPI ➔ better fission rate distribution
- Further "relevant" benchmarking are needed and will be performed: CRISTO-3, MISTRAL, LWR-PROTEUS, ZED-2 and more ICSBEP LCT-052, MST-006, HST-015,016,017,018 and ICT02, HMT-010,016, …GEDEON in EOLE (depletion rates of the odd Gd's isotopes !!!)

"Relevant": mean reactor, energy and "in cycle" wises: BASALA and CAMELEON Gd's experiments were not sensitive enough to Gd's thermal xs

Pitfalls:

- Gd' isotopic distribution uncertainty (experimental composition)
- Gd_2O_3 (solid, black) or $GdNO_3$ (diluted, gray) impact ??
- N-14, O-16 and H-1 evaluation impact, S(a,b) ??
- Keff converged, but what about the flux in the eV range ??
- Reliable, trustable, credible experimental uncertainty
- Why the natural Gd evaluated thermal XS (unchanged since the 80's) is so different from the RPI derived value ??